Appendix C

Detroit River International Crossing Study
Logs of Core Boring

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NTH Consultants, Ltd.

SUMMARY OF ROCK LOG NOMENCLATURE

RUN NUMBER

The number of the individual coring interval starting at the rock interface.

ROCK TYPE/DESCRIPTION

Description of the color, grain size or texture, bedding, foliation, lithology and mineralogy.

Color - When describing the color, use only common colors such as gray, brown, green, etc., or simple combinations of these (e.g., yellow-brown). The degree of color (light vs. dark) should also be employed.

Grain Size/Texture - Terminology used to identify size, shape, and arrangement of the constituent elements: e.g., porphyritic, glassy, amygdaloidal, etc.

Where applicable, the following size classification is utilized:

• Amorphous	Particles too small to be seen with the naked eye.
• Fine grained	Particles barely seen with naked eye.
• Medium grained	Particles barely seen with naked eye to 1/8 in.
• Coarse grained	Particles between 1/8 in. and 1/4 in.
• Very coarse	Particles greater than 1/4 in.

Bedding or Foliation - A bed (or foliation) is the smallest diversion of a stratified series, and marked by a well defined divisional plane from strata or layers above and below. Bedding is the collective term signifying the existence of beds or laminae.

The relative thickness of the bedding planes shall be described as follows:

Bedding Planes	Spacing
• Laminated	Less than 0.4 in. (1 cm)
• Very thin	0.4 inch (1 cm)
• Thin	2 to 12 inches
• Medium	1 to 3 feet
• Thick	3 to 10 feet

Lithology – Rock name or classification and modifiers such as Limestone, Shaly Limestone, Shale, Calcareous Shale, etc.

FIGURE NO. 34

WEATHERING/ALTERATION

Weathering (alteration) of the rock (mineral fabric) is caused by mechanical and chemical action (temperature variations, water, bacteria, physical and chemical attack) and produces deterioration of the rock fabric leading eventually to a disaggregated mass resembling soil. The terms used to describe the relative degree of weathering are as follows:

• F - Fresh	Rock fresh, crystals bright, few joints may show slight staining. Rock rings under hammer if crystalline.
• SW - Slight	Discoloration indicates weathering of rock material and discontinuity surfaces may be somewhat weaker externally than in its fresh condition.
• MW - Moderate	Less than half the rock material is decomposed and or disintegrated to a "soil". Fresh or slight weathered rock present either as a continuous framework or as corestones. Large pieces cannot be broken by hand.
• HW - High	More than half the rock material is decomposed and/or disintegrated to a soil. Rock so weakened by weathering that fairly large pieces can be crumbled by hand. Fresh or discolored rock (slight) may be present as a discontinuous framework or as corestones.
• CW - Complete	Rock reduced to "soil". Rock "fabric" not discernible or discernible only in small scattered locations.
• RS - Residual Soil	The original minerals of the rock have been entirely altered to secondary minerals and the original rock fabric is not apparent.

FIELD HARDNESS

A measure of resistance to scratching or abrasion. The descriptions of the relative degrees of hardness are as follows:

• S - Soft	Reserved for plastic material only.
• F - Friable	Easily crumbled by hand, pulverized or reduced to powder and is too soft to be cut with a pocket knife.
• LH - Low Hardness	Can be gouged deeply or carved with a pocketknife.
• MH - Moderately Hard	Can be readily scratched by a knife blade. Scratch leaves heavy trace of dust and scratch is readily visible after the powder is blown away.
• H - Hard	Can be scratched with difficulty; scratch produces little powder and is often faintly visible; traces of the knife steel may be visible.
• VH - Very Hard	Cannot be scratched with pocketknife; leaves knife steel marks on surface.

GRAPHIC LOG OF FRACTURES

A scaled representation of fractures and discontinuities observed along the length of the core run. Fracture angles with respect to the longitudinal axis of the core run shall be noted were applicable.

DESCRIPTION OF ROCK DEFECTS

Description of rock defects shall include information regarding **discontinuities** as well as **solution cavities** or **voids**.

Discontinuities - Surface representing breaks or fractures separating the rock mass into discrete units.

The types of discontinuities are as follows:

• Crack	A partial or incomplete fracture.
• Joint	A simple fracture along which no visible shear displacement has occurred. May occur with parallel joints to form a joint set.
• Shear	A fracture along which differential movement has taken place parallel to the surface sufficient to produce slickensides, striations or polishing. May be accompanied by a zone of fractured rock (shear zone).
• Fault	A major fracture along which there has been measurable/observable displacement; often accompanied by clayey gouge and/or a severely fractured adjacent zone of rock.
• Shear or Fault Zone	A band or zone of parallel or sub-parallel shears and/or faults.

Discontinuity Spacing – The spacing should be measured in feet to the nearest tenth perpendicular to the plane in the set.

- IF – Intensely Fractured - <0.3ft
- CF – Closely Fractured – 0.3 to 1.0ft
- MF – Moderately Fractured – 1.0 to 3.0ft
- WF – Widely Fractured – 3.0 to 6.0ft
- VWF – Very Widely Fractured - >6ft

Surface Roughness - The terms used to describe the relative degree of surface roughness of the discontinuity are as follows:

• VR - Very Rough	Near "vertical" steps and ridges occur on the discontinuity surface.
• R - Rough	Some ridges and side-angle steps are evident; asperities are clearly visible; discontinuity surface feels very abrasive.
• SR - Slightly Rough	Asperities on the discontinuity surface are distinguishable and can be felt.
• S - Smooth	Surface appears smooth
• SLK - Slickensides	Visual evidence of striations or a smooth glassy-appearing finish.

Other terms used for surface roughness can include stepped, planar, and undulating.

Dip/Attitude - The terms used to describe the angle of inclination of the discontinuities with respect to the plane normal to the longitudinal axis of the core run are as follows:

Horizontal	0 to 5 degrees
Low Angle	5 to 35 degrees
Moderately dipping	35 to 55 degrees
Steep or high angle	55 to 85 degrees
Vertical	85 to 90 degrees

Discontinuity Infilling - A description of the mineralogy, thickness and hardness of observed discontinuity infilling should be noted.

The terms used to define the relative degree of infilling are as follows:

- ST - Surface stain
- Sp - Spotty
- P - Partially filled; half of surface or opening is filled
- F - Filled (partially)
- H - Healed

Solution Cavities and Voids - Open spaces in the subsurface are generally due to removal of rock material by chemical dissolution or the action of running water. Since most of these voids result from the action of groundwater, the openings are not usually equi-dimensional, but rather are elongated in the horizontal plane.

The relative size of voids and cavities are as follows:

- Pit or pitted - Voids barely seen with the naked eye to 1/4 in.
- Vug - Voids 1/4 in. to 2 in. in diameter
- Cavity - Holes 2 in. to 2 ft. in diameter
- Cave - Holes 2 ft. and larger in diameter

PERCENT CORE RECOVERY
The amount of core actually recovered divided by the length of the run (expressed as a percentage). Both intact and weak rock including gravel sized pieces are included in the percent recovery.

RQD (ROCK QUALITY DESIGNATION)
Total length of all "intact" pieces of core greater than 4-inches in length measured along the centerline of the core, divided by the total length of the run. Mechanical discontinuities such as those resulting from the core operation or handling of the core sample should not be included in the length measurements for RQD.

FRACTURES/FOOT
The number of naturally occurring fractures observed over the length of the recovered core divided by the length of the total core run.

CORE BOX NUMBER
The box number in which the core is stored.

COMMENTS
Comments include information on drilling water losses, reasons for core loss or fracture, gas readings, average pull-down pressure used to advance the run, total time required to complete the run and any other data pertinent to the core operation and/or condition of the core.

Miscellaneous Features - Any additional characteristics to further identify and evaluate the rock from the standpoint of engineering properties: secondary mineralization, fossils, swelling and slaking properties, etc.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name:	DRIC Brine Well Investigation		
Project Location:	Detroit, Michigan	Inspector	NTH
NTH Proj. No:	15-050014-12	Contractor:	Advanced and Nevis Energy Services
Drilling Date:	2/7/2007 to 4/8/2007	Driller:	Rig 7, R. Thatcher, R. Ward
Core Size:		Checked By:	Z. Carr, P.E., C. Johnson

											Subsurface Profile	Discontinuities				
Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	**Ground Surface Elevation : 582.7**	Depth (ft)	Type	Dip	Roughness	Infill
										580						
5																
										575						
10																
										570	FILL: SAND with Varying Amounts of Silt, Clay, Gravel, Concrete and Asphalt Debris, and Organic Material					
		13.5														
15																
										565						
20																
										560						
25																
										555						
30																
										550						
35																

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile	Discontinuities Depth (ft)	Type	Dip	Roughness	Infill
										545						
40																
										540						
45																
										535						
50																
										530						
		54									Medium Compact SAND with Trace Clay and Silt					
55																
										525						
60																
										520						
65																
										515						
70																
										510						
75																

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
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Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile	Discontinuities Depth (ft)	Type	Dip	Roughness	Infill
80		80								505	Medium Gray SILTY CLAY with Trace Sand and Gravel					
85 90 95		95.3								500 495 490	HARDPAN: Hard Gray SILTY CLAY with Trace Sand and Gravel					
100 105 110		111.5								485 480 475 470	***DUNDEE LIMESTONE TOP (EL 487.4)*** Start of Rock Coring Runs 103.6 - Vertical Fracture 103.8 - 106.8 - Hydrocarbon Staining Present 106.8 - 109.9 - Hydrocarbon Staining with Few Fossils 110.0 - 113.0 - Pitted and Vuggy Throughout 110.5 - 111.5 - Vertical Crack **Gray Fine Grained LIMESTONE** Slightly Pitted and Vuggy Occasional Fossils Hydrocarbon Staining and Odor 103.8-109.9 Weathered at Top	103.6 104.7 107.7 108.2 108.7 110.1 110.3 110.5 112.3	J J J J J J J J J	H H M M H H V H H	SR SR SR R SR SR SR SR SR	- - - - F - - - -
115		116									**Tan Fine Grained, Fossiliferous LIMESTONE** Occasional Hydrocarbon Staining					

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
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LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)
120									465
125									460
130									455
	1	133	100.0	95	0.5	MH	F	11.4	450
135		134.9							
									445
140		139.7							
		142.2							440
		143.9							
145		145.3							
									435
		148.3							
150		150.2							
		150.7							
		151.8							430
155		155							
		156.5							

Subsurface Profile

Light to Medium Gray Fine Grained Fossiliferous LIMESTONE
Thinly Bedded with Carbonaceous Banding
Pitted/Vuggy with Hydrocarbon Staining 122.0-133.0

Tan Fine Grained LIMESTONE
Occasional Fossils

Gray Fine Grained Fossiliferous LIMESTONE
Vuggy

DRG - LUCAS FORMATION TOP EL 441.7

Tan and Gray Fine to Medium Grained LIMESTONE with Chert
Pitted with Occasional Vugs, Fossils, and Carbonaceous Banding

Tan and Brown Amorphous to Fine Grained LIMESTONE
Carbonaceous Banding

Light Gray Fine Grained LIMESTONE
Occasional Anhydrite Infilling
Slight Hydrocarbon Staining

Tan Fine Grained LIMESTONE
Carbonaceous Banding

Light Tan Fine Grained DOLOMITIC LIMESTONE

Tan and Brown Fine Grained LIMESTONE

Gray Fine Grained DOLOMITIC LIMESTONE

Brown Fine to Medium Grained DOLOMITIC LIMESTONE

Brown Fine to Medium Grained Fossiliferous LIMESTONE

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
117.9	J	H	SR	-
119.8	J	L	SR	-
120.1	J	H	SR	-
127.4	J	L	SR	-
133.8	J	H	SR	-
134.1	J	H	SR	-
134.9	J	M	SR	-
135.2	J	H	SR	-
137.1	J	H	SR	-
138.1	J	H	SR	-
138.7	J	H	R	-
139.7	J	H	R	-
140.6	J	H	SR	-
141.7	J	L	SR	-
142.8	J	H	S	F
143.9	J	H	SR	-
144.7	J	H	SR	-
145.3	J	H	S	-
146.2	J	H	SR	-
147.4	J	H	SR	-
148.3	J	H	SR	-
149.5	C	M	-	H
150.7	J	H	SR	F
151.8	J	H	SR	-
153.9	J	L	SR	-
154.4	J	H	SR	-
155.3	J	H	SR	-
156.5	J	L	R	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

LOG OF CORE BORING NO:

DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)
									425
160	2	161.5	97.2	80	1.2	MH	F	12.9	420
165									415
170									410
175									405
180									400
185									395
190	3	191.5	100.0	96	1	MH	F		390
195		194.6							

Subsurface Profile

Ground Surface Elevation : 582.7

Pitted and Vuggy

Fragmented 160.2-161.5
Tan Medium Grained LIMESTONE
Carbonaceous Banding

Possible Kawkawlin Bentonite at 181.4' (EL 394.3)
Tan and Gray Amorphous to Fine Grained DOLOMITIC LIMESTONE
Occasional Thin Layers of DOLOMITE
Laminated to Thinly Bedded with Vuggy Zones and Anhydrite Infilling

Tan and Gray Amorphous to Fine Grained DOLOMITE
Laminated to Thinly Bedded with Vuggy Zones and Anhydrite Infilling

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
157.4	J	H	R	-
158.7	J	H	SR	-
159.4	J	H	SR	-
160.2	J	L	SR	-
161.0	J	H	R	-
163.3	J	H	SR	-
163.5	J	H	R	-
164.4	J	H	R	-
166.4	J	H	SR	-
167.2	J	H	SR	-
167.3	J	H	SR	-
167.9	J	H	R	-
168.3	J	H	SR	-
169.1	J	H	SR	-
170.9	J	H	R	-
172.0	J	-	-	-
172.9	J	L	R	-
173.3	J	L	SR	-
174.7	J	L	SR	-
175.7	J	L	VR	-
176.0	J	L	VR	-
176.8	J	H	SR	-
177.8	J	H	SR	-
178.2	J	H	SR	-
180.8	J	M	VR	-
181.5	J	M	VR	-
182.3	J	L	R	-
182.9	J	L	R	-
183.8	J	H	R	-
184.2	J	H	R	-
185.3	J	H	R	-
186.9	J	H	R	-
188.7	J	L	R	-
189.3	J	H	R	-
189.9	J	H	SR	-
193.0	J	L	R	-
193.4	J	H	R	-
194.1	J	H	SR	-
194.2	J	H	SR	-
194.6	J	H	R	-
196.6	C	V	-	H

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft): 200, 205, 210, 215, 220, 225, 230, 235

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
	200.3						
4	205	85.0	78	1.1	MH	F	
5	207	75.0	15	5	MH	SW	
6	233	97.0	80	1.3	MH	F	7.4

Profile

Elev (ft): 380, 375, 370, 365, 360, 355, 350, 345

Subsurface Profile

Brown and Gray Fine to Medium Grained DOLOMITE
Laminated to Thinly Bedded
Carbonaceous Bands 194.6-197.5
Pitted/Vuggy 199.0-200.3

Tan Fine Grained DOLOMITE
Laminated Bedding

Tan Amorphous DOLOMITE
Laminated Bedding
Occasional Chert Nodules
Fragmented Zone 207-207.3

Brecciated Zone 212.5-212.8

Brecciated Zone 217.0-217.9

Fragmented Zone 220.1-220.9

Fragmented Zone 232.0-233.0
Tan and Gray Amorphous DOLOMITE and DOLOMITIC LIMESTONE
Massive, Pitted, and Vuggy with Chert Nodules
Occasional Anhydrite Infilling

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
197.5	J	H	SR	-
197.7	J	H	SR	-
198.0	J	H	SR	-
198.8	J	H	SR	F
199.0	J	H	SR	-
199.2	J	H	R	F
199.7	J	H	R	F
200.3	J	H	SR	-
202.0	J	H	SR	F
202.2	J	H	SR	-
203.6	J	H	SR	P
205.3	J	H	SR	-
205.5	J	L	SR	-
205.8	J	L	SR	-
206.0	J	S	SR	-
206.1	J	V	SR	-
207.9	J	L	SR	-
208.2	J	H	R	-
208.4	J	M	R	-
208.6	J	M	R	-
209.1	J	L	SR	-
209.7	J	L	SR	-
210.5	J	H	R	-
210.8	J	L	SR	-
211.1	J	H	SR	-
211.3	J	H	SR	-
211.4	J	V	VR	-
211.7	J	H	R	-
212.2	J	M	R	-
213.4	J	M	R	-
214.3	J	H	SR	-
215.0	J	H	SR	-
216.0	J	H	R	-
216.8	J	V	R	-
217.6	J	L	SR	-
217.7	J	L	R	-
220.0	J	L	SR	-
220.1	J	L	SR	-
221.5	J	L	SR	-
222.0	J	L	SR	-
222.4	J	H	SR	-
222.6	J	H	SR	-
225.1	J	L	SR	-
227.7	J	L	R	-
230.3	J	L	R	-
231.3	J	M	SR	-
231.5	J	H	SR	-
232.5	J	H	SR	-
233.0	J	H	SR	-
233.5	J	H	SR	-
233.7	J	H	SR	-
234.3	J	H	R	-
235.3	J	H	SR	-
235.7	J	H	SR	-
237.5	J	V	VR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
240											
										340	Fragmented Zone 242.5-243.2 **Tan and Gray Amorphous to Fine Grained DOLOMITIC LIMESTONE**
		244									
245											
										335	
250											Calcitic Zone 250.7-251.6 **Tan and Gray Amorphous to Fine Grained DOLOMITIC LIMESTONE** Laminated to Thinly Bedded Anhydrite Nodules, Replacement Zones, and Stringers Occasional Pitting with Vugs
		252									
										330	
255											
										325	
260											**Tan and Gray Amorphous to Fine Grained DOLOMITE and DOLOMITIC LIMESTONE** Laminated to Thinly Bedded Anhydrite Nodules, Replacement Zones, and Stringers Occasional Pitting with Vugs
	7	263	90.0	86	1	MH	F			320	
265											
										315	**Gray and White Amorphous to Fine Grained DOLOMITE and DOLOMITIC LIMESTONE** Laminated Bedding
270											
										310	
275											
										305	

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
238.6	J	L	VR	-
241.0	J	H	SR	-
241.7	J	H	SR	-
242.9	J	H	SR	-
243.3	J	H	SR	-
243.7	J	H	R	-
244.0	J	H	SR	-
244.1	J	V	SR	-
244.4	J	H	SR	-
249.4	J	H	SR	-
250.1	J	H	SR	-
250.2	J	V	R	-
250.6	J	H	R	-
251.5	J	H	R	-
251.6	J	M	R	-
253.7	J	L	VR	-
257.5	J	H	SR	-
259.9	J	H	SR	-
261.1	J	H	SR	-
263.0	J	H	SR	-
266.3	J	S	R	-
266.6	J	M	R	-
270.0	J	L	R	-
272.6	J	H	S	-
276.0	J	M	R	-
277.8	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
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NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
280 285 290	8	293	100.0	100	0.3	MH	F			300 295 290	**Gray and White Amorphous to Fine Grained DOLOMITE and DOLOMITIC LIMESTONE** Laminated Bedding
295		296.7									**Gray and White Fine Grained DOLOMITE** Laminated to Thinly Bedded with Anhydrite Interbeds
300		303.7								285 280	**Gray and Tan Amorphous Fine Grained DOLOMITE** Laminated to Thinly Bedded Occasional Anhydrite Interbeds and Laminae
305 310 315										275 270 265	**Tan to Grayish Tan Amorphous to Fine Grained DOLOMITE**

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
280.0	J	H	SR	-
289.0	J	L	SR	-
290.8	J	H	S	-
294.2	J	H	VR	ST
296.0	J	L	VR	ST
302.7	J	H	S	-
305.9	J	H	SR	-
307.7	J	H	SR	-
310.3	J	H	R	-
311.3	J	H	SR	-
311.8	J	H	SR	ST
313.3	J	H	SR	ST
314.2	J	L	R	ST
314.6	J	H	SR	-
316.0	J	H	SR	-
317.1	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile
320	9	320.6	100.0	100	0.5	MH	F			Laminated to Thinly Bedded Occasional Anhydrite Infilling and Replacement Zones
									260	
325										
									255	
330										
		331								**Tan Amorphous LIMESTONE**
									250	
335										
									245	
340										
									240	
345										
									235	
350	10	350.5	98.0	100	1	MH	F			**Tan and Gray Amorphous to Fine Grained DOLOMITE** Laminated to Thinly Bedded Anhydrite Interbeds Occasional Pitting/Vugs with Anhydrite Infilling
									230	
355										
		357								**Tan and Gray Amorphous to Fine Grained DOLOMITE** Laminated to Thinly Bedded Anhydrite Interbeds Occasional Pitting/Vugs with Anhydrite Infilling
									225	

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
319.9	J	H	S	-
320.6	J	H	SR	-
322.2	J	H	SR	-
322.6	J	H	SR	-
325.0	J	H	SR	-
325.4	J	H	SR	-
327.7	J	H	SR	-
328.3	J	H	SR	-
329.6	J	H	SR	-
330.7	J	H	SR	-
331.9	J	H	SR	-
332.5	J	H	SR	-
333.2	J	H	SR	-
333.7	J	H	SR	-
334.5	J	S	R	-
336.0	J	H	R	-
336.3	J	L	SR	-
336.4	J	H	SR	-
337.8	J	L	SR	-
338.8	J	H	SR	-
339.0	J	H	SR	-
340.9	J	H	SR	-
341.8	J	H	SR	-
343.2	J	H	SR	-
344.2	J	H	SR	-
344.7	J	H	SR	-
345.1	J	H	SR	-
346.1	J	H	SR	-
347.1	J	H	SR	-
347.7	J	H	SR	-
348.6	J	H	SR	-
349.6	J	H	SR	-
352.5	J	H	SR	-
355.9	J	H	SR	-
356.8	J	H	SR	-
357.2	J	H	R	-
357.8	J	L	R	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
		362									**Tan and Gray Amorphous to Fine Grained DOLOMITIC LIMESTONE**
		364								220	**Tan and Gray Amorphous to Fine Grained DOLOMITE**
365		366									**Tan and Gray Amorphous to Fine Grained DOLOMITE** with Anhydrite Nodules
370		370								215	**Tan and Gray Interbedded DOLOMITE and LIMESTONE**
375										210	
380	11	380	100.0	100	0.4	MH	F	12.3		205	Brecciated Zone 378.0-380.0 **Brown to Grayish Brown Amorphous and Argillaceous DOLOMITIC LIMESTONE** Laminated to Thinly Bedded Anhydrite Laminae and Inclusions Slightly Pitted and Vuggy
385	12	384.4	100.0	100	1	MH	F			200	***DRG - AMHERSTBURG FORMATION TOP EL 200.7*** **Tan and Gray Amorphous to Fine Grained DOLOMITE** Laminated to Thinly Bedded Occasional Carbonoceous Banding Slight Pitting and Occasional Vugs
390										195	
395										190	
400										185	

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
362.2	J	H	SR	-
365.0	J	L	R	-
368.0	J	H	R	-
370.3	J	H	SR	-
372.9	J	H	SR	-
375.8	J	M	R	-
376.7	J	H	SR	-
378.7	J	L	SR	-
380.8	J	M	R	-
381.6	J	M	R	-
382.4	J	L	R	-
383.0	J	H	R	-
384.2	J	L	R	-
384.5	J	L	SR	-
384.9	J	L	SR	-
386.9	J	L	SR	-
387.7	J	H	SR	-
388.3	J	H	SR	-
389.2	J	H	SR	-
390.9	J	L	SR	-
392.5	J	L	R	-
392.9	J	L	S	-
394.6	J	L	SR	-
394.8	J	L	R	-
397.7	J	H	S	-
398.7	J	H	SR	-
399.8	J	L	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										180	
405											
										175	
											Solution Features 409.0-409.5
410											
	13	413	95.0	94	0.9	MH	F			170	**Tan and Gray Amorphous to Fine Grained DOLOMITE** Laminated to Very Thinly Bedded Slight Pitting
415											
										165	
420											
										160	
425											
										155	
430											
										150	
435											
										145	
440											

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
400.2	J	H	R	-
400.8	J	H	SR	-
401.5	J	H	SR	-
402.8	J	H	SR	-
406.0	J	H	S	-
406.3	J	H	SR	-
407.1	J	H	SR	-
407.5	J	H	SR	-
409.6	J	H	SR	-
410.2	J	H	SR	-
410.8	J	H	S	-
411.2	J	H	SR	-
412.2	J	L	SR	-
416.9	J	H	S	ST
417.9	J	L	SR	SP
418.7	J	H	SR	-
419.4	J	H	SR	SP
420.1	J	H	S	-
421.1	J	H	S	SP
421.7	J	L	R	P
422.2	J	L	R	P
423.0	J	L	SR	-
423.4	J	L	SR	SP
424.0	J	H	SR	SP
426.1	J	H	S	-
426.9	J	H	S	-
428.2	J	H	S	-
428.5	J	L	S	SP
428.8	J	H	SR	P
429.0	J	H	SR	SP
429.6	J	L	SR	-
431.3	J	H	R	P
432.6	J	H	R	P
433.4	J	L	SR	P
434.4	J	H	S	-
435.5	J	H	S	ST
436.4	J	H	S	-
436.8	J	H	R	P
438.2	J	H	S	ST
439.0	J	H	SR	ST
439.6	J	H	S	ST
440.5	J	H	R	P

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
										140	
445											**Brown and Gray Amorphous DOLOMITE** Massive Bedding Occasional Pitting Occasional Anhydrite Nodules, Laminae, and Interbeds
	14	446	100.0	90.3	1.3	MH	F				
										135	**Brown and Gray Amorphous DOLOMITE** Massive Bedding Occasional Pitting Occasional Anhydrite Nodules, Laminae, and Interbeds
450											
										130	
455											***SYLVANIA SANDSTONE TOP EL 126.9*** **White to Gray Fine Grained SANDSTONE** Massive with Occasional Dark Gray Stylolitic Bands Dolomitic in Sections White Frosted and Etched Grains
										125	
460											
										120	
465											
										115	
470											
										110	**White and Gray Fine Grained SANDSTONE** Massive Bedding Occasional Thin Horzontial Carbonaceous Banding Dolomitic in Sections White Froasted and Etched Grains
475											
	15	476	100.0	99	1.2	H	F	6.6			
										105	
480											

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
441.4	J	H	S	-
442.1	J	H	SR	ST
442.9	J	H	S	-
443.7	J	H	SR	P
444.0	J	V	SR	-
444.1	J	H	SR	-
444.4	J	H	SR	-
445.0	J	V	SR	ST
445.6	J	V	SR	-
445.7	J	H	SR	-
446.4	J	L	R	-
447.6	J	H	SR	-
448.6	J	H	SR	-
449.7	J	L	R	-
451.1	J	L	SR	-
452.6	J	H	SR	-
453.8	J	H	R	-
455.8	J	L	SR	-
456.3	J	H	SR	-
457.1	J	H	SR	-
458.3	J	H	SR	-
459.1	J	H	SR	-
459.6	J	H	SR	-
460.5	J	H	SR	-
461.2	J	L	SR	-
462.3	J	H	SR	-
463.0	J	H	SR	-
464.0	J	H	SR	-
464.6	J	H	SR	-
465.4	J	H	SR	-
465.7	J	H	SR	-
466.4	J	L	SR	-
467.1	J	H	SR	-
467.5	J	H	SR	-
467.9	J	H	SR	-
468.4	J	H	SR	-
469.4	J	H	SR	-
470.5	J	H	SR	-
470.9	J	H	SR	-
471.3	J	H	SR	-
472.2	J	H	SR	-
473.9	J	H	SR	-
474.6	J	H	SR	-
475.9	J	H	SR	-
476.5	J	H	SR	-
477.6	J	H	SR	-
478.0	J	L	SR	-
479.5	J	H	SR	-
480.7	J	H	SR	-
481.2	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										100	
485											
		488.3								95	**White and Gray Fine Grained SANDSTONE** Laminated to Thinly Bedded Dolomitic in Sections White Frosted and Etched Grains
490											
		491.4									**Gray Fine Grained SANDY DOLOMITE** Laminated to Thinly Bedded
		492.4								90	Fragmented Zone 492.1-492.4
495											**White and Light Gray Fine Grained SANDSTONE** Massive Bedding
										85	
500											
										80	
505											**Tan Fine Grained SANDSTONE** Occasional Stylolites and Carbonaceous Banding Dolomitic in Sections White Frosted and Etched Grains
	16	506	100.0	97	1.3	MH	F				
										75	
510											
										70	
515											
										65	
520											

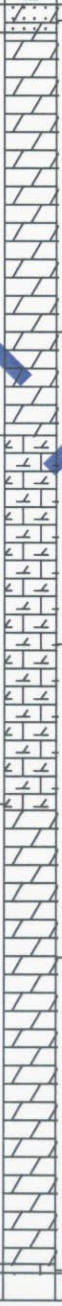
Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
481.4	J	H	SR	-
481.8	J	H	SR	-
482.7	J	H	SR	-
483.6	J	H	SR	-
484.7	J	H	SR	-
485.3	J	H	SR	-
485.8	J	H	SR	-
486.6	J	H	SR	-
487.0	J	H	SR	-
487.5	J	H	SR	-
489.6	J	H	SR	-
491.4	J	H	SR	-
492.0	J	V	SR	-
492.1	J	H	SR	-
492.4	J	H	R	-
494.5	J	H	SR	-
494.6	J	H	SR	-
494.7	J	H	SR	-
495.3	J	H	SR	-
495.7	J	V	SR	-
495.8	J	H	SR	-
496.0	J	H	SR	-
496.9	J	H	SR	-
498.0	J	H	SR	-
498.8	J	H	SR	-
499.3	J	H	SR	-
500.0	J	L	SR	-
501.0	J	V	R	-
501.4	J	H	R	-
502.4	J	H	SR	-
503.3	J	H	R	-
504.2	J	H	SR	-
505.2	J	H	SR	-
505.6	J	H	SR	-
507.0	J	H	SR	-
509.5	J	H	SR	-
511.2	J	S	SR	-
512.6	J	H	SR	-
513.3	J	H	SR	-
514.8	J	L	SR	-
515.9	J	M	R	-
516.1	J	L	R	F
517.1	J	H	SR	F
519.1	J	L	SR	-
520.6	J	H	SR	-
521.2	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)
		523.1							60
525									
									55
530									
									50
535	17	536	100.0	99	1.0	MH	F	9.7	
									45
540									
									40
545		547.8							35
550									
									30
555									
									25
560									
	18	562.5	95.6	95	0.67	MH	F	11.7	20

Subsurface Profile

Ground Surface Elevation : 582.7

BOIS BLANC FORMATION TOP EL 59.6
Gray Fine to Medium Grained SANDY DOLOMITE
Occasional Carbonaceous Banding
Slightly Pitted and Vuggy

Light to Medium Gray Fine to Medium Grained DOLOMITE (Occasionally Sandy)
Slightly Pitted and Vuggy
Occasional Anhydrite Infilling

Gray to Tan Fine to Medium Grained DOLOMITIC LIMESTONE
Occasional Cherty Zones
Occasional Vugs with Anhydrite Infilling
Occasional Carbonaceous Banding

Gray to Tan Medium Grained DOLOMITE
Occasional Cherty Zones
Occasional Pits and Vugs with Anhydrite Infilling

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
522.3	J	L	R	-
522.9	J	H	SR	-
523.1	J	H	SR	-
524.3	J	H	SR	-
525.1	J	H	R	-
526.9	J	H	SR	-
527.6	J	V	SR	-
527.9	J	H	SR	-
529.3	J	L	R	-
529.9	J	H	SR	-
530.0	J	H	SR	-
530.7	J	H	R	-
533.9	J	H	SR	-
534.6	J	H	SR	-
534.9	J	V	R	-
535.5	J	H	R	-
538.5	J	H	SR	-
539.9	J	H	R	ST
543.4	J	H	SR	-
546.9	J	H	SR	P
547.8	J	H	R	-
548.9	J	H	SR	ST
549.8	J	H	R	-
551.0	J	H	R	ST
552.5	J	H	R	ST
554.0	J	H	R	-
555.3	J	L	R	-
557.0	J	H	SR	-
557.1	J	L	SR	-
558.0	J	H	R	ST
558.9	J	H	SR	-
559.9	J	H	SR	-
560.7	J	L	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
19	567	100.0	86.7	1.8	MH		
20	568	50.0	50	0	H	F	
21	578	99.0	69	2.3	H	F	
	596.4						

Depth (ft): 565, 570, 575, 580, 585, 590, 595, 600

Elev (ft): 15, 10, 5, 0, -5, -10, -15, -20

Subsurface Profile

Gray, Grayish White and Blue Gray Amorphous DOLOMITE and CHERTY DOLOMITE
Laminated to Thinly Bedded, Occasional Chert and Anhydrite Nodules

Gray and Light Brown Fine Grained DOLOMITE
Occasional Chert Nodules and Pitting

Gray Amorphous to Fine Grained DOLOMITE
Chert and Anhydrite Nodules
Occasional Zones of Cherty Dolomite
Frequent Carbonaceous Banding
Occasional Vugs with Anhydrite Infilling

White CHERTY DOLOMITE 596.2-596.4
Gray Amorphous to Fine Grained DOLOMITE
Chert and Anhydrite Nodules
Occasional Zones of Cherty Dolomite
Frequent Carbonaceous Banding
Occasional Vugs with Anhydrite Infilling

GARDEN ISLAND FORMATION TOP EL -16.8

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
562.8	J	H	SR	-
563.0	J	H	R	-
564.2	J	H	SR	-
564.8	J	H	R	-
565.3	J	H	R	-
565.7	J	H	R	-
566.4	J	H	R	SP
567.1	J	H	SR	-
568.7	J	H	R	-
569.6	J	H	R	-
569.9	J	L	R	-
570.2	J	L	VR	-
570.5	J	L	SR	-
571.0	J	L	SR	-
571.4	J	H	R	-
571.6	J	L	R	-
572.0	J	H	SR	-
572.1	J	H	SR	-
572.4	J	L	SR	-
572.7	J	H	R	-
573.2	J	H	SR	-
573.5	J	H	SR	-
574.6	J	H	SR	-
574.9	J	H	SR	-
575.4	J	H	SR	-
575.8	J	H	SR	-
576.4	J	H	SR	-
576.9	J	H	SR	-
577.2	J	H	SR	-
577.6	J	H	R	-
579.0	J	H	S	F
580.8	J	H	SR	-
582.6	J	H	SR	F
584.1	J	H	SR	F
585.6	J	H	SR	F
587.4	J	H	SR	-
589.5	J	H	SR	F
591.2	J	H	SR	F
593.9	J	H	SR	-
595.1	J	H	SR	F
596.9	J	H	SR	F
600.2	C	S	-	-
601.3	J	H	SR	F
601.6	J	H	SR	F

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**	Discontinuities Depth (ft)	Type	Dip	Roughness	Infill
												604.1	J	H	S	-
605											**White to Tan Fine Grained SANDSTONE** Occasional Carbonaceous Banding	605.2	J	H	S	-
	22	606	100.0	100	0.5	H	F	27.9			***BASS ISLAND FORMATION TOP EL -23.3***					
										-25	**Gray Amorphous Fine Grained DOLOMITE and CHERTY DOLOMITE** Laminated Bedding Occasional Pits and Vugs	608.7	J	H	S	F
610																
										-30						
615																
										-35						
620																
										-40	Brecciated Zone 622.4-623.3					
625																
										-45						
630												629.8	C	V	R	-
										-50	**Gray Amorphous Fine Grained DOLOMITE and CHERTY DOLOMITE** Laminated Bedding Occasional Pits and Vugs					
	23	634	100.0	100	1.2	H	F									
635												635.9	J	H	R	P
										-55		637.2	J	H	SR	SP
												638.2	J	H	R	F
640												639.7	J	H	R	P
		642.5								-60	**Light Brown to Grayish Brown Amorphous DOLOMITE** Occasionally Cherty Occasional Anhydrite Nodules and Carbonaceous Bands	642.0	J	H	R	F
												643.1	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile
645										
									-65	
650										
									-70	Brecciated Zone 654.5-655.6
655										
									-75	
660										
									-80	Brecciated Zone 662.4-663.3
	24	663.6	100.0	92.6	0.98	MH	F			**Tan to Grayish Tan Amorphous DOLOMITE** Laminated to Thinly Bedded Occasional Carbonaceous Banding Vuggy Zones with Anhydrite Infilling Occasional Cherty Sections
665										
									-85	Brecciated Zone 668.0-668.1
670										Brecciated Zone 671.0-674.5
									-90	**Tan to Brown Amorphous to Fine Grained DOLOMITE** Laminated to Thinly Bedded Occasional Carbonaceous Banding Pitted and Vuggy with Anhydrite Infilling Occasional Cherty Sections
675										
									-95	
680										
									-100	Brecciated Zone 684.0-685.0

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
645.0	J	H	S	F
646.6	J	L	S	SP
647.1	J	H	S	F
648.0	J	H	S	P
649.8	J	H	S	SP
650.7	J	H	SR	-
652.1	J	V	SR	-
653.4	J	H	S	SP
653.9	J	H	SR	P
655.4	J	H	SR	P
655.6	J	H	SR	P
655.7	J	V	SR	SP
655.9	J	H	S	-
656.0	J	L	SR	SP
656.7	J	H	SR	SP
657.3	J	H	SR	-
658.9	J	H	SR	SP
659.4	J	H	SR	P
659.6	J	H	S	-
660.8	J	H	SR	SP
661.5	J	H	SR	P
662.8	J	H	SR	SP
666.3	J	M	R	P
668.2	J	H	SR	-
668.9	J	M	SR	F
674.2	J	L	SR	P
676.1	J	H	SR	F
677.9	J	H	R	F
679.0	J	H	R	SP
679.7	J	H	R	F
684.1	J	L	R	F

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
										Brecciated Zone 685.3-687.0
									-105	
690										
										Tan to Brown Amorphous to Fine Grained DOLOMITE Laminated to Thinly Bedded Occasional Carbonaceous Banding Pitted and Vuggy with Anhydrite Infilling Occasional Cherty Sections
	25	693	98.3	98.3	0.4	MH	F	11.8	-110	
695										
		696.5								**ANHYDRITE**
									-115	**Tan to Brown Amorphous to Fine Grained DOLOMITE**
700										
										Anhydrite 700.7-701.2
									-120	
705										
									-125	
710										
		712.5							-130	**Tan to Brown Amorphous to Fine Grained DOLOMITE**
715										**Tan Fine Grained SANDY DOLOMITE** Massive Bedding Occasional Stylolites
		716.8								
									-135	
720										
										Light Gray to Bluish Gray Amorphous SHALEY DOLOMITE and LIMESTONE Laminated to Thinly Bedded
	26	723	97.1	94	0.86	MH	F		-140	
										Gray Amorphous to Fine Grained DOLOMITE Laminated Brecciated Zone 726.3-728.0
725										

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
687.0	J	H	SR	SP
687.4	J	H	SR	SP
689.0	J	H	S	P
693.5	J	H	SR	-
696.2	J	H	R	-
697.7	J	H	SR	-
698.0	J	L	SR	F
699.3	J	H	SR	-
701.0	J	H	SR	-
702.1	J	H	SR	-
703.6	J	H	SR	-
704.8	J	L	SR	-
705.6	J	H	SR	-
706.4	J	H	R	F
707.4	J	H	SR	P
708.2	J	H	SR	-
709.2	J	H	SR	-
711.4	J	H	SR	-
712.5	J	H	S	F
714.3	J	H	S	-
714.4	J	H	SR	-
716.8	J	L	S	-
717.5	J	L	SR	-
718.4	J	L	SR	-
719.0	J	M	SR	-
719.8	J	L	SR	-
720.8	J	L	SR	-
724.3	J	H	S	ST

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
		725.4									Slightly Pitted/Vuggy
										-145	Brecciated Zone 726.2-726.5
		728									**Gray to Bluish Gray Amorphous to Fine Grained DOLOMITE** Pitted and Vuggy
730											
										-150	
735											**Light Gray Amorphous DOLOMITE** Laminated Bedding
		735.5									**Tan to Grayish Tan Amorphous DOLOMITE** Massive Bedding
		736.6								-155	Pitted and Vuggy with Carbonaceous Infilling
											Brecciated Zone 736.6-737.0
740											**Gray to Dark Gray Amorphous to Fine Grained DOLOMITE** Laminated to Thinly Bedded Occasional Pitting with Vugs
		742.3								-160	
745											
										-165	
											Gray Amorphous to Fine Grained DOLOMITE Thinly Bedded Slight Pitting with Few Vugs Occasional Carbonaceous Banding and Stylolites
750											
	27	750.9	100.0	92.5	0.93	MH	F				
										-170	
755											
		757									**LIMESTONE**
										-175	**Gray Amorphous to Fine Grained DOLOMITE** Thinly Bedded Slight Pitting with Few Vugs Occasional Carbonaceous Banding and Stylolites
760											
										-180	
765											

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
725.4	J	H	S	-
726.8	J	H	S	F
729.0	J	H	S	-
729.8	J	H	S	F
730.6	J	H	SR	F
733.5	J	H	R	-
734.5	J	L	SR	-
735.9	J	H	SR	-
736.4	J	H	SR	-
736.6	J	H	S	F
742.3	J	M	SR	-
742.5	J	L	SR	-
743.5	J	M	S	-
743.8	J	M	S	-
744.3	J	H	SR	-
744.8	J	H	R	-
745.4	J	H	S	-
745.9	J	H	S	-
746.2	J	H	SR	-
746.8	J	H	S	-
747.6	J	H	S	-
748.9	J	H	SR	F
749.2	J	H	S	-
750.2	J	L	SR	-
751.4	J	H	SR	-
752.6	J	H	SR	-
752.7	J	M	SR	-
753.2	J	H	S	-
754.6	J	H	SR	-
755.7	J	H	SR	F
756.0	J	H	S	F
756.1	J	L	SR	-
756.8	J	H	R	-
757.5	J	L	SR	-
759.5	J	H	SR	-
759.6	J	M	SR	-
761.2	J	H	SR	-
762.4	J	H	S	F
762.9	J	H	S	-
764.7	J	H	SR	-
765.2	J	M	SR	F

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
28	781	99.6	92.3	0.53	MH	F	16.8
	796.9						

Depth (ft)	Elev (ft)
	-185
770	
	-190
775	
	-195
780	
	-200
785	
	-205
790	
	-210
795	
	-215
800	
	-220
805	

Subsurface Profile

Brecciated Zone 766.6-766.7

Brecciated Zone 769.7-769.9

Gray Amorphous to Fine Grained DOLOMITE
Thinly Bedded
Slight Pitting with Few Vugs
Occasional Carbonaceous Banding and Stylolites

Dark Gray SHALE 788.1-788.2
Possible Bentonite

Gray Amorphous to Fine Grained LIMESTONE
Occasional Carbonaceous Banding
Anhydrite Nodules

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
766.7	J	L	SR	F
766.9	J	L	SR	F
767.2	J	H	S	-
767.9	J	H	S	F
769.0	J	H	SR	F
769.9	J	H	S	-
770.6	J	L	S	F
771.5	J	H	S	F
773.0	J	H	SR	-
775.6	J	H	SR	-
777.7	J	H	SR	-
779.5	J	H	SR	-
781.8	J	H	SR	-
783.0	J	H	VR	-
783.7	J	H	R	F
784.7	J	H	S	P
786.1	J	H	S	ST
787.0	J	H	S	-
788.1	J	H	S	ST
789.5	J	H	S	ST
790.6	J	H	S	-
790.8	J	H	S	-
792.2	J	H	S	P
792.4	J	H	SR	ST
793.8	J	M	SR	ST
795.7	J	H	SR	-
795.8	J	H	SR	P
796.4	J	H	R	-
796.6	J	L	R	-
798.4	J	H	SR	-
800.4	J	H	S	-
803.5	J	H	SR	-
804.5	J	L	R	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

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Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)
									-225
810									
	29	811	100.0	97	0.9	MH	F		
									-230
815									
		817							
									-235
		817.5							
820									
									-240
825		825							
									-245
830									
									-250
835									
									-255
840	30	840.1	100.0	97.6	0.97	MH	F		
									-260
845									

Subsurface Profile

Gray Amorphous to Fine Grained SHALEY DOLOMITE
Laminated to Thinly Bedded
Frequent Carbonaceous Banding
Moderate Pitting with Vugs
Occasional Anhydrite Nodules

Gray Amorphous to Fine Grained DOLOMITE and LIMESTONE
Laminated to Thinly Bedded
Frequent Carbonaceous Banding
Moderate Pitting with Vugs
Occasional Anhydrite Nodules

ANHYDRITE

Gray Amorphous to Fine Grained DOLOMITE and LIMESTONE
Laminated to Thinly Bedded
Frequent Carbonaceous Banding
Moderate Pitting with Vugs
Occasional Anhydrite Nodules

Light Gray Amorphous DOLOMITE
Medium to Thick Bedding
Occasional Carbonaceous Banding and Stylolites
Slightly Pitted

Brown Amorphous DOLOMITE
Occasionally Greenish Brown

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
806.6	J	H	SR	-
807.2	J	L	SR	ST
807.7	J	L	SR	-
808.7	J	H	S	-
809.3	J	H	R	F
812.2	J	L	R	-
812.7	J	H	SR	-
813.5	J	H	SR	-
814.6	J	H	S	-
815.8	J	H	S	-
816.0	J	H	S	-
816.5	J	H	SR	-
817.6	J	L	S	-
819.0	J	H	SR	-
819.5	J	H	S	-
820.6	J	H	SR	-
821.5	J	H	SR	-
822.4	J	H	S	-
823.2	J	H	SR	-
824.0	J	H	SR	-
824.1	J	H	SR	-
824.2	J	H	SR	-
825.7	J	H	S	-
827.0	J	H	S	-
827.7	J	H	S	F
827.9	J	H	SR	-
829.2	J	H	S	-
832.0	J	L	SR	-
832.4	J	H	SR	-
834.6	J	H	SR	-
835.1	J	H	SR	-
838.0	J	L	SR	-
840.4	J	H	SR	-
842.7	J	H	S	-
844.3	J	H	SR	-
846.7	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
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DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

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Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile
		848.7							-265	Thinly Bedded Occasional Carbonaceous Banding Slightly Pitted
850		853.2							-270	Anhydrite Healed Cracks 850.3-851.3 **Greenish Gray Amorphous SHALEY DOLOMITE** Thinly Bedded Frequent Carbonaceous Banding
855 860 865		866							-275 -280	**Gray Amorphous DOLOMITIC LIMESTONE** Laminated to Thinly Bedded Carbonaceous Banding Occasional Shaley Dolomite Interbeds
	31	869.5	100.0	99.4	0.69	MH	F	20.5	-285	**Light Gray Amorphous DOLOMITE** Laminated to Massive Bedding Occasional Anhydrite Nodules Slightly Pitted
870		873.3							-290	**Gray Amorphous to Fine Grained SHALEY DOLOMITE** Anhydrite Laminae and Nodules Slightly Pitted
875 880		882							-295	**Greenish Gray SHALE** Laminated to Thinly Bedded Frequent Anhydrite Laminae Occasional Dolomite/Dolomitic Shale Interbeds
885									-300	**Greenish Gray SHALE** Laminated to Thinly Bedded Frequent Anhydrite Laminae Occasional Dolomite/Dolomitic Shale Interbeds

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
847.9	J	H	SR	-
848.7	J	H	S	-
850.3	J	L	SR	F
851.3	J	H	S	-
851.9	J	H	SR	-
853.2	J	H	SR	F
854.6	J	H	S	-
856.4	J	H	S	-
858.0	J	H	S	-
858.8	J	L	SR	-
859.8	J	H	S	-
861.2	J	H	SR	-
862.7	J	H	S	-
864.1	J	L	SR	-
866.0	J	H	S	-
867.6	J	H	SR	-
869.2	J	H	S	-
869.6	J	H	SR	-
872.0	J	H	SR	-
873.6	J	H	SR	-
874.8	J	H	S	-
875.3	J	H	SR	F
876.1	J	H	S	-
877.8	C	H	-	H
878.0	J	H	SR	-
879.0	C	L	-	H
879.5	J	H	S	-
880.8	J	H	SR	-
882.1	J	H	S	-
882.2	C	V	-	H
884.0	J	H	S	-
885.8	C	H	-	H
886.9	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
	891						
32	900.4	93.7	93.7	0.64	MH	F	
	908.3						

Depth (ft): 890, 895, 900, 905, 910, 915, 920, 925

Elev (ft): -310, -315, -320, -325, -330, -335, -340, -345

Subsurface Profile

Greenish Gray Interbedded SHALE and ANHYDRITE

SALINA GROUP - G Unit (G-SHALE) TOP EL -308.3

Light Gray Amorphous to Fine Grained DOLOMITIC SHALE
Thinly Bedded
Occasional Anhydrite Laminae
Minor Pitting with Few Vugs with Anhydrite Infilling
Occasional Solution Features

Light and Dark Gray SHALE
Thinly Bedded
Tan Banding Present 923.5-930.4
Anhydrite Laminae and Nodules
Slightly Vuggy with Anhydrite Infilling

Gray Amorphous to Fine Grained SHALE
Occasional Anhydrite Nodules and Infilling

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
888.7	J	H	SR	-
890.9	J	H	S	-
891.7	J	H	S	-
893.5	J	H	S	-
895.3	J	H	S	-
897.1	J	H	S	-
901.1	J	H	S	-
901.3	J	H	S	-
901.5	J	H	SR	-
902.3	J	H	SR	F
902.4	J	L	SR	-
903.1	J	L	SR	-
904.3	J	H	S	-
905.9	J	H	SR	-
906.2	J	L	SR	-
906.9	J	H	SR	-
907.2	C	M	-	F
908.3	J	H	SR	F
908.6	C	M	-	F
909.2	J	H	S	-
909.3	C	L	-	F
909.7	J	H	S	F
911.8	J	H	S	-
912.7	J	L	SR	-
913.2	J	H	SR	-
913.6	J	H	S	-
915.4	J	H	SR	-
917.2	J	H	S	-
919.2	J	H	SR	-
920.6	J	H	S	-
922.3	J	H	R	-
923.5	J	H	SR	-
925.6	J	H	S	-
926.0	J	H	S	F
926.1	C	L	-	F
927.3	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
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DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

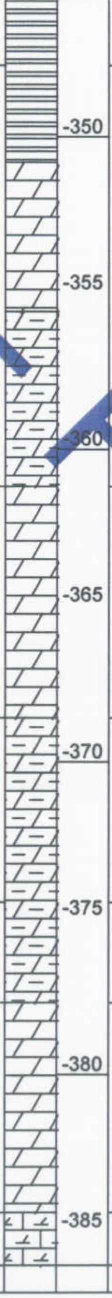
Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft): 930, 935, 940, 945, 950, 955, 960, 965

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
33	930.4	100.0	98.1	0.93	MH	F	18.8
	943.9						
	951.3						
	957.2						
34	960.4	99.7	99.6	0.67	MH	F	
	967.1						

Profile



Subsurface Profile

Gray Amorphous to Fine Grained SHALE
Occasional Anhydrite Nodules and Infilling

Gray DOLOMITE Interbed 933.5-938.3

Anhydrite Interbeds

Gray and Greenish Gray Amorphous to Fine Grained SHALEY DOLOMITE
Brown and Gray Zone 947.7-949.1
Anhydrite Nodules

Anhydrite Interbeds

Brown and Gray Fine Grained DOLOMITE
Anhydrite Nodules and Interbeds

Anhydrite Interbeds
Grayish Green SHALEY DOLOMITE
Anhydrite Nodules

Dark Gray Amorphous to Fine Grained SHALEY DOLOMITE
Anhydrite Nodules

Brown Amorphous to Fine Grained DOLOMITE
Thinly Bedded
Slightly Pitted and Vuggy

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
928.9	J	H	S	-
930.1	J	L	SR	-
931.9	J	H	SR	-
933.1	J	H	S	F
933.7	J	L	S	-
933.9	J	H	S	-
935.9	J	H	S	-
937.9	J	H	SR	-
938.3	J	L	SR	-
939.8	J	H	SR	-
941.5	J	H	SR	F
943.4	J	H	SR	-
945.2	J	H	SR	-
945.5	J	H	S	F
948.8	J	H	S	-
950.7	J	H	S	-
952.4	J	H	S	-
953.8	J	H	SR	-
955.8	J	H	S	-
957.7	J	H	S	-
959.1	J	H	SR	-
960.2	J	H	SR	-
962.3	J	H	S	-
964.9	J	H	S	-
965.6	J	L	SR	F
967.8	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
970		970.6					SW				**Gray DOLOMITIC LIMESTONE**
										-390	
975											
										-395	
		978.5				MH	F				***SALINA GROUP - F UNIT (F-SALT) TOP EL -395.8*** **Gray SHALE** Occasional Anhydrite Laminae Orange Salt Veins at 977.0
980											
										-400	
985											
										-405	
	35	989.4	98.7	98.7	0.5	LH	F				**Light Brownish Orange and Opaque HALITE** (F4 Bed) Occasional Shale Laminae
990											
										-410	
995											
										-415	
		998									**Light Gray and Brown LIMESTONE** Thinly Bedded Slightly Pitted
1000											
		1003								-420	**Light Gray and Brown DOLOMITE** Thinly Bedded Slightly Pitted Anhydrite Nodules 997.0-1003.0
1005											
										-425	**Clear to Dark Brown HALITE** (F3 Bed) Massive Bedding Occasional Dolomite Laminae

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
969.8	J	H	SR	-
970.6	J	H	S	-
972.7	J	H	S	-
974.5	J	H	S	F
976.7	J	L	SR	F
978.5	J	H	SR	F
980.0	J	H	SR	-
980.6	J	H	SR	-
981.3	J	H	SR	-
982.8	J	H	SR	-
987.0	J	H	SR	-
991.0	J	H	SR	-
991.3	J	H	SR	F
993.5	J	H	S	F
995.4	J	H	SR	F
997.1	J	H	S	F
999.2	J	H	SR	-
1001.4	J	H	S	-
1004.0	J	H	SR	-
1008.1	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
1010 1015	36	1019.4	96.0	89.2	0.6	LH	F			-430 -435	**Clear to Dark Brown HALITE** (F3 Bed) Massive Bedding Occasional Dolomite Laminae
1020 1025 1030		1031.8								-440 -445	Rotary Drilling Techniques Used to Clear Debris from Borehole **Dark Gray and Brown to Light Tan and Yellow HALITE** (F3 Bed) Occasional Gray Dolomite Laminae
1035		1036.1								-450	**Brown Fine Grained DOLOMITE** Occasional Anhydrite Laminae Slightly Pitted with Vuggy with Anhydrite and Salt Infilling
		1038.8								-455	**Light Gray and Tan DOLOMITIC LIMESTONE** Thinly Bedded Slightly Pitted
1040 1045		1046.7								-460	**Brown Fine Grained DOLOMITIC LIMESTONE** Thinly Bedded Slightly Pitted with Anhydrite Infilling
1050										-465	**Gray and Tan Amorphous DOLOMITIC LIMESTONE**

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
1009.8	J	H	SR	-
1011.2	J	H	S	-
1012.3	J	H	S	-
1012.5	J	H	S	-
1014.6	J	H	S	-
1015.9	J	H	S	-
1017.3	J	H	SR	-
1018.5	J	H	R	-
1018.8	J	H	SR	-
1019.0	J	H	SR	-
1022.7	J	H	SR	SP
1024.9	J	H	SR	-
1026.1	J	H	S	-
1027.7	J	H	SR	-
1029.2	J	H	S	-
1030.8	J	H	S	-
1032.9	J	H	SR	-
1034.8	J	H	SR	-
1036.1	J	H	SR	-
1038.5	J	H	S	-
1038.8	J	H	SR	F
1041.0	J	H	SR	-
1042.3	J	H	SR	F
1043.0	J	L	S	-
1043.8	J	H	SR	-
1044.7	J	L	SR	-
1044.8	J	L	S	-
1045.1	J	L	S	-
1045.5	J	M	SR	-
1046.2	J	M	SR	-
1047.4	J	M	SR	-
1049.3	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.7**
	37	1051	100.0	96.7	0.7	LH	F				Laminated Bedding Slightly Pitted and Vuggy
	38	1052	95.8	85.4	2.0	MH	F				
										-470	**Gray and Tan Amorphous DOLOMITIC LIMESTONE** Laminated
											Brown Amorphous DOLOMITIC LIMESTONE Thinly Bedded Occasional Anhydrite Nodules and Inclusions Slightly Pitted and Vuggy 1056.3-1056.7 Occasional Solution Features 1054.9-1055.3
1055											
		1056.7									
										-475	
											Gray and Brown Amorphous DOLOMITE Laminated to Thinly Bedded Occasional Solution Features 1059.0-1059.1 Slightly Pitted Occasional Anhydrite Healed Cracks
1060											
		1061.6									
										-480	
1065											
										-485	
1070											
										-490	
1075											
										-495	
1080											
	39	1082	100.0	95.1	1.1	MH	F				**White to Brown HALITE** (F2 Bed) Occasional Anhydrite Interbeds
										-500	**White to Brown HALITE** (F2 Bed) Occasional Anhydrite Interbeds
1085											
										-505	
1090											**Gray SHALEY DOLOMITE** Laminated Bedding

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1050.2	J	L	R	-
1051.4	J	H	SR	-
1053.9	J	H	SR	-
1055.3	J	H	SR	-
1056.7	J	H	SR	F
1058.2	J	L	S	-
1059.3	J	H	SR	-
1059.9	J	H	S	-
1060.1	J	H	SR	-
1060.5	J	H	SR	-
1060.6	J	H	SR	-
1062.0	J	H	SR	-
1062.5	J	H	R	-
1063.6	J	H	R	-
1063.9	J	H	SR	-
1064.1	J	H	SR	-
1064.4	J	H	SR	-
1064.7	J	H	SR	-
1065.9	J	H	SR	-
1066.7	J	H	SR	-
1067.8	J	H	S	-
1068.2	J	H	SR	-
1068.3	J	H	SR	-
1068.5	J	H	SR	-
1068.9	J	H	SR	-
1069.0	J	H	SR	-
1070.8	J	H	SR	-
1071.7	J	H	SR	-
1072.7	J	H	SR	-
1074.2	J	H	S	-
1075.5	J	H	SR	-
1083.6	J	H	S	-
1086.1	J	H	S	-
1087.9	J	H	S	-
1089.8	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
		1091.3									Occasional Brown Halite Interbeds
										-510	**Brown and Tan HALITE** (F1 Bed) Massive Bedding Occasional Dolomite and Anhydrite Laminae
1095											
										-515	
1100											
										-520	Dolomitic Banding
1105											
										-525	
1110											**Brown and Tan HALITE** (F1 Bed) Massive Bedding Occasional Dolomite and Anhydrite Laminae
	40	1112	98.0	98	0.51	MH	F				
										-530	
1115											
										-535	
1120											
										-540	Dolomite Banding
1125											
										-545	
1130											Dolomite Banding

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1091.8	J	H	R	-
1096.0	J	H	S	-
1099.6	J	H	R	-
1100.4	J	L	SR	-
1101.7	J	H	SR	-
1103.1	J	H	SR	-
1104.1	J	H	S	-
1107.8	J	L	SR	-
1108.5	J	H	S	-
1109.3	J	H	S	-
1109.9	J	H	S	-
1112.6	J	H	SR	-
1113.3	J	H	SR	-
1114.9	J	H	SR	-
1116.5	J	H	SR	-
1116.7	J	H	SR	-
1117.5	J	H	SR	-
1118.6	J	H	SR	-
1120.3	J	H	SR	-
1122.1	J	H	S	-
1122.6	J	H	S	-
1124.6	J	H	SR	-
1125.8	J	H	R	-
1126.2	J	H	S	-
1127.8	J	H	SR	-
1129.1	J	H	SR	-
1129.4	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
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Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										-550	
1135											
										-555	
1140											**Brown HALITE** Massive Bedding Occasionally White Gray to Orange Occasional Light Gray Dolomite Laminae and Replacement Zones 1122.1-1138.7
	41	1142	98.7	96.4	0.51	LH	F				
										-560	***SALINA GROUP - E UNIT (E-DOLOMITE) TOP EL -559.3***
1145											
		1148								-565	**SHALEY DOLOMITE**
1150											Interbedded Orange and Brown HALITE with Gray Amorphous DOLOMITE Anhydrite Interbed
											Anhydrite Interbed
										-570	
1155											
										-575	
1160											
										-580	
1165											
										-585	
1170											**Gray Fine Grained DOLOMITE** Occasional Halite Laminae Slightly Pitted and Vuggy with Anhydrite Infilling 1159.2-1164.4
	42	1171	100.0	100	0.4	LH	F				

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1132.1	J	H	S	-
1133.4	J	H	SR	-
1135.3	J	H	SR	-
1138.1	J	H	SR	-
1140.0	J	H	SR	-
1142.5	J	H	SR	-
1145.9	J	H	SR	-
1149.8	J	H	SR	-
1151.8	J	H	SR	-
1154.0	J	H	SR	-
1156.6	J	M	SR	-
1159.2	J	L	SR	-
1168.8	J	H	S	-
1170.8	J	S	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										-590	
1175											
										-595	
1180											
										-600	Anhydrite Interbed
1185											
										-605	
1190											
										-610	
1195											
										-615	**Gray SHALEY DOLOMITE and Tan Amorphous to Fine Grained DOLOMITE** Slightly Pitted and Vuggy with Anhydrite Infilling Occasional Carbonaceous Banding
1200	43	1201	99.3	99.3	0.9	MH	F	30.9			
										-620	
1205		1206.3									**Gray and Tan Amorphous SHALEY DOLOMITE** Laminted to Thinly Bedded Occasional Carbonaceous Banding
										-625	
1210											**Light Tan to Light Grayish Tan Amorphous DOLOMITE** Massive Bedding Slightly Pitted and Vuggy

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
1171.8	J	H	S	-
1177.0	J	H	S	SP
1178.9	J	H	S	SP
1180.5	J	H	S	-
1182.3	J	H	SR	-
1183.3	J	H	S	-
1184.1	J	H	SR	-
1185.1	J	H	S	-
1186.0	J	H	SR	-
1186.1	J	H	S	SP
1187.6	J	H	SR	-
1188.5	J	H	S	-
1189.5	J	H	SR	SP
1190.3	J	H	S	SP
1191.2	J	H	SR	-
1192.1	J	H	SR	-
1193.0	J	H	S	-
1194.1	J	H	S	-
1195.1	J	H	S	-
1196.4	J	H	S	-
1197.7	J	H	SR	-
1198.1	J	H	SR	-
1199.2	J	H	SR	-
1200.3	J	H	S	-
1202.2	J	H	SR	-
1202.6	J	H	SR	-
1204.1	J	H	SR	-
1205.7	J	H	SR	-
1208.0	J	H	SR	-
1210.6	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
	1213.5						
	1219.5						
	1226						
44	1231	100.0	100	0.4	MH	F	28.2
	1242						
	1252.3				LH		

Depth (ft): 1215, 1220, 1225, 1230, 1235, 1240, 1245, 1250

Elev (ft): -635, -640, -645, -650, -655, -660, -665, -670

Subsurface Profile

Occasional Anhydrite Inclusions and Carbonaceous Banding

Gray to Brownish Gray Amorphous DOLOMITE
Laminated to Thinly Bedded
Slightly Pitted and Vuggy
Occasional Carbonaceous Banding

Gray, Tan, and Brown Amorphous to Fine Grained DOLOMITE
Thickly Bedded
Slightly Pitted and Vuggy
Occasional Carbonaceous Banding

Gray to Tannish Gray Amorphous DOLOMITE and SHALEY DOLOMITE
Anhydrite Inclusions
Occasional Carbonaceous Banding

SALINA GROUP - D UNIT (D-SALT) TOP -659.3
Gray Blackish and Whiteish Gray and Tan Amorphous to Fine Grained DOLOMITE and SHALEY DOLOMITE
Laminated to Thinly Bedded
Slightly Pitted and Vuggy

Orange-Brown to White HALITE
(D3 Bed)

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1217.4	J	H	SR	-
1223.1	J	H	SR	-
1225.5	J	H	SR	-
1227.3	J	H	SR	-
1231.8	J	H	S	-
1233.4	J	H	S	-
1234.7	J	H	S	-
1235.3	J	H	S	-
1236.2	J	H	SR	-
1237.6	J	H	S	-
1239.4	J	H	S	-
1240.9	J	H	S	-
1242.5	J	H	SR	-
1244.4	J	H	SR	-
1245.7	J	H	SR	-
1246.2	J	H	SR	-
1247.4	J	H	SR	-
1248.0	J	H	SR	-
1248.4	J	H	SR	-
1249.3	J	H	SR	-
1249.9	J	H	SR	-
1250.8	J	H	SR	-
1251.4	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

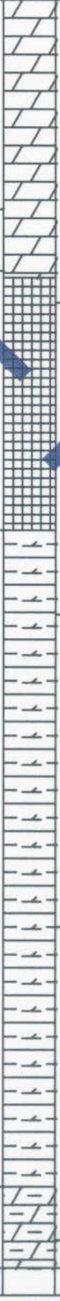
Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)
1255									
									-675
		1259.7							
1260									
	45	1261.7	98.5	96.3	0.88	MH	F		
									-680
1265									
									-685
1270		1270				LH			
									-690
1275									
									-695
1280									
									-700
1285									
									-705
1290									
	46	1291	95.7	94.7	0.8	MH	F	12.5	
									-710

Profile

Subsurface Profile

Interbedded HALITE and Gray and Tan Amorphous to Fine Grained DOLOMITE
Laminated to Thinly Bedded

Gray Amorphous to Fine Grained DOLOMITE
Occasional Tan Laminations

SALINA GROUP - C UNIT (C-SHALE) TOP EL -687.3
Gray SHALEY HALITE
(D2 Bed)
Occasional Orange Halite Laminae, Veins, and Replacement Zones
Occasional Anhydrite Nodules

Green and Gray DOLOMITIC SHALE
Occasional Orange Halite Veins and Laminae
Occasional Anhydritic Zones

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1255.3	J	H	SR	-
1255.4	J	H	SR	-
1257.2	J	H	SR	-
1259.0	J	H	S	-
1259.9	J	H	S	-
1261.9	J	H	SR	-
1262.3	J	H	S	-
1263.0	J	H	SR	-
1263.8	J	H	SR	-
1264.1	J	H	SR	-
1266.6	J	H	SR	-
1267.0	J	H	SR	-
1267.4	J	H	SR	-
1269.0	J	H	SR	-
1269.2	J	H	SR	-
1270.4	J	H	SR	-
1270.9	J	H	SR	-
1271.8	J	H	SR	-
1274.1	J	H	SR	-
1277.9	J	H	SR	-
1285.3	J	H	SR	-
1288.2	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
1295											
										-715	
											Gray and Green SHALE and SHALEY DOLOMITE Occasional Orange Halite Veins and Laminae Occasional Anhydritic Zones
1300											
										-720	
1305											
										-725	
1310											
										-730	
1315											
											Anhydrite Interbed
										-735	
											Anhydrite Interbed **Gray and Green SHALE and SHALEY DOLOMITE** Occasional Orange Halite Veins and Laminae Occasional Anhydritic Zones
1320	47	1320.3	99.6	99.1	0.33	MH	F	9.3			
										-740	
											Vertical Orange Halite Veins 1323.8-1324.4
1325											
										-745	
1330											
										-750	

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
1295.6	J	H	SR	-
1299.1	J	H	S	-
1301.2	J	H	S	-
1303.8	J	H	SR	-
1309.2	J	S	SR	-
1309.7	J	S	SR	-
1312.5	J	H	SR	F
1315.0	J	H	SR	-
1317.1	J	H	SR	-
1320.3	J	H	SR	-
1324.3	J	H	SR	-
1326.5	J	S	SR	-
1327.3	J	H	SR	F
1330.6	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile
1335										
									-755	
1340										
									-760	Vertical Orange Halite Veins 1343.6-1344.7
1345										
									-765	
1350										**Orange HALITE and Greenish Gray DOLOMITIC SHALE** Occasional Anhydrite Nodules
	48	1351	99.0	99	0.37	MH	F			
									-770	
1355										
									-775	
1360										**Green to Greenish Gray SHALEY DOLOMITE** Vertical Red HALITE Vein 1351.8-1360.0
		1361.3								
									-780	
1365										
									-785	
1370										
									-790	

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1336.0	J	H	SR	-
1337.0	J	H	S	-
1338.1	J	H	SR	-
1339.0	J	H	SR	-
1347.5	J	H	SR	-
1348.1	J	H	SR	-
1350.1	J	H	SR	-
1351.3	J	H	R	-
1354.6	J	H	R	-
1358.1	J	H	R	-
1358.4	MB	H	R	-
1358.9	MB	H	R	-
1359.8	J	H	R	-
1361.5	J	H	S	-
1362.7	J	H	S	-
1365.9	J	H	S	-
1366.2	J	H	S	-
1369.7	J	H	S	-
1371.7	J	H	R	-
1372.5	J	H	R	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)
1380
1385
1390
1395
1400
1405
1410
1415

Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)
	1376.4						
	1378						
49	1381	100.0	97.3	0.53	MH	F	10.5
	1392.2						
	1393.6						
	1400						
50	1410.6	98.7	98.7	0.7	MH	F	

Profile

Elev (ft)
-795
-800
-805
-810
-815
-820
-825
-830

Subsurface Profile

Gray Amorphous to Fine Grained SHALEY DOLOMITE
Thinly Bedded
Occasional Black Shale Zones

Light Grayish Green DOLOMITIC SHALE
Occasional Anhydrite Nodules

Vertical Red Halite Vein 1380.4-1380.8
Gray Amorphous to Fine Grained SHALEY DOLOMITE
Laminated to Thinly Bedded
Occasional Anhydrite Nodules

Vertical Orange Halite Vein 1381.0-1382.2
Anhydrite Interbed

Gray, Green, Blue-Gray, Tan Amorphous to Fine Grained DOLOMITE and DOLOMITIC LIMESTONE
Laminated Bedding

Tan and Gray DOLOMITE
Slightly Pitted and Vuggy
Vertical, Clear Halite Veins 1391.2 to 1392.7

Tan to Gray Amorphous DOLOMITE
Thinly Bedded Pitted/Vuggy

Massive Interbedded ANHYDRITE

Anhydrite Interbed

Anhydrite Interbed

Vertical Orange Halite Veins 1406.5-1407.2

Anhydrite Interbed
Tan to Gray Amorphous DOLOMITE
Thinly Bedded Pitted/Vuggy
Vertical Clear Salt Veins 1391.2-1392.7

SALINA GROUP - B UNIT (B-SALT) TOP EL -828.8
Tan and Brown HALITE
Massive Occasional to Frequent DOLOMITE Inclusions and Stringers

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
1376.4	J	H	S	-
1376.8	J	H	SR	-
1378.0	J	H	S	-
1379.9	J	H	SR	-
1382.0	J	H	SR	SALT
1383.3	J	H	SR	-
1384.7	J	H	S	-
1386.2	J	H	SR	-
1389.2	J	H	SR	-
1390.7	J	H	SR	-
1391.2	J	H	SR	-
1393.0	J	H	S	-
1394.0	J	H	SR	-
1395.3	J	H	S	-
1396.3	J	H	SR	-
1397.4	J	H	SR	-
1398.4	J	H	SR	-
1400.1	J	H	SR	-
1402.2	J	H	SR	-
1403.0	J	H	SR	-
1404.2	J	H	SR	-
1405.5	J	H	S	-
1407.5	J	H	SR	-
1408.6	J	H	SR	-
1410.6	J	H	SR	-
1412.3	J	H	SR	-
1415.1	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

Figure No.

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										-835	
1420											
										-840	
1425											
		1426.8									**Tan and Brown SHALE STRINGER**
										-845	
1430											Anhydrite Stringer
										-850	
1435											
										-855	
1440	51	1441	100.0	100	0.47	MH	F				**Tan and Brown HALITE** Massive Occasional to Frequent DOLOMITE Inclusions and Stringers Tan Shaley Dolomite Interbeds 1424.5-1426.8
										-860	
1445											
										-865	
		1449									**DOLOMITIC SHALE STRINGER**
1450											**Light Gray to White HALITE** Massive Bedding Occasional Shaley Dolomite Stringers
										-870	
1455											

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1417.5	J	H	SR	-
1419.9	J	H	SR	-
1422.2	J	H	SR	-
1422.8	J	H	SR	-
1424.7	J	H	SR	-
1426.9	J	H	SR	-
1429.7	J	H	SR	-
1432.0	J	H	SR	-
1435.2	J	H	S	-
1437.0	J	H	SR	-
1439.0	J	H	SR	-
1440.1	J	L	R	-
1441.2	J	L	SR	-
1445.4	J	H	S	-
1447.9	J	H	S	-
1449.0	J	H	S	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX10TB7 (TB-7)

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.7

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Elev (ft)	Subsurface Profile
									-875	
1460										
									-880	
1465										
									-885	
1470	52	1470 1470.5	100.0	100	0.3	MH	F			**DOLOMITIC SHALE STRINGER** **Light Gray to White HALITE** Massive Bedding Occasional Shaley Dolomite Stringers
1475										TB-11 Continued As Rotary Boring At 1470.5 feet.
1480										
1485										
1490										
1495										

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
1461.2	J	M	S	-
1464.8	J	H	S	-
1467.1	J	L	SR	-
1469.0	J	H	S	-
1469.8	J	H	SR	-

NOTES: Core logged by: D. Adler, H. Audet, M. Firestone, S. Gole, Z. Kiefer, J. Wahlstrom, K. Warning
Elevations noted are above mean-sea level (AMSL)
DRG - Detroit River Group

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (B))

NTH CONSULTANTS, LTD.

Project Name:	DRIC Brine Well Investigation		
Project Location:	Detroit, Michigan	Inspector	NTH
NTH Proj. No:	15-050014-12	Contractor:	Advanced and Nevis Energy Services
Drilling Date:	1/23/2007 to 4/16/2007	Driller:	Rig 8, K. Vestal, R. Ward
Core Size:		Checked By:	Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile Ground Surface Elevation : 582.9
											START OF CORING AT APPROXIMATELY 925.0
930		930.6						18.2		-345	
935		936								-350	**Dark Gray Amorphous to Fine Grained SHALE and DOLOMITIC SHALE** Frequent Anhydrite Nodules and Inclusions Occasional Anhydrite Laminae
		936.5								-355	**Green and Gray Amorphous to Fine Grained DOLOMITIC SHALE** Laminated Bedding
940 945		949.2						17.7		-360 -365	
950 955	3	955	97.7	97	0.38	MH	F			-370	**Dark Gray Amorphous to Fine Grained SHALE and DOLOMITIC SHALE** Frequent Anhydrite Nodules and Inclusions Occasional Anhydrite Laminae
960										-375	

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
926.8	J	H	S	-
928.7	J	L	SR	-
933.2	J	H	S	-
935.4	J	H	S	-
938.7	J	H	SR	-
939.7	J	H	SR	-
940.0	J	H	SR	-
944.2	J	H	SR	-
945.9	J	H	SR	-
946.3	J	H	SR	-
948.6	J	H	SR	-

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (B))

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation

Project Location: Detroit, Michigan

NTH Proj. No: 15-050014-12

Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile	Discontinuities				
											Ground Surface Elevation : 582.9	Depth (ft)	Type	Dip	Roughness	Infill
										-380						
965																
										-385						
970																
										-390						
975																
		978								-395	**Dark Gray Amorphous to Fine Grained SHALE and DOLOMITIC SHALE** Laminated to Massive Bedding Frequent Anhydrite Laminae, Inclusions and Nodules					
980																
		981.9						25.4			**White and Gray Amorphous to Fine Grained SHALEY DOLOMITE**					
		982.2								-400	**Gray DOLOMITIC SHALE** Frequent Anhydrite Nodules					
											Solution Features 983.2 to 983.7 **White and Gray Amorphous to Fine Grained SHALEY DOLOMITE**					
985	4	985	100.0	100	0	MH	F									
											White Anhydrite Speckling 985.3 to 987.4	986.4	J	H	SR	-
										-405						
990																
										-410						
												994.3	J	M	SR	-
995												995.3	J	H	SR	-
										-415						
												998.5	J	H	SR	-
1000												999.5	J	H	SR	-

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (B))

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.9

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
1005		1007.4								-420	**Gray Amorphous to Fine Grained DOLOMITE** Frequent Anhydrite Laminae
1010		1011.1						18.5		-425	**Brown Amorphous to Fine Grained DOLOMITE** Slightly Pitted with Vugs with Selenite Infilling Occasional Anhydrite Inclusions
1015	5	1015	98.6	97.5	0.51	MH	F			-430	**Gray Amorphous to Fine Grained SHALEY DOLOMITE** Massive Bedding Occasional Anhydrite Laminae, Inclusions, and Nodules
		1017.3								-435	1/2-inch stringer of DOLOMITIC SHALE **Gray Amorphous to Fine Grained SHALEY DOLOMITE** Massive Bedding Occasional Anhydrite Laminae, Inclusions and Nodules
1020		1020.3									2-inch DOLOMITIC SHALE Zone **Gray Amorphous DOLOMITE and Clear Orange HALITE** Frequent Vigs with Halite Infilling
1025 1030		1034.2								-440 -445 -450	Salina Group - F Unit (F-Salt) Top EL -437.4 **Clear to Brown HALITE** (F4 Bed) Irregular Pitting with Vugs Occasional Dolomite Laminae
1035	6	1035	100.0	100	0.15						**White to Gray SHALEY DOLOMITE** Slightly Pitted with few Halite Infilled Vugs
1040											TB-11 Continued As Rotary Boring At 1035 feet.

Discontinuities				
Depth (ft)	Type	Dip	Roughness	Infill
1003.3	J	H	SR	-
1003.8	J	H	SR	-
1004.5	J	L	SR	-
1005.1	J	L	SR	-
1005.3	J	L	SR	-
1005.9	J	L	S	-
1008.2	J	H	S	CARB
1015.3	J	H	S	SP
1022.2	J	H	S	-
1032.2	J	H	SR	-

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (A))

NTH CONSULTANTS, LTD.

Project Name:	DRIC Brine Well Investigation		
Project Location:	Detroit, Michigan	Inspector	NTH
NTH Proj. No:	15-050014-12	Contractor:	Advanced and Nevis Energy Services
Drilling Date:	1/23/2007 to 4/16/2007	Driller:	Rig 8, K. Vestal, R. Ward
Core Size:		Checked By:	Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.9**
											START OF CORING AT APPROXIMATELY 495.0
										85	
500											
		503.2						16.6		80	**Gray Amorphous to Fine Grained DOLOMITE** Massive Bedding Slight Pitting Occasional Stylolites and Anhydrite Nodules
505											
										75	
510											
										70	
515											
										65	
520											
										60	
525	1	525	84.3	82.3	1.12	MH	F	9.7			**White to Light Tan Fine Grained SANDSTONE** Occasional Carbonaceous Banding and Stylolites
										55	
530											

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
496.7	J	H	R	-
497.2	J	H	R	F
499.8	J	H	S	-
500.6	J	H	SR	F
502.0	J	H	SR	-
503.2	J	H	SR	F
506.1	J	H	SR	-
507.4	J	H	S	-
508.1	J	H	SR	-
509.0	J	H	SR	-
510.2	J	H	S	-
511.3	J	H	R	-
511.6	J	H	R	-
511.9	J	H	SR	-
512.4	J	H	SR	-
512.8	J	H	SR	-
513.8	J	H	SR	-
514.3	J	H	SR	-
515.1	J	H	R	-
515.7	J	H	SR	-
516.1	J	H	S	-
516.6	J	H	SR	F
517.0	J	H	SR	-
518.2	J	H	SR	-
518.7	J	H	SR	-
519.3	J	H	R	-
520.2	J	H	R	-
524.7	J	H	SR	-
524.8	J	L	S	-
525.4	J	H	SR	-
525.8	J	L	SR	-
526.8	J	L	S	-
527.7	J	H	SR	-
528.6	J	H	SR	-
529.6	J	H	S	-

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (A))

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.9

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
										50	
535		537									**White to Light Gray Fine Grained SANDSTONE** Massive Bedding Frequent Carbonaceous Bands
										45	
540		542.1						14.4			**Medium Gray Fine Grained DOLOMITIC SANDSTONE** Massive Bedding Frequent Carbonaceous Banding and Stylolites
										40	
545											
										35	
550	2	550.1	87.1	80.7	1.4	MH	SW				Fragmented 549.8 to 550.1◆ **White to Light Tan Fine Grained SANDSTONE** Massive Bedding Occasional Carbonaceous Banding and Stylolites
											TB-11 Continued As Rotary Boring At 550.1 feet.
555											
560											
565											
570											

Discontinuities

Depth (ft)	Type	Dip	Roughness	Infill
530.2	J	H	S	-
530.9	J	H	S	-
531.8	J	L	SR	-
532.4	J	H	S	-
532.9	J	H	SR	-
534.3	J	H	S	-
534.7	J	H	SR	CARB
535.5	J	H	S	CARB
535.7	J	H	S	CARB
537.0	J	H	R	-
537.6	J	H	SR	-
539.2	J	H	S	-
539.9	J	H	S	-
540.6	J	H	SR	-
541.7	J	H	SR	-
542.5	J	H	SR	-
542.6	J	H	SR	-
543.2	J	H	SR	-
543.6	J	H	R	-
544.2	J	H	R	-
544.9	J	H	SR	-
545.6	J	L	SR	-
546.2	J	L	SR	-
547.3	J	H	SR	-
547.8	J	H	R	-
548.2	J	L	R	-
549.1	J	H	SR	-
549.8	J	H	SR	-

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (C))

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Drilling Date: 1/23/2007 to 4/16/2007
Core Size:
Inspector: NTH
Contractor: Advanced and Nevis Energy Services
Driller: Rig 8, K. Vestal, R. Ward
Checked By: Z. Carr, P.E., C. Johnson

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile **Ground Surface Elevation : 582.9**	Discontinuities Depth (ft)	Type	Dip	Roughness	Infill
											START OF CORING AT APPROXIMATELY 1235.0	1236.7	J	L	SR	P
										-655	Note: Lithology for Run No. 7 based on bag samples collected during re-drilling using rotary methods after core sample was lost in borehole.					
1240																
										-660	**Dark Gray and Brown Amorphous DOLOMITE** with Occasional Anhydrite					
1245																
											Tan and Gray Amorphous DOLOMITE with Occasional Anhydrite					
										-665						
1250																
										-670						
1255																
										-675						
1260																
										-680	**Tan to Gray Amorphous DOLOMITE** Massive Bedding Occasional Anhydrite Nodules and Inclusions Occasional Chert Nodules Slightly Pitted with Vugs with Anhydrite Infilling					
	7	1264	6.0			MH	F	9.7								
1265											**Tan to Gray Amorphous SHALEY DOLOMITE** Massive Bedding Occasional Anhydrite Nodules and Inclusions Occasional Styolites					
	8	1267	86.7	86.6	0	MH	F									
										-685						
1270																

NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.
Run 7 Recovery Low - Lost Sample in Borehole

LOG OF CORE BORING NO:
DRICX11TB11 (TB-11 (C))

NTH CONSULTANTS, LTD.

Project Name: DRIC Brine Well Investigation
Project Location: Detroit, Michigan
NTH Proj. No: 15-050014-12
Checked By: Z. Carr, P.E., C. Johnson

Ground Surface Elevation : 582.9

Depth (ft)	Run No.	Depth (ft)	Recovery (%)	RQD	Fractures/Foot	Hardness	Weathering	Unc Comp (ksi)	Profile	Elev (ft)	Subsurface Profile
1275		1275								-690	**Gray Amorphous SHALEY DOLOMITE** Frequent Carbonaceous Bands
1280		1279.6				LH		17.1		-695	**Intermittent Thin, Horizontal Layers of Dark Gray DOLOMITIC SHALE and Gray SHALEY DOLOMITE** Anhydrite Inclusions
1285 1290		1291.2				LH				-700 -705	**White HALITE** with Trace Anhydrite (D3 Bed) Frequent Dolomite Inclusions Occasional Vugs with Halite infilling
		1294				LH		8.2		-710	**Brown and Gray Amorphous to Fine Grained DOLOMITE** Truncated Laminations
1295	9	1296	100.0	100	0.17	MH	F				**Brown and Gray Amorphous to Fine Grained SHALEY DOLOMITE**
1300 1305 1310											TB-11 Continued As Rotary Boring At 1296 feet.

Discontinuities

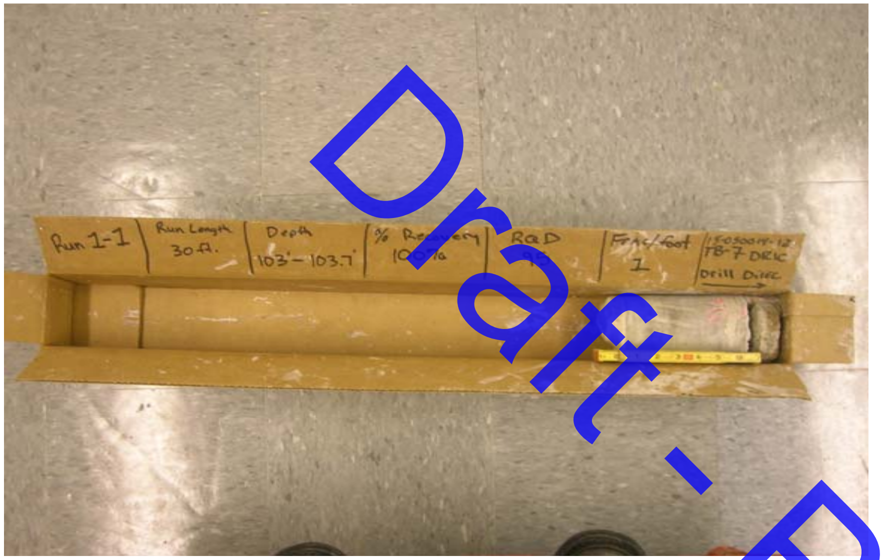
Depth (ft)	Type	Dip	Roughness	Infill
1270.5	J	H	S	CARB
1271.1	J	H	S	CARB
1273.0	J	H	S	CARB
1274.8	J	H	S	CARB
1286.5	J	H	SR	CARB

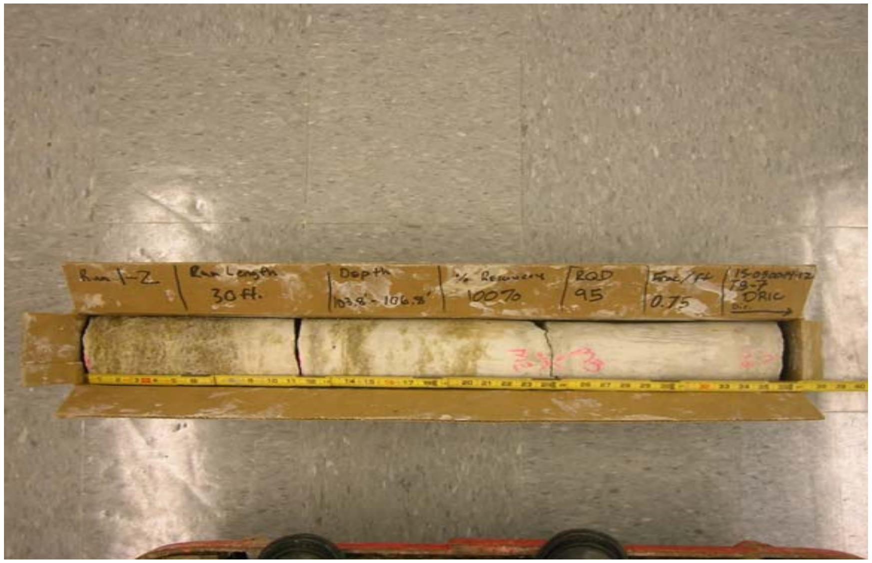
NOTES: Core Sample Logged By: D. Adler, M. Firestone, S. Gole, K. Warning
TB-11 was primarily rotary bored with selected zones of core boring.
Run 7 Recovery Low - Lost Sample in Borehole

LOG OF CORE BORING ROCK CORE LOGS.GPJ NTH CORE.GDT 9/18/07

Appendix D

Detroit River International Crossing Study
Photographs of Rock Cores





Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-1	30.0	103.0 – 103.7	100.0	95.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-2	30.0	103.8–106.8	100.0	95.0	0.75

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-3	30	106.8-109.9	100	95.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-4	30.0	110.0-113.0	100.0	95.0	1.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-5	30.0	113.0 – 116.0	100.0	95.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-6	30.0	116.0–119.0	100.0	95.0	1

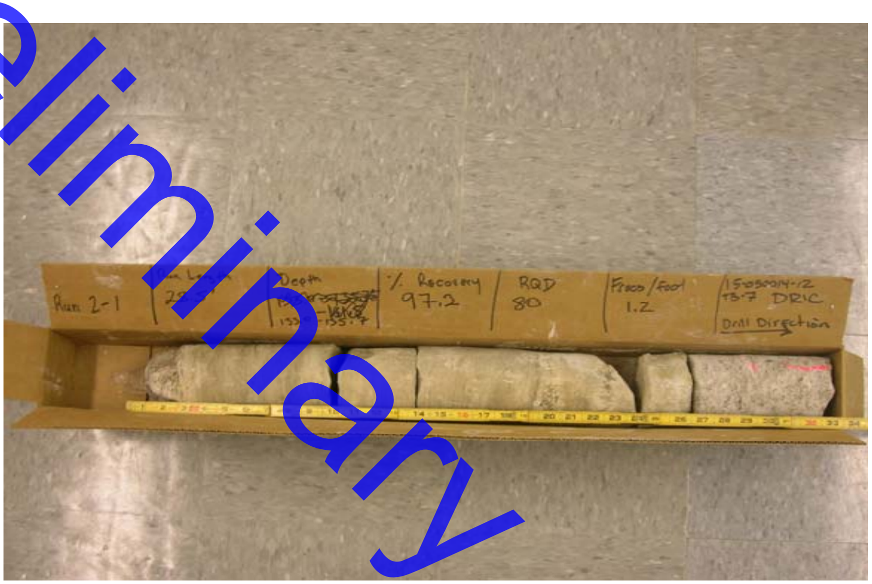
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-7	30.0	119.0 – 121.8	100.0	95.0	0.75

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-8	30.0	122.0–125.0	100.0	95.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-9	30.0	125.0 – 127.3	100.0	95.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-10	30.0	127.3–130.0	100.0	95.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	1-11	30.0	130.0 – 133.0	100.0	95.0	0



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-1	28.5	133.0–135.7	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-2	28.5	135.7–138.7	97.2	80.0	1.2

06.12.2007

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-3	28.5	138.7–141.7	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-4	28.5	141.7–144.7	97.2	80.0	1.2

06.12.2007

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-5	28.5	144.7–147.4	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-6	28.5	147.4–150.2	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-7	28.5	150.2–153.1	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-8	28.5	153.1–155.9	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-9	28.5	155.9–158.6	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	2-10	28.5	158.6–161.5	97.2	80.0	1.2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-1	30.0	161.5–163.3	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-2	30.0	163.3–166.0	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-3	30.0	166.0–169.1	100	96.0	1

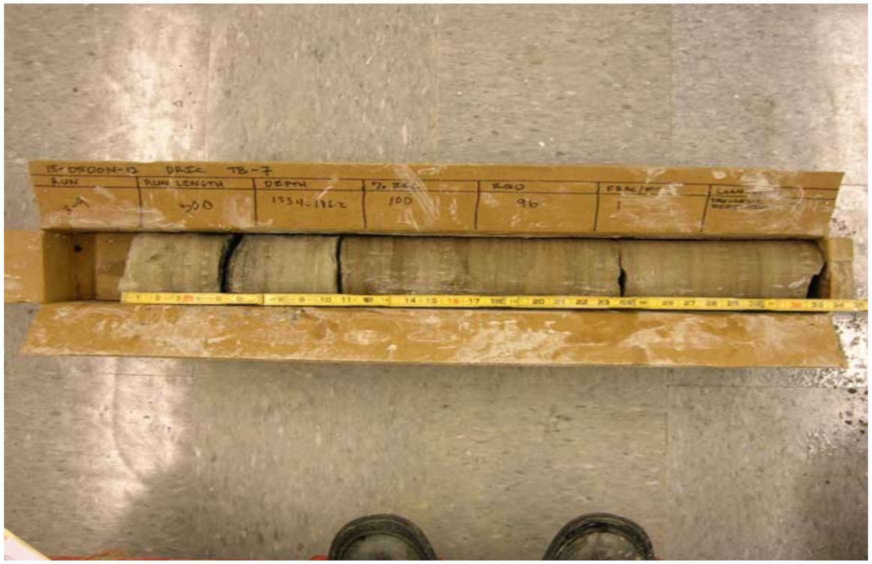
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-4	30.0	169.1–172.0	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-5	30.0	172.0–175.7	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-6	30.0	175.7–177.8	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-7	30.0	177.8–180.5	100	96.0	1

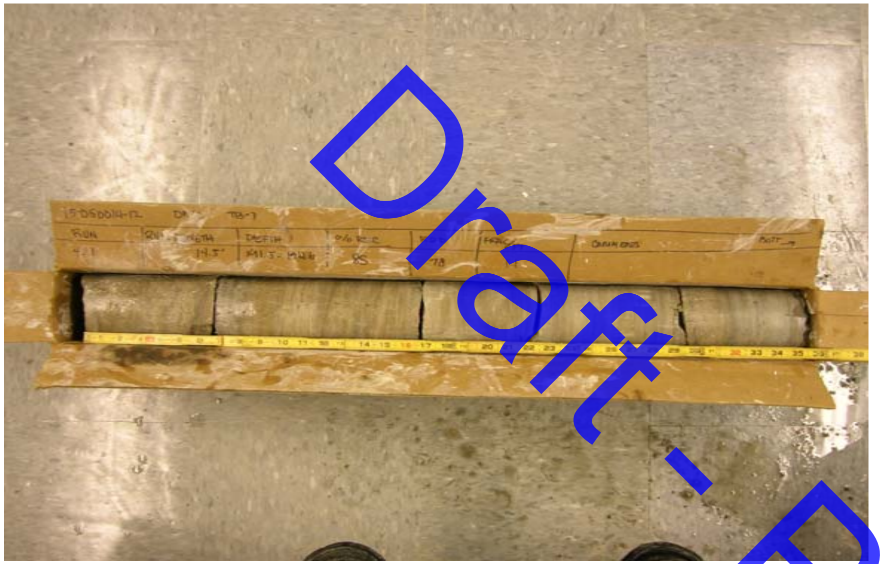
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-8	30.0	180.5–183.4	100	96.0	1



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-9	30.0	183.4–186.2	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-10	30.0	186.2–188.8	100	96.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	3-11	30.0	188.8–191.5	100	96.0	1



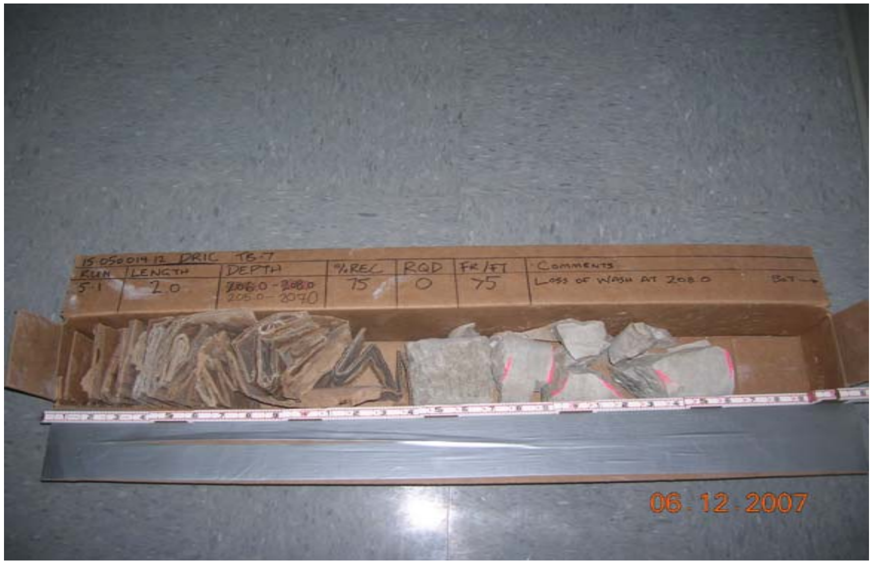
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	4-1	14.5	191.5–194.6	85.0	78.0	1.1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	4-2	14.5	194.6–197.5	85.0	78.0	1.1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	4-3	14.5	197.5–200.3	85.0	78.0	1.1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	4-4	14.5	200.3–203.3	85.0	78.0	1.1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	4-5	14.5	203.3–206.0	85.0	78.0	1.1



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	5-1	2.0	205.0 – 207.0	75.0	0	>5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-1	26.5	207.0 – 210.0	96.0	80.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-2	26.5	211.1–213.9	96.0	80.0	1.0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-3	26.5	213.9-216.4	96.0	80.0	1.0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-4	26.5	216.4–217.9	96.0	80.0	1.0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-5	26.5	217.9–220.6	96.0	80.0	1.0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-6	26.5	220.6-223.1	96.0	80.0	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-7	26.5	223.1-225.6	96.0	80.0	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-8	26.5	225.6-228.2	96.0	80.0	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-9	26.5	228.2-230.8	96.0	80.0	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	6-10	26.5	230.8-232.5	96.0	80.0	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-1	30.0	233.0-235.6	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-2	30.0	235.6-238.6	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-3	30.0	238.6-241.6	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-4	30.0	241.6-244.1	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-5	30.0	244.1-246.6	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-6	30.0	246.6-249.7	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-7	30.0	249.7-252.2	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-8	30.0	252.2-254.8	91.0	87.0	1

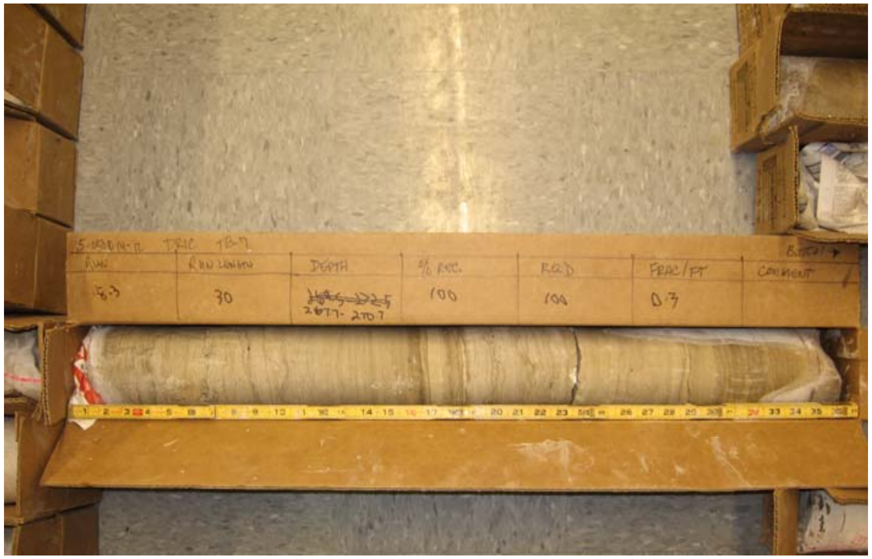
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-9	30.0	254.8-257.6	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-10	30.0	257.6-260.1	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	7-11	30.0	260.1-263.0	91.0	87.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-1	30.0	263.0-266.4	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-2	30.0	266.4-267.7	100.0	100.0	0.3



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-3	30.0	267.7-270.7	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-4	30.0	270.7-273.7	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-5	30.0	273.7-276.4	100.0	100.0	0.3

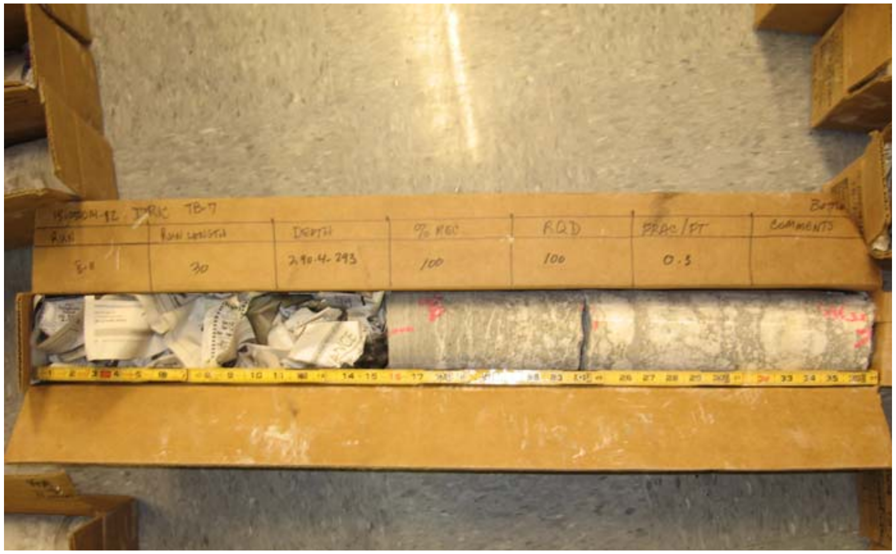
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-6	30.0	276.4-279.1	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-7	30.0	279.1-282.2	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-8	30.0	282.2-285.0	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-9	30.0	285.0-287.4	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-10	30.0	287.4-290.4	100.0	100.0	0.3



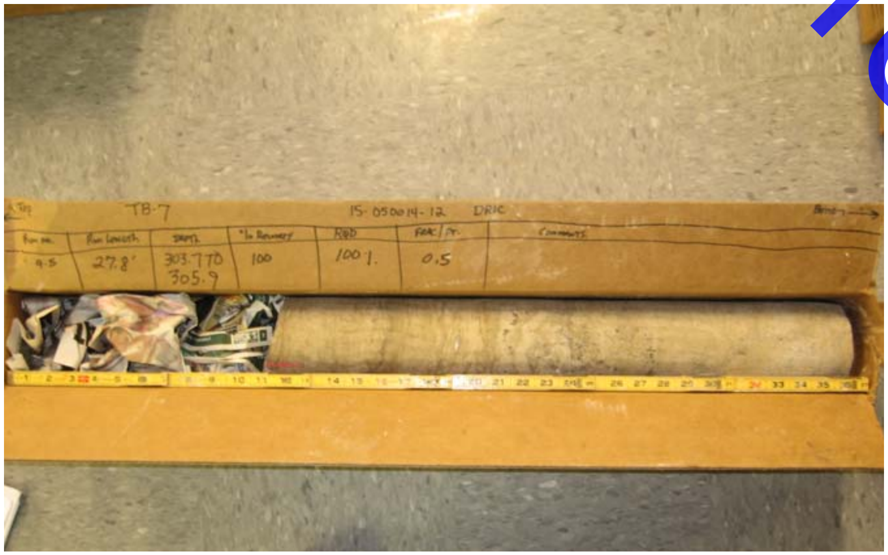
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	8-11	30.0	290.4-293.0	100.0	100.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-1	27.8	293.0-296.0	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-2	27.8	296.0-298.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-3	27.8	298.9-301.8	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-4	27.8	301.8-303.7	100.0	100.0	0.5



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-5	27.8	303.7-305.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-6	27.8	305.9-308.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-7	27.8	308.6-311.3	100.0	100.0	0.5

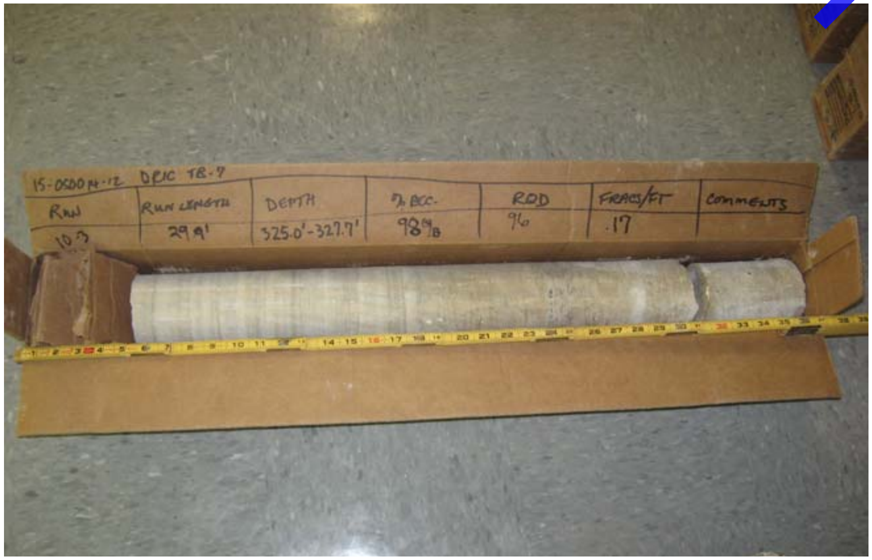
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-8	27.8	311.3-314.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-9	27.8	314.6-317.7	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	9-10	27.8	317.7-320.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-1	29.9	320.6-322.2	98.0	96.0	0.17

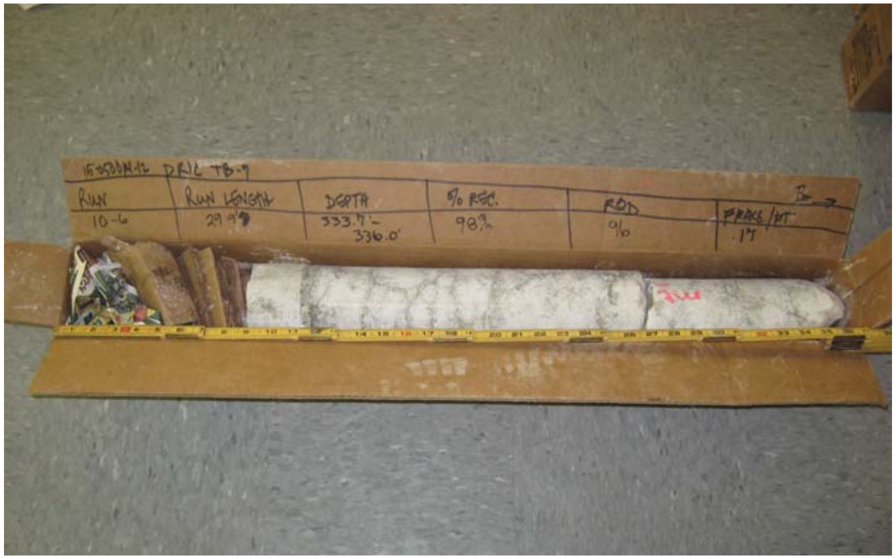
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-2	29.9	322.2-325.0	98.0	96.0	0.17



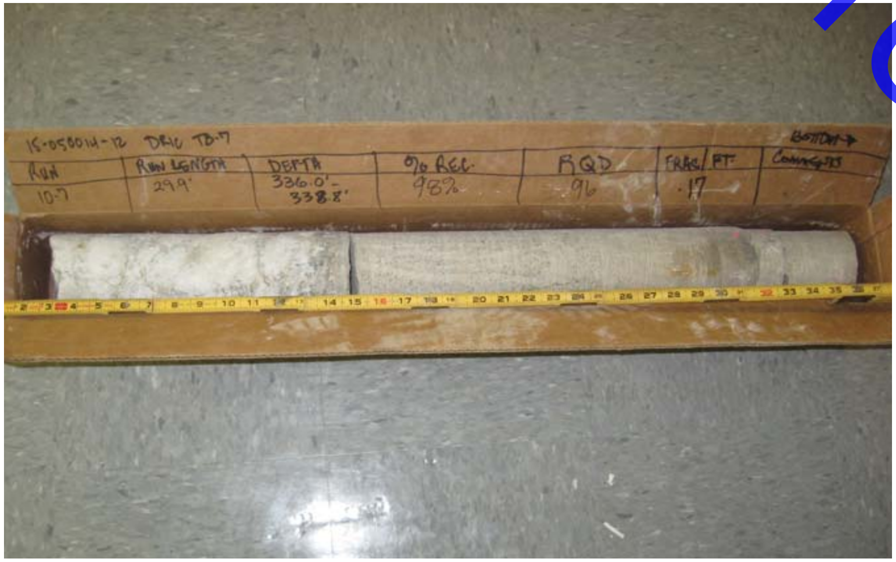
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-3	29.9	325.0-327.7	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-4	29.9	327.7-330.7	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-5	29.9	330.7-333.7	98.0	96.0	0.17



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-6	29.9	333.7-336.0	98.0	96.0	0.17



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-7	29.9	336.0-338.8	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-8	29.9	338.8-341.8	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-9	29.9	341.8-344.7	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-10	29.9	344.7-347.7	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	10-11	29.9	347.7-350.5	98.0	96.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-1	30.0	350.5-352.5	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-2	30.0	352.5-355.3	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-3	30.0	355.3-358.3	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-4	30.0	358.3-361.1	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-5	30.0	361.1-363.9	100.0	100.0	0.4

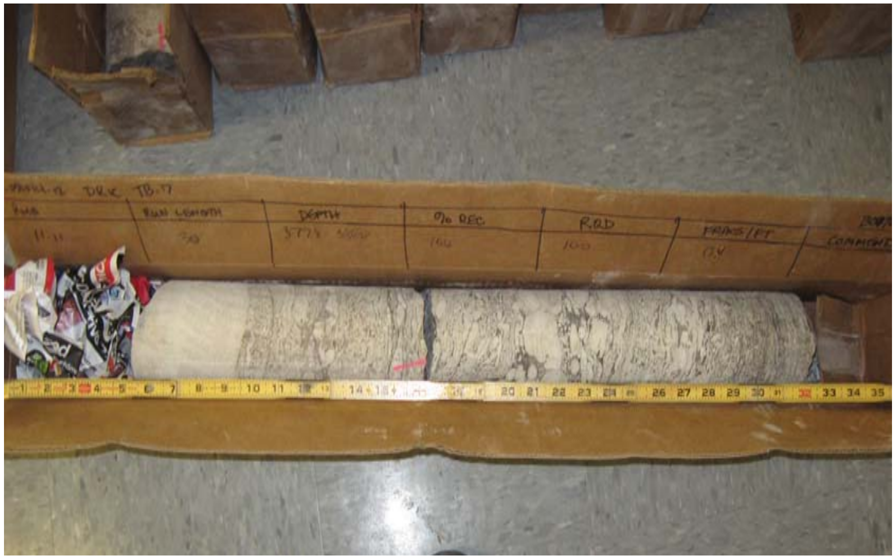
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-6	30.0	363.9-366.5	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-7	30.0	366.5-369.2	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-8	30.0	369.2-372.0	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-9	30.0	372.0-374.9	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-10	30.0	374.9-377.8	100.0	100.0	0.4



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	11-11	30.0	377.8-380.0	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	12-1	4.5	380.0-381.6	100.0	100.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	12-2	4.5	381.6-384.0	100.0	100.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-1	29.0	384.0-386.9	100.0	99.0	0.9

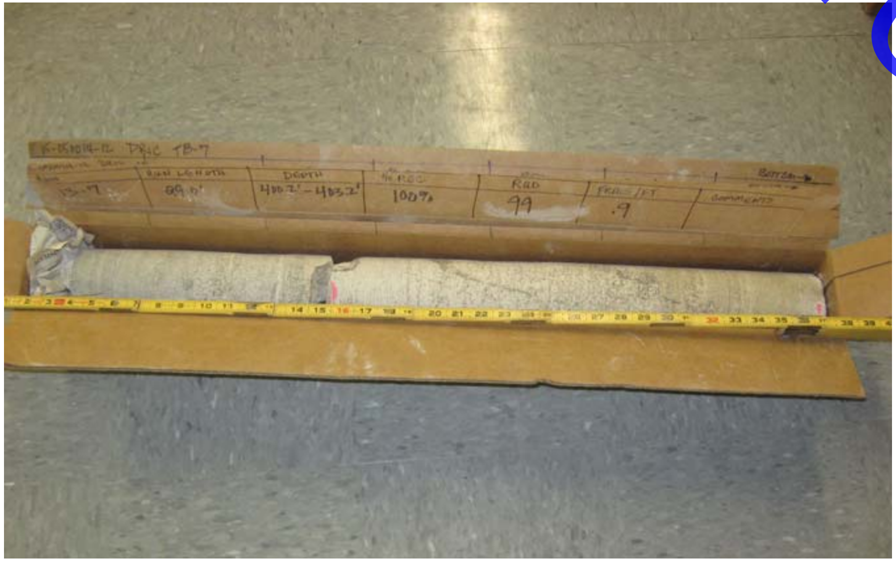
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-2	29.0	386.9-389.6	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-3	29.0	389.6-392.5	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-4	29.0	392.5-394.8	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-5	29.0	394.8-397.7	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-6	29.0	397.7-400.2	100.0	99.0	0.9



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-7	29.0	400.2-403.2	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-8	29.0	403.2-406.0	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-9	29.0	406.0-408.5	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-10	29.0	408.5-410.8	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	13-11	29.0	410.8-413.0	100.0	99.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-1	30.0	416.0-418.7	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-2	30.0	418.7-421.1	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-3	30.0	421.1-424.0	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-4	30.0	424.0-426.9	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-5	30.0	426.9-429.6	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-6	30.0	429.6-432.6	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-7	30.0	432.6-435.5	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-8	30.0	435.5-438.2	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-9	30.0	438.2-441.0	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-10	30.0	441.0-443.7	100.0	90.3	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	14-11	30.0	443.7-446.0	100.0	90.3	1.3

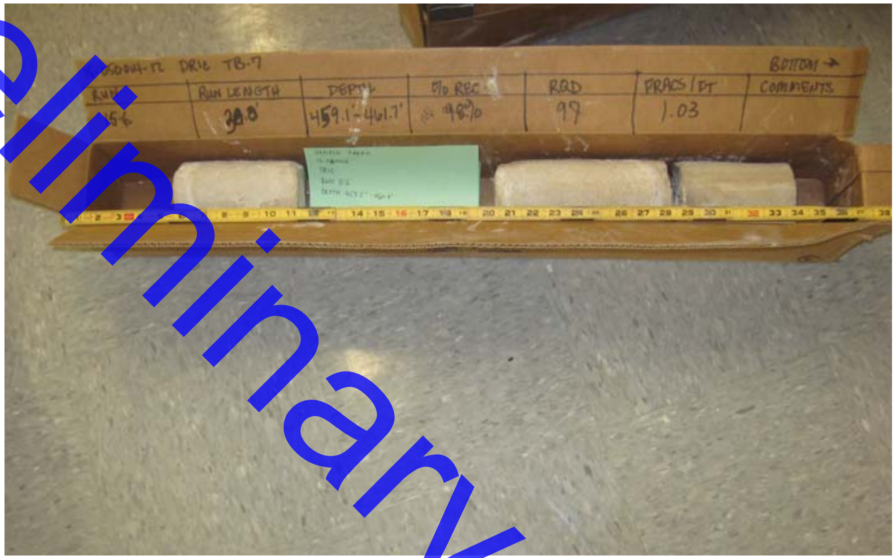
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-1	30.0	446.0-448.6	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-2	30.0	448.6-451.1	100.0	97.0	1.03

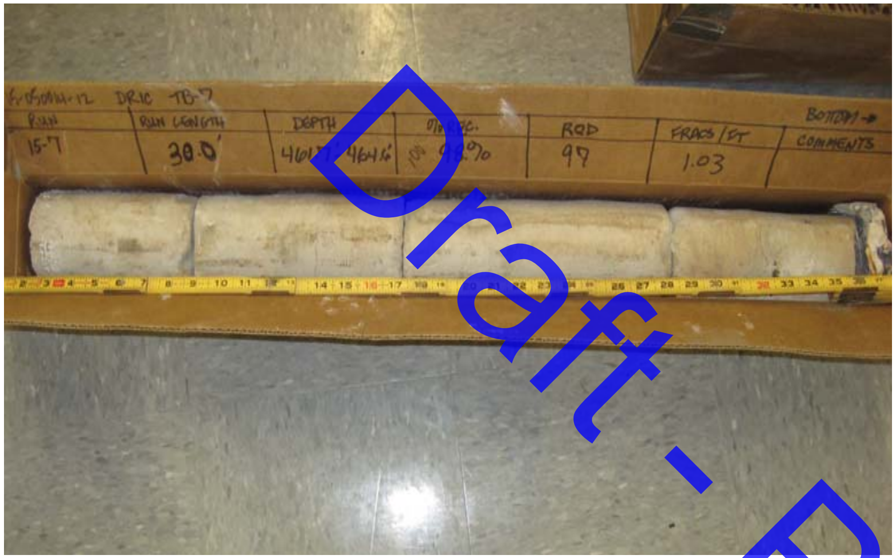
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-3	30.0	451.1-453.8	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-4	30.0	453.8-456.3	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-5	30.0	456.3-459.1	100.0	97.0	1.03



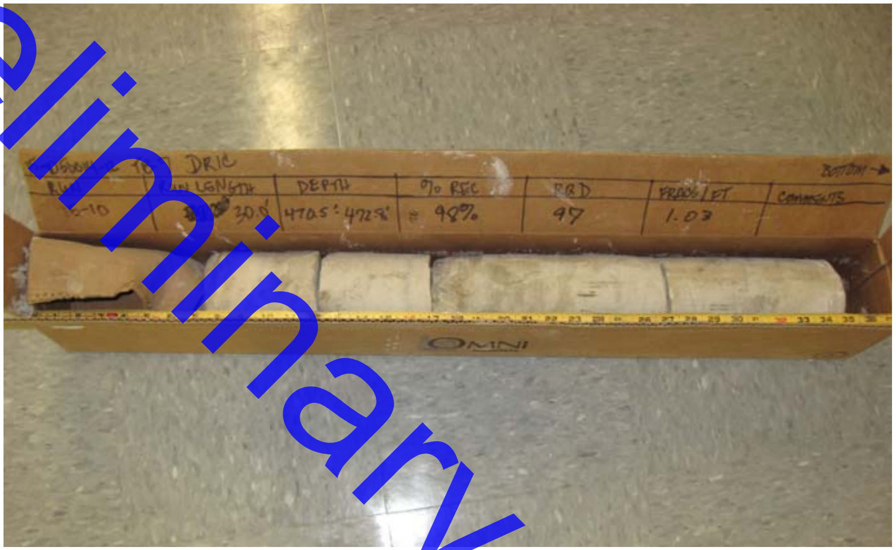
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-6	30.0	459.1-461.7	100.0	97.0	1.03



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-7	30.0	461.7-464.6	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-8	30.0	464.6-467.5	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-9	30.0	467.5-470.5	100.0	97.0	1.03



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-10	30.0	470.6-472.8	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	15-11	30.0	472.8-476.0	100.0	97.0	1.03

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-1	30.0	476.0-477.1	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-2	30.0	477.1-479.8	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-3	30.0	479.8-482.7	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-4	30.0	482.7-485.3	99.0	96.0	1.3

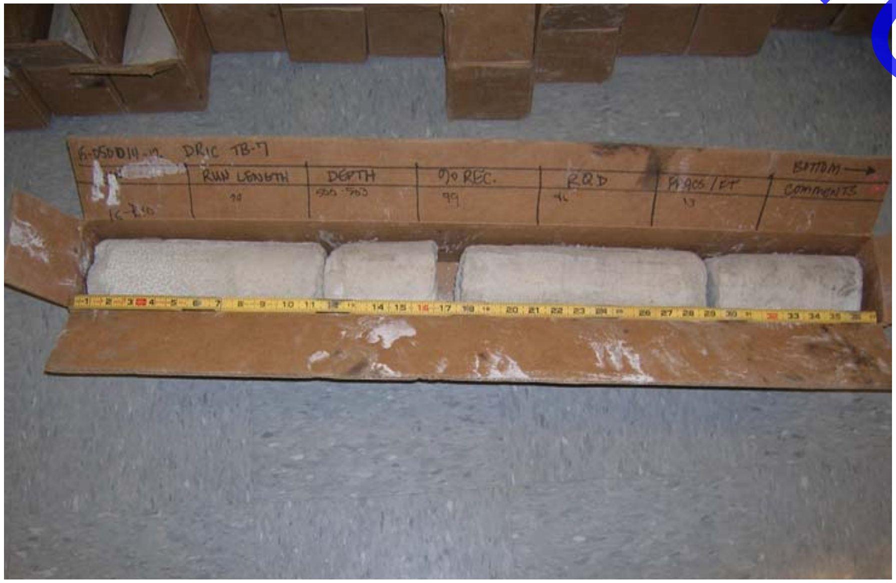
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-5	30.0	485.3-488.3	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-6	30.0	488.3-491.1	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-7	30.0	491.1-494.2	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-8	30.0	494.2-496.9	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-9	30.0	496.9-500.0	99.0	96.0	1.3



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-10	30.0	500.0-503.0	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	16-11	30.0	503.0-506.0	99.0	96.0	1.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-1	30.0	506.0-508.1	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-2	30.0	508.1-510.5	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-3	30.0	510.5-513.3	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-4	30.0	513.3-516.1	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-5	30.0	516.1-519.1	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-6	30.0	519.1-522.0	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-7	30.0	522.0-525.1	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-8	30.0	525.1-527.6	100.0	99.0	1

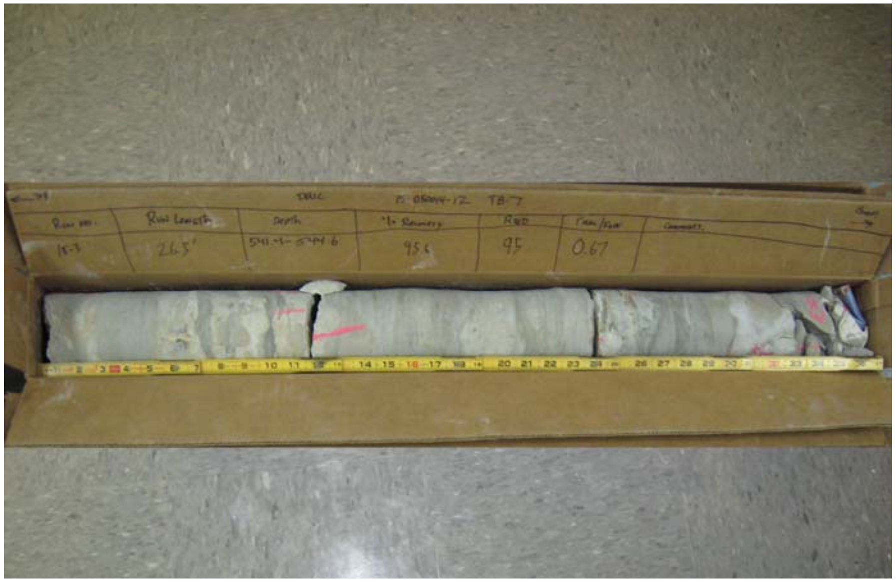
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-9	30.0	527.6-530.3	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-10	30.0	530.6-533.0	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	17-11	30.0	533.0-536.0	100.0	99.0	1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-1	26.5	536.0-538.5	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-2	26.5	538.5-541.4	95.6	95.0	0.67



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-3	26.5	541.4-544.6	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-4	26.5	544.6-547.5	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-5	26.5	547.5-550.3	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-6	26.5	550.3-553.2	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-7	26.5	553.2-555.7	95.6	95.0	0.67

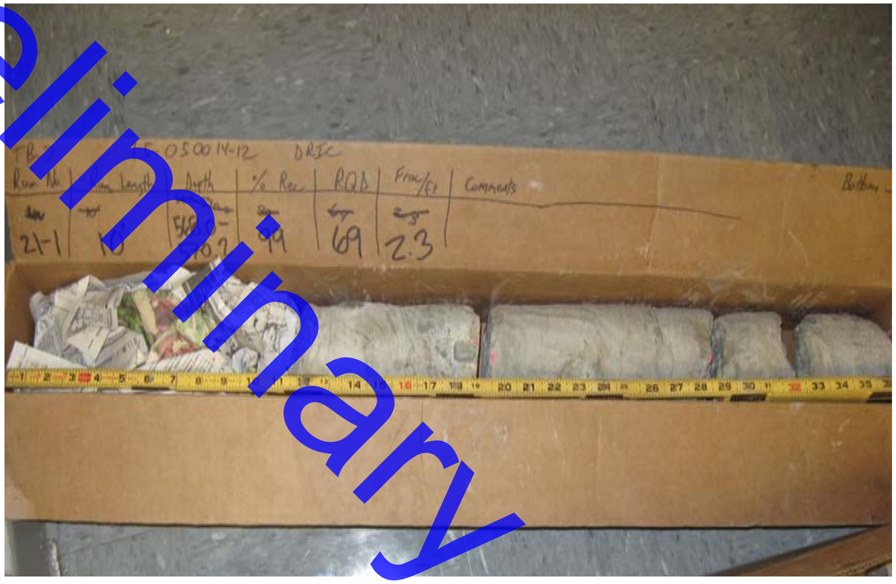
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-8	26.5	555.7-558.5	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	18-9	26.5	558.5-561.3	95.6	95.0	0.67

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	19-1	4.5	562.5-564.2	100.0	86.7	1.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	19-2	4.5	564.2-567.0	100.0	86.7	1.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	20-1	1.0	567.0-568.0	50.0	50.0	0



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	21-1	10.0	568.0-570.2	99.0	69.0	2.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	21-2	10.0	570.2-572.7	99.0	69.0	2.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	21-3	10.0	572.7-575.4	99.0	69.0	2.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	21-4	10.0	575.4-578.0	99.0	69.0	2.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-1	28.0	578.0-579.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-2	28.0	579.6-582.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-3	28.0	582.6-585.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-4	28.0	585.6-588.6	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-5	28.0	588.6-591.2	100.0	100.0	0.5

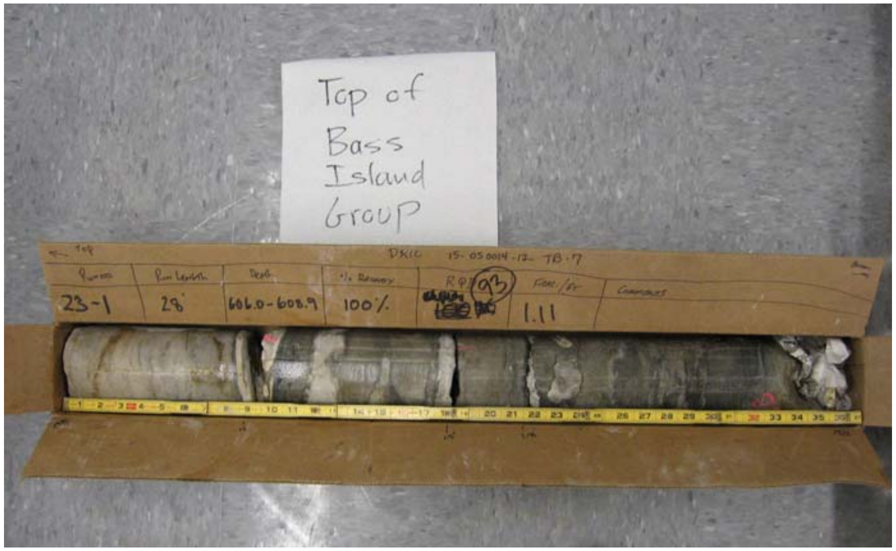
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-6	28.0	591.2-593.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-7	28.0	593.9-596.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-8	28.0	596.9-599.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-9	28.0	599.9-602.9	100.0	100.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	22-10	28.0	602.9-606.0	100.0	100.0	0.5

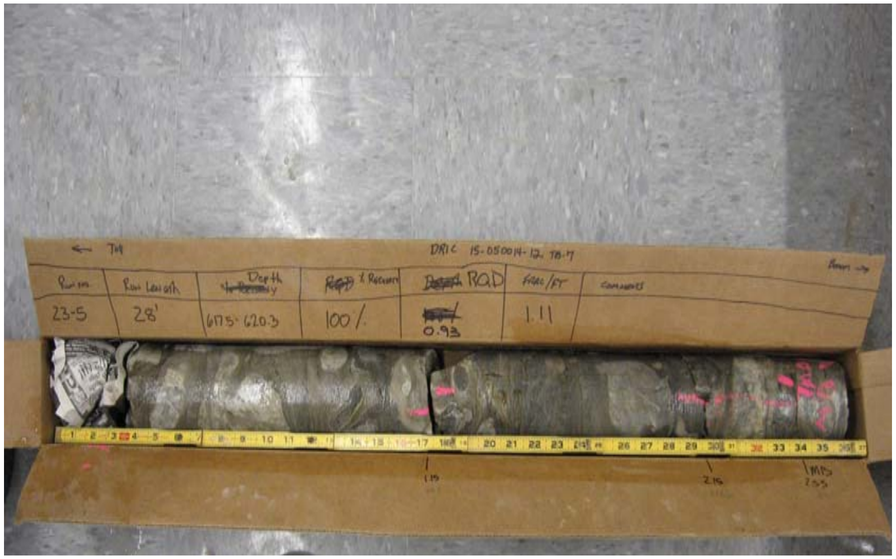


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-1	28.0	606.0-608.9	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-2	28.0	608.9-611.3	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-3	28.0	611.3-614.4	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-4	28.0	614.4-617.3	100.0	93.0	1.11



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-5	28.0	617.3-620.3	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-6	28.0	620.3-623.2	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-7	28.0	623.2-626.1	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-8	28.0	626.1-628.8	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-9	28.0	628.8-631.4	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	23-10	28.0	631.4-634.0	100.0	93.0	1.11

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-1	29.6	634.0-636.6	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-2	29.6	636.6-639.7	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-3	29.6	639.7-642.0	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-4	29.6	642.0-645.0	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-5	29.6	645.0-648.0	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-6	29.6	648.0-650.7	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-7	29.6	650.7-653.4	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-8	29.6	653.4-655.9	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-9	29.6	655.9-658.9	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-10	29.6	658.9-660.8	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	24-11	29.6	660.8-663.6	100.0	92.6	0.98

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-1	29.0	664.0-665.6	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-2	29.0	665.6-668.6	98.0	98.0	0.4

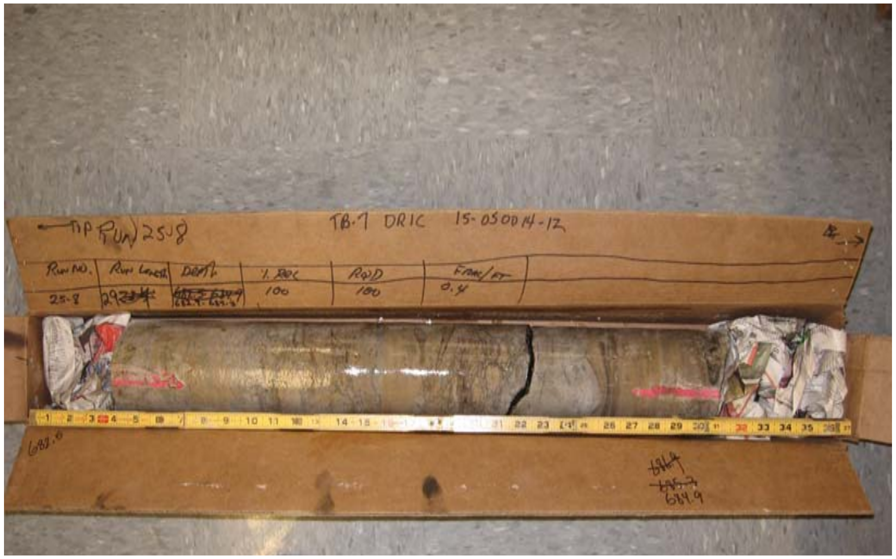
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-3	29.0	668.6-671.6	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-4	29.0	671.6-674.6	98.0	98.0	0.4

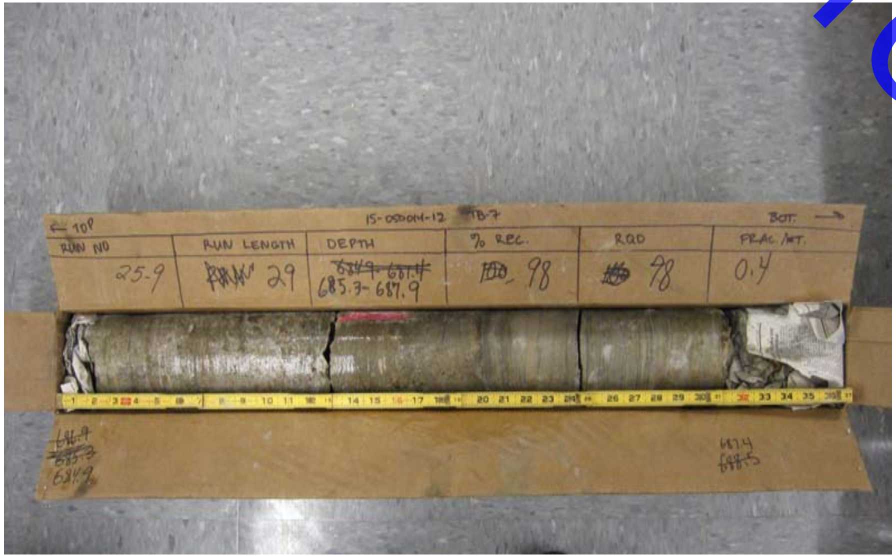
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-5	29.0	674.6-677.2	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-6	29.0	677.2-680.1	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-7	29.0	680.1-682.9	98.0	98.0	0.4



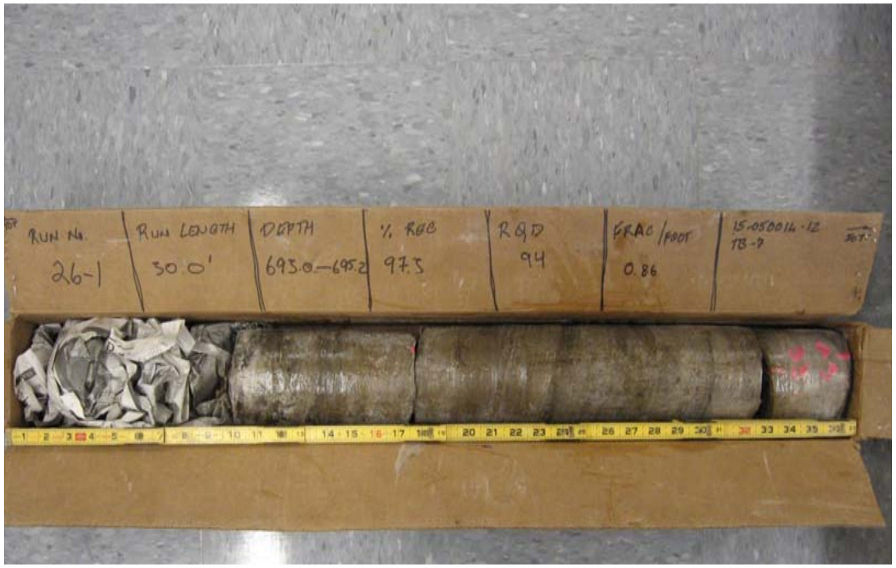
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-8	29.0	682.9-685.3	98.0	98.0	0.4



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-9	29.0	685.3-687.9	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-10	29.0	687.9-689.4	98.0	98.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	25-11	29.0	689.4-693.0	98.0	98.0	0.4

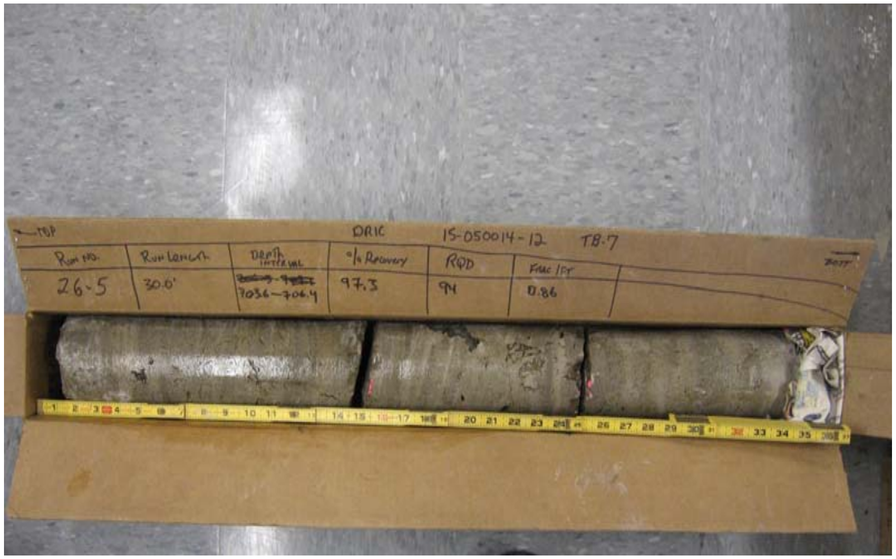


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-1	30.0	693.0-695.2	97.3	94.0	0.86

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-2	30.0	695.3-698.0	97.3	94.0	0.86

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-3	30.0	698.0-701.0	97.3	94.0	0.86

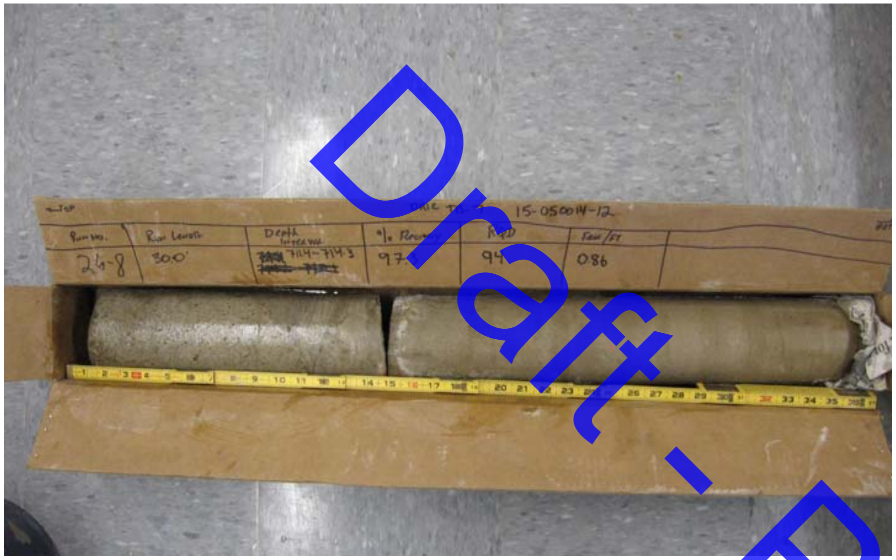
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-4	30.0	701.0-703.6	97.3	94.0	0.86



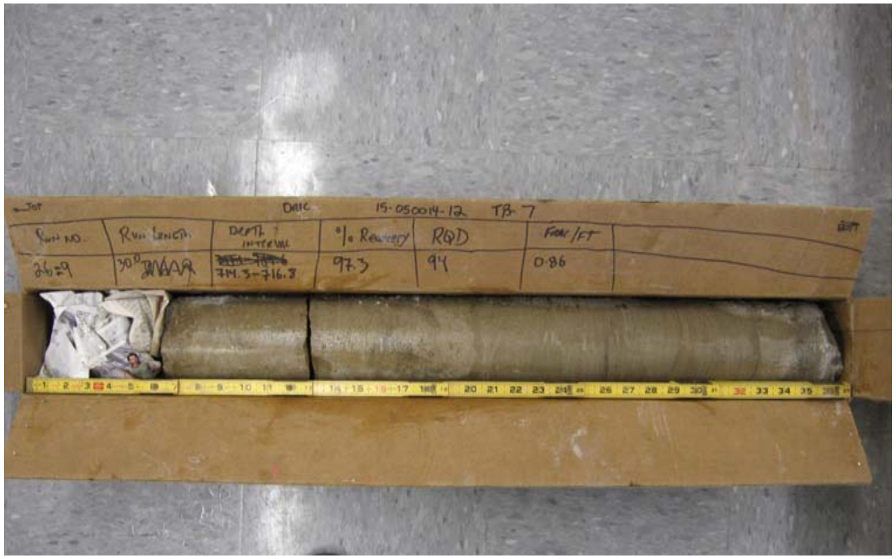
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-5	30.0	703.6-706.4	97.3	94.0	0.86

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-6	30.0	706.4-709.2	97.3	94.0	0.86

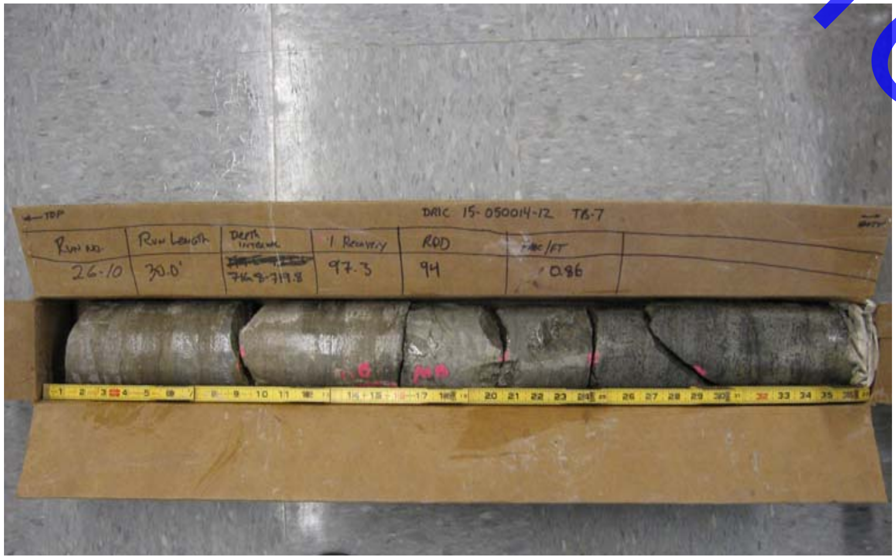
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-7	30.0	709.2-711.4	97.3	94.0	0.86



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-8	30.0	711.4-714.3	97.3	94.0	0.86

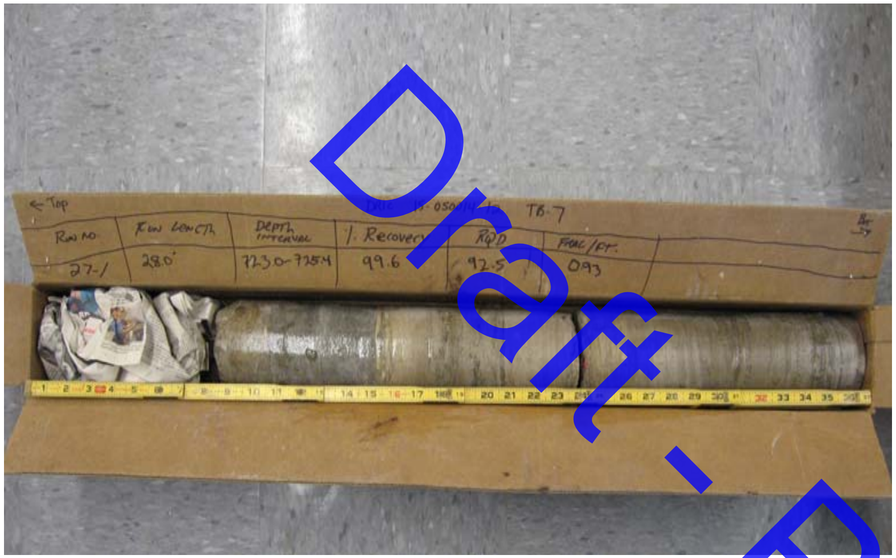


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-9	30.0	714.3-716.8	97.3	94.0	0.86

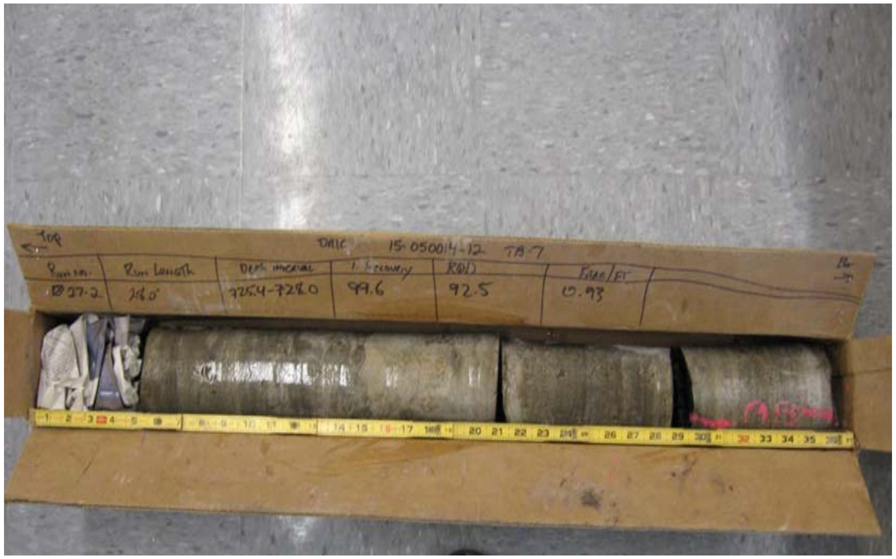


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-10	30.0	716.8-719.8	97.3	94.0	0.86

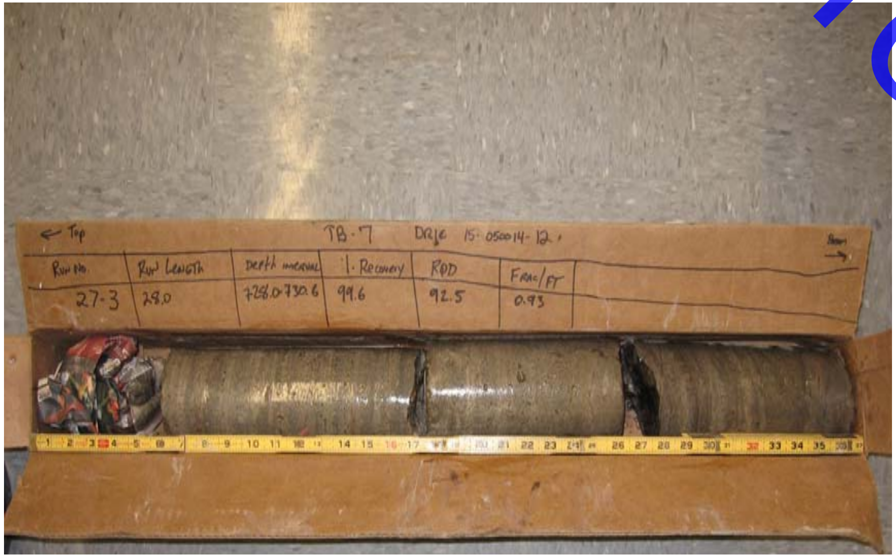
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	26-11	30.0	719.8-722.2	97.3	94.0	0.86



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-1	28.0	722.2-725.4	99.6	92.5	0.93



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-2	28.0	725.4-728.0	99.6	92.5	0.93

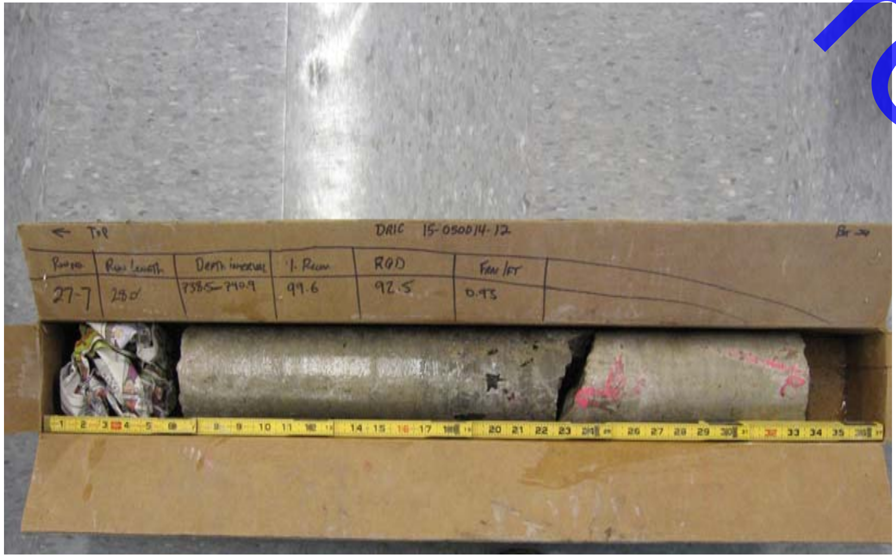


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-3	28.0	728.0-730.6	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-4	28.0	730.6-733.5	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-5	28.0	733.5-735.9	99.6	92.5	0.93

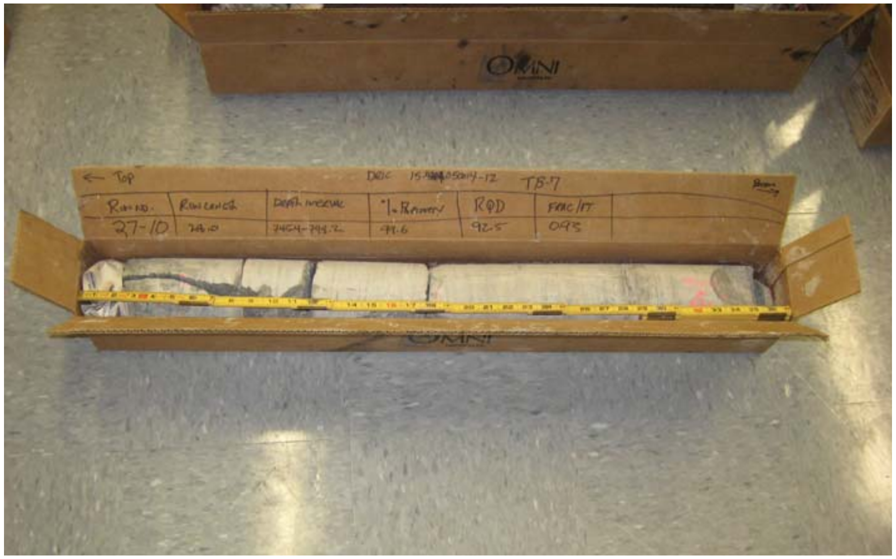
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-6	28.0	735.9-738.5	99.6	92.5	0.93



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-7	28.0	738.5-740.9	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-8	28.0	740.9-743.5	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-9	28.0	743.5-745.4	99.6	92.5	0.93



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-10	28.0	745.4-748.2	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	27-11	28.0	748.2-750.9	99.6	92.5	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-1	30.0	751.0-753.4	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-2	30.0	753.4-756.0	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-3	30.0	756.0-758.5	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-4	30.0	758.5-761.2	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-5	30.0	761.2-762.9	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-6	30.0	762.9-765.2	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-7	30.0	765.2-767.2	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-8	30.0	767.2-769.9	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-9	30.0	769.9-772.1	100.0	93.5	0.9

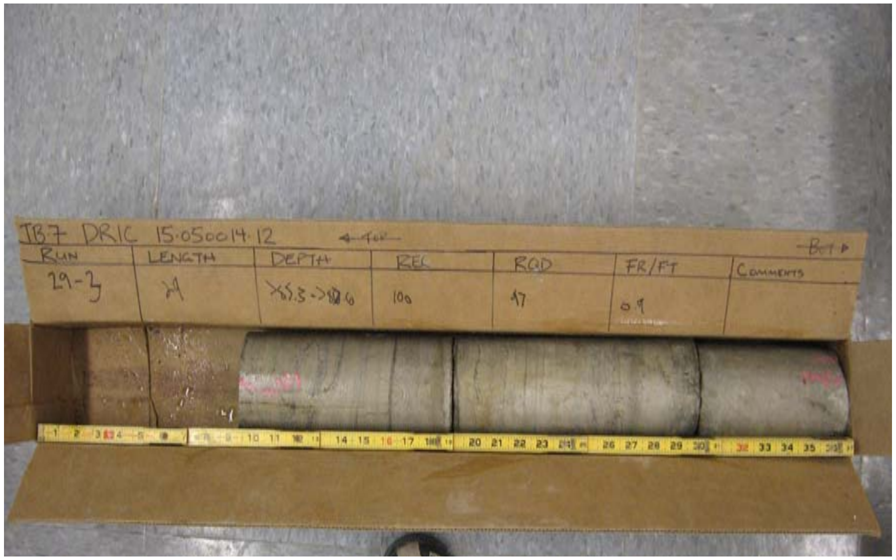
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-10	30.0	772.1-775.0	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-11	30.0	775.0-777.9	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	28-12	30.0	777.9-781.0	100.0	93.5	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-1	29.0	781.0-783.0	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-2	29.0	783.0-785.3	100.0	97.0	0.9

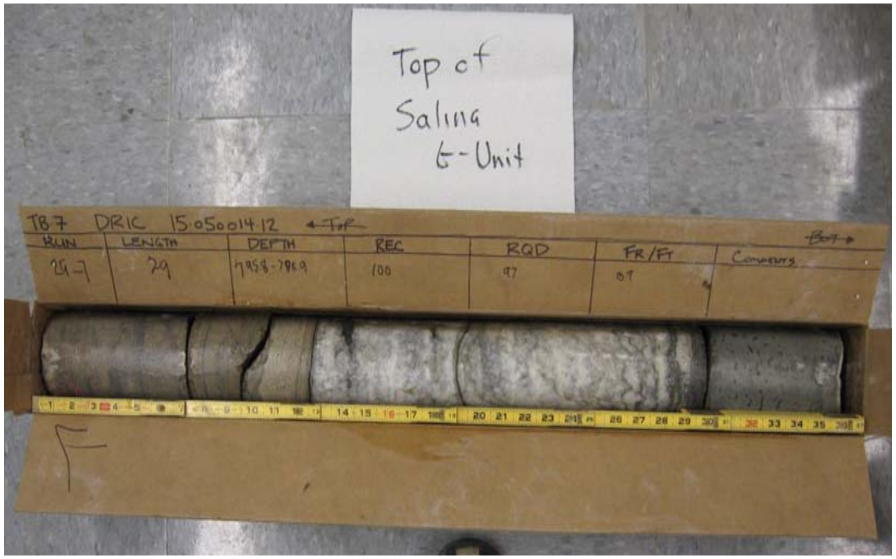


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-3	29.0	785.3-787.6	100.0	97.0	0.9

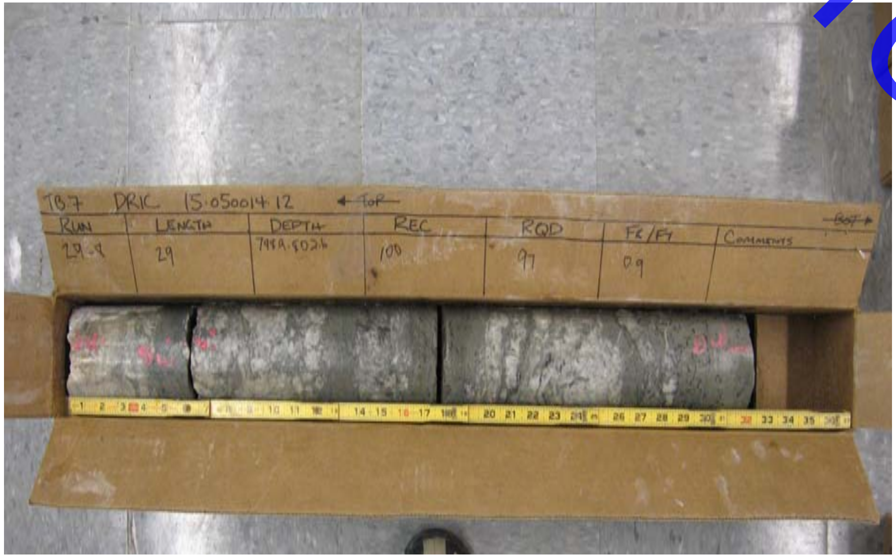
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-4	29.0	787.6-790.2	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-5	29.0	790.2-793.0	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-6	29.0	793.0-795.8	100.0	97.0	0.9



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-7	29.0	795.8-798.9	100.0	97.0	0.9



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-8	29.0	798.9-802.6	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-9	29.0	802.6-805.3	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-10	29.0	805.3-808.2	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	29-11	29.0	808.2-811.0	100.0	97.0	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-1	29.0	811.0-813.5	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-2	29.0	813.5-816.5	100.0	97.6	0.97

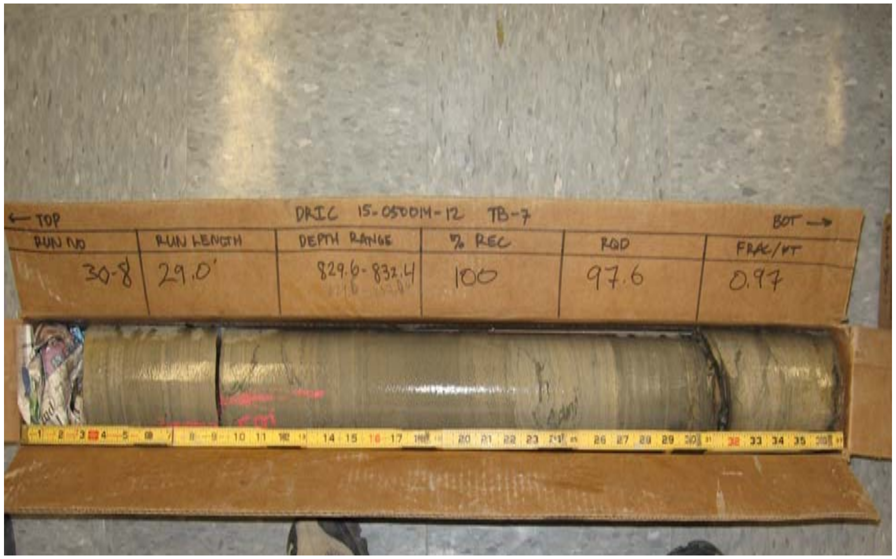
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-3	29.0	816.5-819.0	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-4	29.0	819.0-821.5	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-5	29.0	821.5-824.2	100.0	97.6	0.97

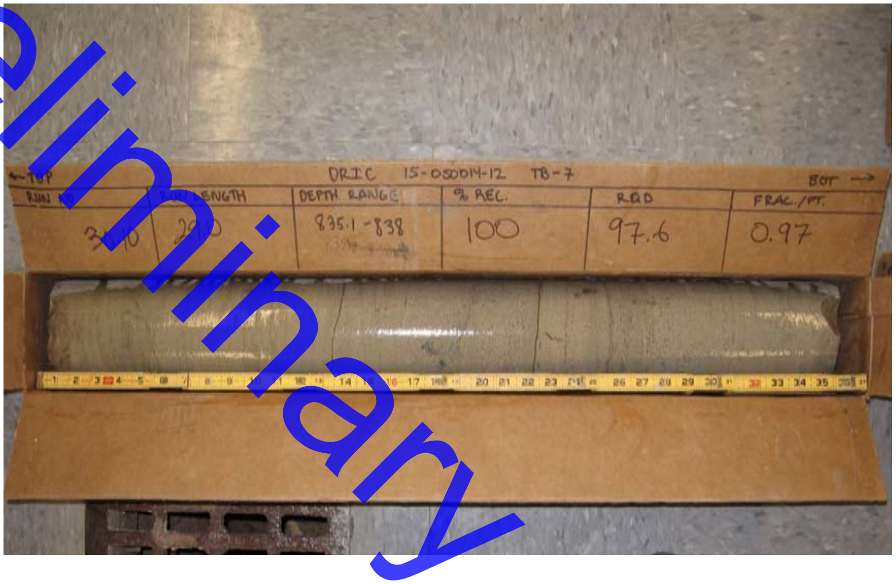
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-6	29.0	824.2-827.0	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-7	29.0	827.0-829.6	100.0	97.6	0.97



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-8	29.0	829.6-832.4	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-9	29.0	832.4-835.1	100.0	97.6	0.97



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-10	29.0	835.1-838.0	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	30-11	29.0	838.0-840.1	100.0	97.6	0.97

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-1	29.5	840.0-841.0	100.0	97.4	0.68

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-2	29.5	841.0-843.7	100.0	97.4	0.68

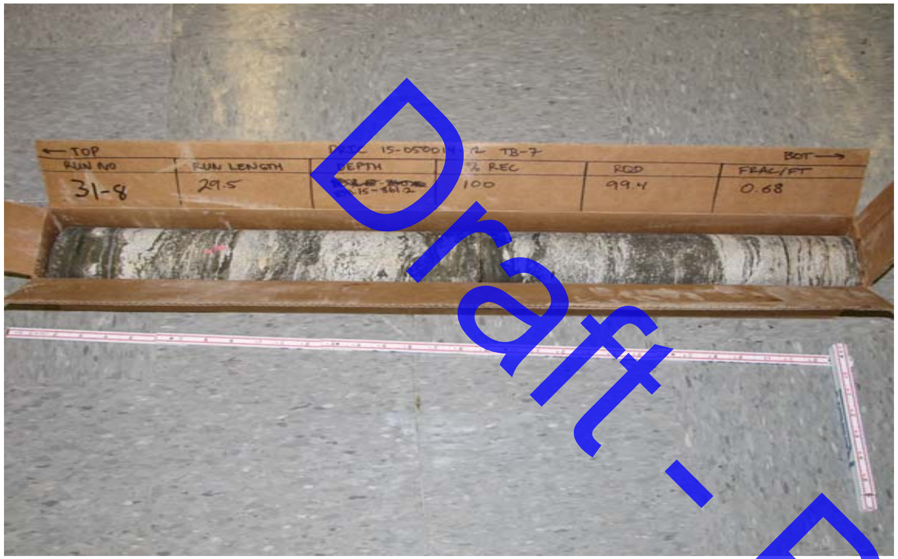
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-3	29.5	843.7–846.7	100.0	99.4	0.68

Bore Hole Run Run Length (feet) Depth (feet) Recovery (%) RQD Fractures Per Foot
TB-7 31-4 29.5 846.7–849.6 100.0 99.4 0.68 TB-7

Bore Hole Run Run Length (feet) Depth (feet) Recovery (%) RQD Fractures Per Foot
31-5 29.5 849.6–852.6 100.0 99.4 0.68

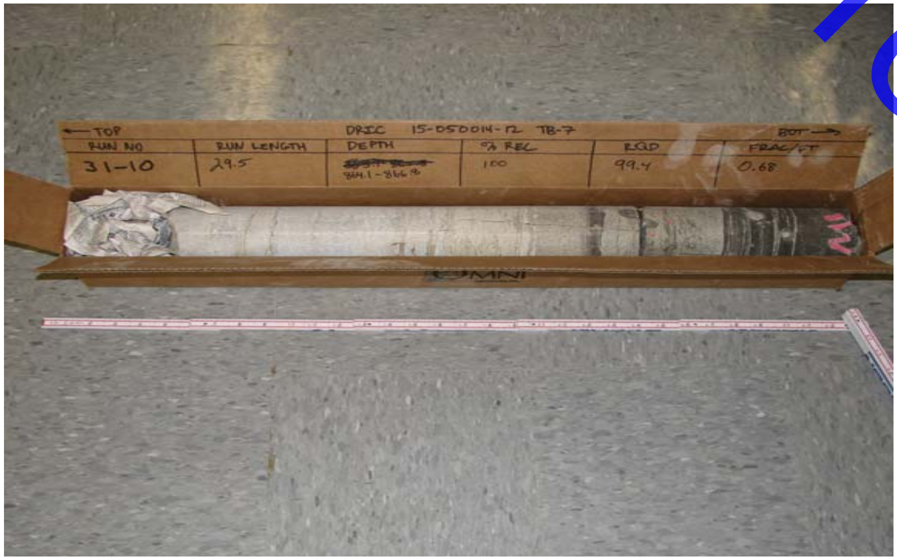
Bore Hole Run Run Length (feet) Depth (feet) Recovery (%) RQD Fractures Per Foot
TB-7 31-6 29.5 852.6–855.4 100.0 99.4 0.68 TB-7

Bore Hole Run Run Length (feet) Depth (feet) Recovery (%) RQD Fractures Per Foot
31-7 29.5 855.4–858.2 100.0 99.4 0.68



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-8	29.5	858.2–861.2	100.0	99.4	0.68

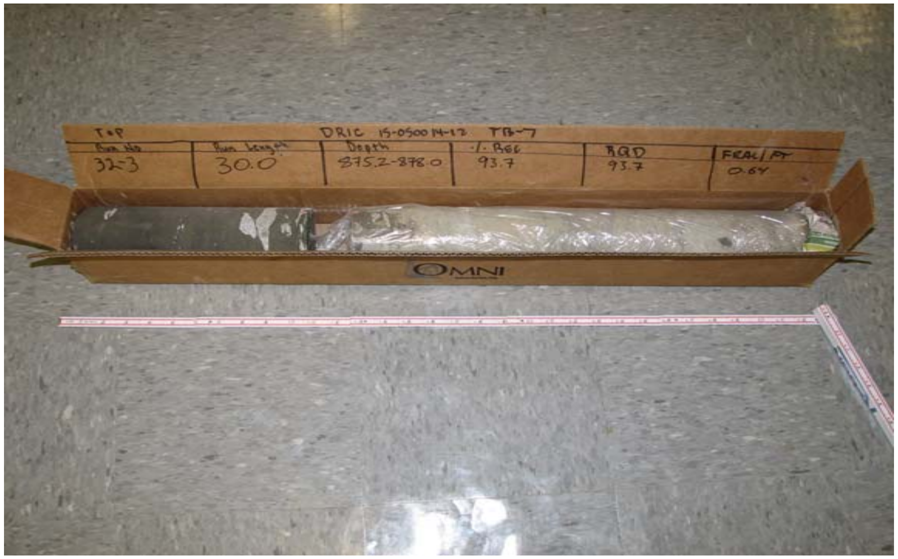
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-9	29.5	861.2–864.1	100.0	99.4	0.68



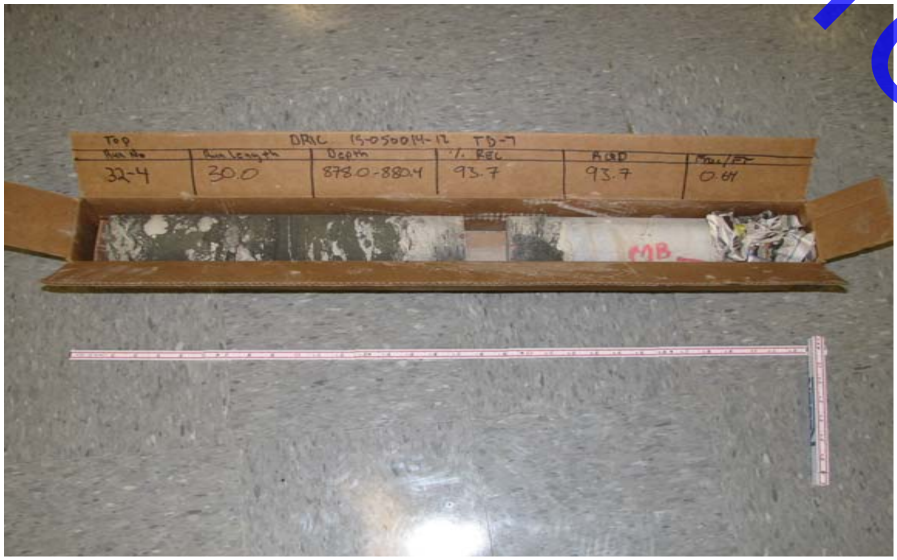
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-10	29.5	864.1–866.8	100.0	99.4	0.68

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	31-11	29.5	866.8–869.7	100.0	99.4	0.68

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-1	30.0	870.4–872.9	93.7	93.7	0.6



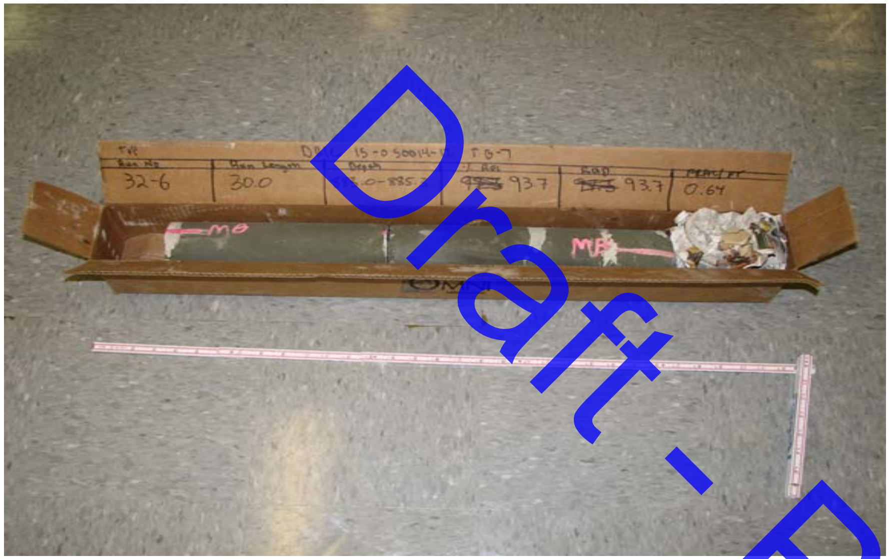
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-3	30.0	875.2–878.0	93.7	93.7	0.64



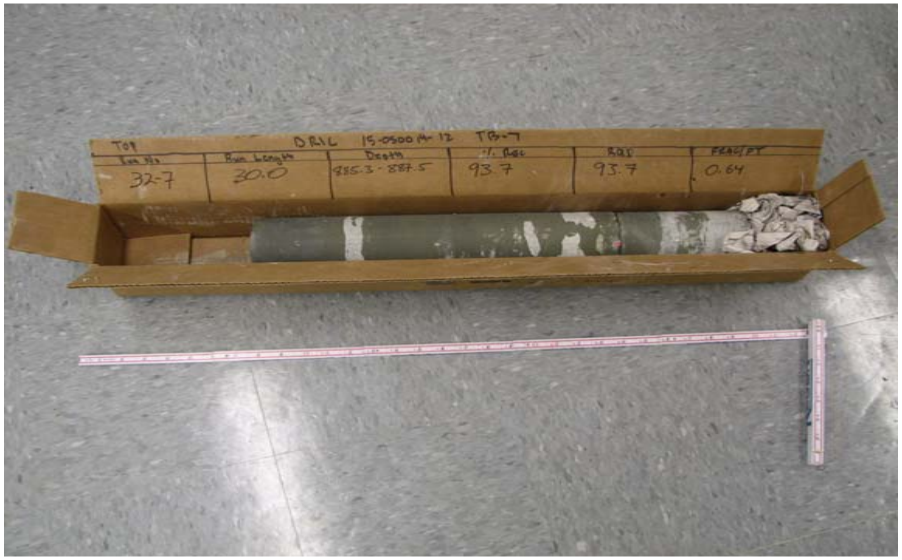
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-4	30.0	878.0-880.4	93.7	93.7	0.64

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-5	30.0	880.4–883.0	93.7	93.7	0.64

Bore Hole	Run	Run Length (Feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-2	30.0	872.9-875.2	9.37	93.7	0.64



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-6	30.0	883.0-885.3	93.7	93.7	0.64

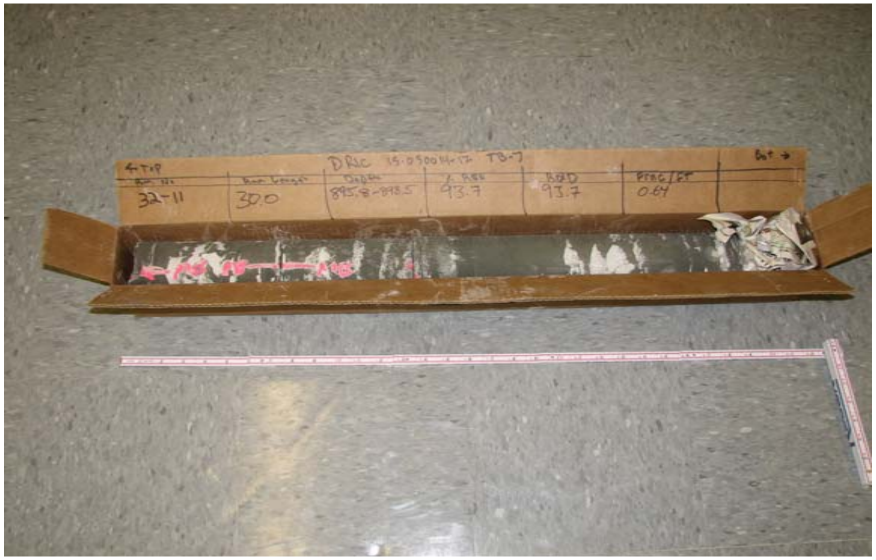


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-7	30.0	885.3–887.5	93.7	93.7	0.64

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-8	30.0	887.5-890.0	93.7	93.7	0.64

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-9	30.0	890.0–893.0	93.7	93.7	0.64

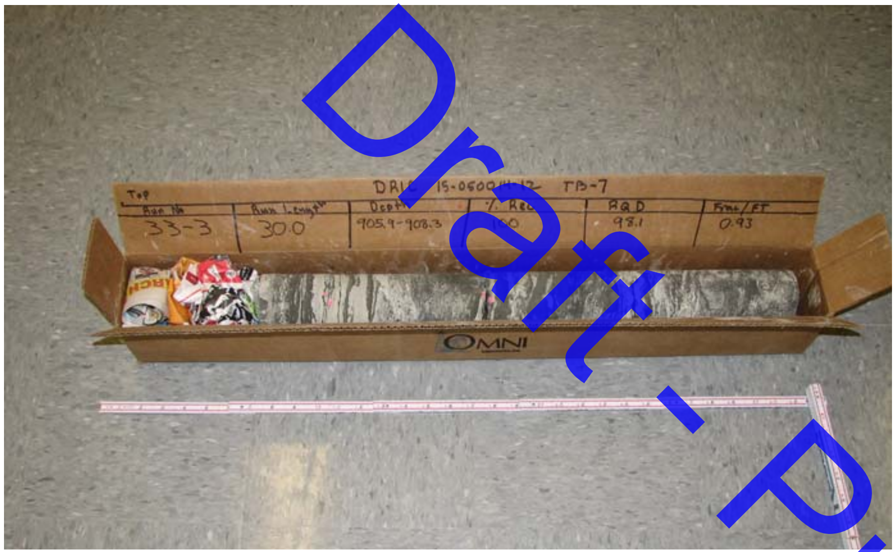
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-10	30.0	893.0-895.8	93.7	93.7	0.64



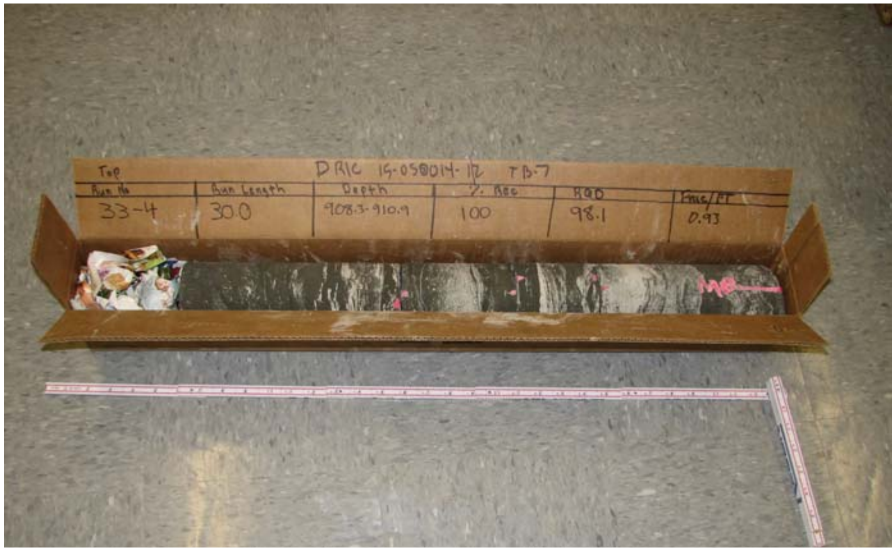
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	32-11	30.0	895.8–898.5	93.7	93.7	0.64

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-1	30.0	900.4-903.1	100.0	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-2	30.0	903.1-905.9	100.0	98.1	0.93



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-3	30.0	905.9-908.3	100.0	98.1	0.93



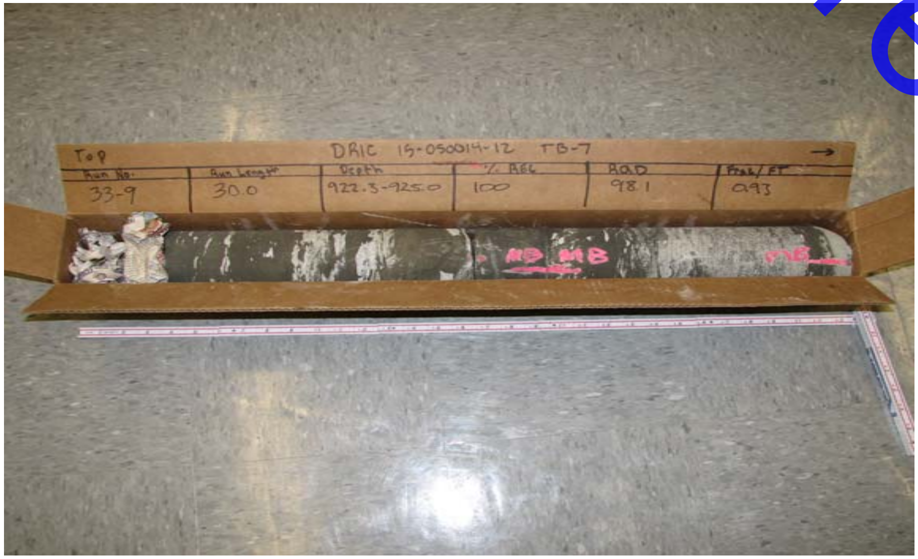
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-4	30.0	908.3-910.9	100.0	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-5	30.0	910.9–913.6	100	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-6	30.0	913.6-916.6	100	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-7	30.0	916.6–919.4	100	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-8	30.0	919.4-922.3	100	98.1	0.93



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-9	30.0	922.3–925.0	100	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-10	30.0	925.0-927.7	100	98.1	0.93

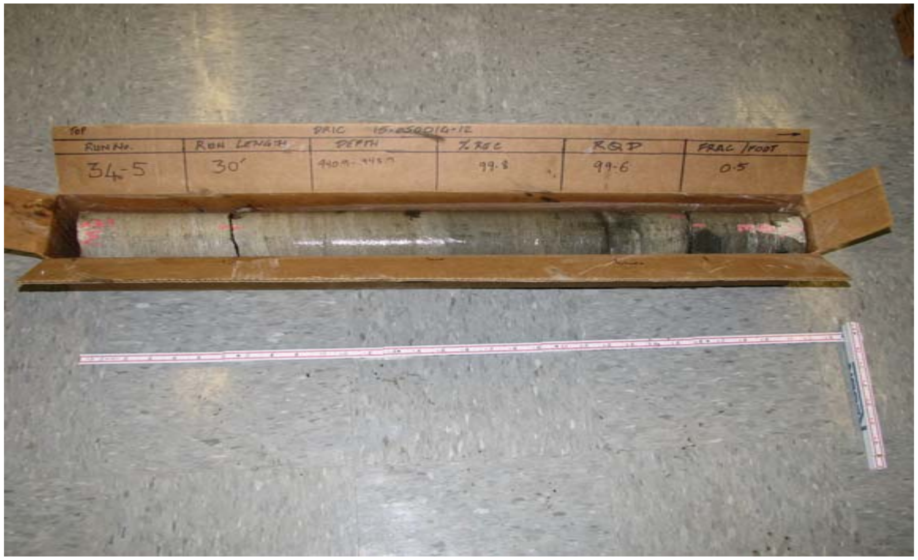
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	33-11	30.0	927.7–930.4	100	98.1	0.93

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-1	30.0	930.4-931.9	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-2	30.0	931.9-935.0	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-3	30.0	935.0-937.9	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-4	30.0	937.9-940.9	99.8	99.6	0.5



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-5	30.0	940.9-943.9	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-6	30.0	943.9-946.9	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-7	30.0	946.9-949.9	99.8	99.6	0.5

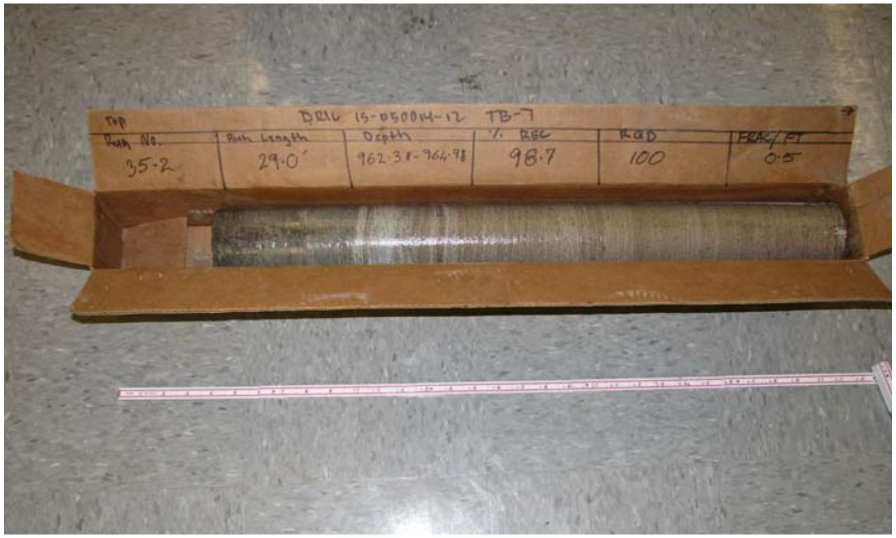
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-8	30.0	949.9 -952.8	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-9	30.0	952.8-955.8	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-10	30.0	955.8-957.7	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	34-11	30.0	957.7-960.5	99.8	99.6	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-1	29.0	960.4-962.3	98.7	98.7	0.5

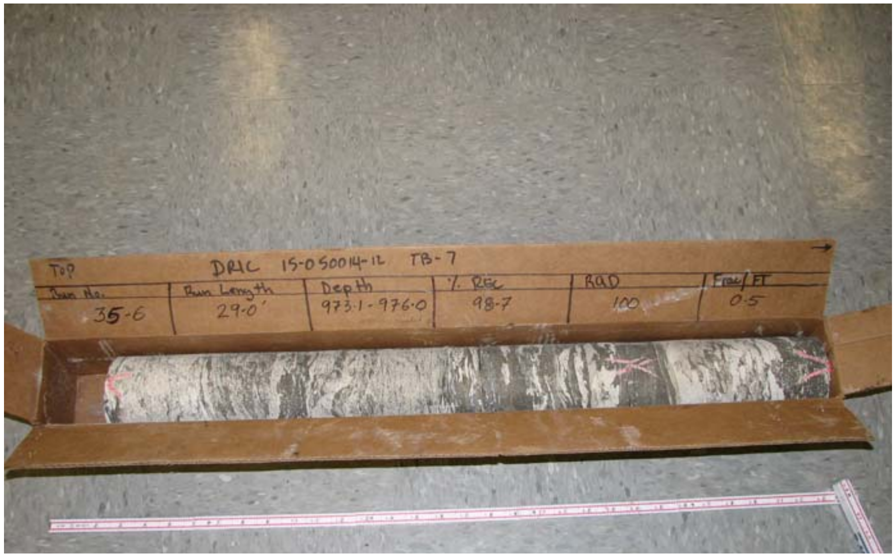


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-2	29.0	962.3-964.9	98.7	98.7	0.5

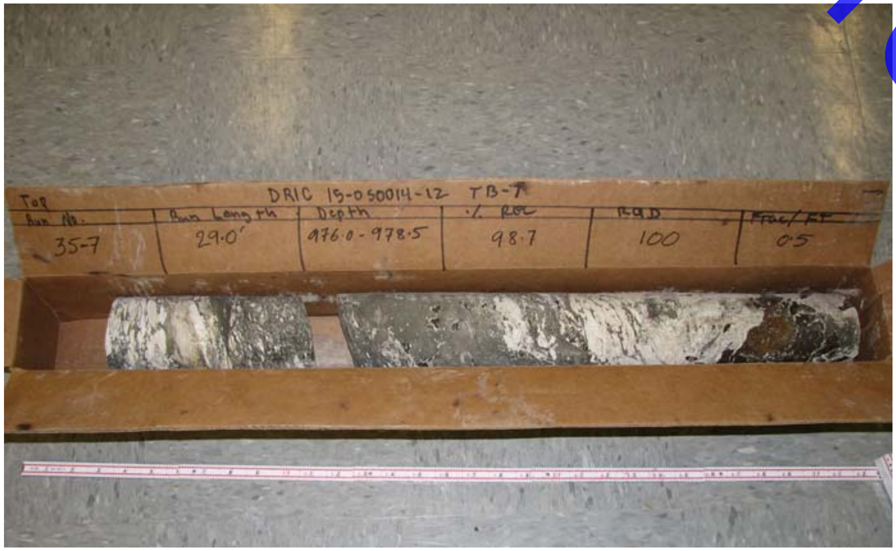
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-3	29.0	964.9-967.8	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-4	29.0	967.8-970.6	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-5	29.0	970.6-973.1	98.7	98.7	0.5



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-6	29.0	973.1-976.0	98.7	98.7	0.5



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-7	29.0	976.0-978.5	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-8	29.0	978.5-981.3	98.7	98.7	0.5

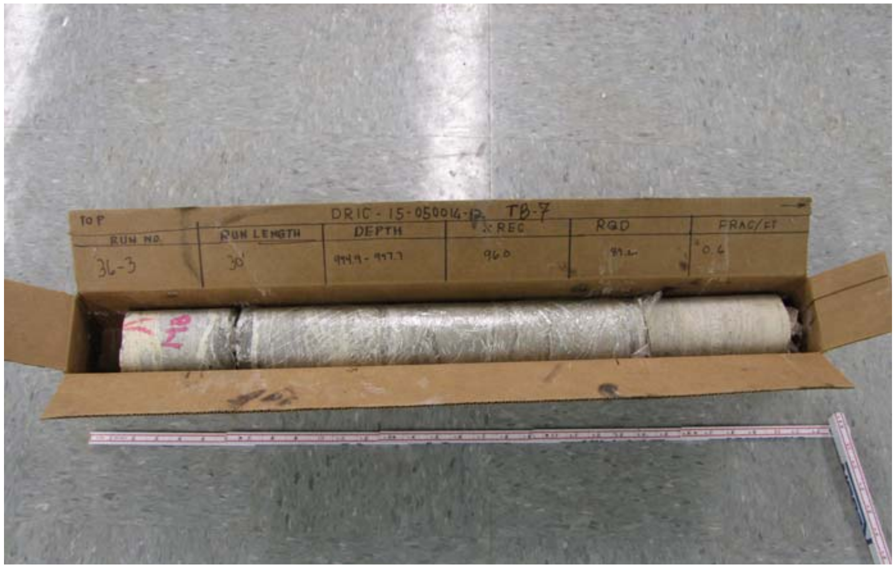
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-9	29.0	981.3-983.8	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-10	29.0	983.8-986.4	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	35-11	29.0	986.4-989.1	98.7	98.7	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-1	30.0	989.1-991.9	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-2	30.0	991.9-994.9	96.0	89.2	0.6



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-3	30.0	994.9-997.7	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-4	30.0	997.7-1000.4	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-5	30.0	1000.4-1002.5	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-6	30.0	1002.5-1005.4	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-7	30.0	1005.4-1008.1	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-8	30.0	1008.1-1011.2	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-9	30.0	1011.2-1013.8	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-10	30.0	1013.8-1016.5	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	36-11	30.0	1016.5-1019.4	96.0	89.2	0.6

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-1	30.0	1021.0-1023.2	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-2	30.0	1023.2-1026.1	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-3	30.0	1026.1-1028.4	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-4	30.0	1028.4-1031.3	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-5	30.0	1031.3-1034.1	100	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-6	30.0	1034.1-1037.1	100	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-7	30.0	1037.1-1040.1	100	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-8	30.0	1040.1-1043.0	100	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-9	30.0	1043.0-1045.9	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-10	30.0	1045.9-1048.6	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	37-11	30.0	1048.6-1051.0	100.0	96.7	0.73

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	38-1	1.0	1051.0-1052.0	95.8	85.4	2

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-1	30.0	1052.0-1053.9	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-2	30.0	1053.9-1056.7	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-3	30.0	1056.7-1059.3	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-4	30.0	1059.3-1062.0	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-5	30.0	1062.0-1064.7	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-6	30.0	1064.7-1067.8	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-7	30.0	1067.8-1070.8	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-8	30.0	1070.8-1073.6	100	95.1	1.1

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-9	30.0	1073.6-1076.3	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-10	30.0	1076.3-1079.2	100	95.1	1.13

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	39-11	30.0	1079.2-1082.0	100	95.1	1.13

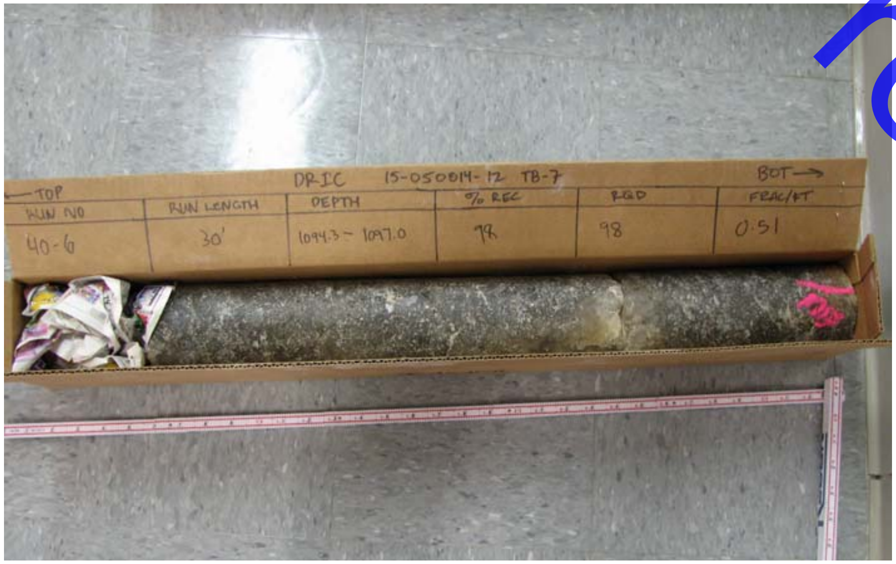
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-1	30.0	1082.0-1082.6	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-2	30.0	1082.6-1085.6	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-3	30.0	1085.6-1088.4	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-4	30.0	1088.4-1091.3	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-5	30.0	1091.3-1094.3	98.0	98.0	0.51



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-6	30.0	1094.2-1097.0	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-7	30.0	1097.0-1099.8	98.0	98.0	0.51

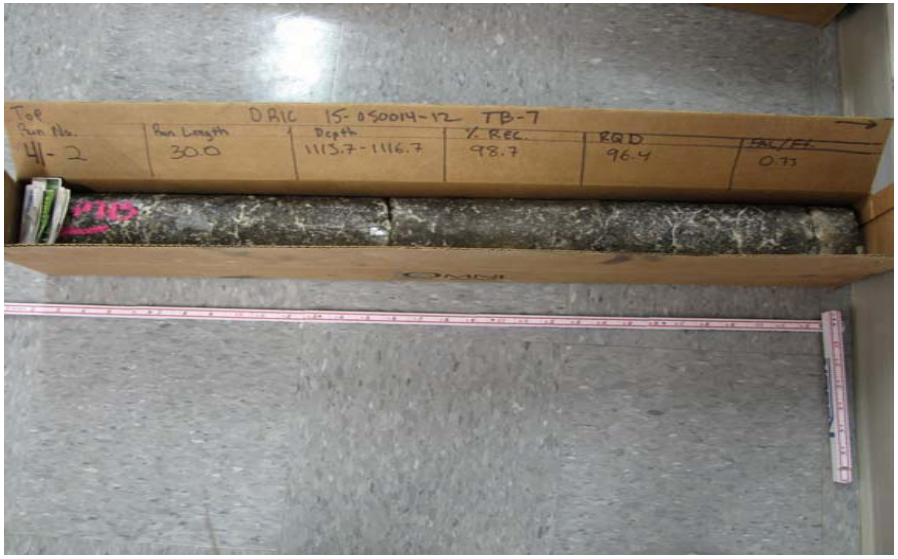
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-8	30.0	1100.6-1103.6	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-9	30.0	1103.6-1106.3	98.0	98.0	0.51

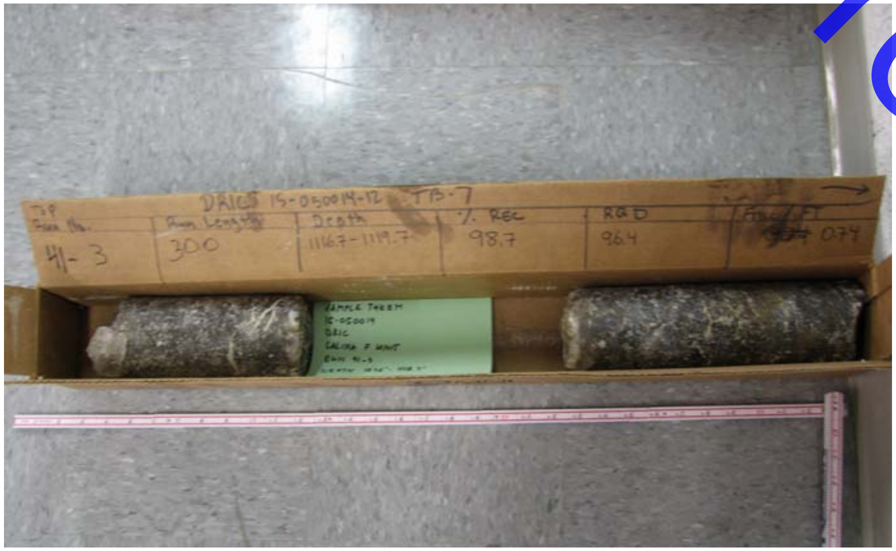
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-10	30.0	1106.3-1109.3	98.0	98.0	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	40-11	30.0	1109.3-1112.0	98.0	98.0	0.51

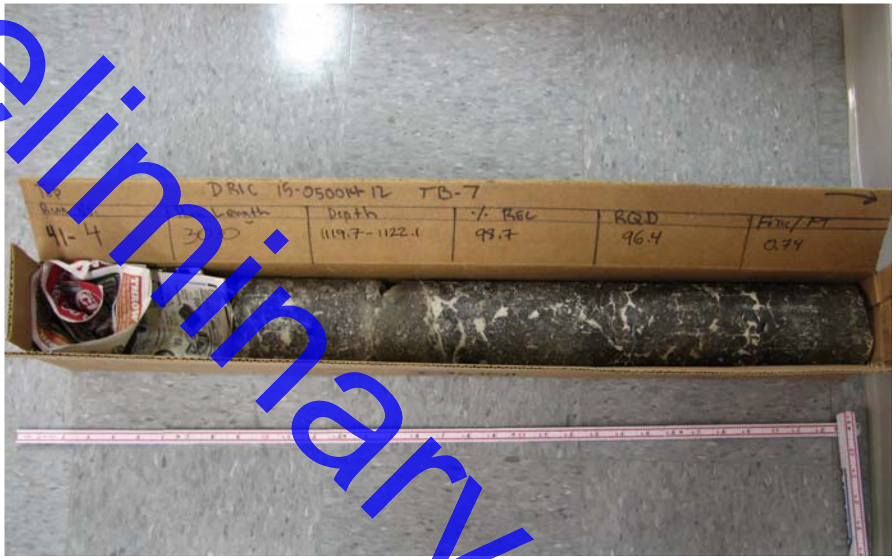
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-1	30.0	1112.0-1113.7	98.7	96.4	0.74



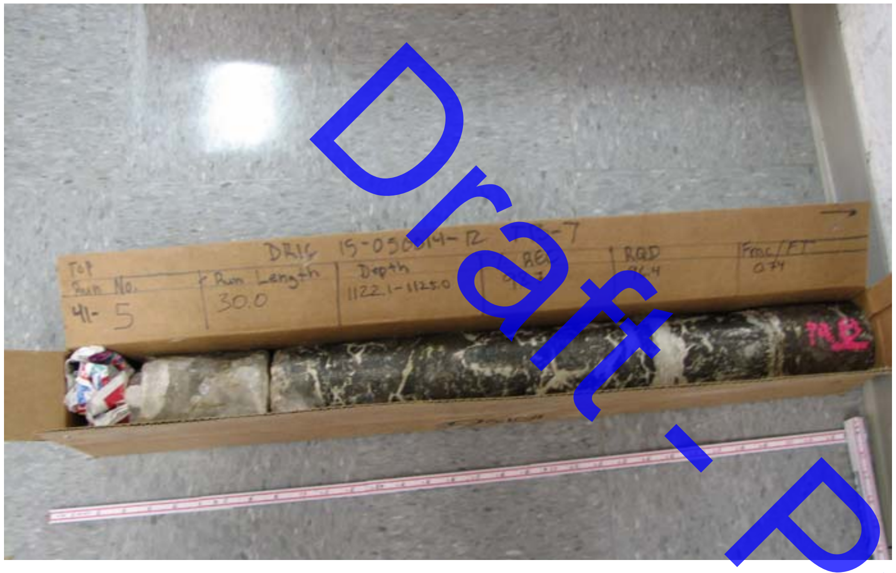
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-2	30.0	1113.7-1116.7	98.7	96.4	0.74



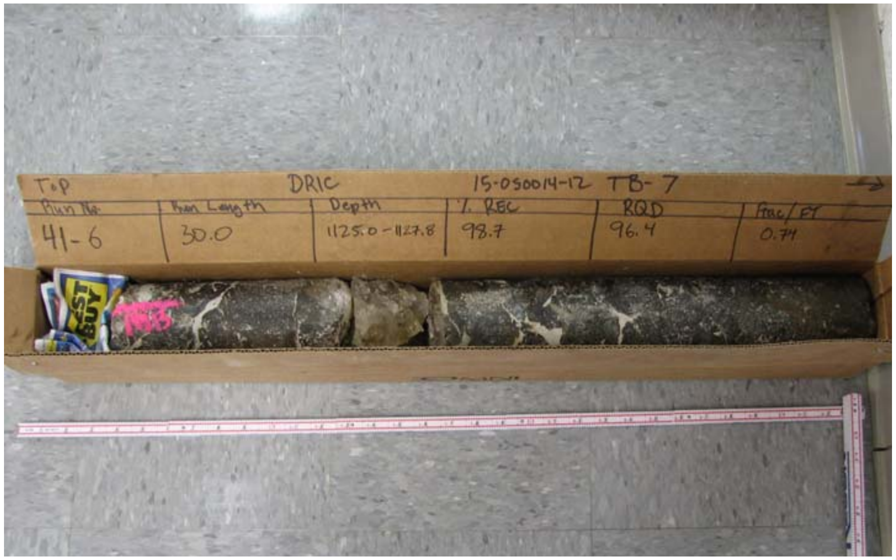
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-3	30.0	1116.7-1119.7	98.7	96.4	0.74



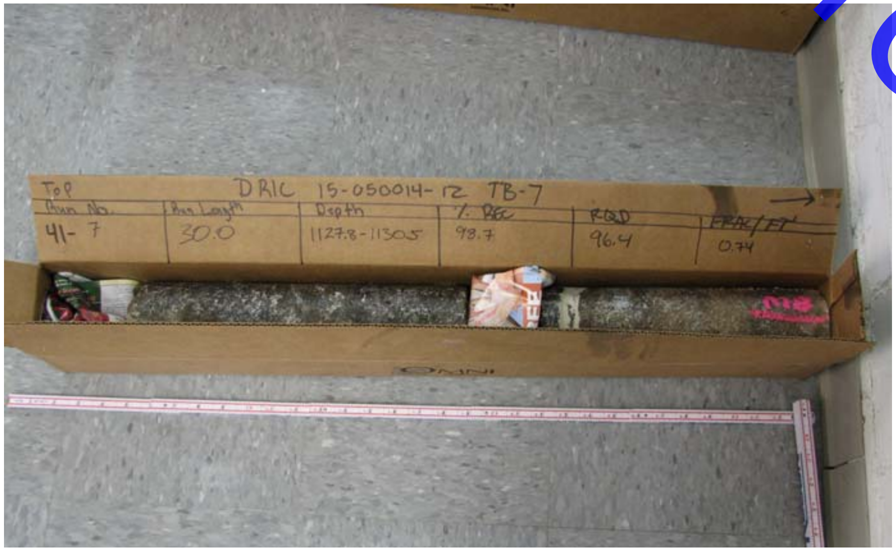
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-4	30.0	1119.7-1122.1	98.7	96.4	0.74



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-5	30.0	1122.1-1125.0	98.7	96.4	0.74



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-6	30.0	1125.0-1127.8	98.7	96.4	0.74



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-7	30.0	1127.8-1130.5	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-8	30.0	1130.5-1133.4	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-9	30.0	1133.4-1135.9	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-10	30.0	1135.9-1138.7	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-11	30.0	1138.7-1141.6	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	41-12	30.0	1141.5-1142.0	98.7	96.4	0.74

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-1	29.0	1142.0-1144.4	100.0	99.0	0. 4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-2	29.0	1144.4-1147.2	100.0	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-3	29.0	1147.2-1149.8	100.0	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-4	29.0	1149.8-1152.5	100.0	99.0	0.4

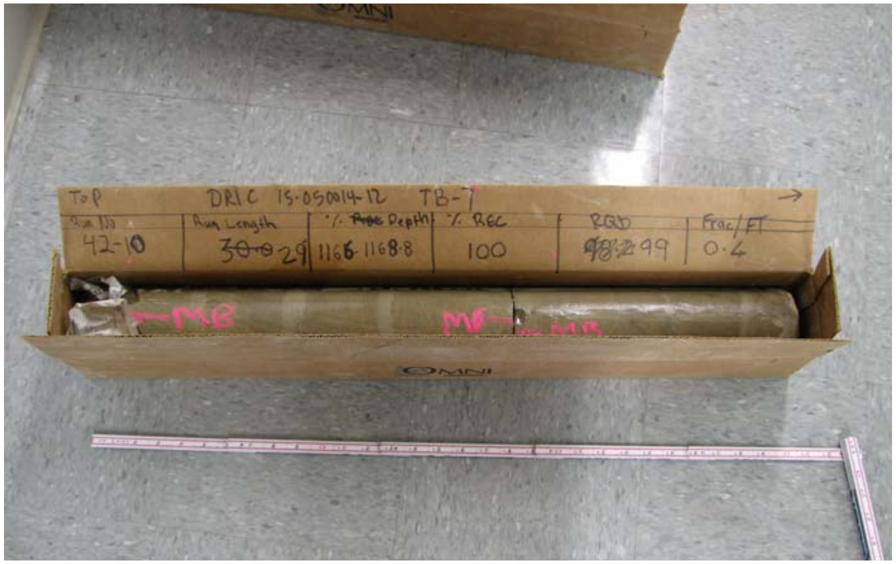
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-5	29.0	1152.5-1155.4	100	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-6	29.0	1155.4-1157.9	100	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-7	29.0	1157.9-1160.7	100.0	99.0	0.4

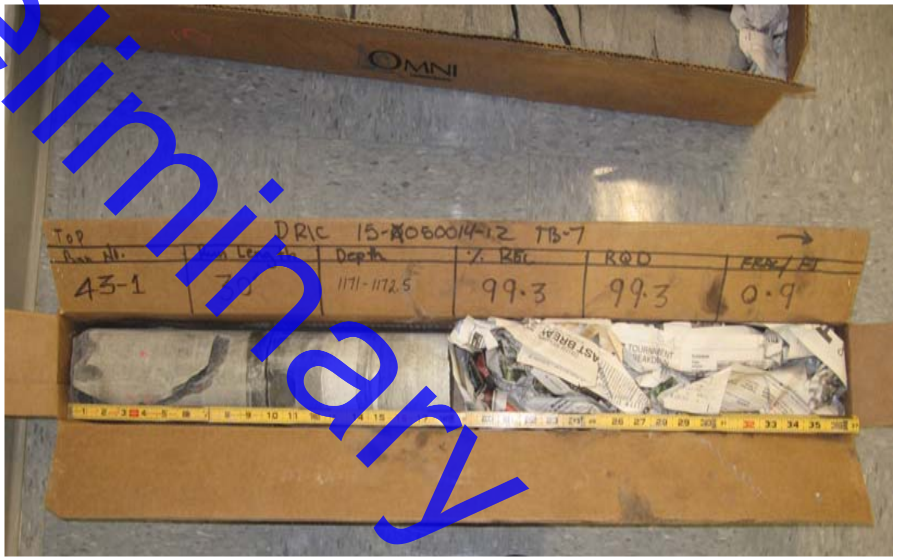
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-8	29.0	1160.7-1163.3	100.0	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-9	29.0	1163.3-1166.0	100.0	99.0	0.4



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-10	29.0	1166.0-1168.8	100.0	99.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	42-11	29.0	1168.8-1171.0	100.0	99.0	0.4



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-1	30.0	1171.0-1172.5	93.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-2	30.0	1172.5-1175.4	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-3	30.0	1175.4-1178.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-4	30.0	1178.1-118.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-5	30.0	1181.1-1184.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-6	30.0	1184.1-1186.8	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-7	30.0	1186.8-1189.5	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-8	30.0	1189.5-1192.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-9	30.0	1192.1-1195.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-10	30.0	1195.1-1198.1	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	43-11	30.0	1198.1-1201.0	99.3	99.3	0.9

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-1	30.0	1201.0-1202.6	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-2	30.0	1202.6-1205.6	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-3	30.0	1205.6-1208.6	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-4	30.0	1208.6-1211.4	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-5	30.0	1211.4-1214.1	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-6	30.0	1214.1-1216.8	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-7	30.0	1216.8-1219.5	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-8	30.0	1219.5-1222.2	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-9	30.0	1222.2-1225.2	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-10	30.0	1225.2-1228.0	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	44-11	30.0	1228.0-1231.0	100.0	100.0	0.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-1	30.0	1231.0-1231.8	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-2	30.0	1231.8-1234.7	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-3	30.0	1234.7-1237.6	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-4	30.0	1237.6-1240.3	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-5	30.0	1240.3-1242.8	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-6	30.0	1242.8-1245.7	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-7	30.0	1245.7-1248.8	98.3	96.3	0.88

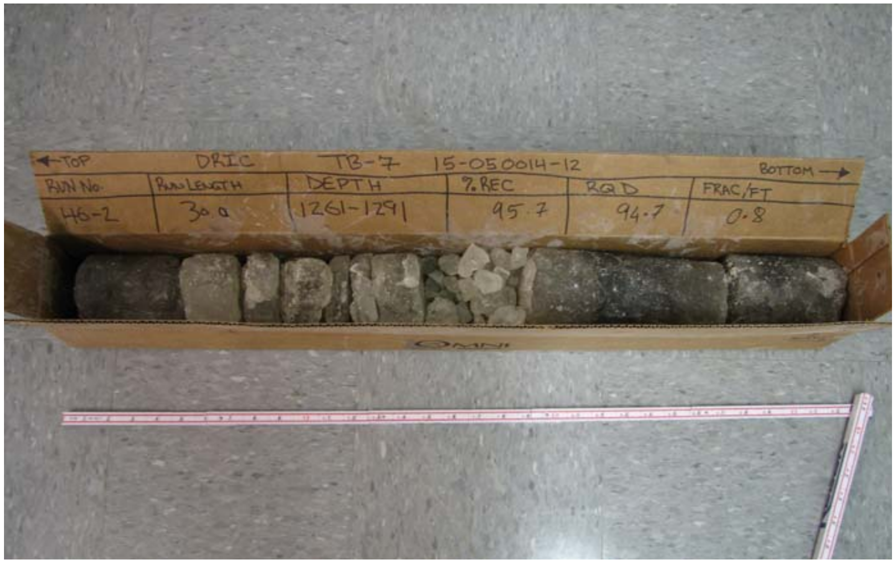
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-8	30.0	1248.8-1251.7	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-9	30.0	1251.7-1254.6	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-10	30.0	1254.6-1257.5	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	45-11	30.0	1257.5-1261.0	98.3	96.3	0.88

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-1	30.0	1261.0-1264.0	95.7	94.6	0.8



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-2	30.0	1264.0-1267.0	95.7	94.6	0.8

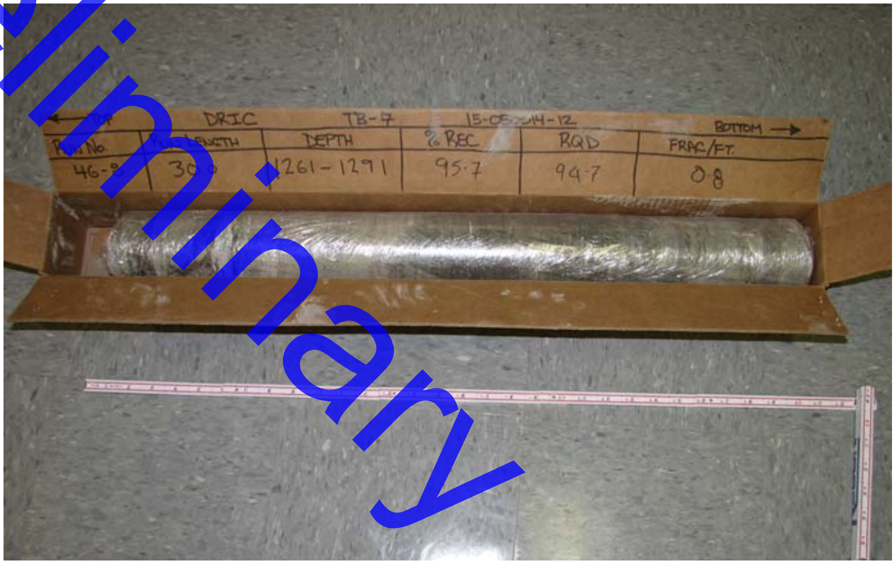
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-3	30.0	1267.0-1270.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-4	30.0	1270.0-1273.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-5	30.0	1273.0-1276.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-6	30.0	1276.0-1279.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-7	30.0	1279.0-1282.0	95.7	94.6	0.8



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-8	30.0	1282.0-1285.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-9	30.0	1285.0-1288.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	46-10	30.0	1288.0-1291.0	95.7	94.6	0.8

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-1	30.0	1291.0-1294.3	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-2	30.0	1294.3-1297.3	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-3	30.0	1297.3-1300.1	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-4	30.0	1300.1-1303.1	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-5	30.0	1303.1-1305.4	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-6	30.0	1305.4-1308.2	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-7	30.0	1308.2-1310.8	99.6	99.1	0.33

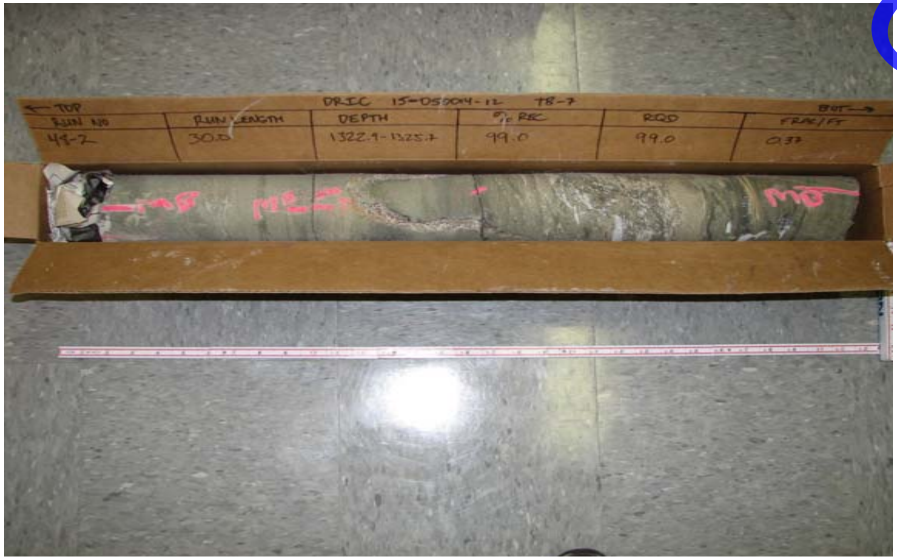
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-8	30.0	1310.8-1313.3	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-9	30.0	1313.3-1316.2	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-10	30.0	1316.2-1318.6	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	47-11	30.0	1318.6-1320.3	99.6	99.1	0.33

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-1	30.0	1321.0-1322.9	99.6	99.1	0.33



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-2	30.0	1322.9-1325.7	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-3	30.0	1325.7-1328.6	99.0	99.0	0.37

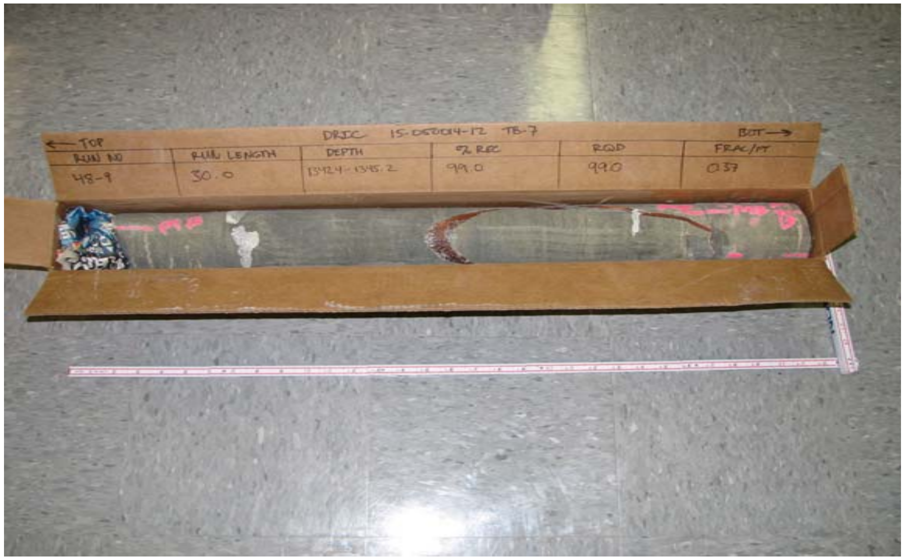
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-4	30.0	1328.6-1331.5	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-5	30.0	1331.5-1334.3	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-6	30.0	1334.3-1337.0	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-7	30.0	1337.0-1339.7	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-8	30.0	1339.7-1342.4	99.0	99.0	0.37



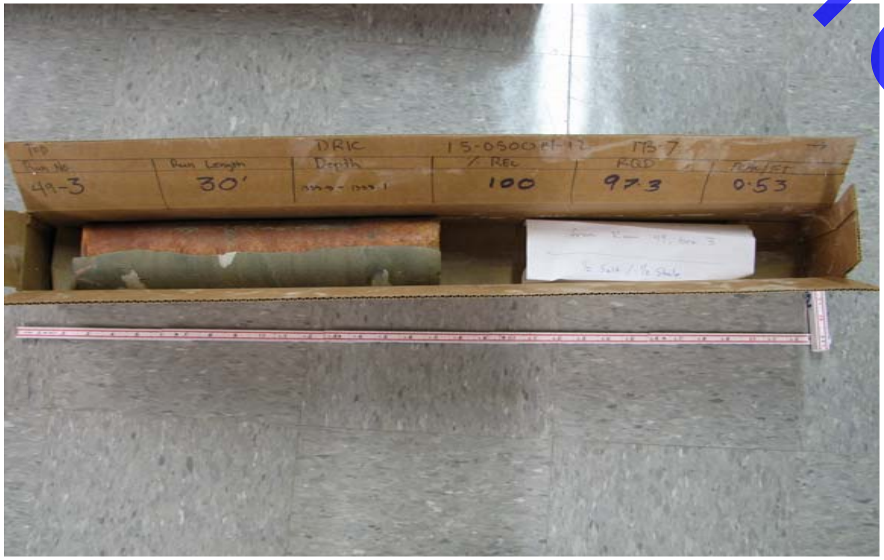
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-9	30.0	1342.4-1345.2	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-10	30.0	1345.2-1348.1	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	48-11	30.0	1348.1-1350.7	99.0	99.0	0.37

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-1	30.0	1351.0-1352.9	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-2	30.0	1352.9-1355.8	100	97.3	0.53



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-3	30.0	1355.8-1358.1	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-4	30.0	1358.1-1360.6	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-5	30.0	1360.6-1363.7	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-6	30.0	1363.7-1366.7	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-7	30.0	1366.7-1369.7	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-8	30.0	1369.7-1372.5	100	97.3	0.53

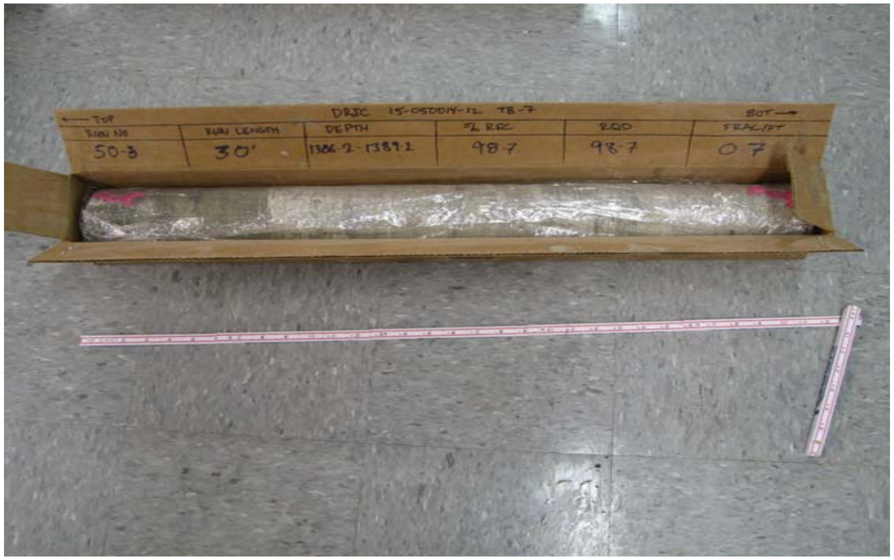
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-9	30.0	1372.5-1375.3	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-10	30.0	1375.3-1378.0	100	97.3	0.53

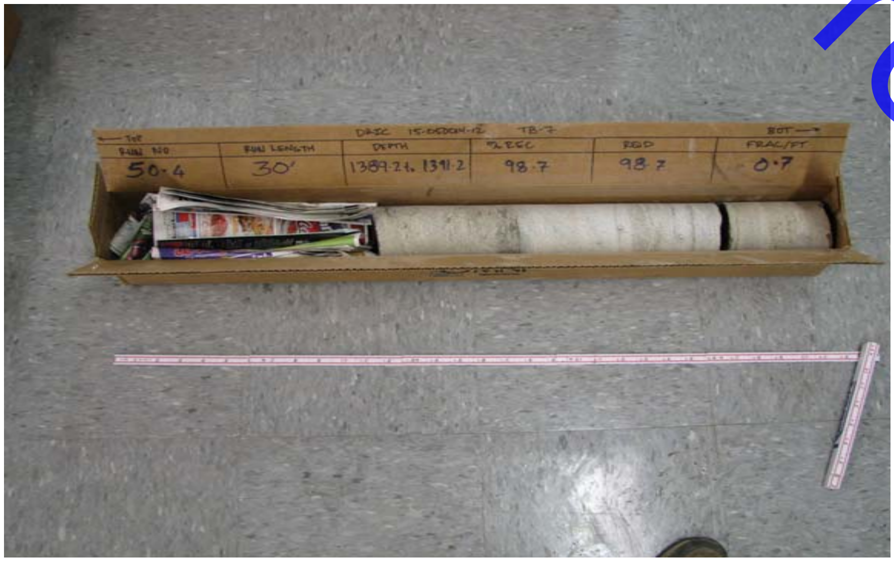
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	49-11	30.0	1378.0-1380.8	100	97.3	0.53

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-1	30.0	1381.0-1383.3	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-2	30.0	1383.3-1386.2	98.7	98.7	0.7



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-3	30.0	1386.2-1389.2	98.7	98.7	0.7



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-4	30.0	1389.2-1391.2	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-5	30.0	1391.2-1394.0	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-6	30.0	1394.0-1396.8	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-7	30.0	1396.8-1399.4	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-8	30.0	1399.5-1402.2	98.7	98.7	0.7

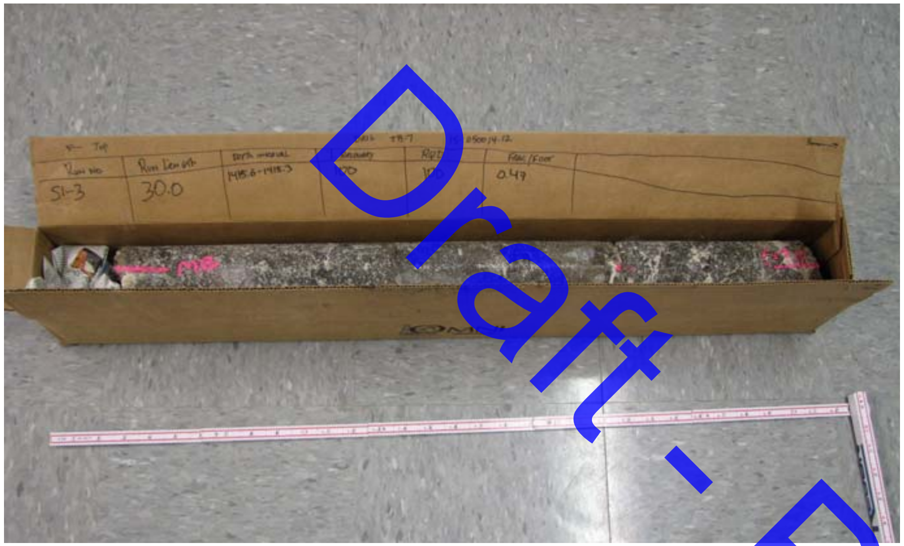
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-9	30.0	1402.2-1405.0	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-10	30.0	1405.2-1407.5	98.7	98.7	0.7

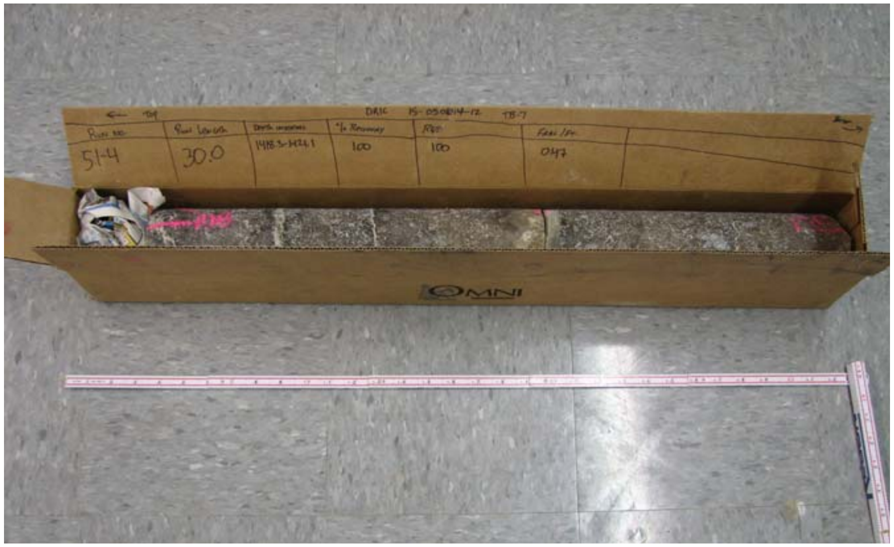
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	50-11	30.0	1407.5-1410.6	98.7	98.7	0.7

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-1	30.0	1411.0-1412.9	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-2	30.0	1412.9-1415.6	100.0	100.0	0.47



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-3	30.0	1415.6-1418.3	100.0	100.0	0.47



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-4	30.0	1418.3-1421.1	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-5	30.0	1421.1-1424.1	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-6	30.0	1424.1-1426.4	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-7	30.0	1426.4-1429.7	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-8	30.0	1429.7-1432.5	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-9	30.0	1432.5-1435.2	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-10	30.0	1435.2-1438.1	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	51-11	30.0	1438.1-1441.0	100.0	100.0	0.47

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-1	30.0	1441.0-1442.6	98.0	97.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-2	30.0	1442.6-1445.4	98.0	97.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-3	30.0	1445.4-1447.9	98.0	97.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-4	30.0	1447.9-1450.6	98.0	97.0	0.5

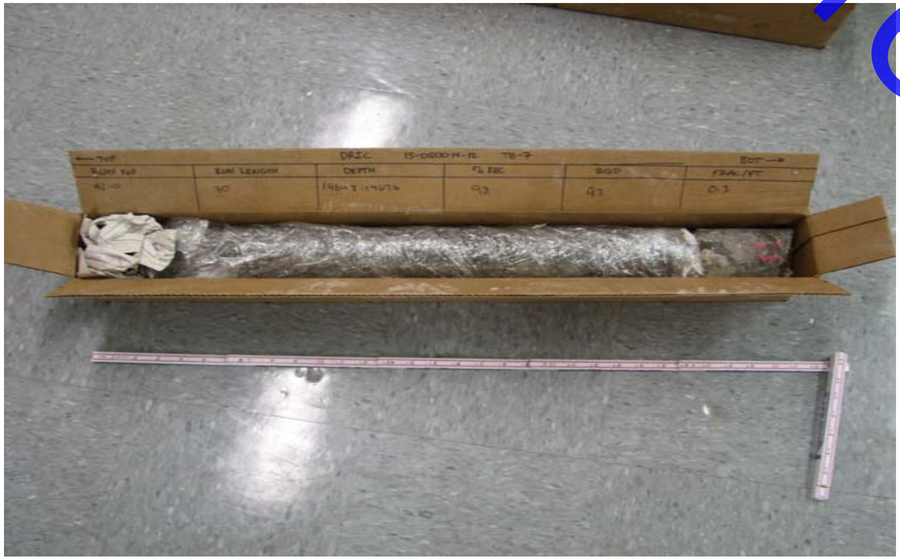
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-5	30.0	1450.6-1453.3	98.0	97.0	0.5

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-6	30.0	1453.3-1456.3	98.0	97.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-7	30.0	1456.4-1458.8	98.0	97.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-8	30.0	1458.8-1461.7	98.0	97.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-7	30.0	1461.7-1464.8	98.0	97.0	0.3

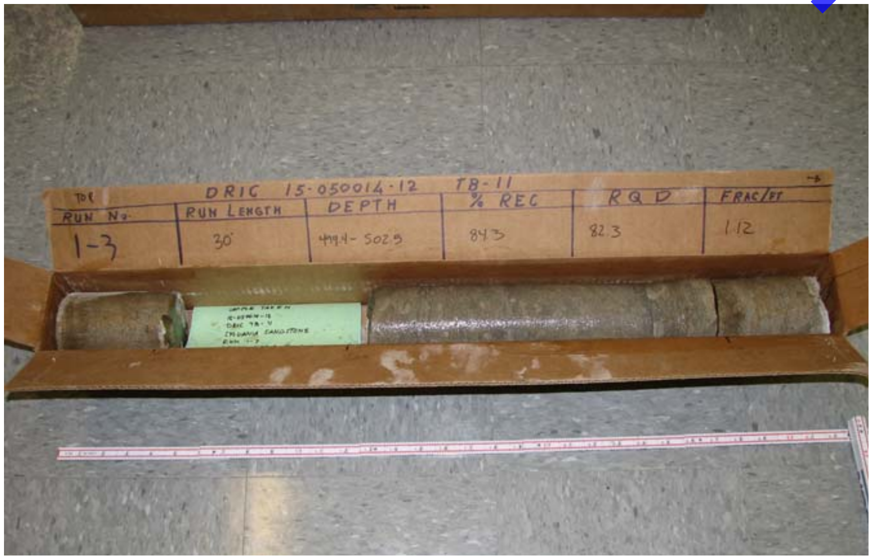


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-10	30.0	1464.8-1367.6	98	97.0	0.3

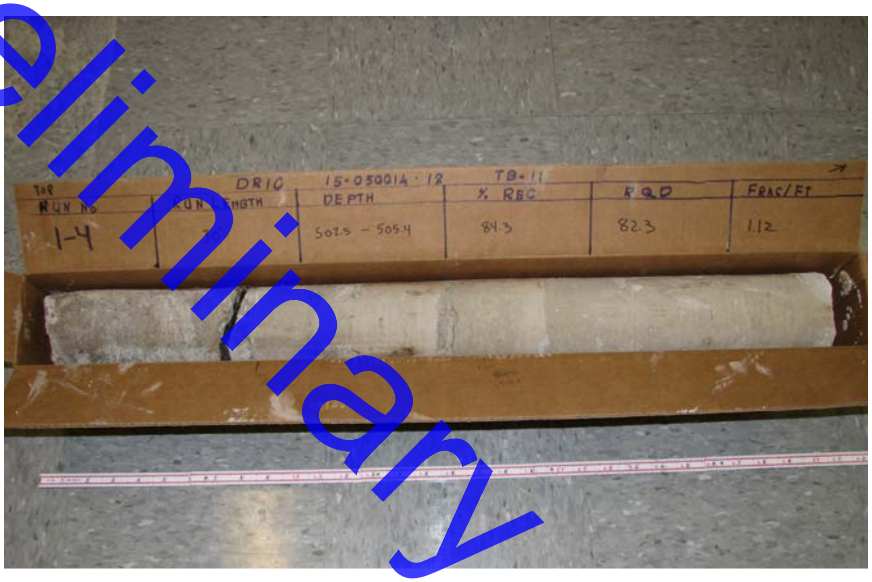
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-7	52-11	30.0	1467.6-1470.5	98	97.0	0.3

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-1	30.0	495.0-496.3	84.3	82.3	1.12

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-2	30.0	496.3-499.4	84.3	82.3	1.12

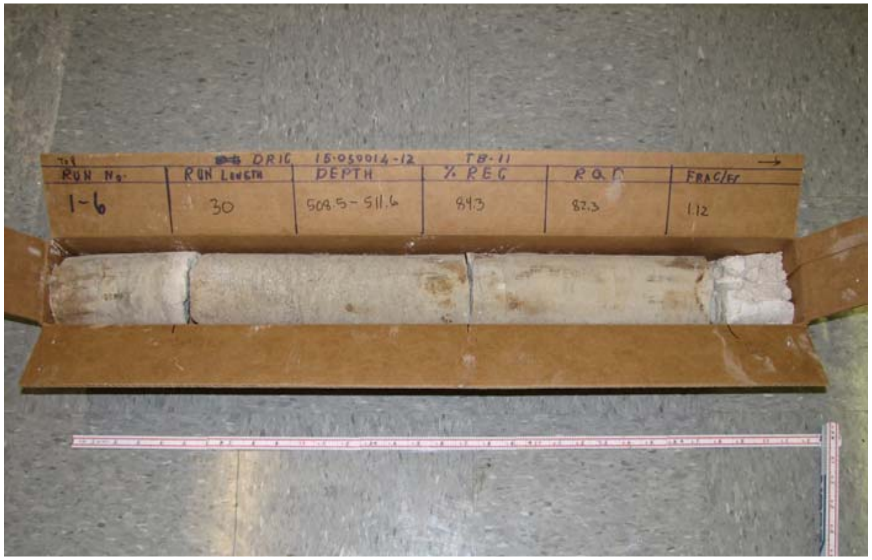


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-3	30.0	499.4-502.4	84.3	82.3	1.12

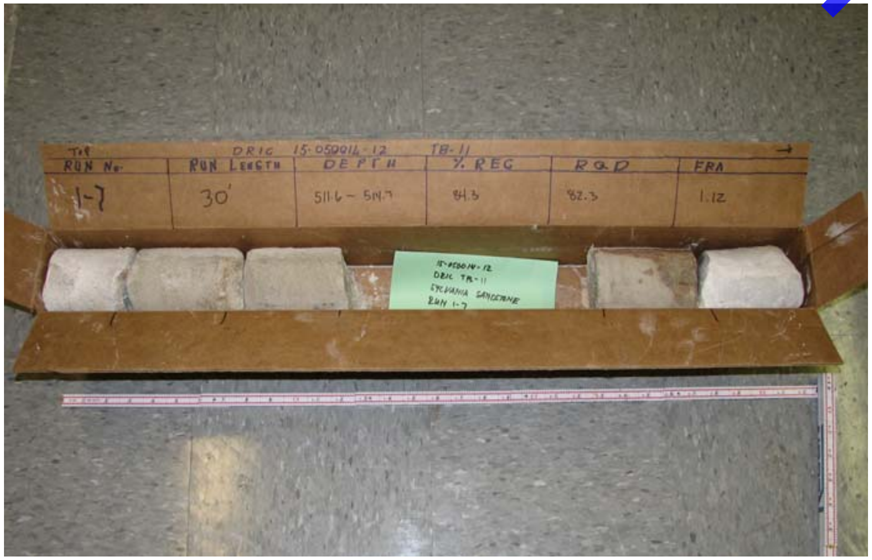


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-4	30.0	502.5-505.4	84.3	82.3	1.12

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-5	30.0	505.4-508.5	84.3	82.3	1.12



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-6	30.0	508.5-511.6	84.3	82.3	1.12



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-7	30.0	511.6-514.7	84.3	82.3	1.12

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-8	30.0	514.7-517.7	84.3	82.3	1.12

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	1-9	30.0	517.7-520.5	84.3	82.3	1.12

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-1	30.0	524.0-526.3	87.0	80.7	1.4

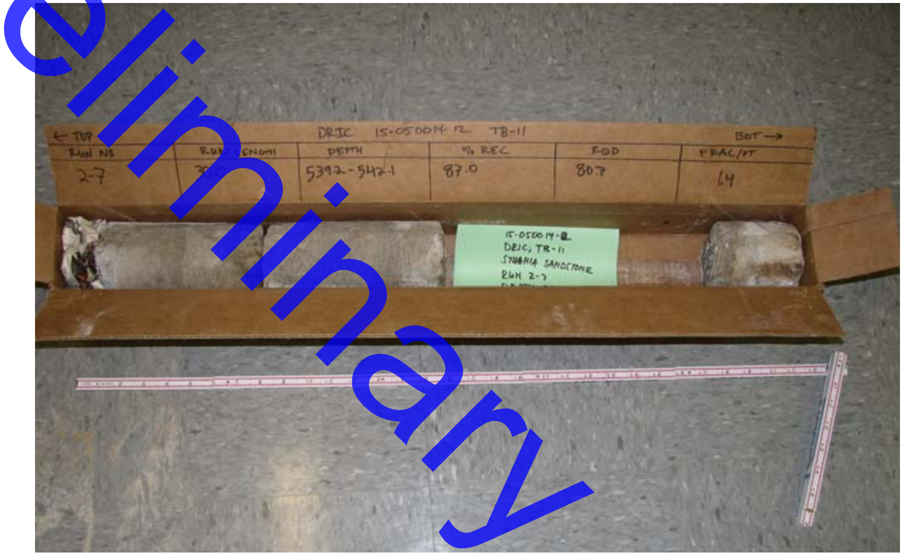
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-2	30.0	526.3-529.0	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-3	30.0	529.0-531.8	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-4	30.0	531.8-534.3	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-5	30.0	534.3-537.0	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-6	30.0	537.0-539.2	87.0	80.7	1.4



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-7	30.0	539.2-542.1	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-8	30.0	542.1-544.9	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-9	30.0	544.9-547.3	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	2-10	30.0	547.3-550.1	87.0	80.7	1.4

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-1	30.0	925.0-926.8	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-2	30.0	926.8-929.6	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-3	30.0	929.6-932.4	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-4	30.0	932.4-935.4	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-5	30.0	935.4-938.1	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-6	30.0	938.1-940.8	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-7	30.0	940.8-943.3	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-8	30.0	943.3-945.9	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-9	30.0	945.9-948.6	97.7	97.0	0.38

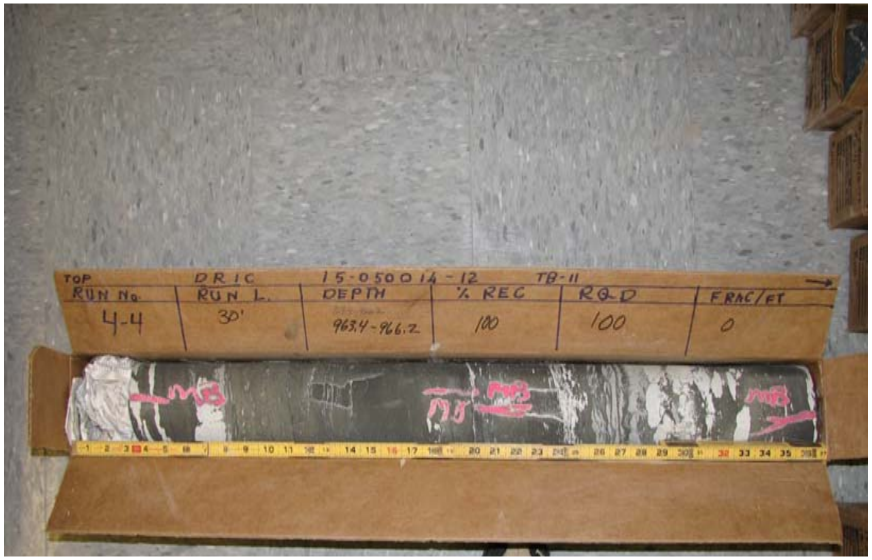
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-10	30.0	948.6-951.4	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	3-11	30.0	951.4-954.3	97.7	97.0	0.38

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-1	30.0	955.0-957.7	100.0	100.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-2	30.0	957.7-960.7	100.0	100.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-3	30.0	960.7-963.4	100.0	100.0	0

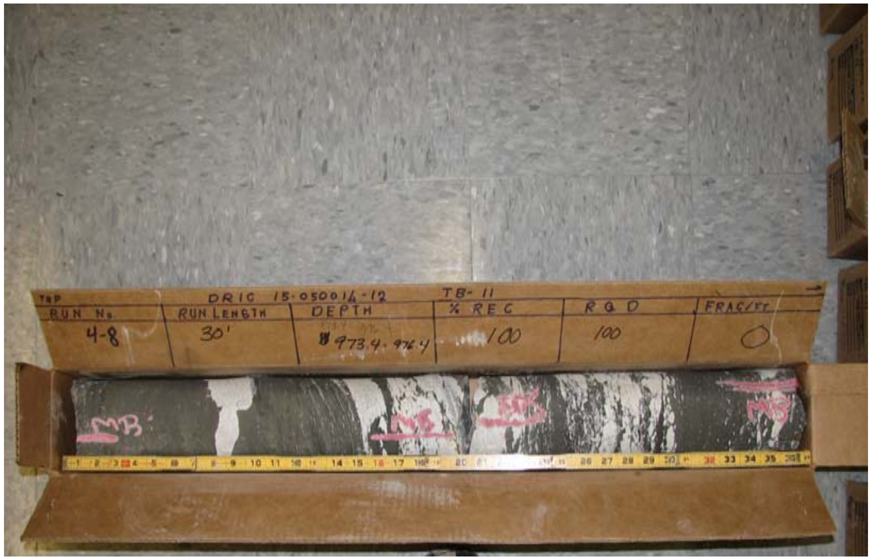


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-4	30.0	963.4-966.2	100.0	100.0	0

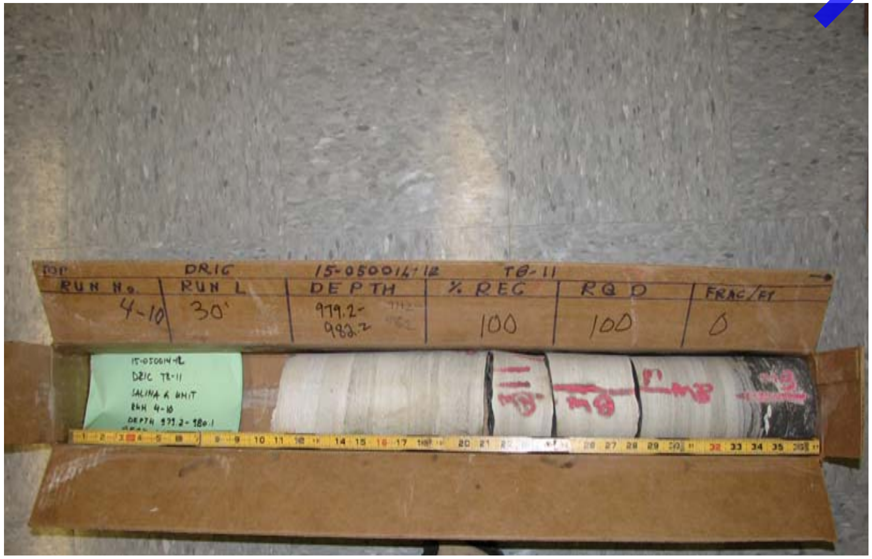
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-5	30.0	966.2-969.0	100.0	100.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-6	30.0	969.0-970.6	100.0	100.0	0

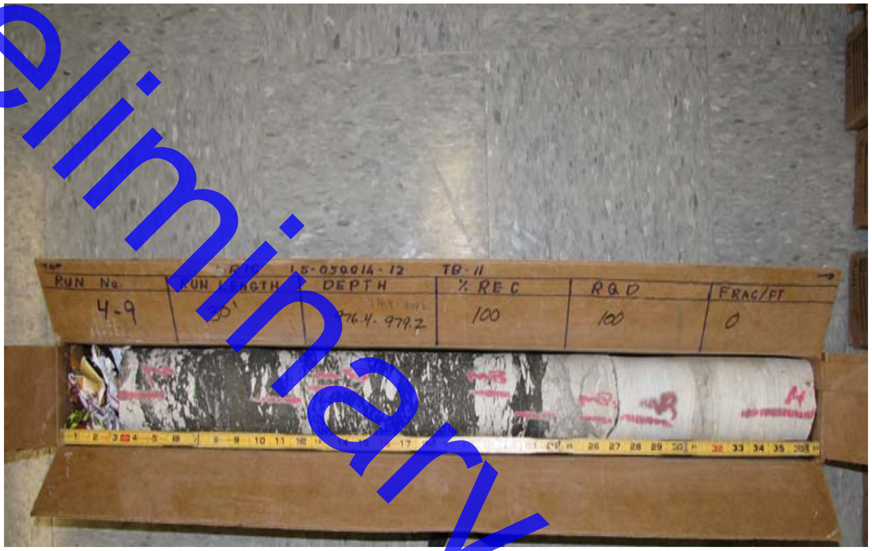
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-7	30.0	970.6-973.4	100.0	100.0	0



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-8	30.0	973.4-976.4	100.0	100.0	0

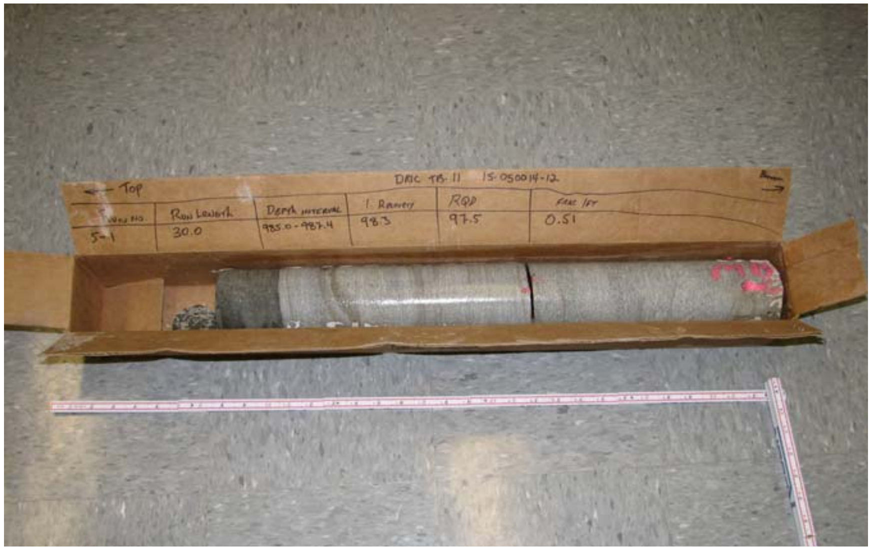


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-9	30.0	976.4-979.2	100.0	100.0	0

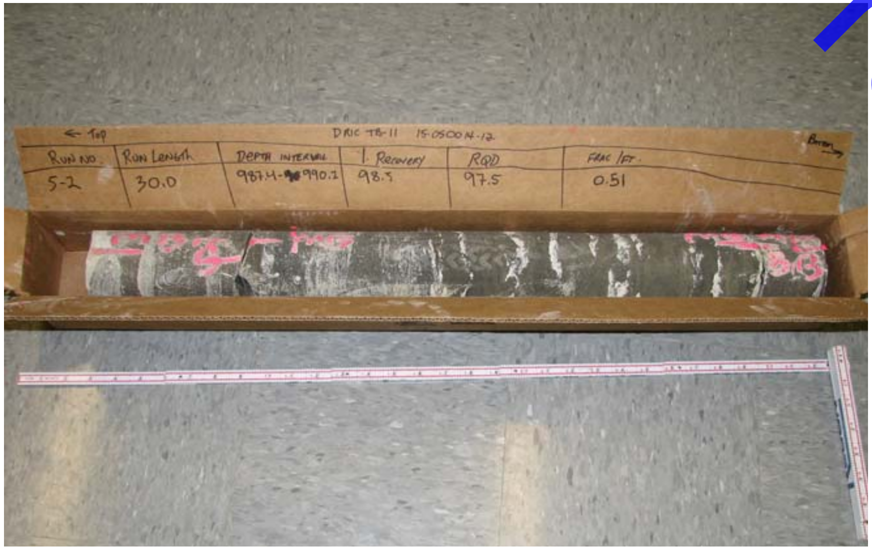


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-10	30.0	979.2-982.2	100.0	100.0	0

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	4-11	30.0	982.2-985.0	100.0	100.0	0



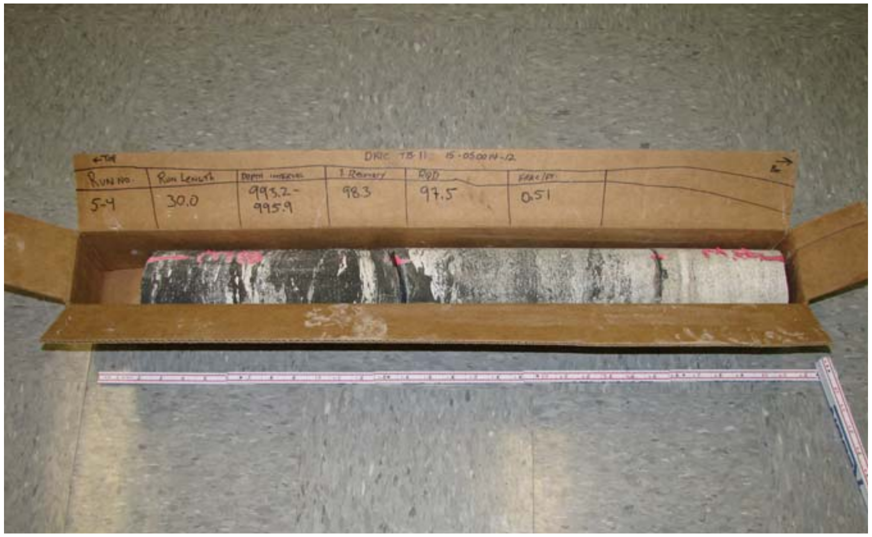
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-1	30.0	985.0-987.4	98.3	97.5	051



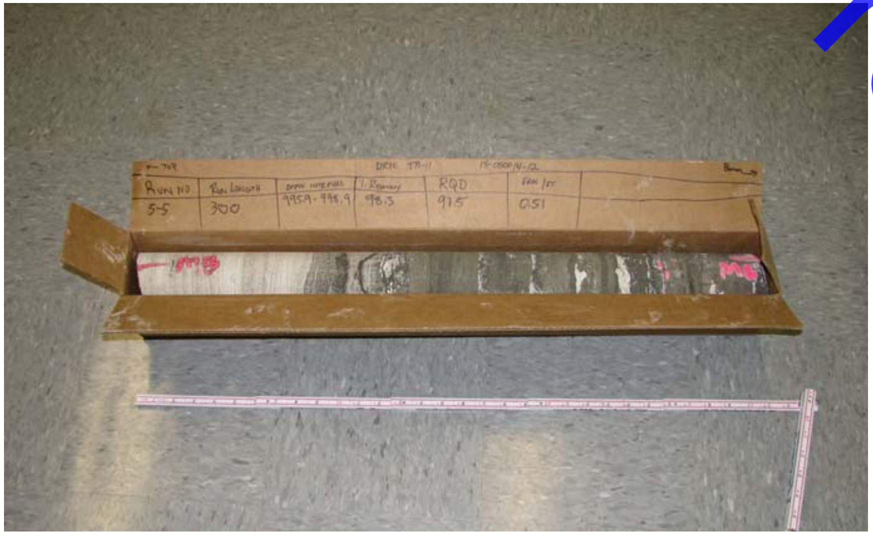
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-2	30.0	987.4-990.2	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-3	30.0	990.2-993.2	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-4	30.0	993.2-995.9	98.3	97.5	0.51



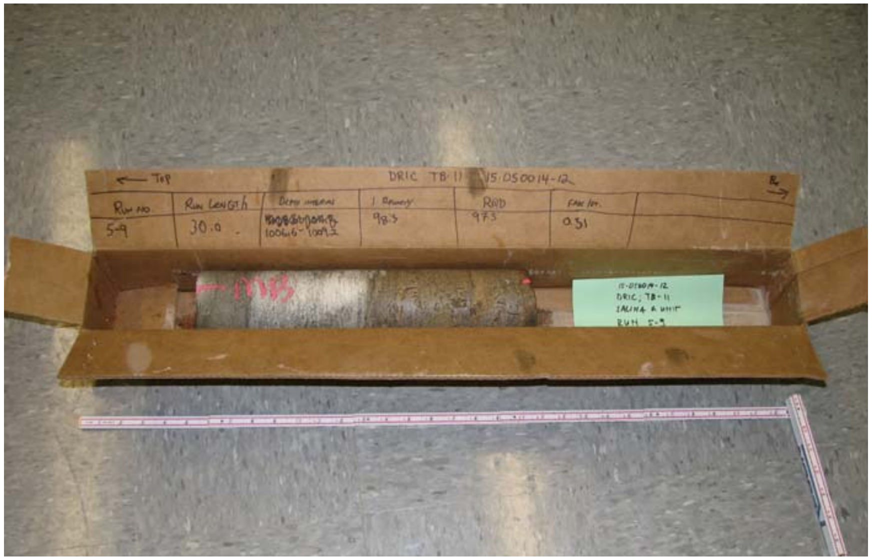
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-5	30.0	995.9-998.9	98.3	97.5	0.51



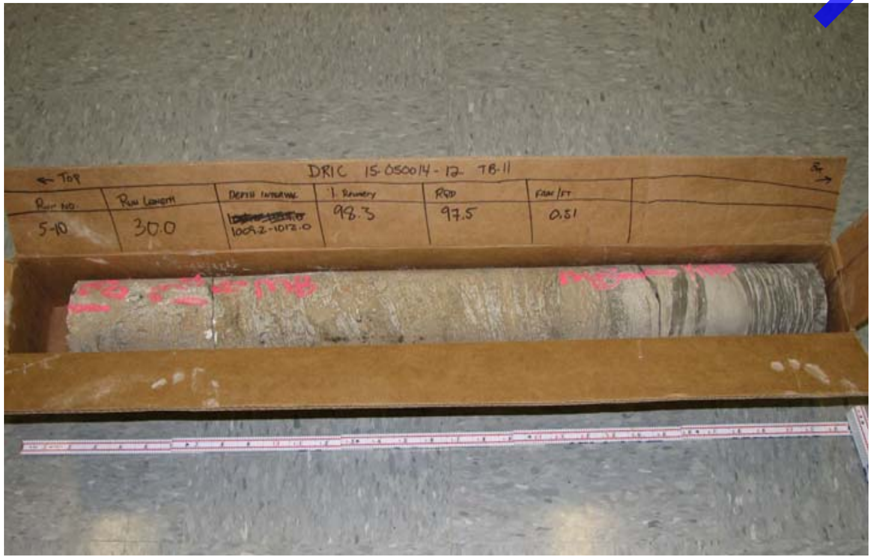
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-6	30.0	998.9-1001.5	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-7	30.0	1001.5-1003.8	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-8	30.0	1003.8-1006.6	98.3	97.5	0.51



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-9	30.0	1006.6-1009.8	98.3	97.5	0.51

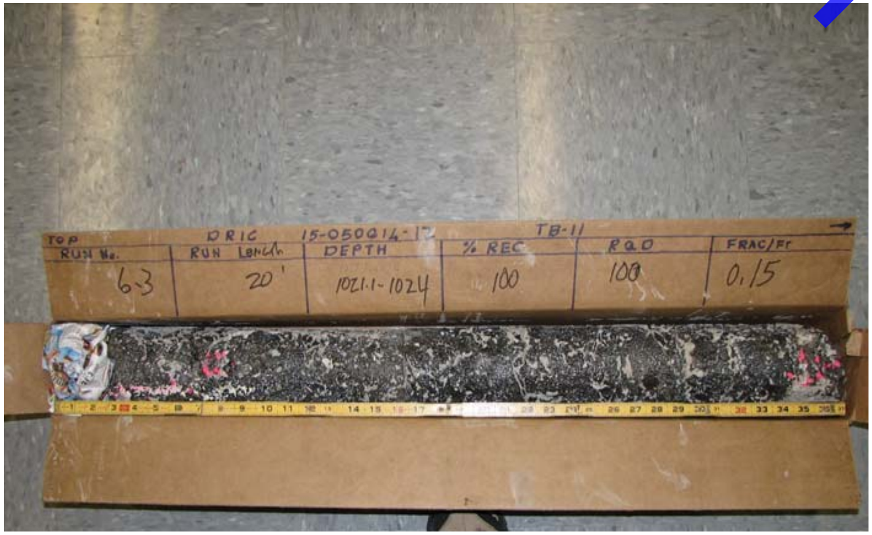


Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-10	30.0	1009.2-1012.0	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	5-11	30.0	1012.0-1014.5	98.3	97.5	0.51

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-1	20.0	1015.0-1018.3	100.0	100.0	0.15

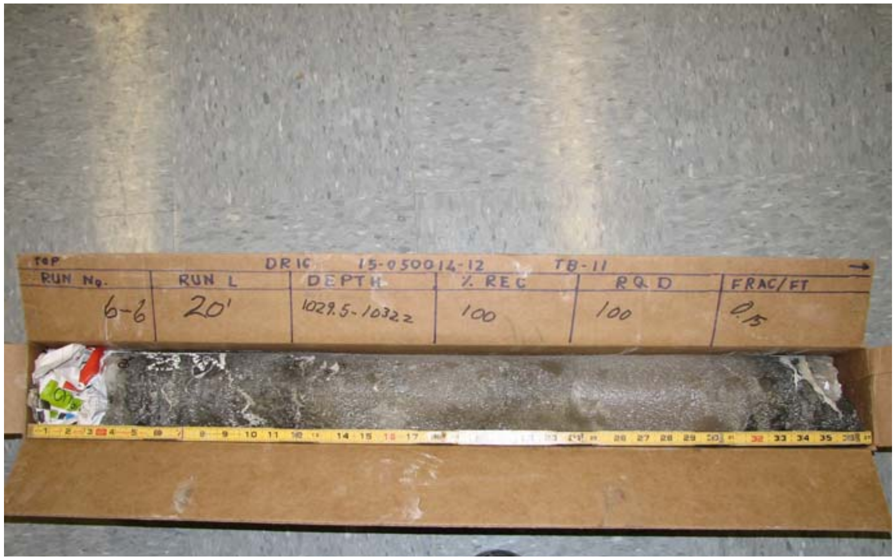
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-2	20.0	1018.3-1021.1	100.0	100.0	0.15



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-3	20.0	1021.1-1024.0	100.0	100.0	0.15

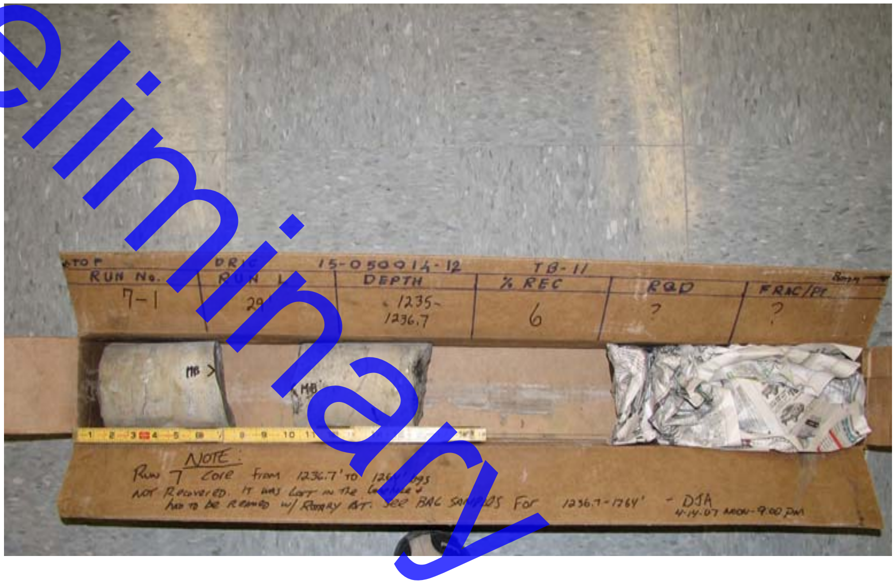
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-4	20.0	1024.0-1026.7	100.0	100.0	0.15

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-5	20.0	1026.7-1029.5	100.0	100.0	0.15



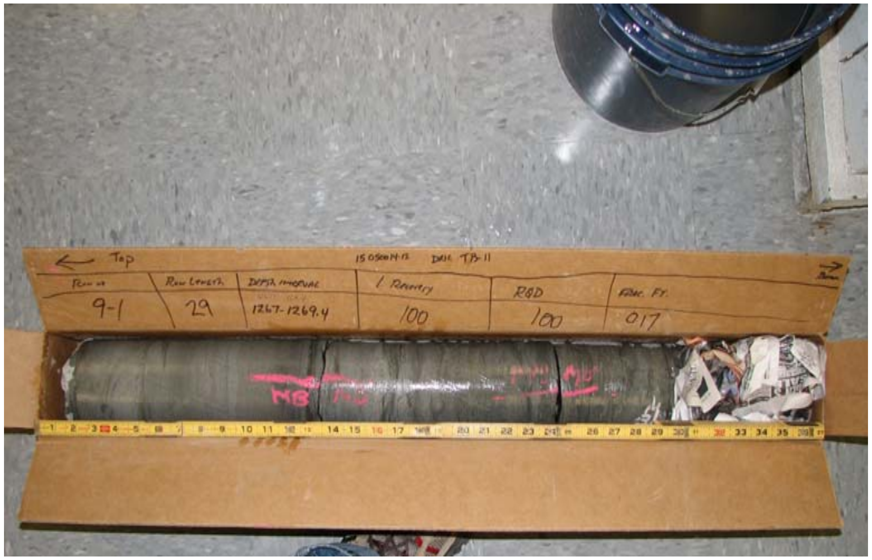
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-6	20.0	1029.5-1032.2	100.0	100.0	0.15

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	6-7	20.0	1032.2-1035.0	100.0	100.0	0.15



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	7-1	29.0	1235.0-1236.7	6.0	-	-

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	8-1	3.0	1264.0-1266.6	86.6	86.6	0.38



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-1	29.0	1267.0-1269.4	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-2	29.0	1269.4-1271.4	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-3	29.0	1271.4-1273.5	100.0	100.0	0.17

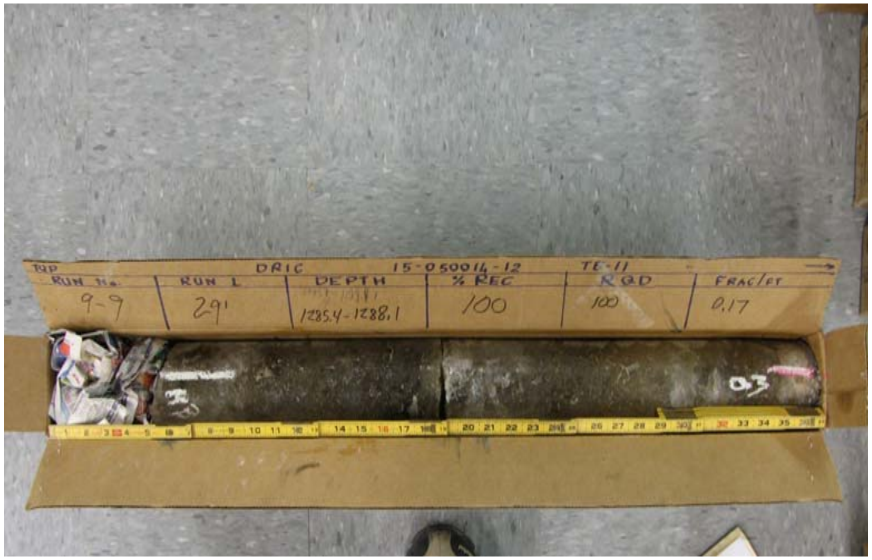
Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-4	29.0	1273.5-1275.7	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-5	29.0	1275.7-1278.3	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-6	29.0	1278.3-1280.6	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-7	29.0	1280.6-1283.0	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-8	29.0	1283.0-1285.4	100.0	100.0	0.17



Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-9	29.0	1285.4-1288.1	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-10	29.0	1288.1-1290.8	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-11	29.0	1290.8-1293.4	100.0	100.0	0.17

Bore Hole	Run	Run Length (feet)	Depth (feet)	Recovery (%)	RQD	Fractures Per Foot
TB-11	9-12	29.0	1293.4-1296.0	100.0	100.0	0.17

Appendix E

Detroit River International Crossing Study
Crosswell Seismic Composite Images

Z SEIS Reservoir Seismic

Enclosure 5
Tomographic Image Reflection Overlay

County: Wayne
Field: Detroit River Crossing
Location:
Profile: TB5 to TB4
Company: NTH Consultants

Company: NTH Consultants
Profile: TB5 to TB4
Field: Detroit River Crossing
Location: Wayne Michagan

Project Datum: 600 ft MSL Elev.: 600
Date Acquired:

Receiver Well Location:	Source Well Location:
Northing: 0 Easting: 0	Northing: 0 Easting: 0

Acquisition Parameters

	Reciever Well	Source Well
Well Name	TB5	TB4
Depth Sample Interval	0	
Top Log Interval		
Bottom Log Interval		
Receiver Description		
Serial Number		
Number of Sondes		
Sample period (us)		
Record Length (ms)		
Trace Delay (ms)		
Listen Time (ms)		
Low-cut filter (Hz)		
High-cut filter (Hz)		
Source Description		
Serial Number		
Sweep type		
Sweep Length (ms)		
Sweep Start (Hz)		
Sweep Stop (Hz)		
Stacks per trace		
Recorded by		
Witnessed by		

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Houston Texas 77040 USA
(713) 690 - 5880 / (713) 690 - 5970 (fax)
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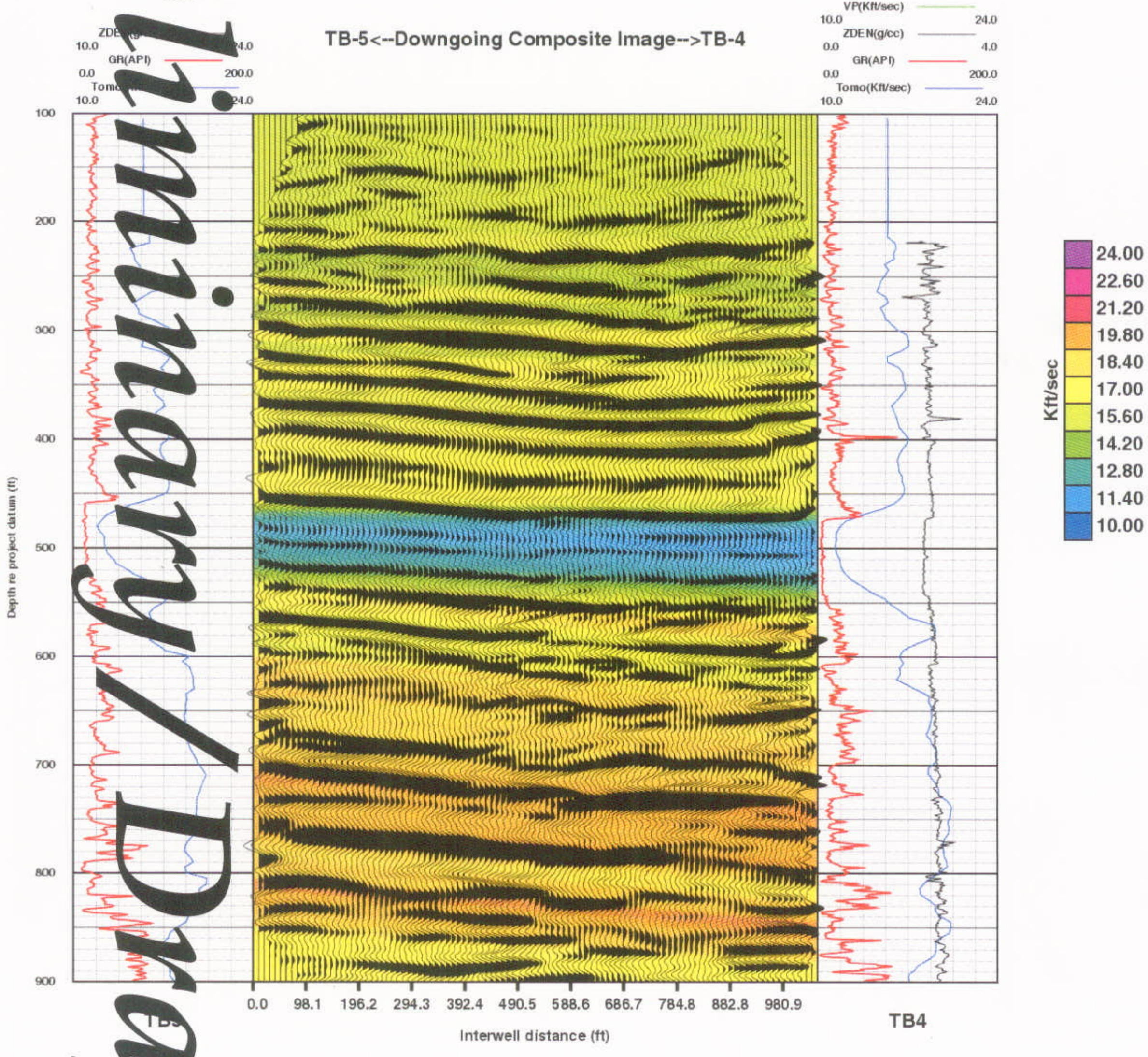

Z SEIS Reservoir Seismic

Enclosure 3
Tomographic Image Reflection Overlay

County: Wayne
Field: Detroit River Crossing
Location:
Profile: TB5 to TB4
Company: NTH Consultants

Company: NTH Consultants
Profile: TB5 to TB4
Field: Detroit River Crossing
Location: Wayne Michagan

Project Datum: 600 ft MSL Elev.: 600
Date Acquired:

Receiver Well Location: Northing: 0 Easting: 0	Source Well Location: Northing: 0 Easting: 0

Acquisition Parameters

	Reciever Well	Source Well
Well Name	TB5	TB4
Depth Sample Interval	0	
Top Log Interval		
Bottom Log Interval		
Receiver Description		
Serial Number		
Number of Sondes		
Sample period (us)		
Record Length (ms)		
Trace Delay (ms)		
Listen Time (ms)		
Low-cut filter (Hz)		
High-cut filter (Hz)		
Source Description		
Serial Number		
Sweep type		
Sweep Length (ms)		
Sweep Start (Hz)		
Sweep Stop (Hz)		
Stacks per trace		
Recorded by		
Witnessed by		

All interpretations are inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, cost, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current price schedule.

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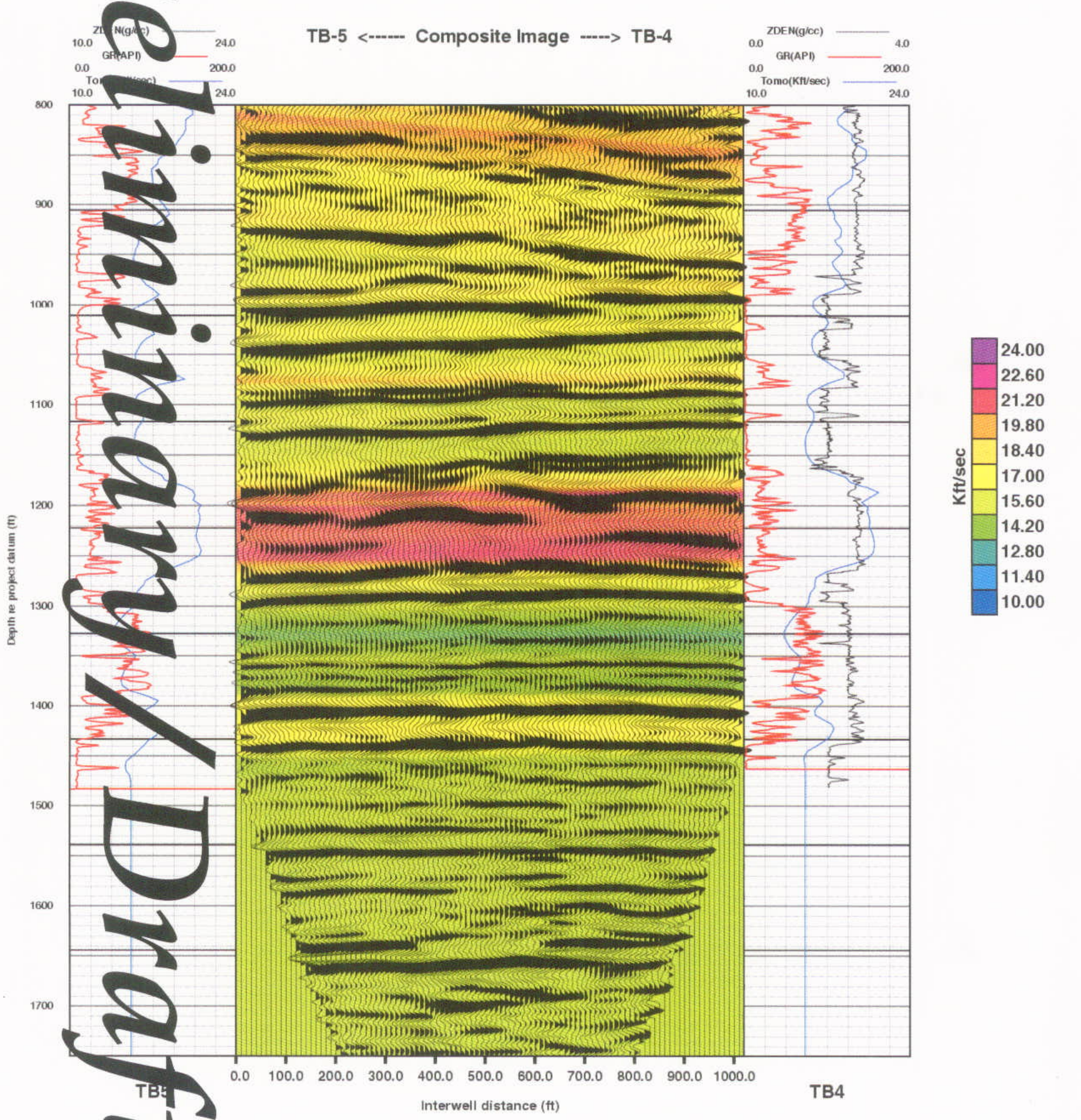
TB-5 <------ Composite Image -----> TB-4



Z SEIS Reservoir Seismic

Enclosure 5
Tomographic Image Reflection Overlay

Company: NTH Consultants

Profile: TB4 to TB2

Field: Detroit River Crossing

Location: Wayne Michagan

County: Wayne
Field: Detroit River Crossing
Location:
Profile: TB4 to TB2
Company: NTH Consultants

Project Datum: 600 ft MSL Elev.: 600
Date Acquired:

Receiver Well Location:
Northing: 0
Easting: 0

Source Well Location:
Northing: 0
Easting: 0

Acquisition Parameters

	Reciever Well	Source Well
Well Name	TB4	TB2
Depth Sample Interval	0	
Top Log Interval		
Bottom Log Interval		
Receiver Description		
Serial Number		
Number of Sondes		
Sample period (us)		
Record Length (ms)		
Trace Delay (ms)		
Listen Time (ms)		
Low-cut filter (Hz)		
High-cut filter (Hz)		
Source Description		
Serial Number		
Sweep type		
Sweep Length (ms)		
Sweep Start (Hz)		
Sweep Stop (Hz)		
Stacks per trace		
Recorded by		
Witnessed by		

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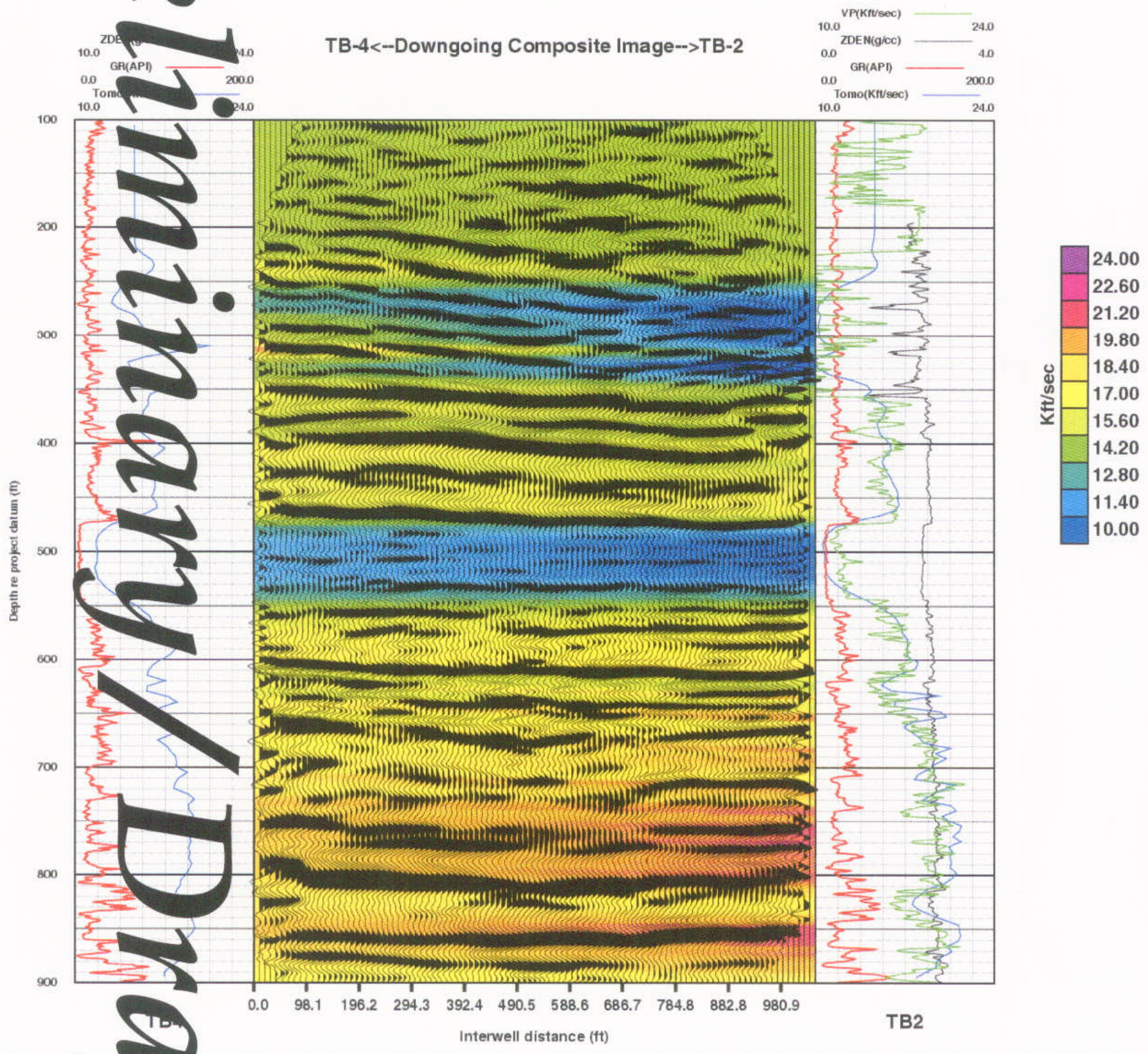

Z SEIS
Reservoir Seismic

Enclosure 3
Tomographic Image Reflection Overlay

County: Wayne
Field: Detroit River Crossing
Location:
Profile: TB4 to TB2
Company: NTH Consultants

Company: NTH Consultants
Profile: TB4 to TB2
Field: Detroit River Crossing
Location: Wayne Michagan

Project Datum: 600 ft MSL Elev.: 600
Date Acquired:

Receiver Well Location:
Northing: 0
Easting: 0

Source Well Location:
Northing: 0
Easting: 0

Acquisition Parameters

	Reciever Well	Source Well
Well Name	TB4	TB2
Depth Sample Interval	0	
Top Log Interval		
Bottom Log Interval		
Receiver Description		
Serial Number		
Number of Sondes		
Sample period (us)		
Record Length (ms)		
Trace Delay (ms)		
Listen Time (ms)		
Low-cut filter (Hz)		
High-cut filter (Hz)		
Source Description		
Serial Number		
Sweep type		
Sweep Length (ms)		
Sweep Start (Hz)		
Sweep Stop (Hz)		
Stacks per trace		
Recorded by		
Witnessed by		

All interpretations are inferences from electrical or other measurements and we cannot and do not guarantee the accuracy or correctness of any interpretation, and we shall not, except in the case of gross or willful negligence on our part, be liable or responsible for any loss, cost, damages or expenses incurred or sustained by anyone resulting from any interpretation made by any of our officers, agents or employees. These interpretations are also subject to our general terms and conditions set out in our current price schedule.

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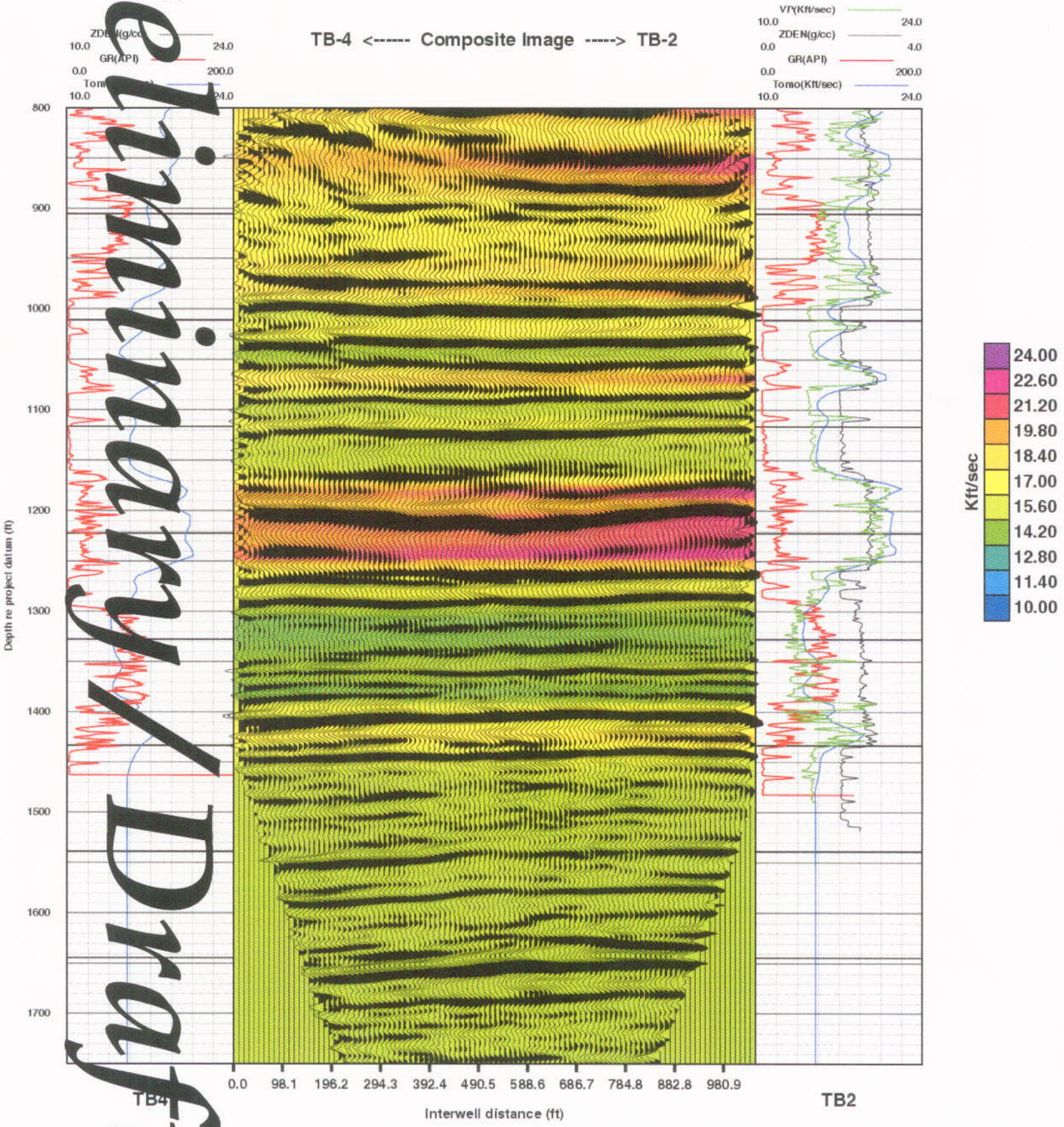


Appendix F

Detroit River International Crossing Study
Report on Results of Rock Testing

Earth Mechanics Institute

Project Name : Detroit River International Crossing

Location: Detroit, MI

Client: NTH Consultants Ltd.

Colorado School of Mines

Mining Engineering Department

Date: 06/05/2007	Rock Type	Average Length	Average Diameter	Density	Uniaxial Compressive Strength		Static Elastic Constants			Notes *(Failure type)*
Sample ID							Young's Modulus		Poisson's Ratio	
		(in)	(in)	(lb/ft^3)	(psi)	(MPa)	(ksi)	(GPa)		
1-3@499.9-501.6*	Sedimentary	4.466	2.249	153	16,577	114	6,[illegible]	42	0.[illegible]2	Non-Structural
1-5@115.0-116.0	Sedimentary	4.776	2.250	158	11,404	79	NA	NA	NA	Structural
1-7@512.8-513.8	Sedimentary	4.748	2.250	141	9,720	67	4,025	[illegible]28	1.33	Non-Structural
2-2@137.1-138.1	Sedimentary	4.755	2.250	157	12,927	89	6,482	45	0.29	Non-Structural
2-7@540.6-541.7	Sedimentary	4.787	2.254	149	14,378	99	[illegible]838	40	0.40	Non-Structural
3-3@929.6-930.7	Sedimentary	5.723	2.251	137	18,228	[illegible]26	4,[illegible]2	31	0.21	Non-Structural
3-8@943.3-944.2	Sedimentary	4.726	2.250	171	17,696	[illegible]	4,083	28	0.23	Non-Structural
4-10@979.2-980.1*	Sedimentary	4.319	2.251	183	25,[illegible]8	[illegible]	10,302	71	0.36	Non-Structural
5-9@1008.0-1009.2	Sedimentary	4.820	2.249	162	[illegible]98	128	3,536	24	0.50	Non-Structural
6-3@213.9-214.9	Sedimentary	4.708	2.250	133	7,38[illegible]	51	4,464	31	0.41	Non-Structural
7-1@1235.5-1236.2	Sedimentary	4.748	2.250	14[illegible]	9,[illegible]	67	4,706	32	0.37	Non-Structural
9-6@1278.8-1279.7	Sedimentary	4.765	2.248	178	17,[illegible]74	118	6,185	43	0.37	Non-Structural
9-12@1295.1-1296.0	Sedimentary	4.823	2.253	1[illegible]	8,235	57	NA	NA	NA	Structural
11-3@355.8-356.7	Sedimentary	4.740	2.[illegible]52	145	12,335	85	5,040	35	0.53	Non-Structural
15-6@459.5-460.4	Sedimentary	4.798	2.24[illegible]	[illegible]41	6,580	45	4,139	29	0.86	Non-Structural
17-2@509.5-510.5	Sedimentary	4.730	2.[illegible]51	146	9,731	67	4,856	33	0.53	Non-Structural
18-9@558.9-559.8	Sedimentary	4.[illegible]7	2.250	147	11,716	81	5,270	36	0.51	Non-Structural
22-5@588.6-589.5	Sedimentary	4.[illegible]4	[illegible]252	166	27,920	193	6,923	48	0.51	Non-Structural
25-6@679.3-680.1	Sedimentary	[illegible].842	2.255	163	11,789	81	8,117	56	0.27	Structural
28-9@770.6-771.5	Sedimentary	4.[illegible]	2.251	167	16,788	116	11,124	77	0.35	Structural
31-4@848.7-849.5	Sedimentary	[illegible]816	2.251	171	20,492	141	6,922	48	0.28	Non-Structural
33-11@927.7-928.9	Sedimentary	4.699	2.251	175	18,801	130	6,785	47	0.25	Non-Structural
43-4@1178.1-1178.9	Sedimentary	4.781	2.253	183	30,970	214	10,063	69	0.37	Non-Structural
44-9@12[illegible].2-12[illegible]2	Sedimentary	4.804	2.247	171	28,173	194	10,141	70	0.55	Non-Structural
46-9[illegible]285.3-12[illegible]3	Sedimentary	4.777	2.245	167	12,490	86	3,106	21	0.27	Non-Structural
47-11@13[illegible]321.0	Sedimentary	4.869	2.250	162	9,251	64	2,628	18	0.17	Structural
49-9@1372.5-[illegible]3.4*	Sedimentary	4.469	2.258	160	10,473	72	9,656	67	0.37	Non-Structural

Note (*): The sample Length to Diameter Ratio slightly less than 2:1, required by ASTM.

Figure No. 39

Earth Mechanics Institute
Project Name : Detroit River International Crossing
Location: Detroit, MI
Client: NTH Consultants Ltd.

Colorado School of Mines
Mining Engineering Department

Date: 06/05/2007 Sample ID	Rock Type	Average Length	Average Diameter	Indirect (Brazilian) Tensile Strength		Notes (Failure type)
		(in)	(in)	(psi)	(MPa)	
1-7@512.8-513.8	Sedimentary	1.34	[illegible]	242	1.7	Non-Structural
2-7@540.6-541.7	Sedimentary	1.23	2.252	711	4.9	Non-Structural
3-3@929.6-930.7	Sedimentary	1.31	2.250	848	5.8	Non-Structural
3-8@943.3-944.2	Sedimentary	1.35	2.245	670	4.6	Non-Structural
15-6@459.5-460.4	Sedimentary	1.32	2.253	123	0.8	Non-Structural
17-2@509.5-510.5	Sedimentary	1.27	2.243	243	1.7	Structural

Figure No. 39

Earth Mechanics Institute
Project Name : Detroit River International Crossing
Location: Detroit, MI
Client: NTH Consultants Ltd.

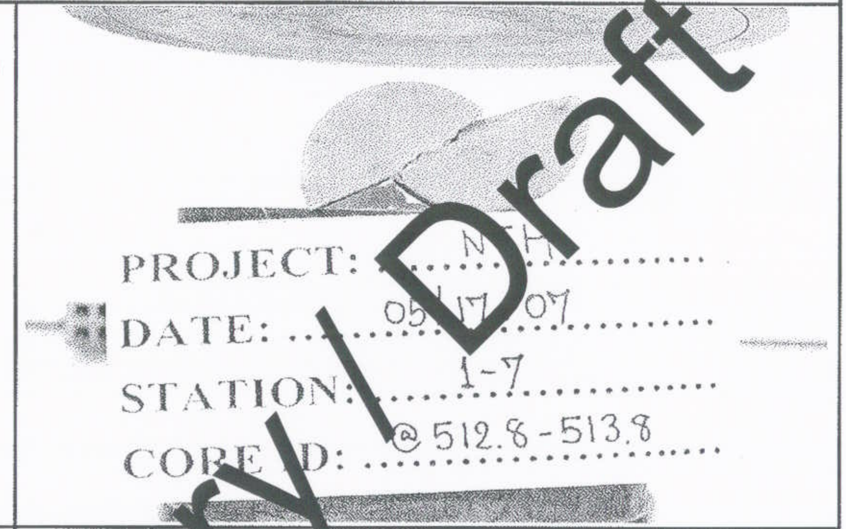
Colorado School of Mines
Mining Engineering Department

Date: 06/05/2007		Water Temperature		Moisture	Slake Durability	Notes
Sample ID	Rock Type	Range (°C)	Average (°C)	Content (%)	Index ($I_{d(2)}$) (%)	(Retained Fragments Description)
1-7@512.8-513.8	Sedimentary	23.0-22.0	22.5	[illegible]	21.1	Type II - Retained material consist of large and small fragments
2-7@540.6-541.7	Sedimentary	22.0-21.0	21.5	[illegible]	97.1	Type I - Retained pieces remain virtually unchanged.
3-3@929.6-930.7	Sedimentary	24.0-21.5	22.8	2.4	98.4	Type I - Retained pieces remain virtually unchanged.
3-8@943.3-944.2	Sedimentary	34.0-25.5	29.8	0.9	98.2	Type I - Retained pieces remain virtually unchanged.
15-6@459.5-460.4	Sedimentary	22.0-21.0	21.5	2.0	34.0	Type II - Retained material consist of large and small fragments
17-2@509.5-510.5	Sedimentary	27.0-22.5	24.8	2.4	[illegible]	[illegible] - Retained pieces remain virtually unchanged.
33-11@927.7-928.9	Sedimentary	24.0-22.5	23.3	1.1	99.2	Type [illegible] Retained pieces remain virtually unchanged.
47-11@1320.0-1321.0	Sedimentary	23.0-22.0	22.5	2.7	94.6	Type [illegible] - Retained pieces remain virtually unchanged.
49-9@1372.5-1373.4	Sedimentary	29.0-24.5	26.8	0.2	90.6	Type II - R[illegible] material consist of large and small fragments

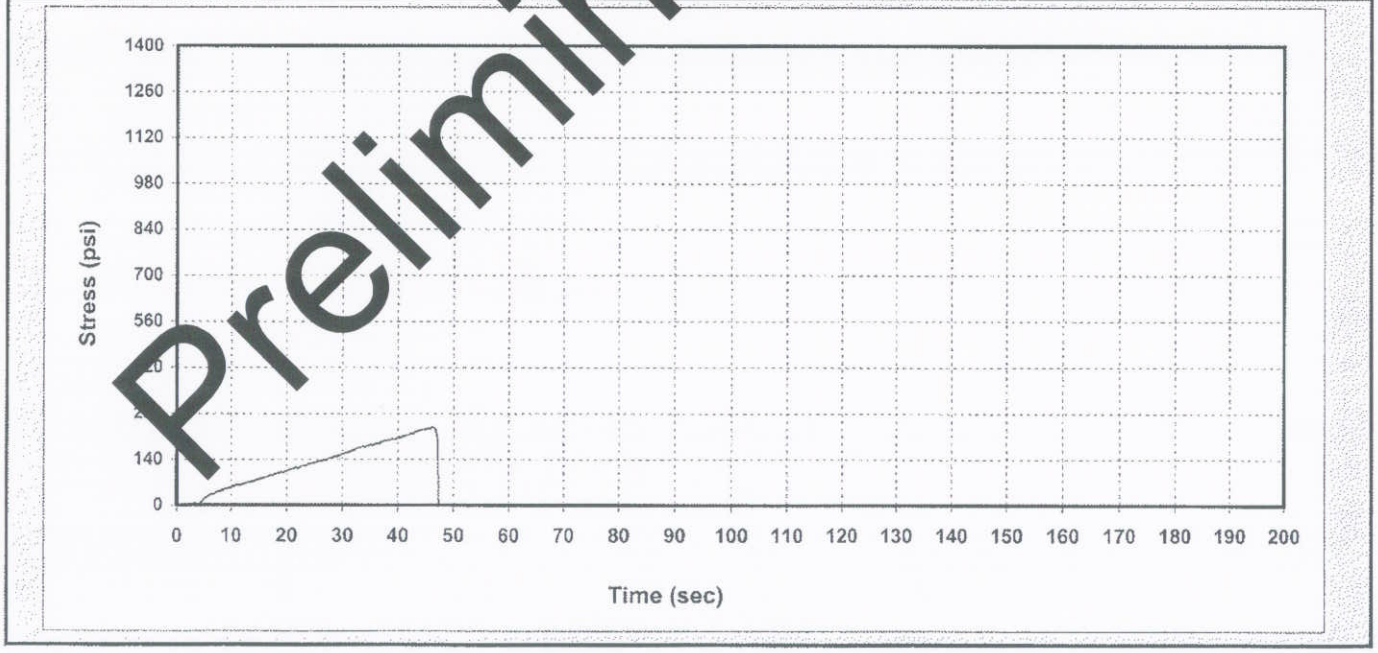
Figure No. 39

Earth Mechanics Institute
Mining Engineering Department, CSM
BTS Reduction Program (Ver. 2.0)

Project Name :	Detroit International Crossing
Location :	Detroit, MI
Rock Type :	Sedimentary
Rock Name :	Sandstone
Characteristics :	light gray, massive
Test Performed by :	PIPAT
Date Tested :	5/17/2007
Data Reduced by :	mcs
Date Reduced :	6/5/2007
Rock Source :	drill core
Core ID :	1-7@512.8-513.8
File Name :	1-7@512.8-513.8

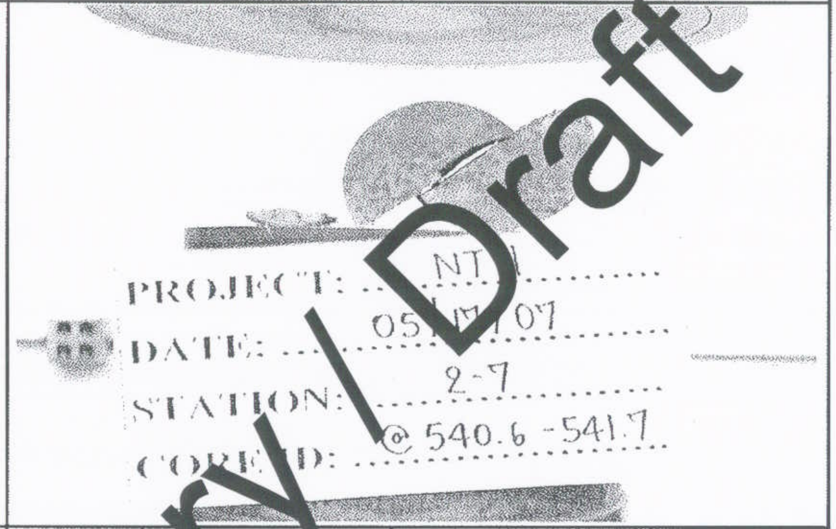


Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	[illegible]	N	psi	MPa	Mode
1.34	3.40	2.252	5.72	0.5[illegible]	1,144	5,090	242	1.7	Non-Structural

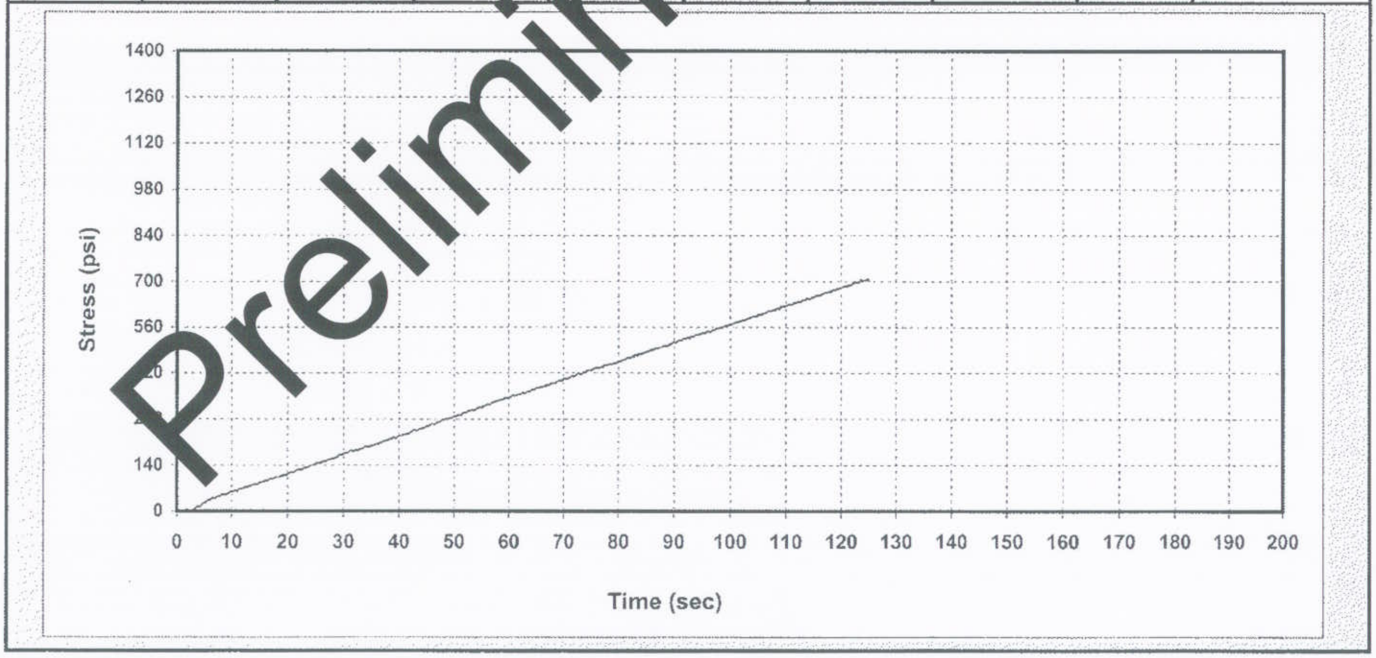


Earth Mechanics Institute
Mining Engineering Department, CSM
BTS Reduction Program (Ver. 2.0)

Project Name : Detroit International Crossing
Location : Detroit, MI
Rock Type : Sedimentary
Rock Name : Sandstone
Characteristics : light gray, massive
Test Performed by : PIPAT
Date Tested : 5/17/2007
Data Reduced by : mcs
Date Reduced : 6/5/2007
Rock Source : drill core
Core ID : 2-7@540.6-541.7
File Name : 2-7@540.6-541.7



Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
1.23	3.13	2.252	5.72	0.[illegible]	3,097	13,775	711	4.9	Non-Structural

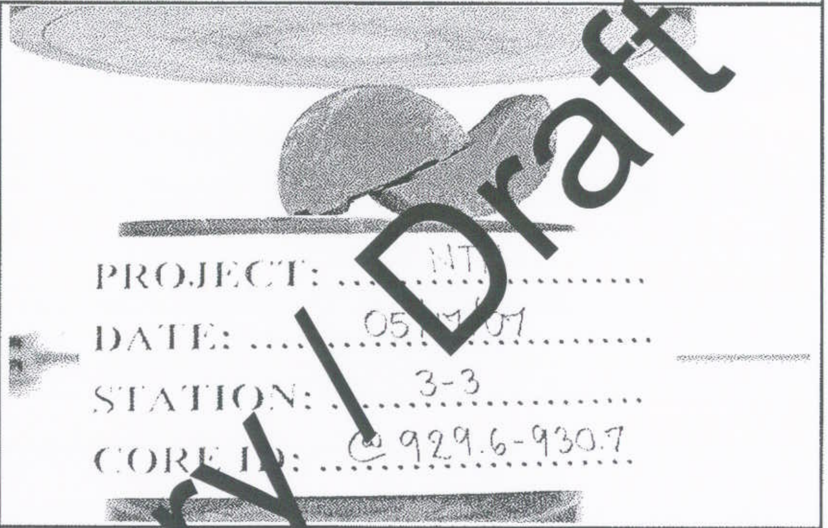


Earth Mechanics Institute

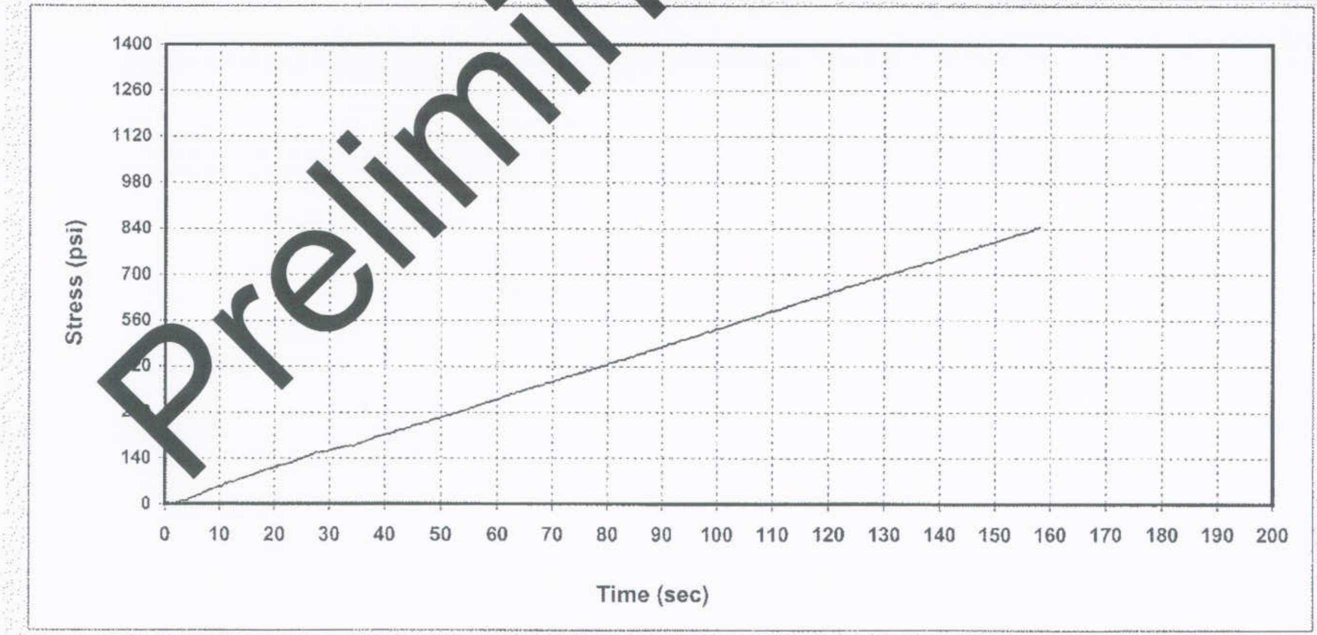
Mining Engineering Department, CSM

BTS Reduction Program (Ver. 2.0)

Project Name : Detroit International Crossing
Location : Detroit, MI
Rock Type : Sedimentary
Rock Name : Shale
Characteristics : light gray, mild laminations
Test Performed by : PIPAT
Date Tested : 5/17/2007
Data Reduced by : mcs
Date Reduced : 6/5/2007
Rock Source : drill core
Core ID : 3-3@929.6-930.7
File Name : 3-3@929.6-930.7

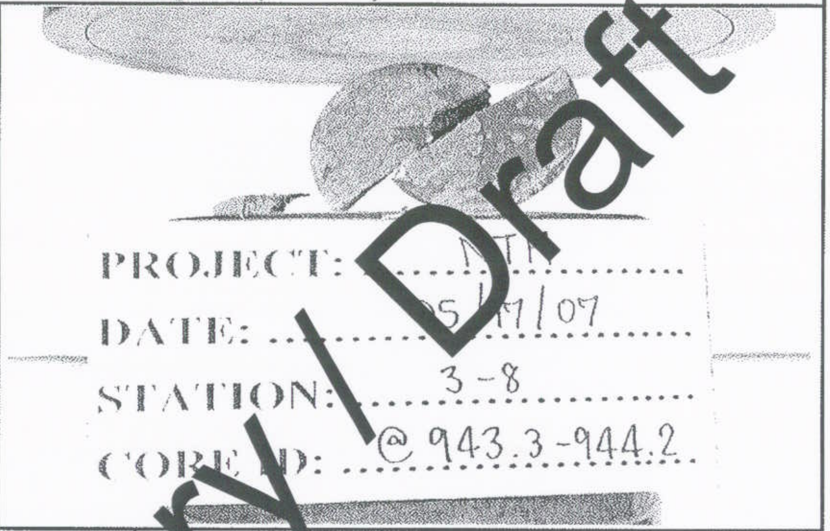


Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
1.31	3.33	2.250	5.72	0.5	3,931	17,488	848	5.8	Non-Structural



Earth Mechanics Institute
Mining Engineering Department, CSM
BTS Reduction Program (Ver. 2.0)

Project Name : Detroit International Crossing
Location : Detroit, Mi
Rock Type : Sedimentary
Rock Name : Shale/Dolomitic Shale
Characteristics : light gray
Test Performed by : PIPAT
Date Tested : 5/17/2007
Data Reduced by : mcs
Date Reduced : 6/5/2007
Rock Source : drill core
Core ID : 3-8@943.3-944.2
File Name : 3-8@943.3-944.2



PROJECT: NTH
DATE: 05/17/07
STATION: 3-8
CORE ID: @943.3-944.2

Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
1.35	3.42	2.245	5.70	0.6	3,179	14,143	670	4.6	Non-Structural

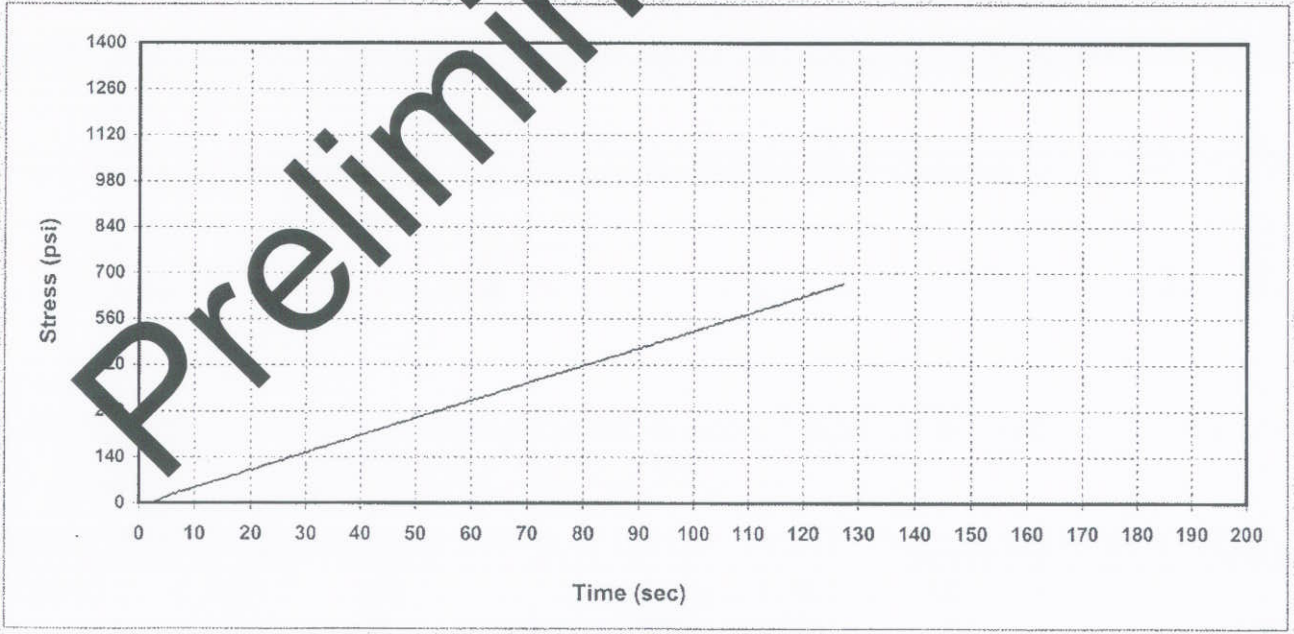
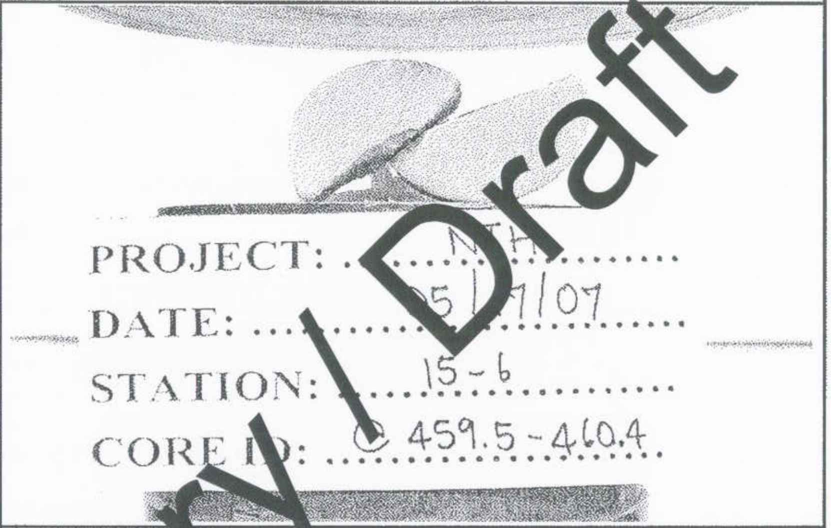


Figure No. 39

Earth Mechanics Institute
Mining Engineering Department, CSM
BTS Reduction Program (Ver. 2.0)

Project Name : Detroit International Crossing
Location : Detroit, MI
Rock Type : Sedimentary
Rock Name : Sandstone
Characteristics : white
Test Performed by : PIPAT
Date Tested : 5/17/2007
Data Reduced by : mcs
Date Reduced : 6/5/2007
Rock Source : drill core
Core ID : 15-6@459.5-460.4
File Name : 15-6@459.5-460.4



Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
1.32	3.34	2.253	5.72	0.5	572	2,544	123	0.8	Non-Structural

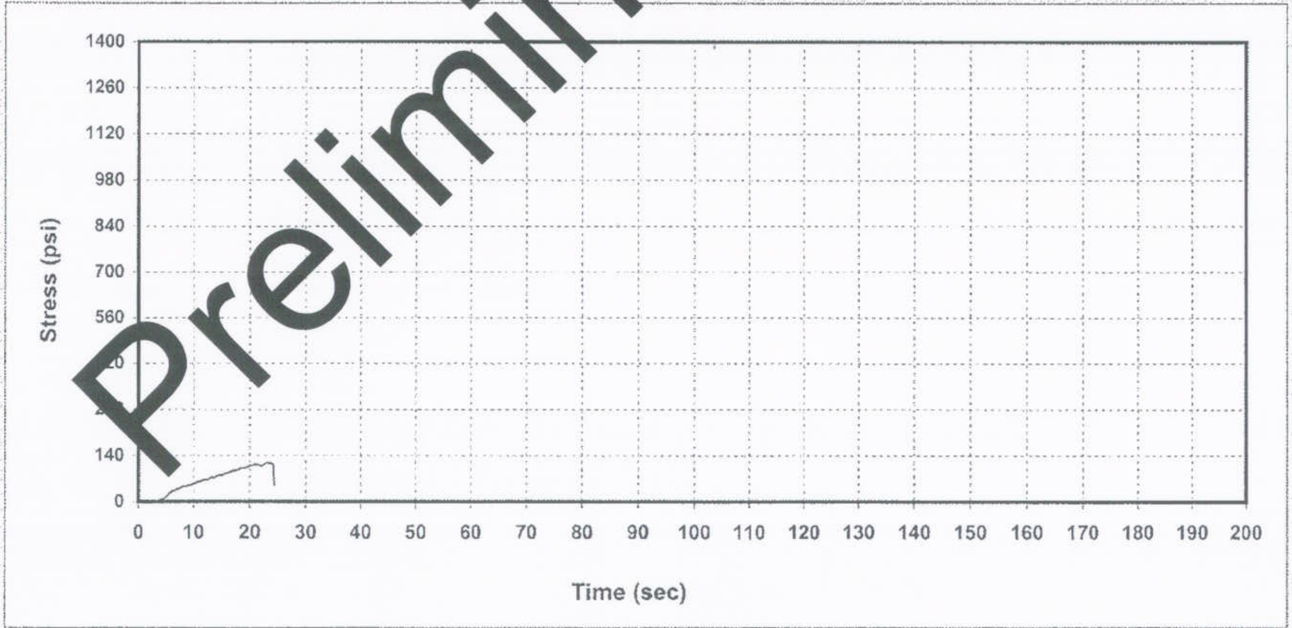
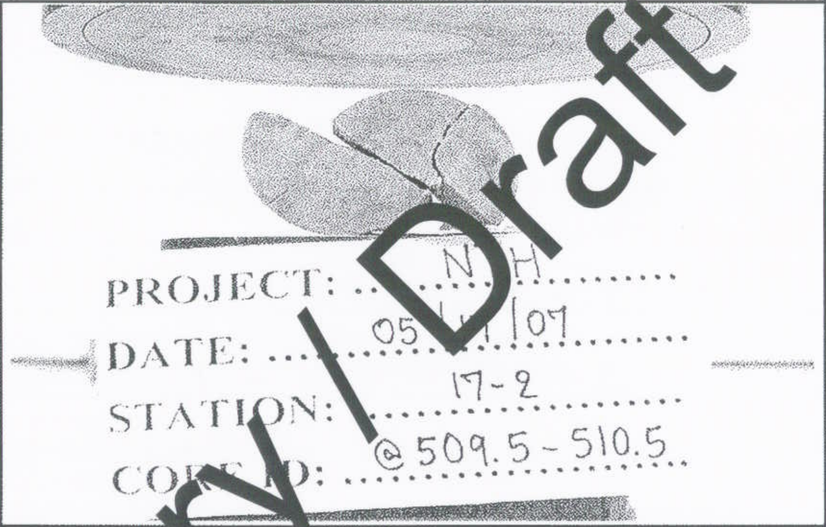


Figure No. 39

Earth Mechanics Institute
Mining Engineering Department, CSM
BTS Reduction Program (Ver. 2.0)

Project Name : Detroit International Crossing
Location : Detroit, MI
Rock Type : Sedimentary
Rock Name : Dolomitic Sandstone
Characteristics : light gray, massive
Test Performed by : PIPAT
Date Tested : 5/17/2007
Data Reduced by : mcs
Date Reduced : 6/5/2007
Rock Source : drill core
Core ID : 17-2@509.5-510.5
File Name : 17-2@509.5-510.5



Disc Thickness		Disc Diameter		L/D	Failure Load		BTS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
1.27	3.24	2.243	5.70	0.[illegible]	1,089	4,845	243	1.7	Structural

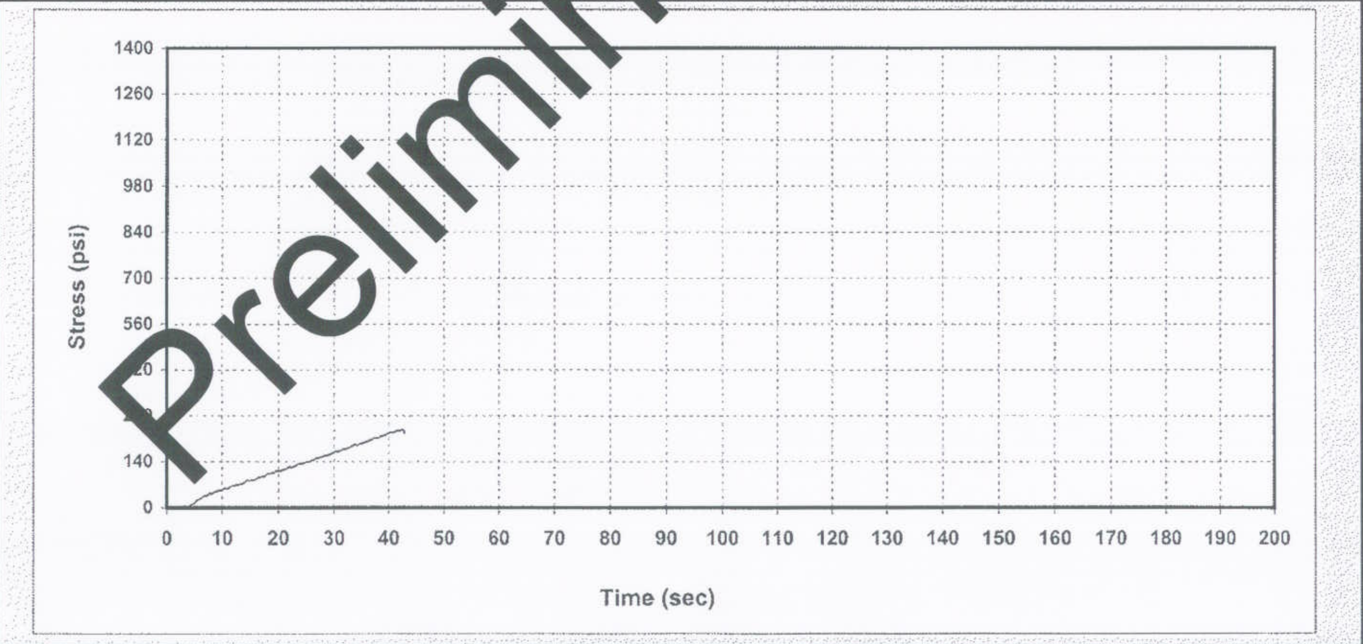


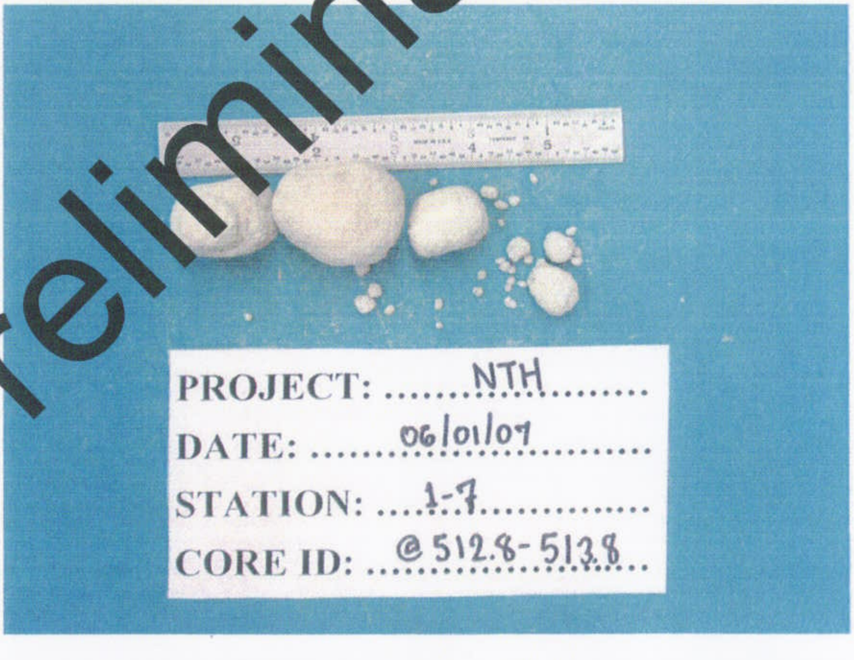
Figure No. 39

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 1-7@512.8-513.8

PROJECT: NTH
DATE: 05/29/07
STATION: 1-7
CORE ID: @512.8-513.9

(Before Slaking)



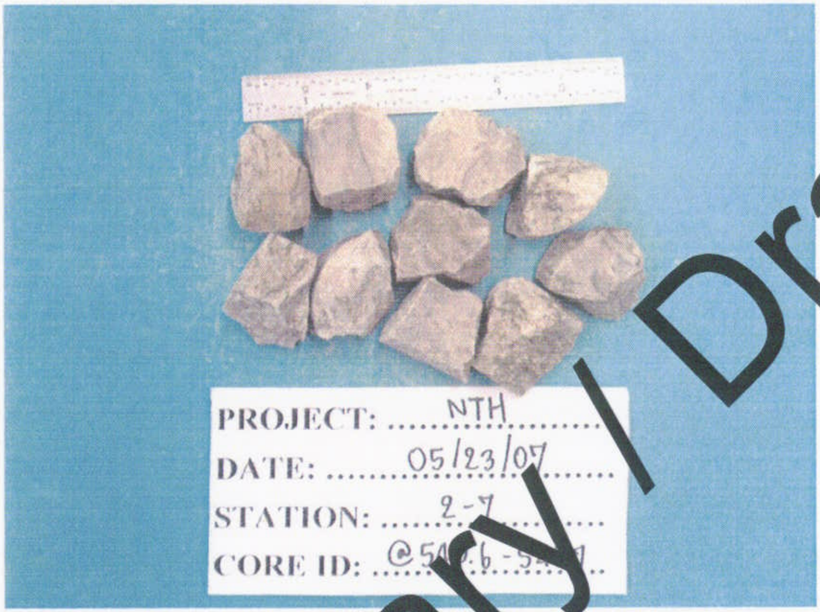
PROJECT: NTH
DATE: 06/01/07
STATION: 1-7
CORE ID: @512.8-513.8

(Dried sample After 2nd Cycle)

Description: Type II - Retained materials consist of large and small pieces.

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 2-7@540.6-541.7



PROJECT: NTH
DATE: 05/23/07
STATION: 2-7
CORE ID: @5[illegible]6-5[illegible]

(Before Soaking)

PROJECT: NTH
DATE: 05/29/07
STATION: 2-7
CORE ID: @540.6-541.7

(Dried sample After 2nd Cycle)

Description: Type I - Retained pieces remain virtually unchanged.

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 3-3@929.6-930.7

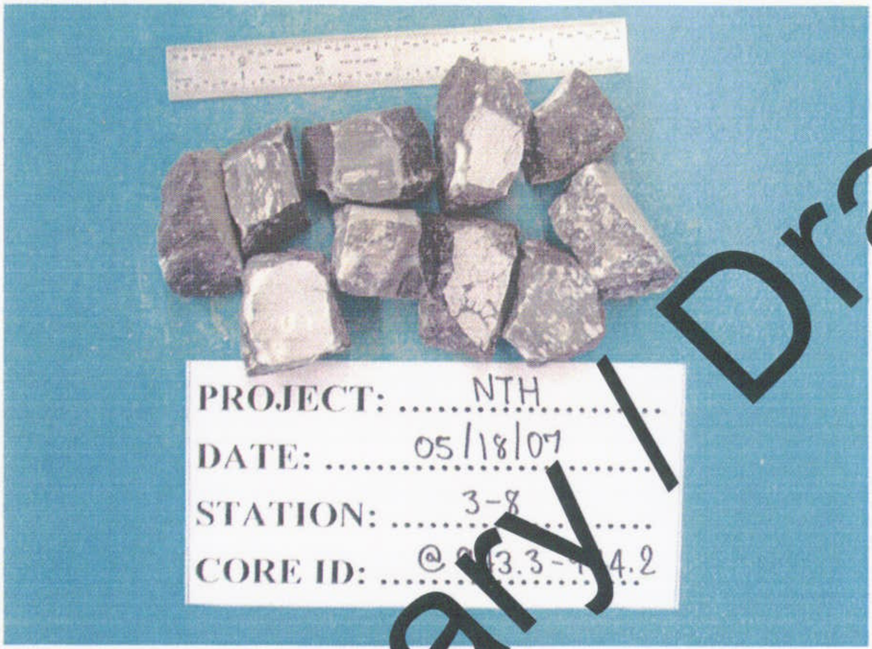
(Before Slaking)

(Dried sample After 2nd Cycle)

Description: Type I - Retained pieces remain virtually unchanged.

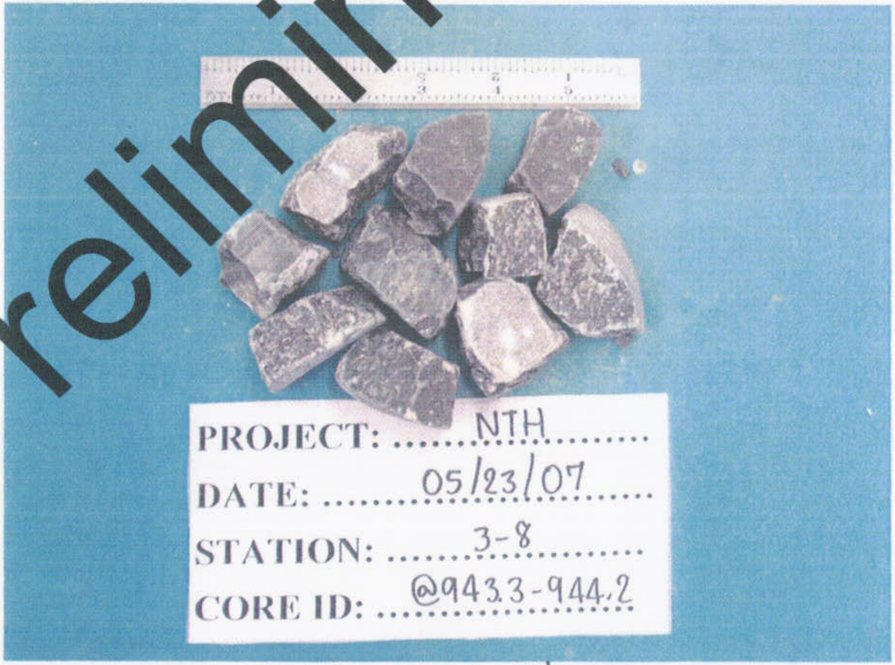
Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 3-8@943.5-944.2



PROJECT: NTH
DATE: 05/18/07
STATION: 3-8
CORE ID: @943.3-944.2

(Before Slaking)



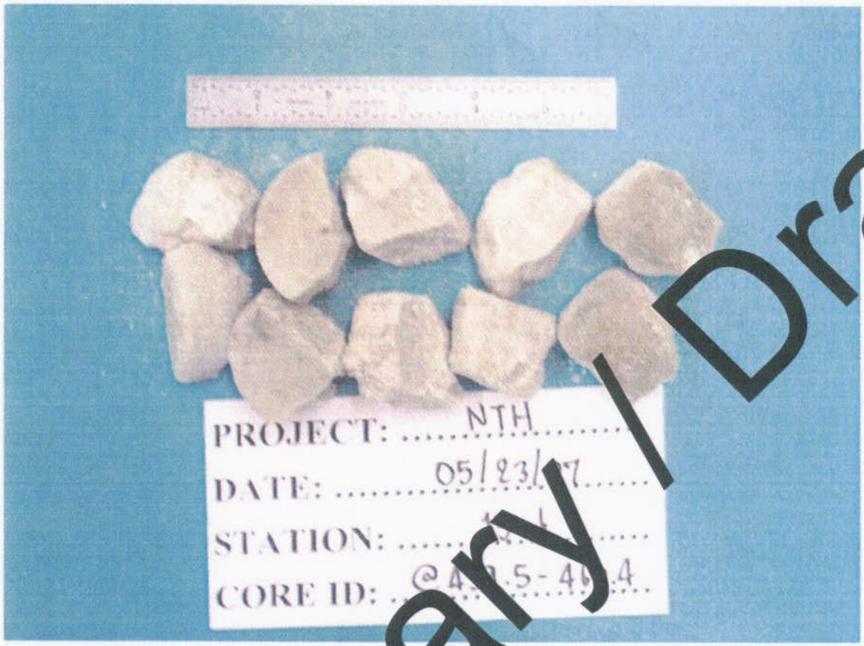
PROJECT: NTH
DATE: 05/23/07
STATION: 3-8
CORE ID: @943.3-944.2

(Dried sample After 2nd Cycle)

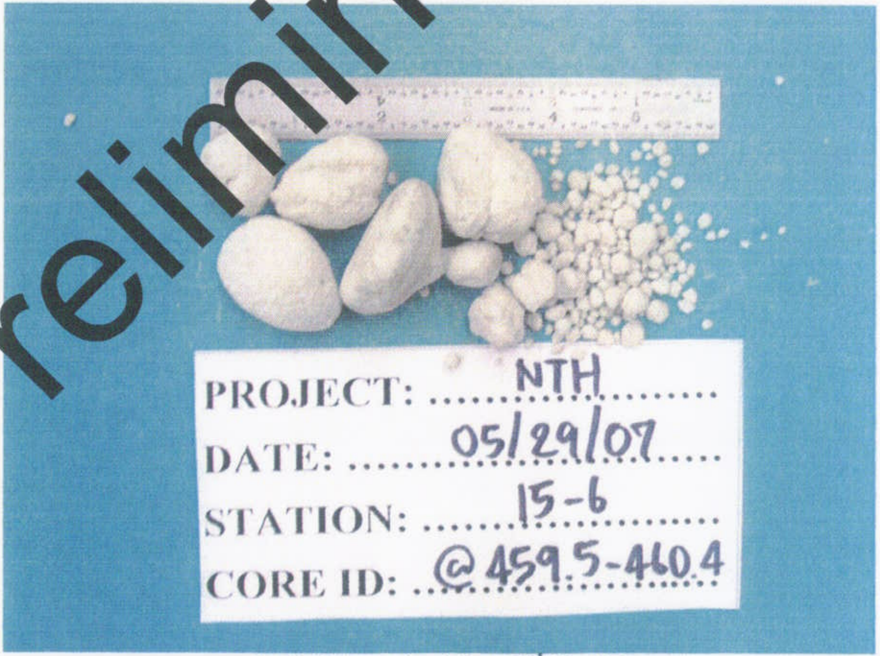
Description: Type I - Retained pieces remain virtually unchanged.

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 15-6@459.5-460.4


PROJECT: NTH
DATE: 05/23/[illegible]7
STATION: [illegible]
CORE ID: @4[illegible].5-4[illegible].4

(Before Slaking)


PROJECT: NTH
DATE: 05/29/07
STATION: 15-6
CORE ID: @459.5-460.4

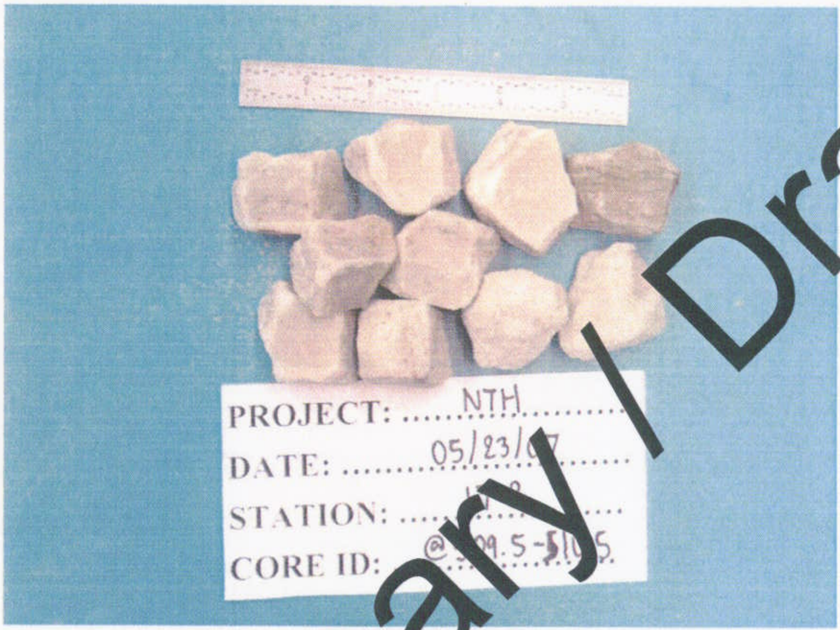
(Dried sample After 2nd Cycle)

Description: Type II - Retained materials consist of large and small pieces.

Figure No. 39

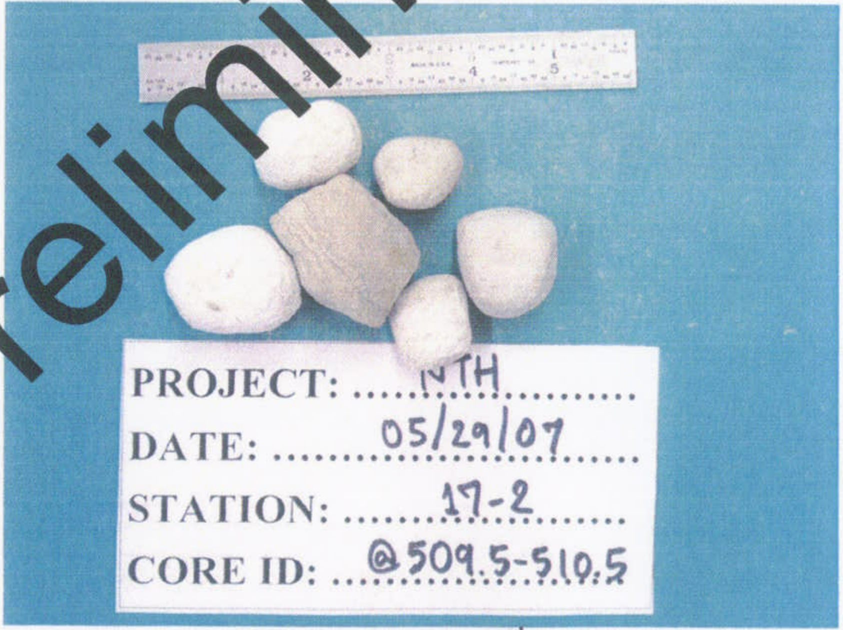
Pictures of Slake Durability Test

Project: Detroit International Crossing
Location: Detroit, MI
Sample ID: 17-2@509.5-510.5



PROJECT: ....NTH.........
DATE: ....05/23/07......
STATION: .....17-2.......
CORE ID: ..@509.5-510.5

(Before Slaking)



PROJECT: ....NTH..........
DATE: ....05/29/07.....
STATION: ....17-2.......
CORE ID: ..@509.5-510.5

(Dried sample After 2nd Cycle)

Description: Type I - Retained pieces remain virtually unchanged.

Earth Mechanics Institute, CSM **6/6/2007**

Figure No. 39

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 33-11@927.7-928.9

(Before Slaking)

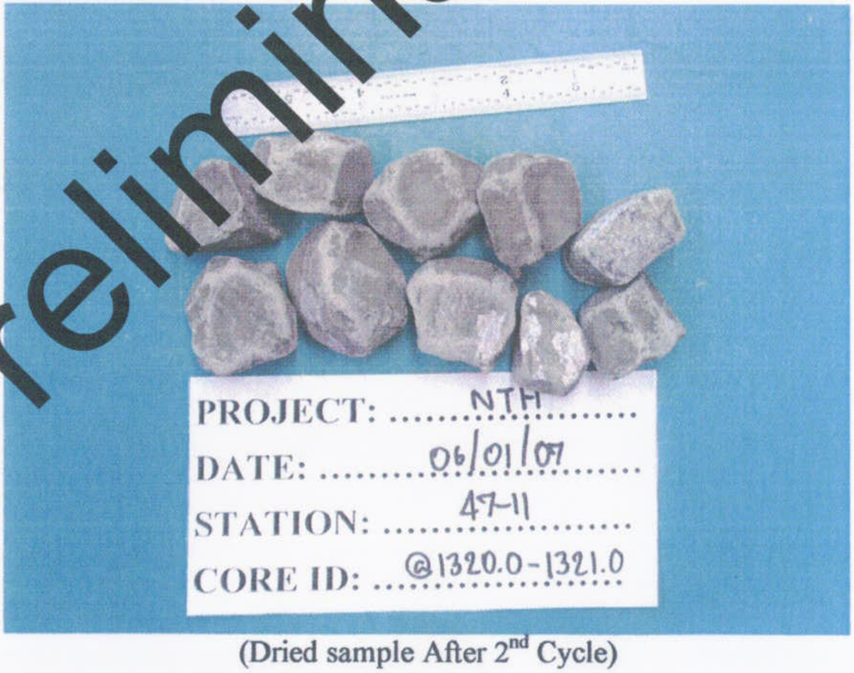
(Dried sample After 2nd Cycle)

Description: Type I – Retained pieces remain virtually unchanged.

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 47-11@1320.0-1321.0

(Before Slaking)



(Dried sample After 2nd Cycle)

Description: Type I - Retained pieces remain virtually unchanged.

Pictures of Slake Durability Test

Project: Detroit River International Crossing
Location: Detroit, MI
Sample ID: 49-9@1372.5-1373.4

(Before Slaking)

(Dried sample After 2nd Cycle)

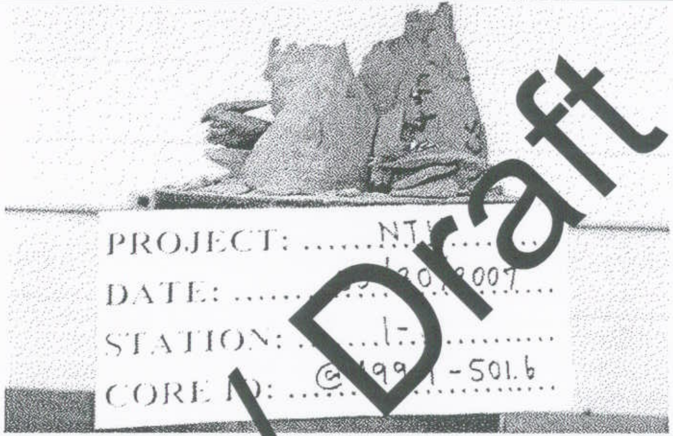
Description: Type II- Retained Materials consist of large and small pieces.

Earth Mechanics Institute

Mining Engineering Department, CSM

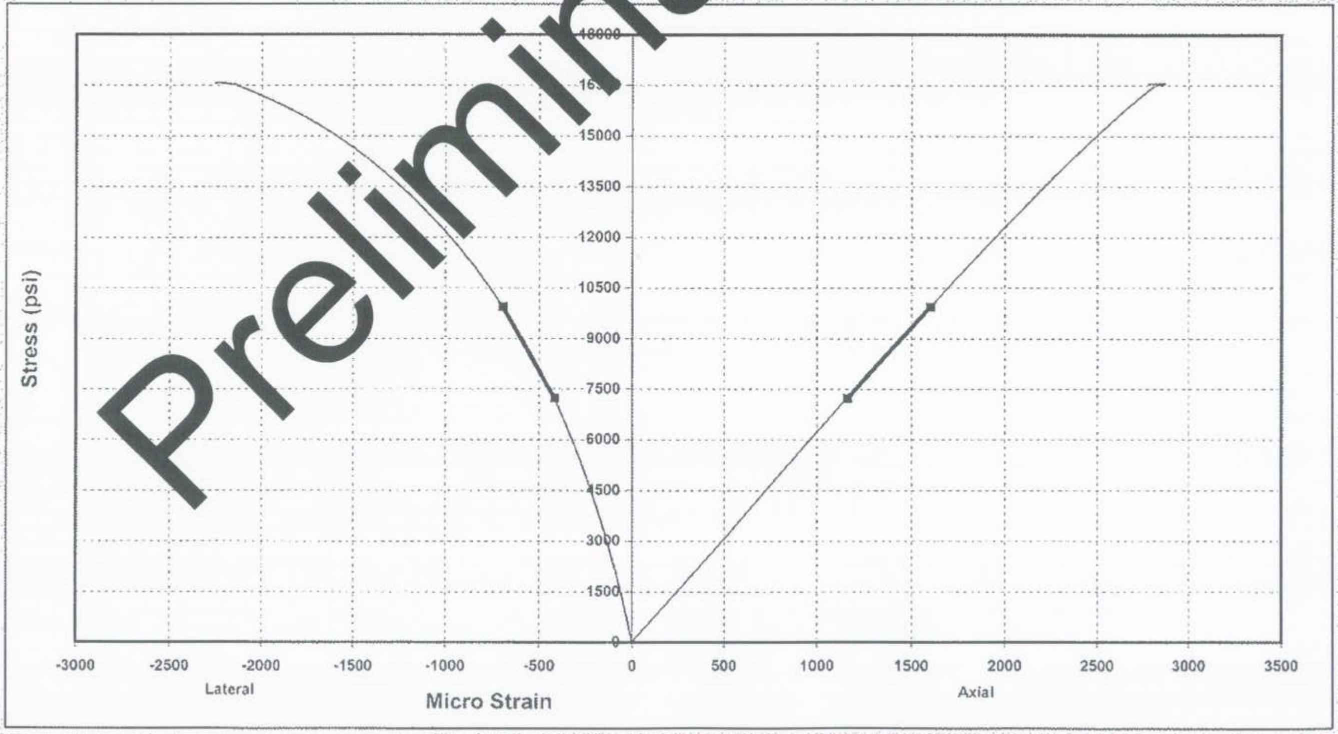
Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Dolomite
Characteristics:	brown
Core ID:	1-3@499.9-501.6
File Name:	1-3@499.9-501.6
Test Performed by:	PIPAT
Date Tested:	05/30/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	kN	psi	MPa	Mode
4.466	11.34	2.249	5.71	1.99	65,825	[illegible]	16,577	114	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	6,160	42	0.62	153	2.45



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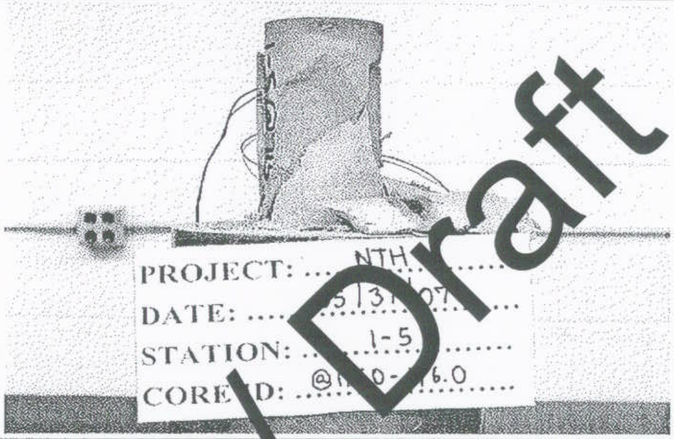
Earth Mechanics Institute

Mining Engineering Department, CSM

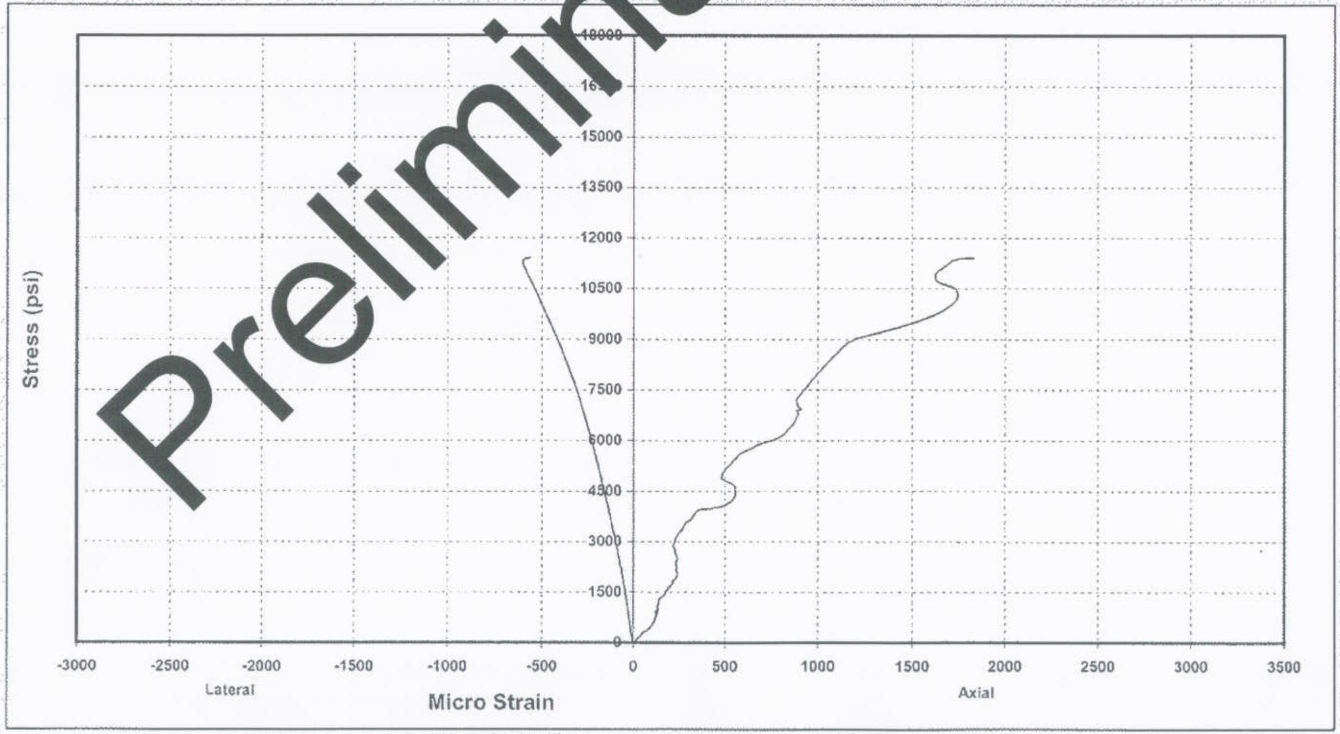
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Limestone
Characteristics: gray, jointed
Core ID: 1-5@115.0-116.0
File Name: 1-5@115.0-116.0
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	kN	psi	MPa	Mode
4.776	12.13	2.250	5.72	2.12	45,343	[illegible]01.69	11,404	79	Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	158	2.54



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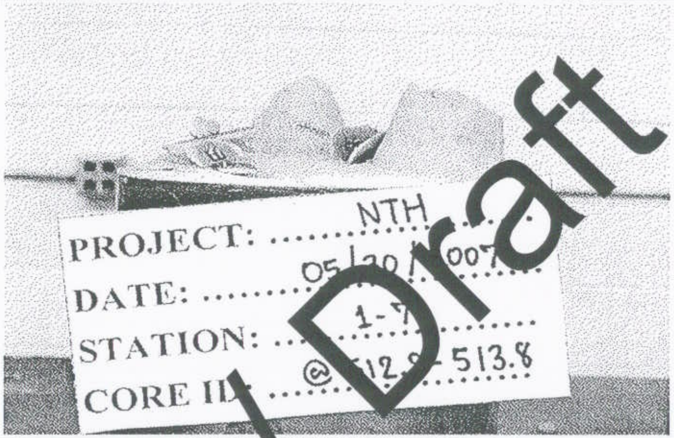
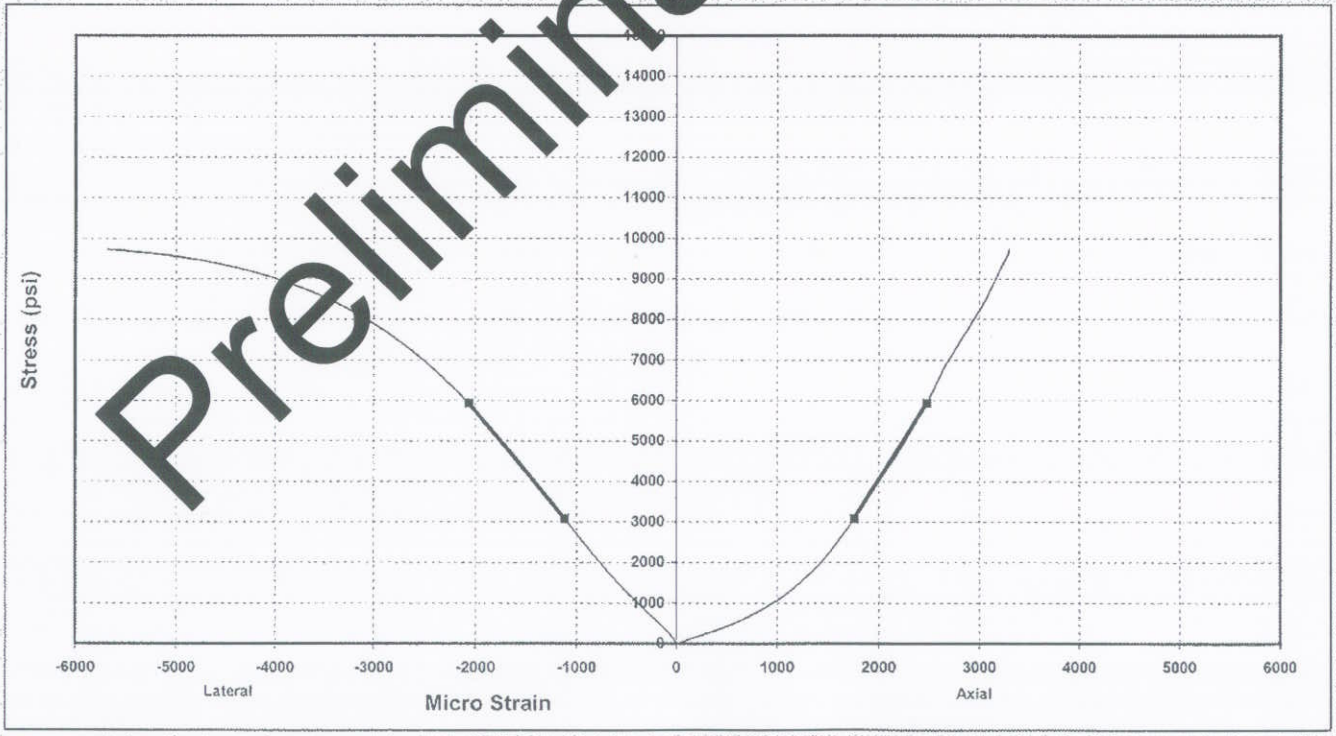
Earth Mechanics Institute
Mining Engineering Department, CSM
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Sandstone
Characteristics: light gray
Core ID: 1-7@512.8-513.8
File Name: 1-7@512.8-513.8
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	psi	MPa	
4.748	12.06	2.250	5.71	2.11	38,631	71.83	9,720	67	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,025	28	1.33	141	2.26



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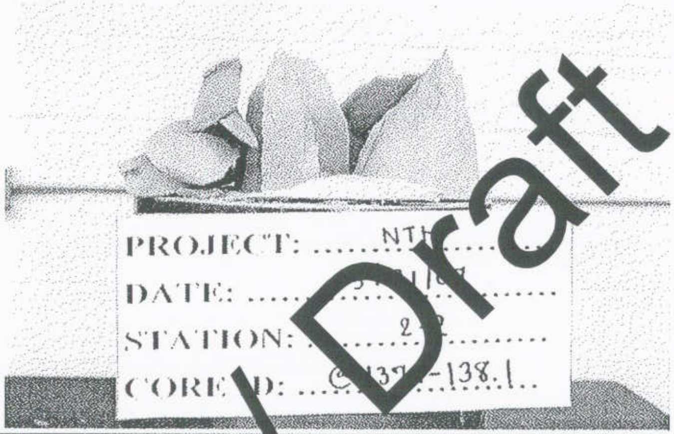
Earth Mechanics Institute

Mining Engineering Department, CSM

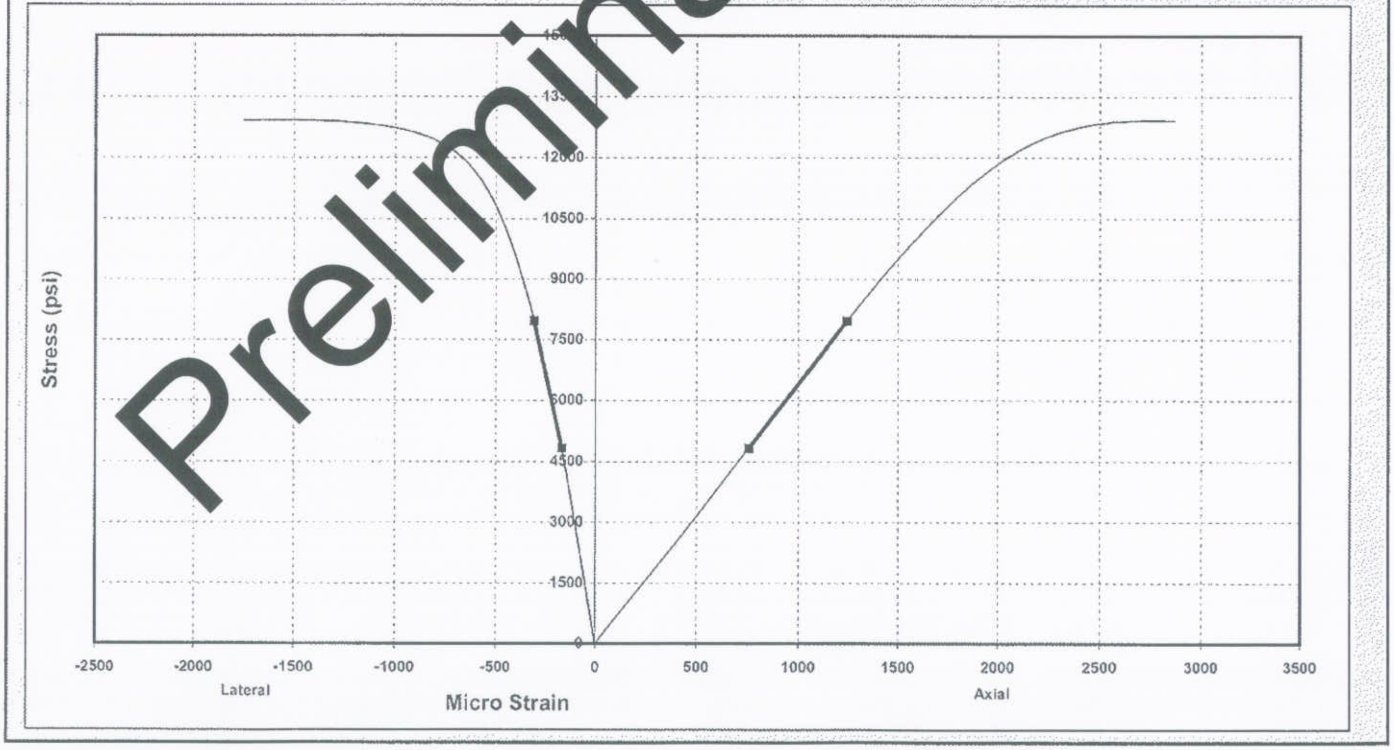
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Limestone
Characteristics: gray, massive
Core ID: 2-2@137.1-138.1
File Name: 2-2@137.1-138.1
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.755	12.08	2.250	5.72	2.11	51,400	228.63	12,927	89	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	6,482	45	0.29	157	2.52



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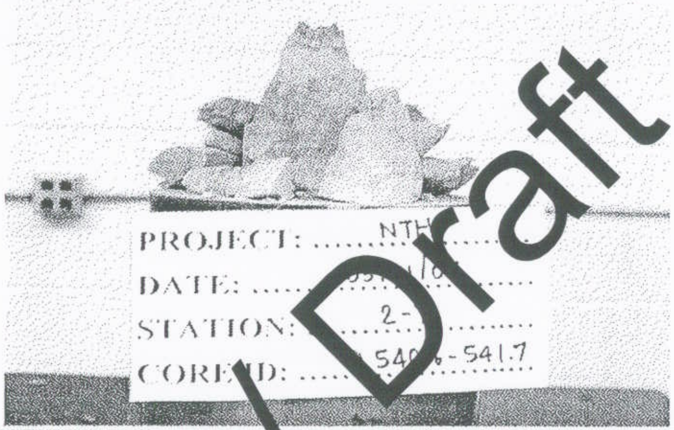
Earth Mechanics Institute

Mining Engineering Department, CSM

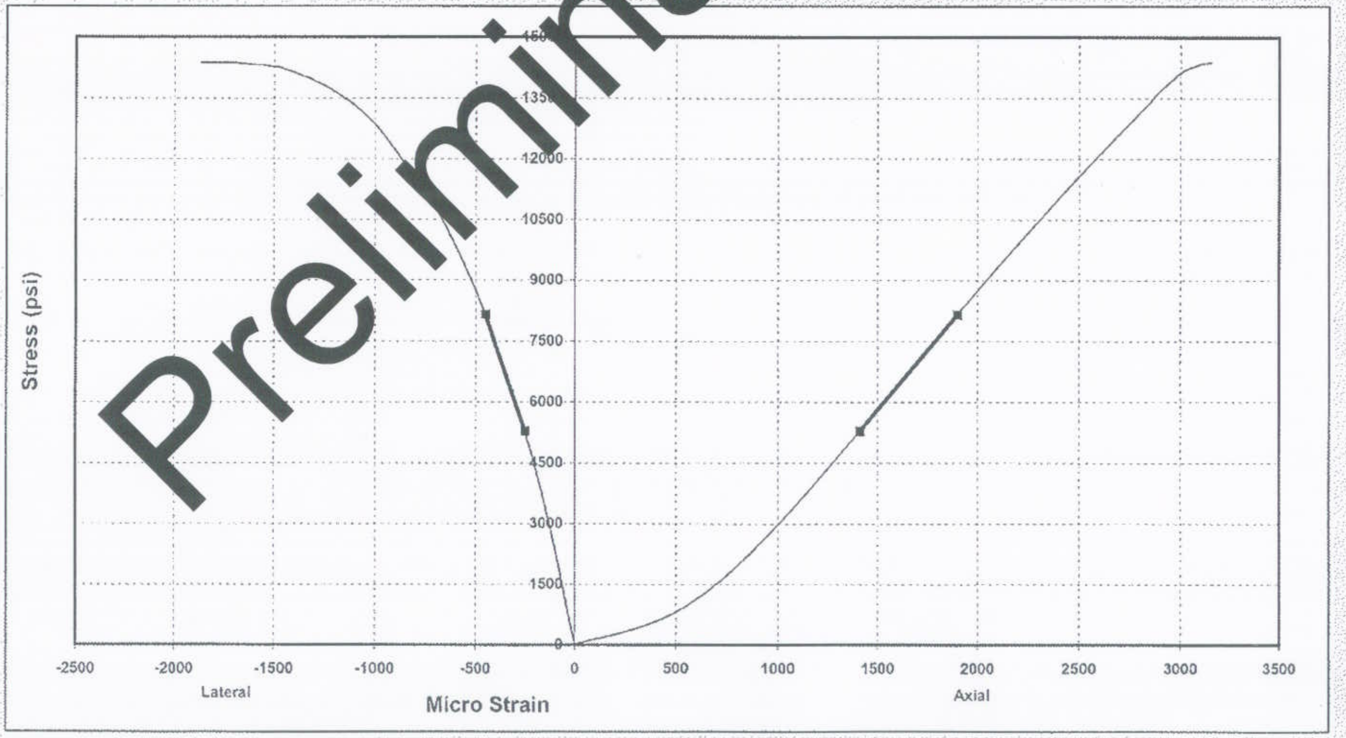
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Sandstone
Characteristics: gray, massive
Core ID: 2-7@540.6-541.7
File Name: 2-7@540.6-541.7
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	psi	MPa	
4.787	12.16	2.254	5.72	2.12	57,347	[illegible]5.09	14,378	99	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GP	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	5,838	40	0.40	149	2.39



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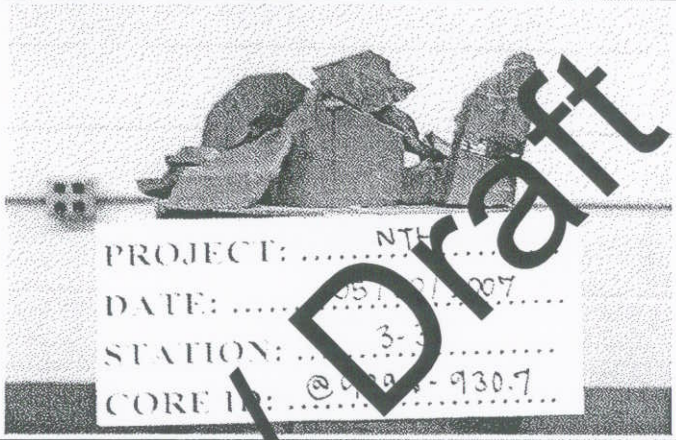
Earth Mechanics Institute

Mining Engineering Department, CSM

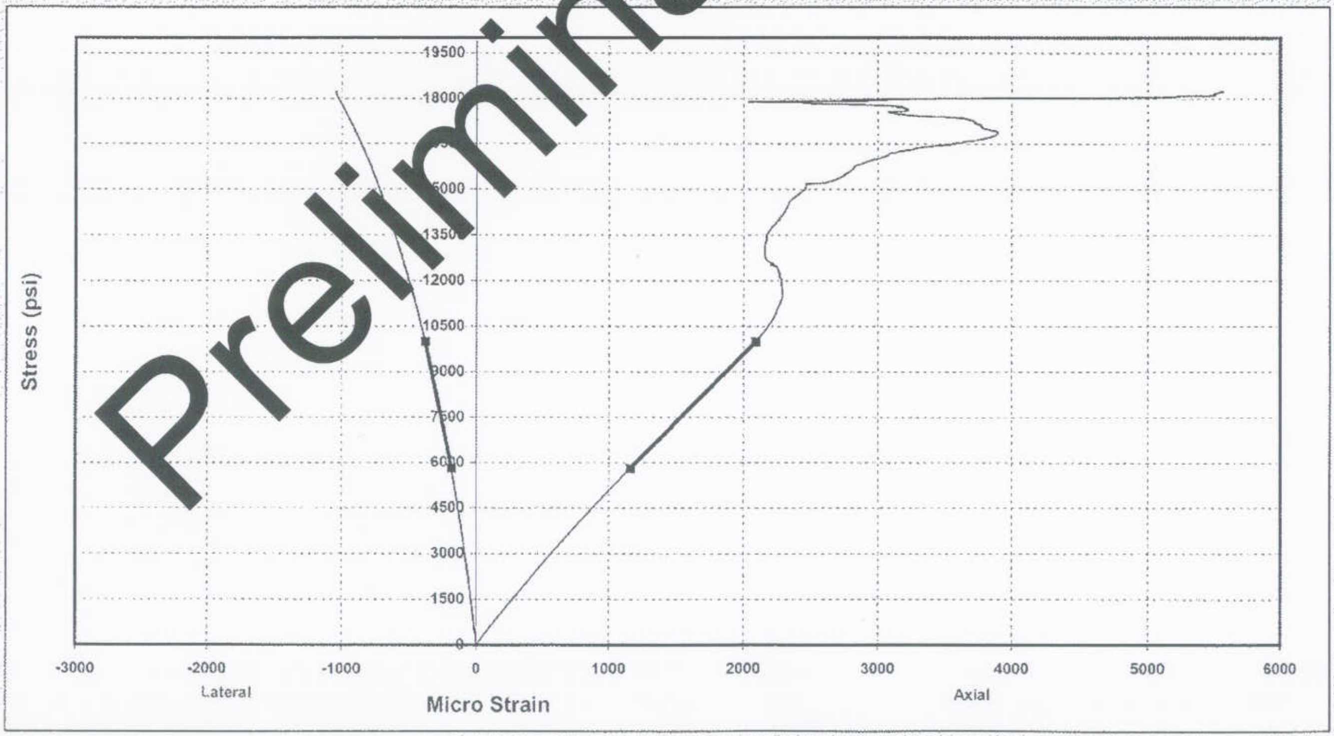
Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Shale
Characteristics:	dark green,gray
Core ID:	3-3@929.6-930.7
File Name:	3-3@929.6-930.7
Test Performed by:	PIPAT
Date Tested:	06/01/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
5.723	14.54	2.251	5.72	2.54	72,510	[illegible]2.53	18,228	126	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,502	31	0.21	137	2.19



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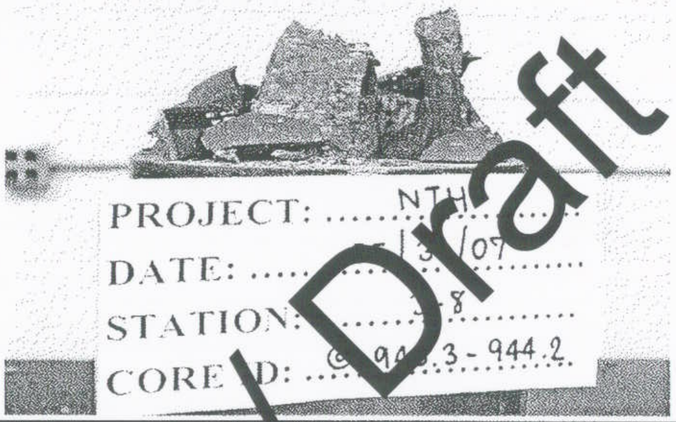
Earth Mechanics Institute

Mining Engineering Department, CSM

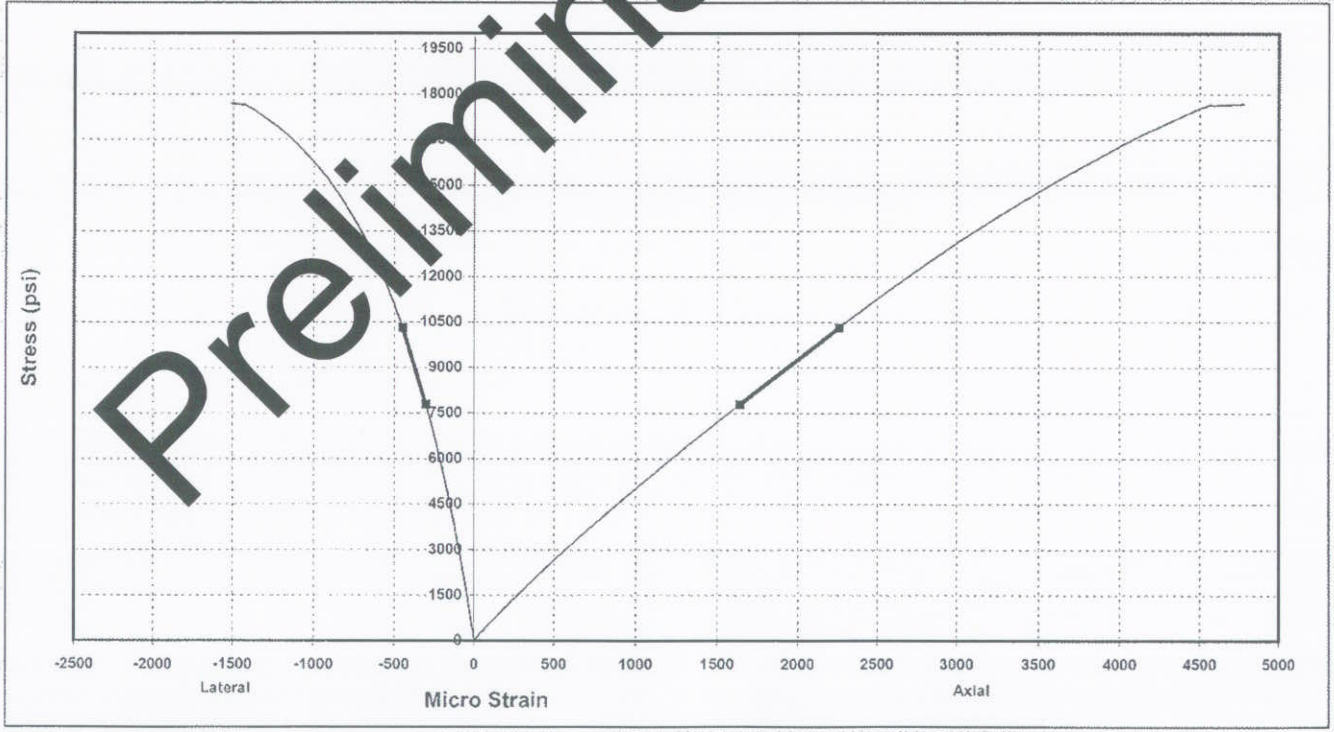
Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Shale / Dolomitic Shale
Characteristics:	Dark gray, white spots
Core ID:	3-8@943.3-944.2
File Name:	3-8@943.3-944.2
Test Performed by:	PIPAT
Date Tested:	05/30/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.726	12.00	2.250	5.71	2.10	70,330	[illegible]	17,696	122	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	*v*	ksi	GPa	*v*	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,083	28	0.23	171	2.73



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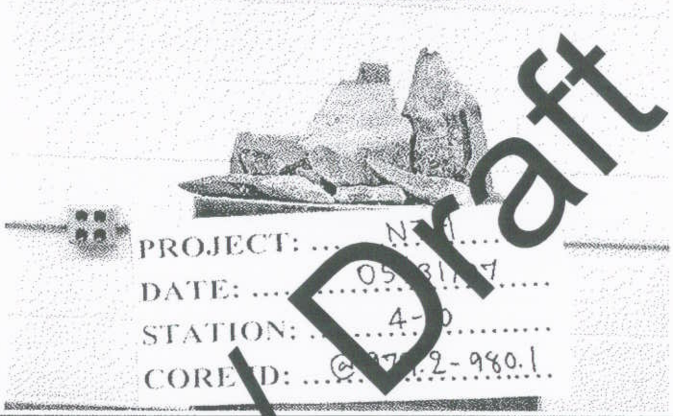
Earth Mechanics Institute

Mining Engineering Department, CSM

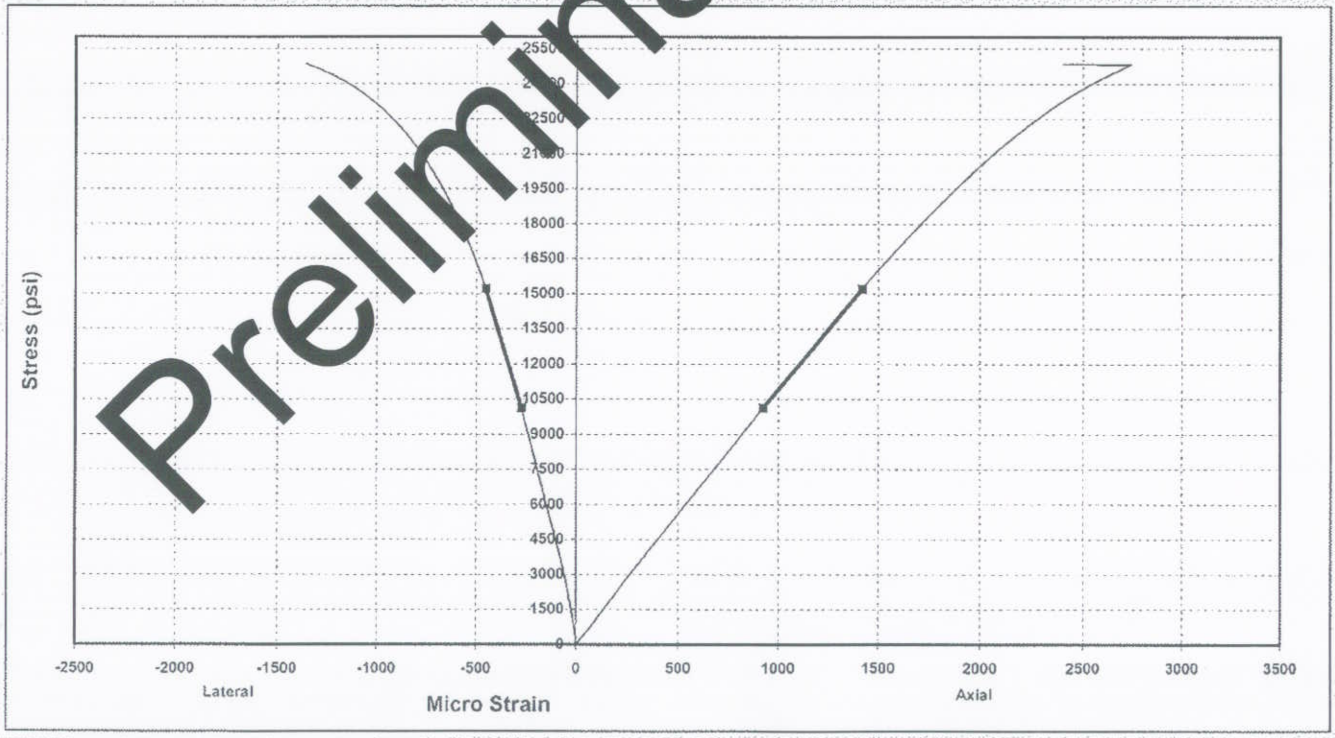
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitic
Characteristics: gray
Core ID: 4-10@979.2-980.1
File Name: 4-10@979.2-980.1
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.319	10.97	2.251	5.72	1.92	101,028	[illegible]9.39	25,398	175	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	G[illegible]	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	[illegible]A	NA	10,302	71	0.36	183	2.93



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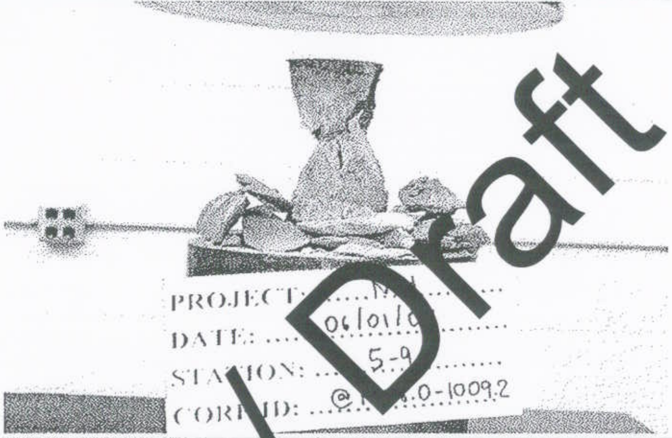
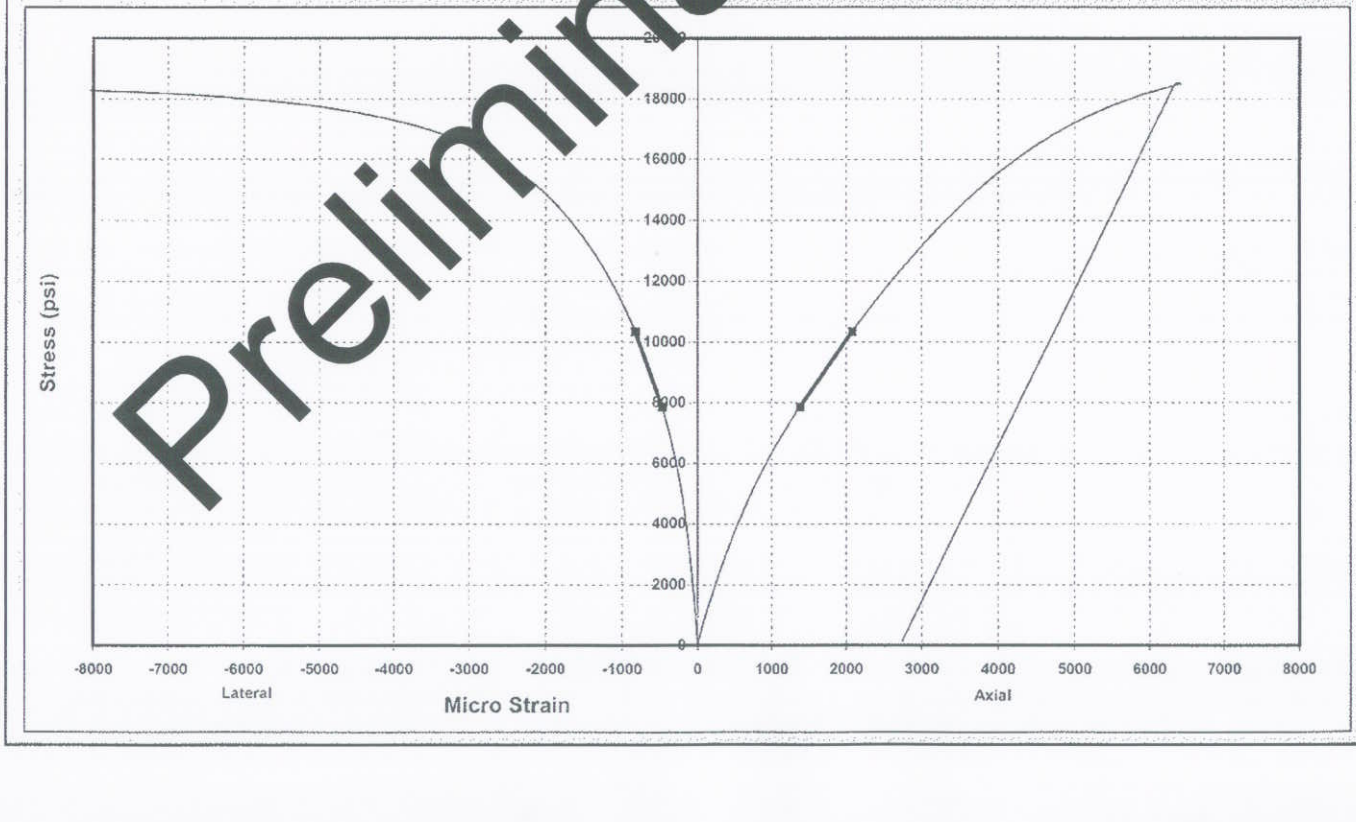
Earth Mechanics Institute
Mining Engineering Department, CSM
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitie
Characteristics: gray, porous
Core ID: 5-9@1008.0-1009.2
File Name: 5-9@1008.0-1009.2
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.820	12.24	2.249	5.71	2.14	73,482	[illegible]6.86	18,498	128	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GP	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	3,536	24	0.50	162	2.59



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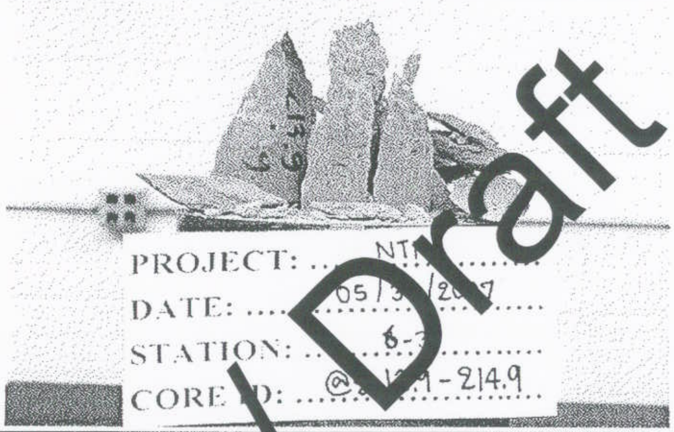
Earth Mechanics Institute

Mining Engineering Department, CSM

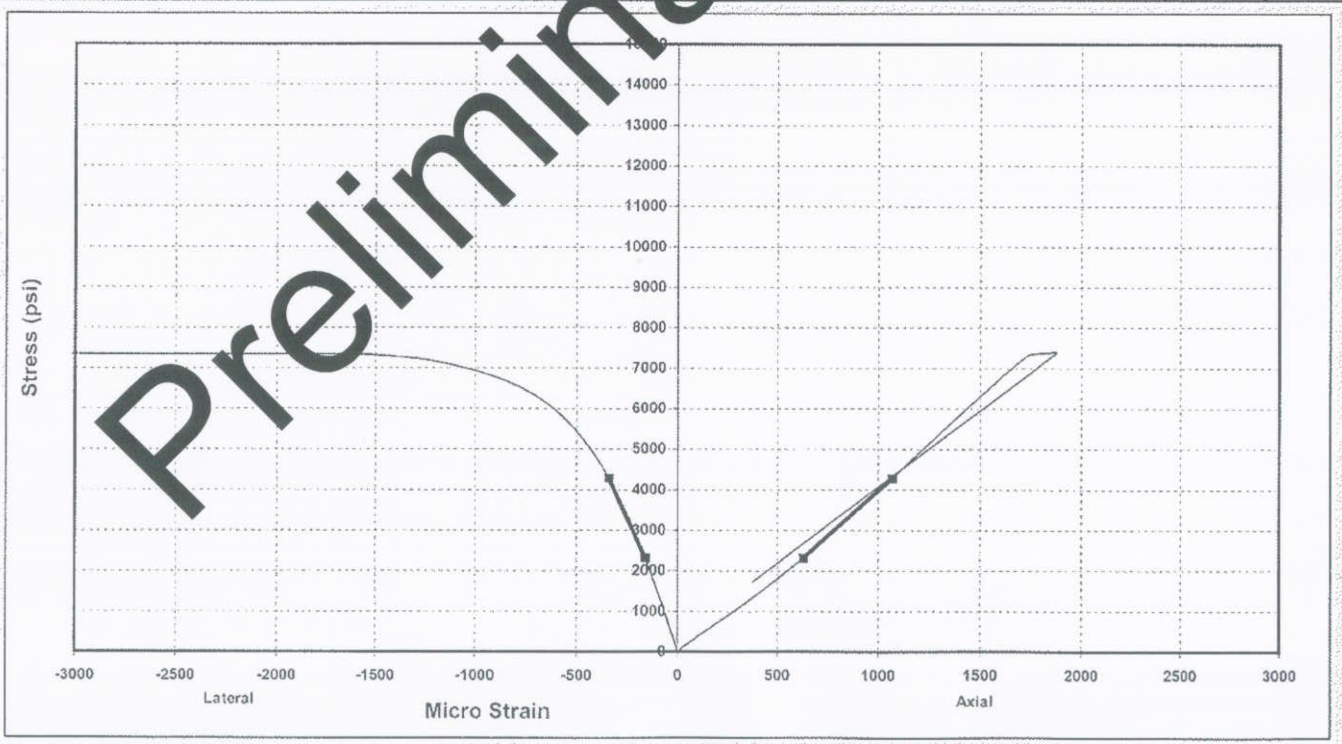
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite
Characteristics: light brown, porous
Core ID: 6-3@213.9-214.9
File Name: 6-3@213.9-214.9
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	kN	psi	MPa	Mode
4.708	11.96	2.250	5.71	2.09	29,359	130.59	7,387	51	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,464	31	0.41	133	2.13



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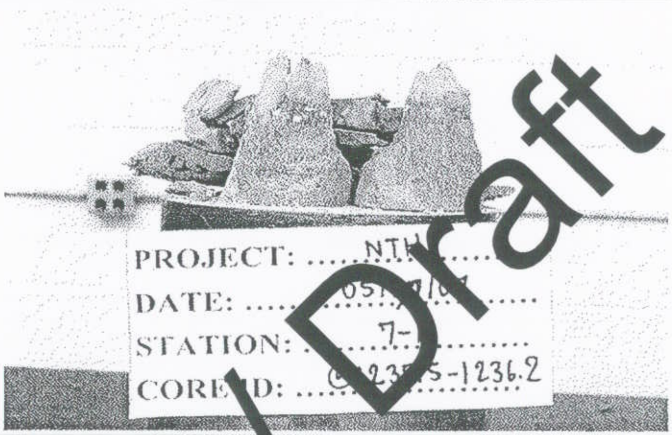
Earth Mechanics Institute

Mining Engineering Department, CSM

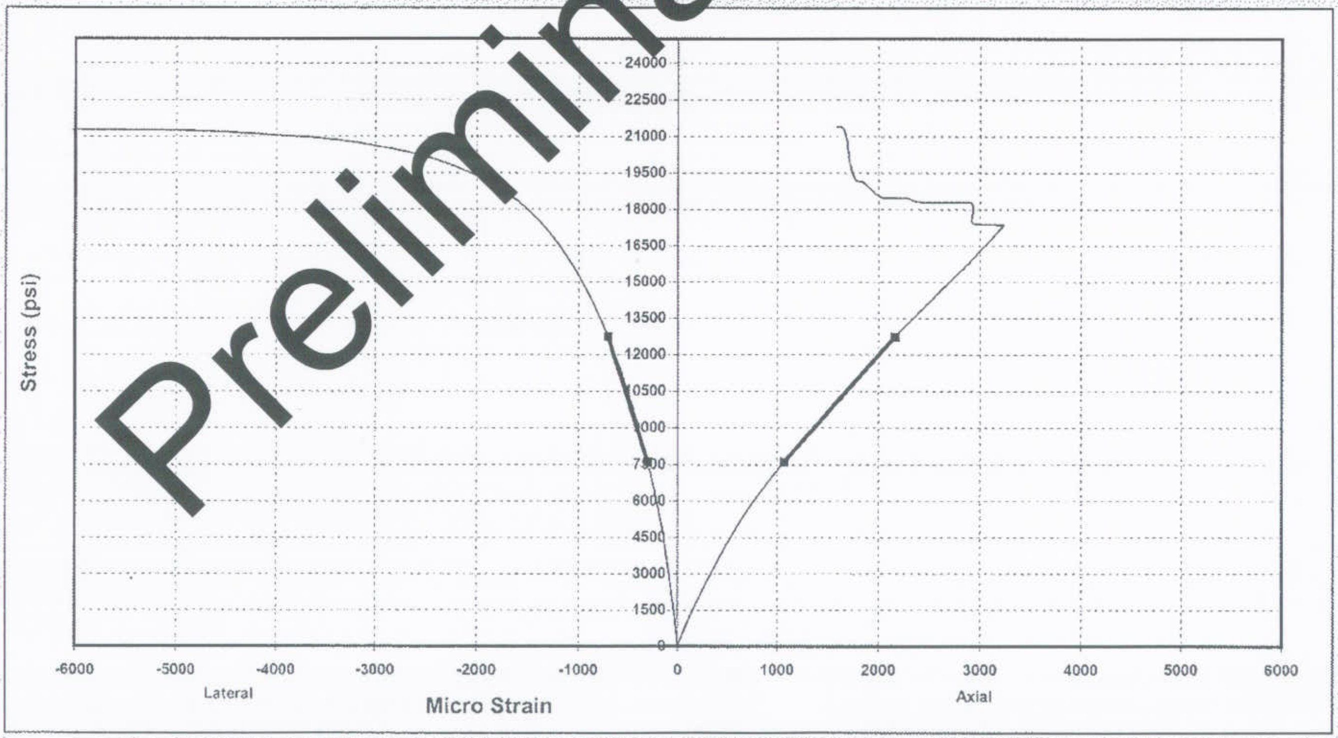
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite
Characteristics: brown, porous
Core ID: 7-1@1235.5-1236.2
File Name: 7-1@1235.5-1236.2
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	kN	psi	MPa	
4.748	12.06	2.250	5.71	2.11	38,631	171,83	9,720	67	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,706	32	0.37	141	2.26



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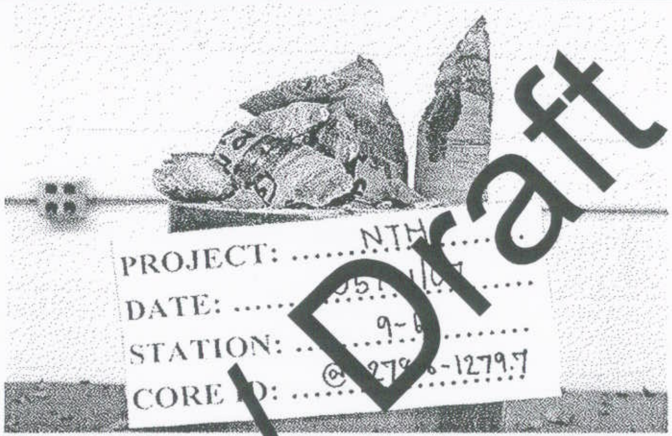
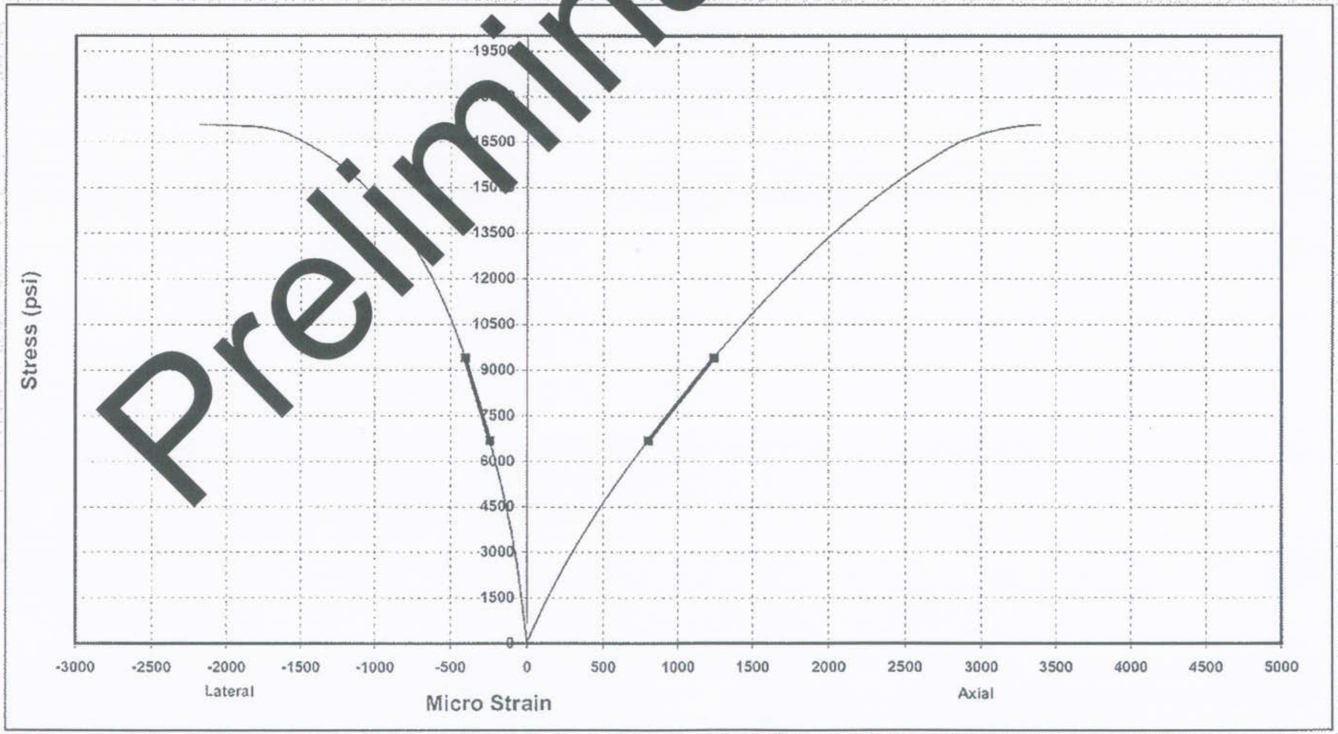
Earth Mechanics Institute
Mining Engineering Department, CSM
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitie
Characteristics: gray, laminations, porous
Core ID: 9-6@1278.8-1279.7
File Name: 9-6@1278.8-1279.7
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.765	12.10	2.248	5.71	2.12	67,736	[illegible]	17,074	118	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	6,185	43	0.37	178	2.85



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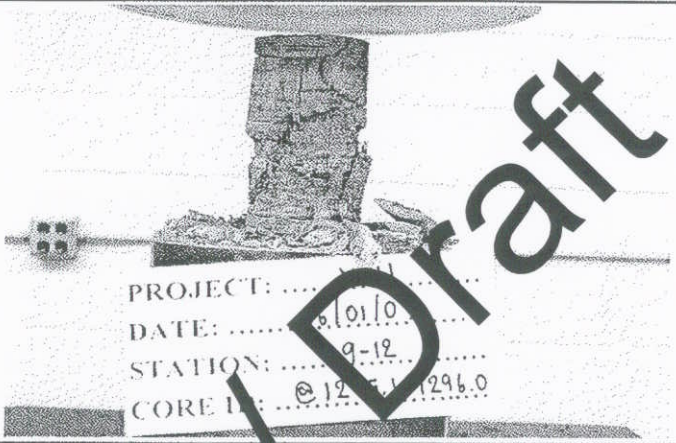
Earth Mechanics Institute

Mining Engineering Department, CSM

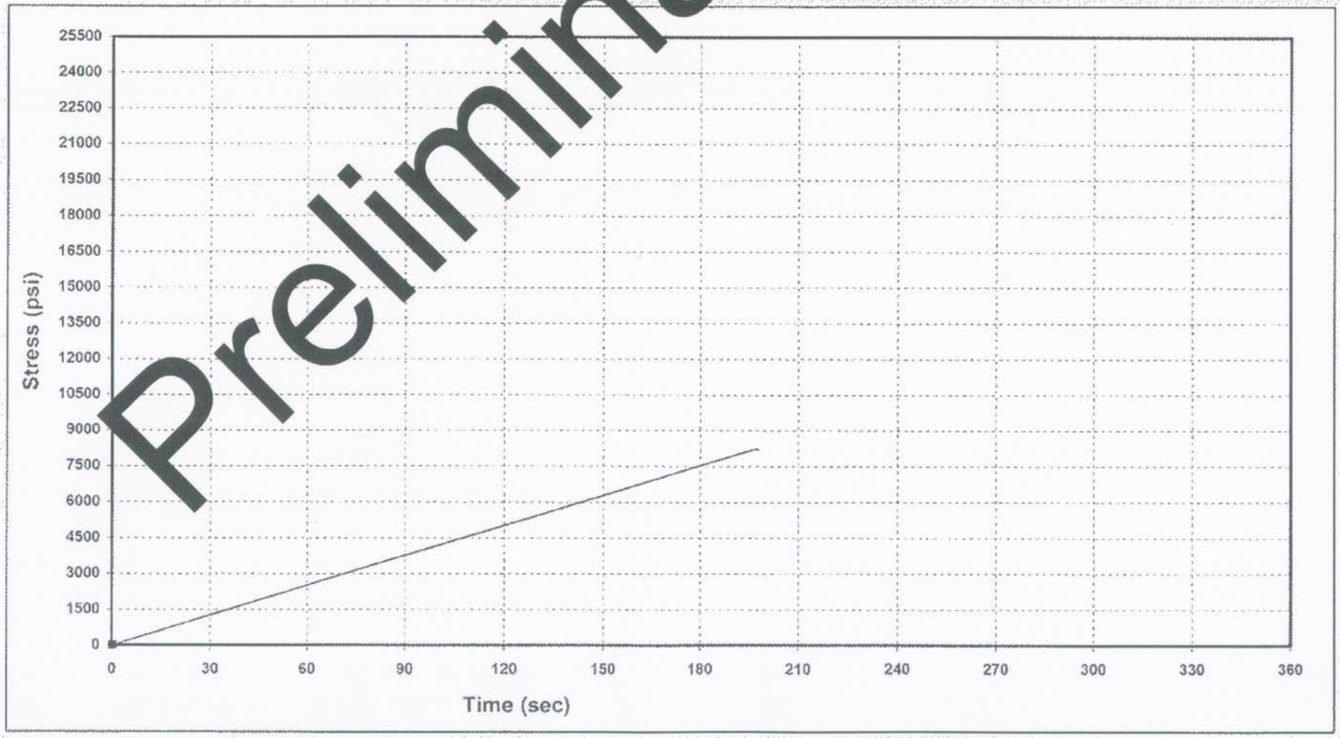
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite
Characteristics: voids, porous
Core ID: 9-12@1295.1-1296.0
File Name: 9-12@1295.1-1296.0
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	ps	MPa	
4.823	12.25	2.253	5.72	2.14	32,829	46.03	8,235	57	Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	G	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	A	NA	NA	NA	NA	148	2.38



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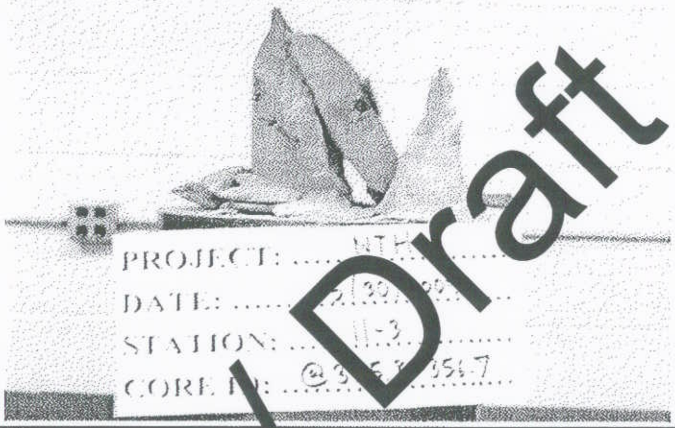
Earth Mechanics Institute

Mining Engineering Department, CSM

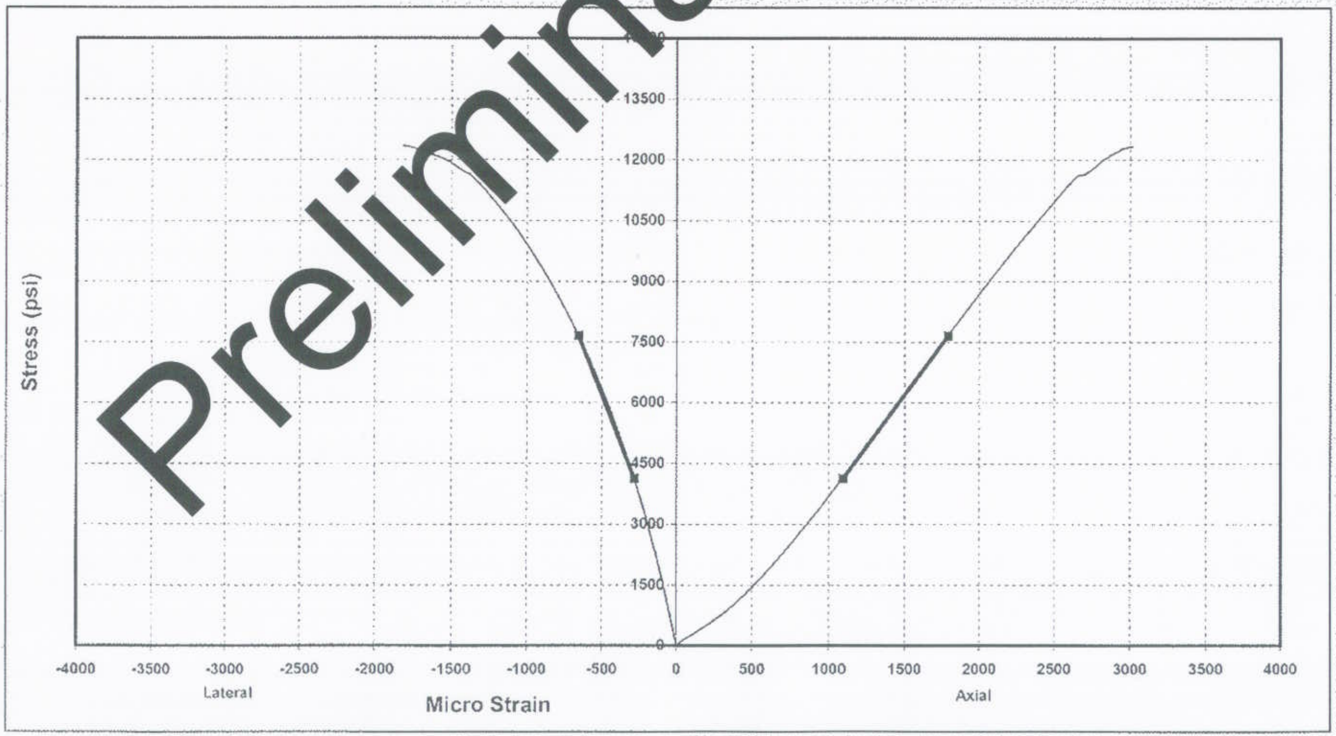
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite
Characteristics: light brown
Core ID: 11-3@355.8-356.7
File Name: 11-3@355.8-356.7
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.740	12.04	2.252	5.72	2.10	49,131	218,54	12,335	85	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	5,040	35	0.53	145	2.33



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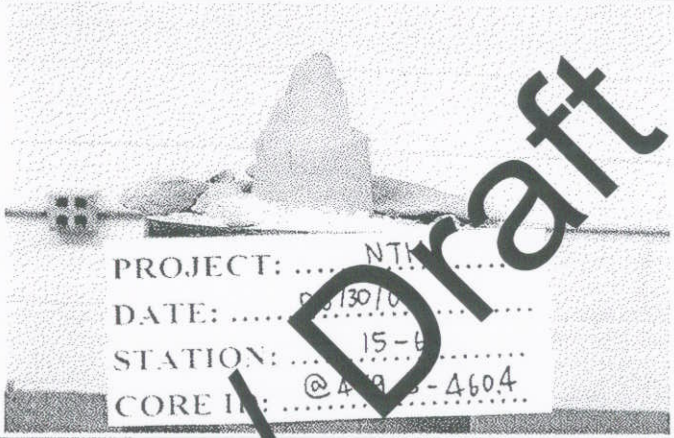
Earth Mechanics Institute

Mining Engineering Department, CSM

Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Sandstone
Characteristics:	white
Core ID:	15-6@459.5-460.4
File Name:	15-6@459.5-460.4
Test Performed by:	PIPAT
Date Tested:	05/30/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	psi	MPa	
4.798	12.19	2.245	5.70	2.14	26,034	115.80	6,580	45	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	*v*	ksi	GPa	*v*	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,139	29	0.86	141	2.26

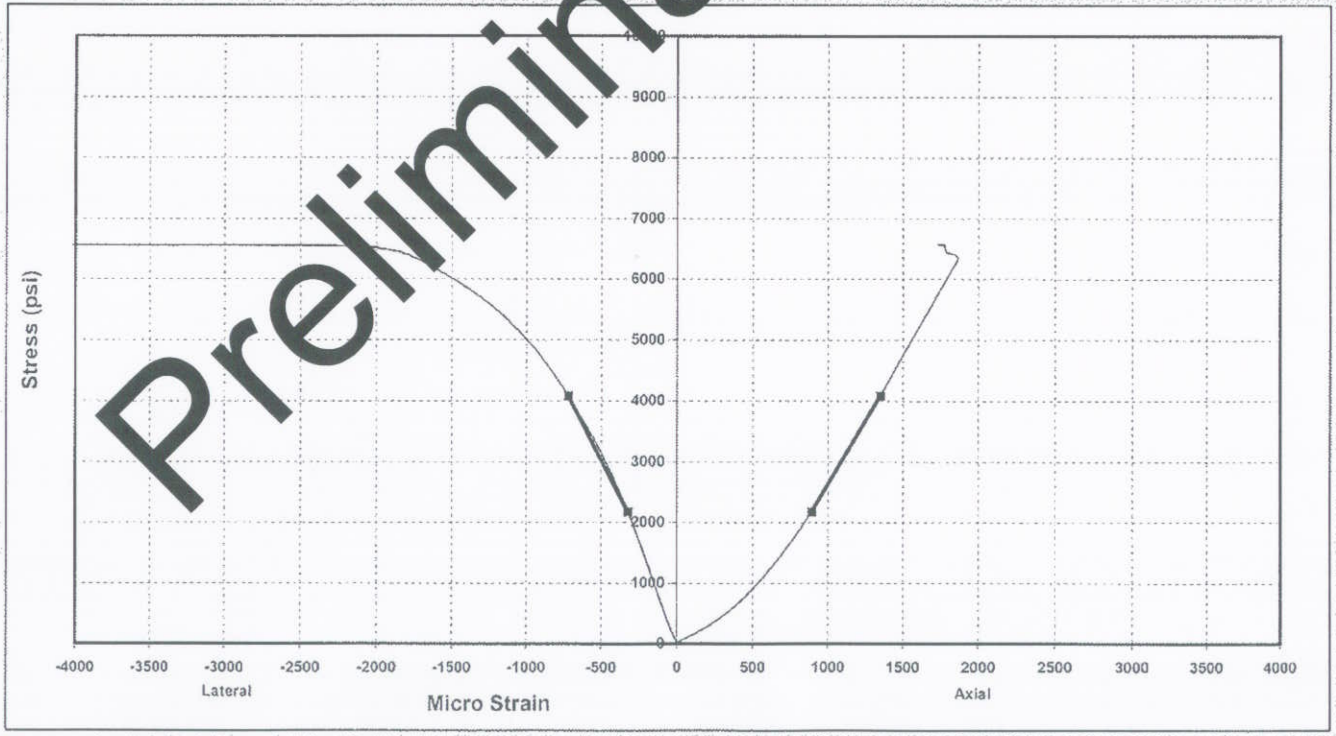


Figure No. 39

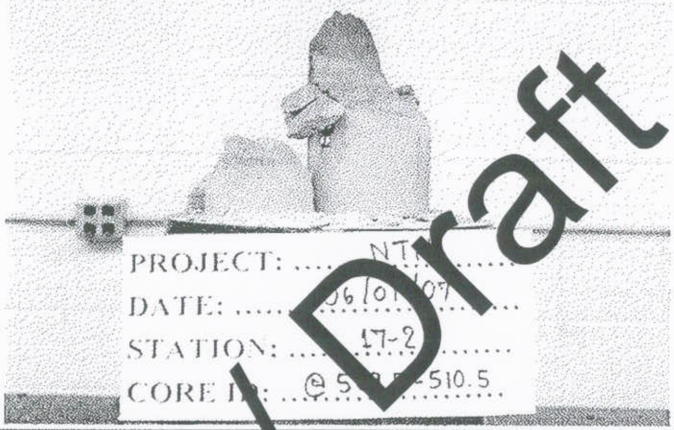
6/6/2007

Earth Mechanics Institute

Mining Engineering Department, CSM

Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Dolomitic Sandstone
Characteristics:	light gray
Core ID:	17-2@509.5-510.5
File Name:	17-2@509.5-510.5
Test Performed by:	PIPAT
Date Tested:	06/01/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.730	12.01	2.251	5.72	2.10	38,707	172,17	9,731	67	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	G	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	4,856	33	0.53	146	2.33

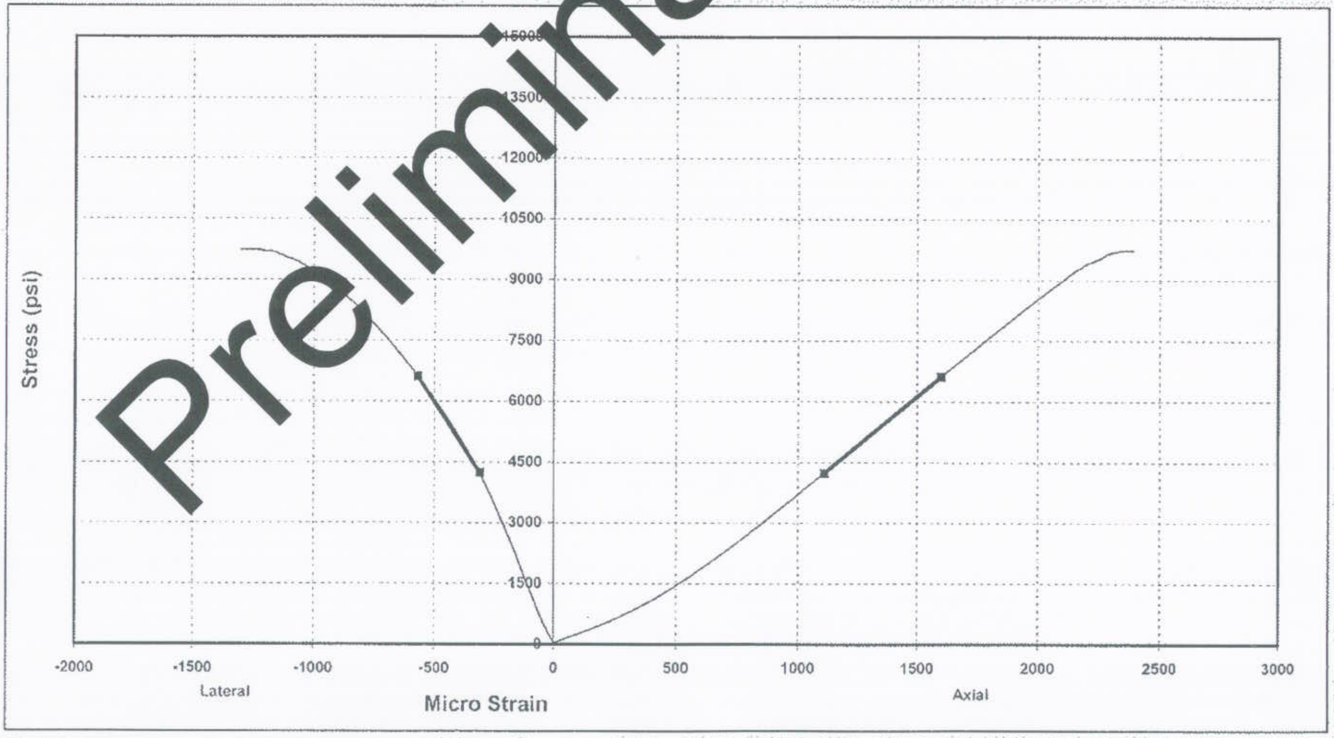


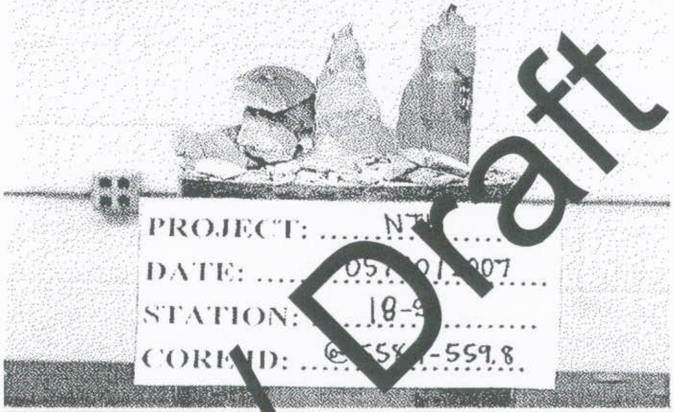
Figure No. 39
6/6/2007

Earth Mechanics Institute

Mining Engineering Department, CSM

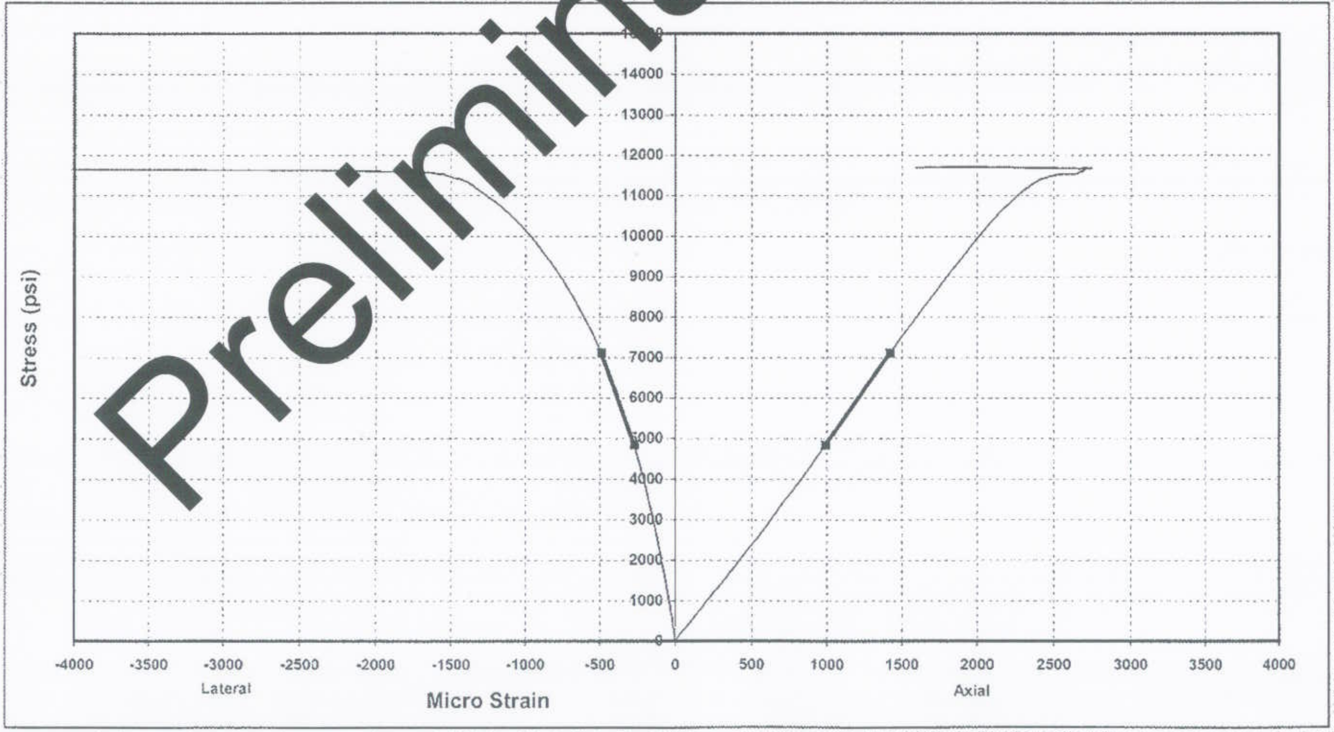
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Cherty Dolomite
Characteristics: light gray, w/lenses
Core ID: 18-9@558.9-559.8
File Name: 18-9@558.9-559.8
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.747	12.06	2.250	5.72	2.11	46,585	[illegible]	11,716	81	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	*v*	ksi	GPa	*v*	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	[illegible]	NA	5,270	36	0.51	147	2.35

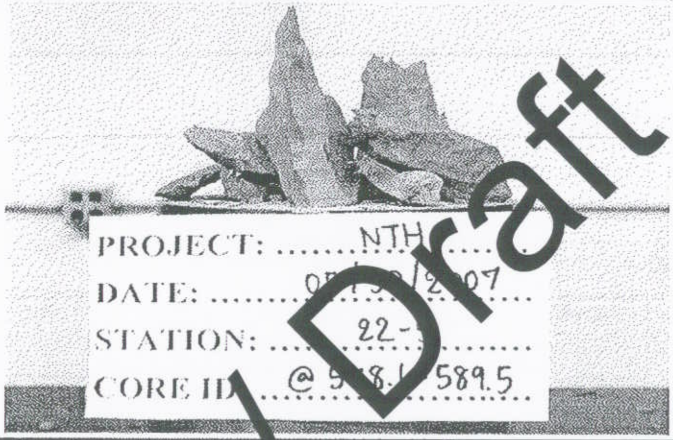


Earth Mechanics Institute

Mining Engineering Department, CSM

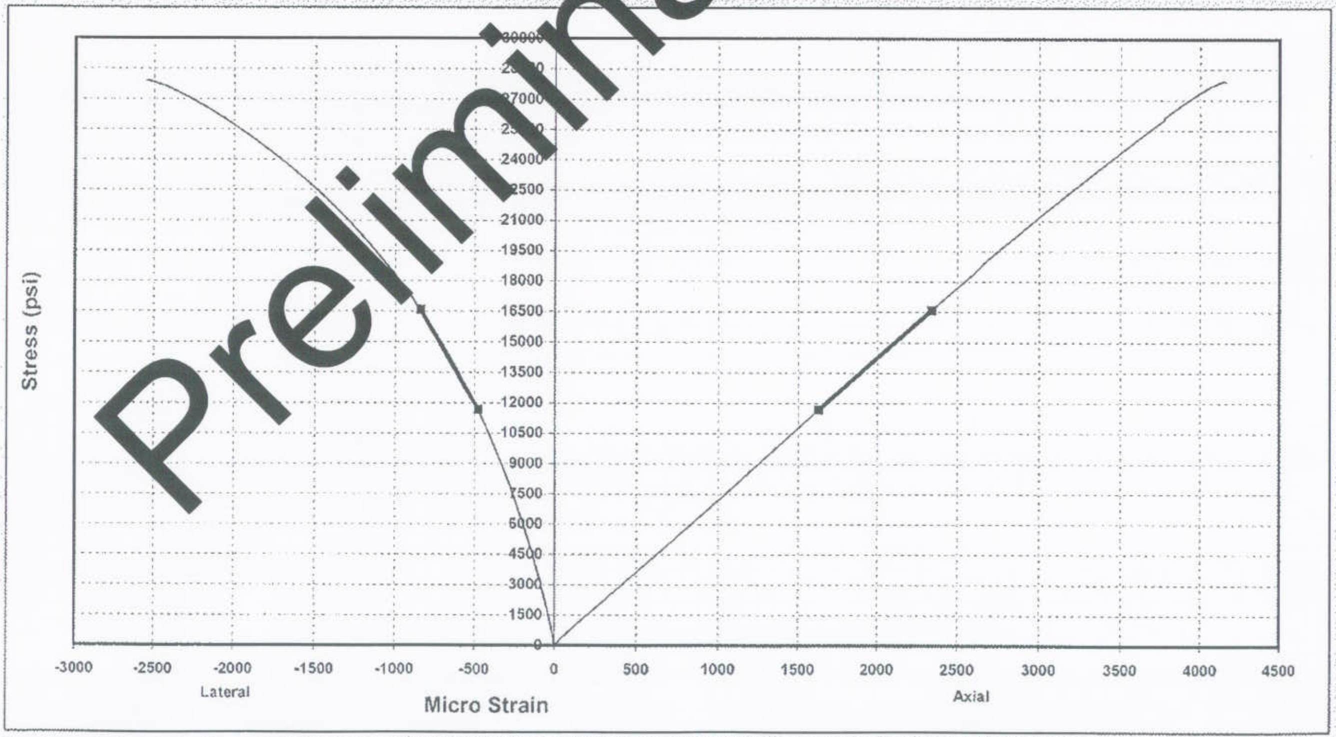
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite
Characteristics: light gray
Core ID: 22-5@588.6-589.5
File Name: 22-5@588.6-589.5
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07


PROJECT: NTH
DATE: 0 / /2 07
STATION: 22-
CORE ID @ 5 8. 589.5

Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	ps	MPa	
4.794	12.18	2.252	5.72	2.13	111,210	94.68	27,920	193	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	G	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	A	NA	6,923	48	0.51	166	2.66

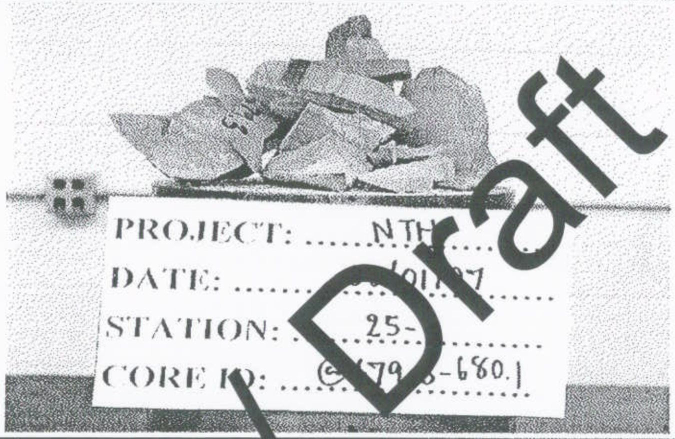


Earth Mechanics Institute

Mining Engineering Department, CSM

Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Dolomitie
Characteristics:	light gray, cracks
Core ID:	25-6@679.3-680.1
File Name:	25-6@679.3-680.1
Test Performed by:	PIPAT
Date Tested:	06/01/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	kN	psi	MPa	
4.842	12.30	2.255	5.73	2.15	47,061	[illegible]09.33	11,789	81	Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	8,117	56	0.27	163	2.60

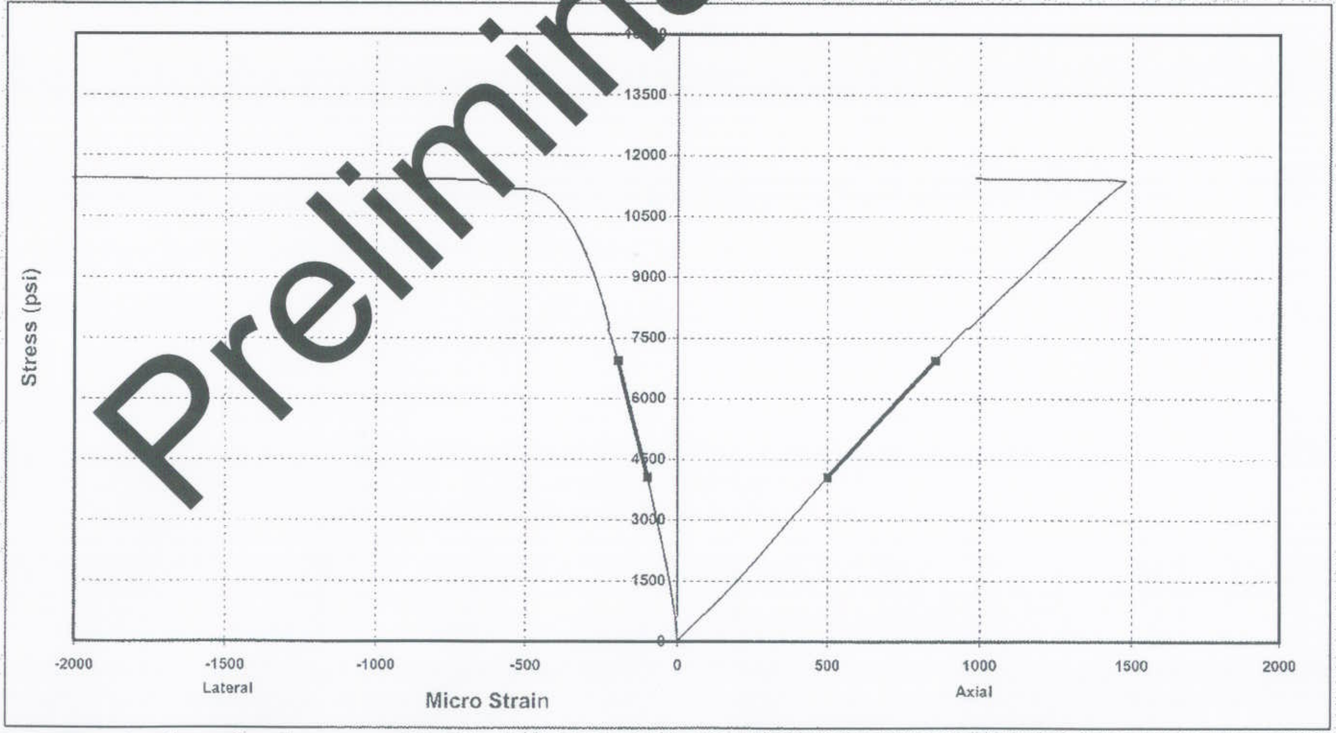


Figure No. 39

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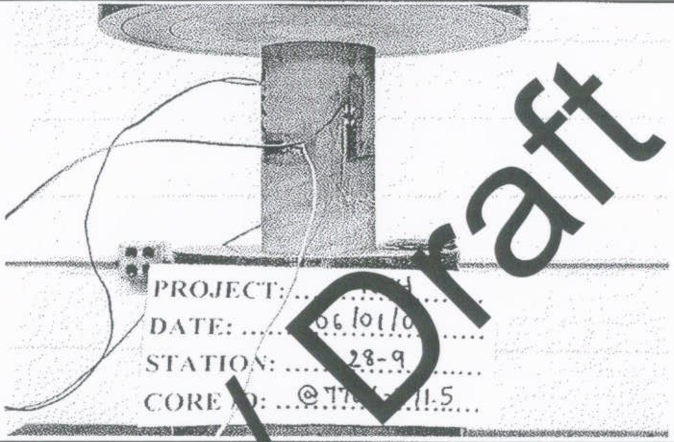
Earth Mechanics Institute

Mining Engineering Department, CSM

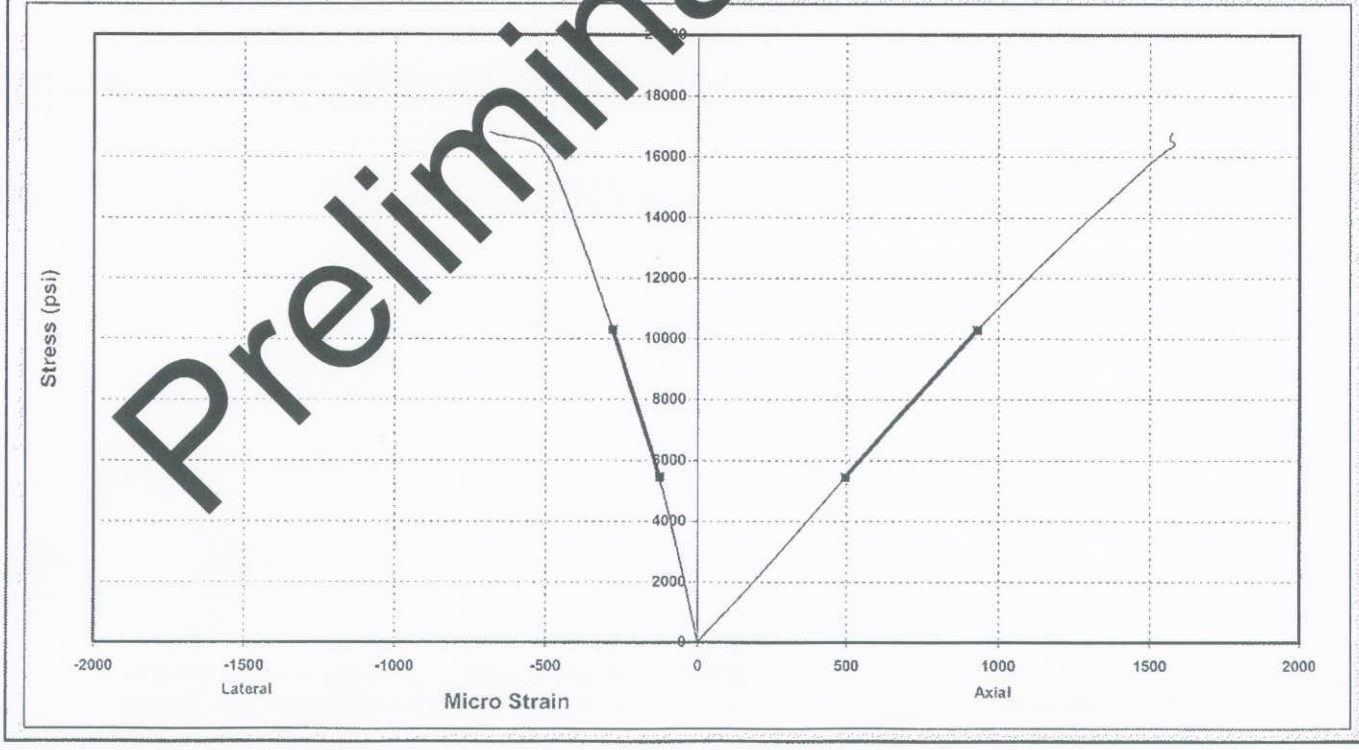
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitie
Characteristics: light gray, laminations, crack
Core ID: 28-9@770.6-771.5
File Name: 28-9@770.6-771.5
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	psi	MPa	
4.672	11.87	2.251	5.72	2.08	66,811	297,19	16,788	116	Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	11,124	77	0.35	167	2.67



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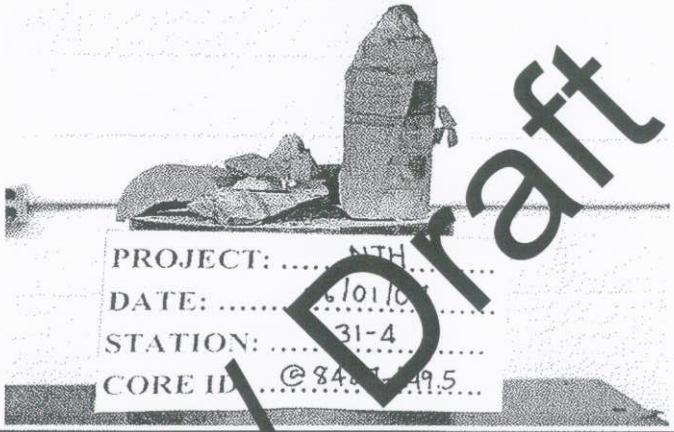
Earth Mechanics Institute

Mining Engineering Department, CSM

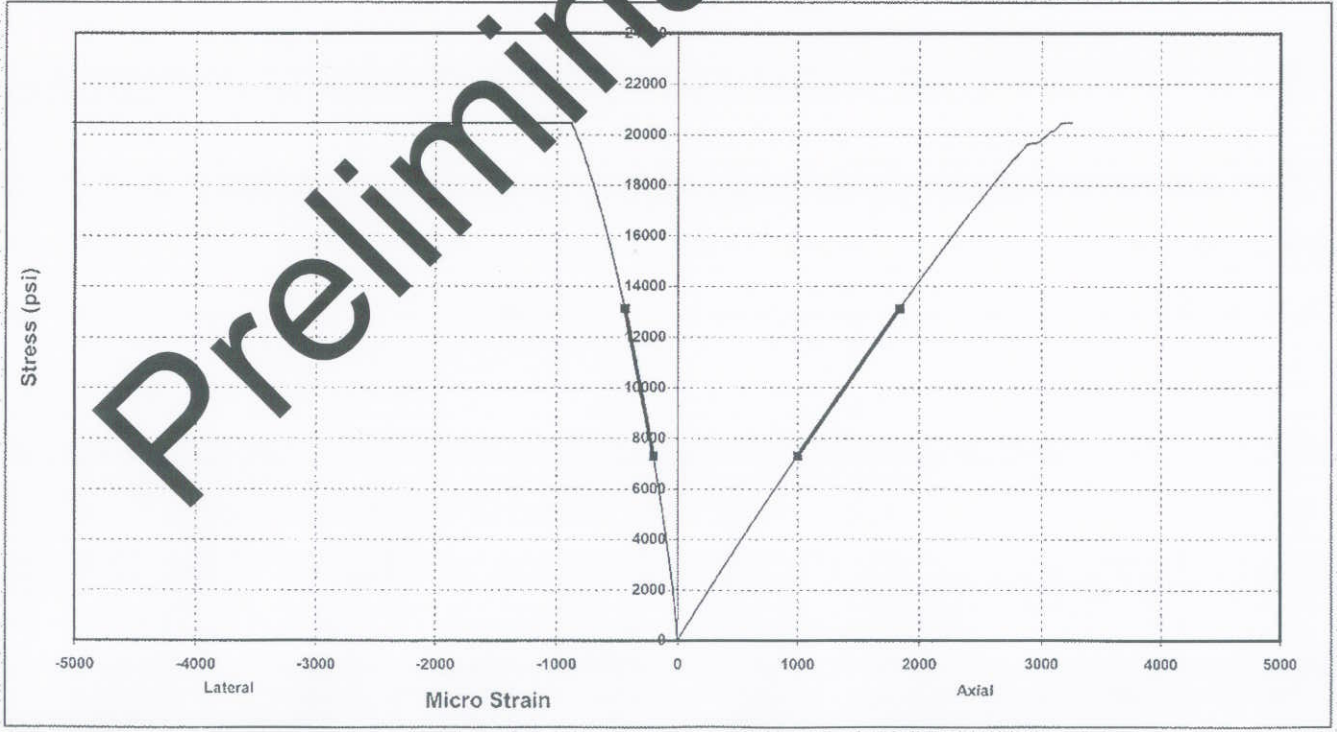
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitie
Characteristics: dark gray, laminations
Core ID: 31-4@848.7-849.5
File Name: 31-4@848.7-849.5
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	kN	psi	MPa	Mode
4.816	12.23	2.251	5.72	2.14	81,512	362.58	20,492	141	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	6,922	48	0.28	171	2.75



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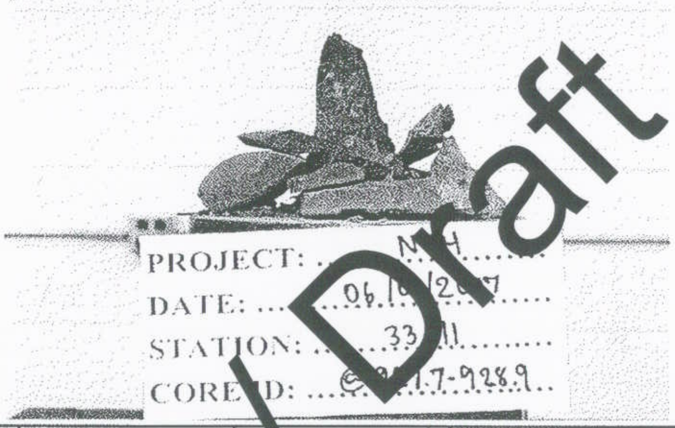
Earth Mechanics Institute

Mining Engineering Department, CSM

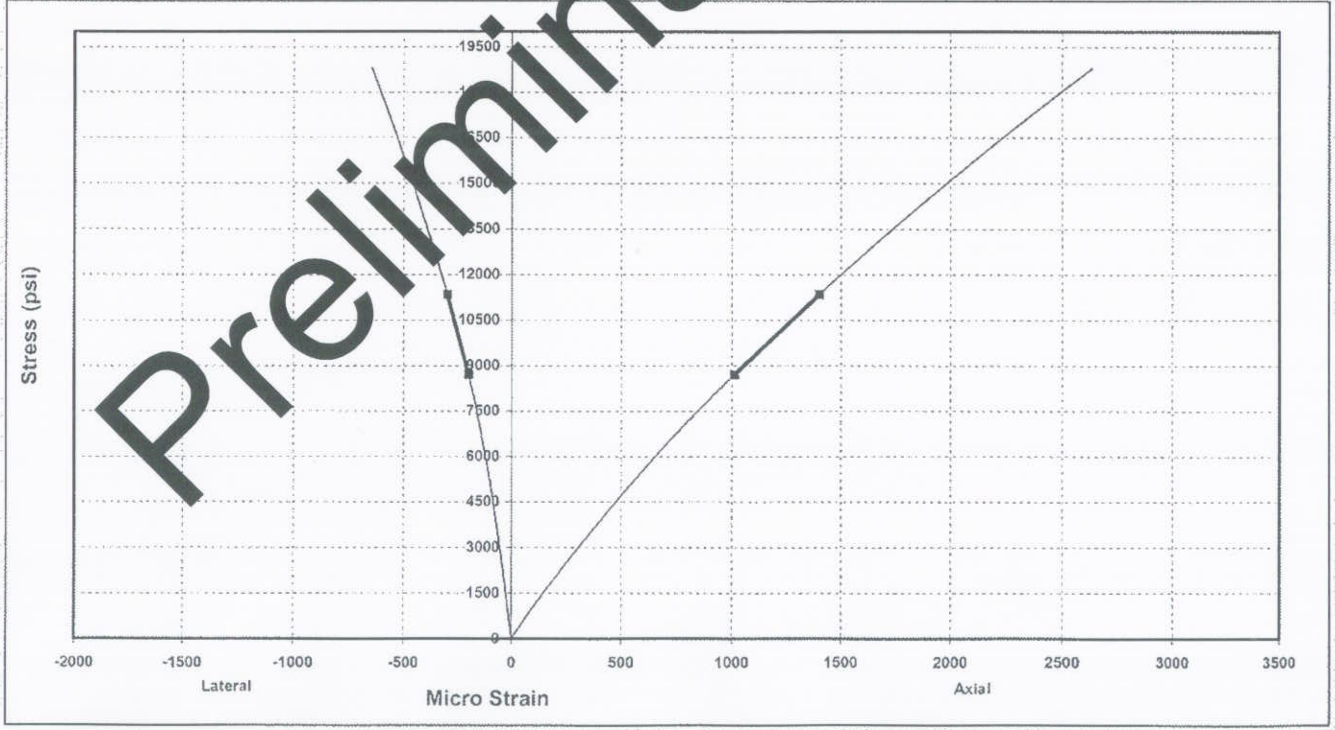
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomitic Shale
Characteristics: dark gray
Core ID: 33-11@927.7-928.9
File Name: 33-11@927.7-928.9
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	[illegible]N	psi	MPa	
4.699	11.94	2.251	5.72	2.09	74,786	[illegible]2.66	18,801	130	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	G[illegible]	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	[illegible]A	NA	6,785	47	0.25	175	2.81



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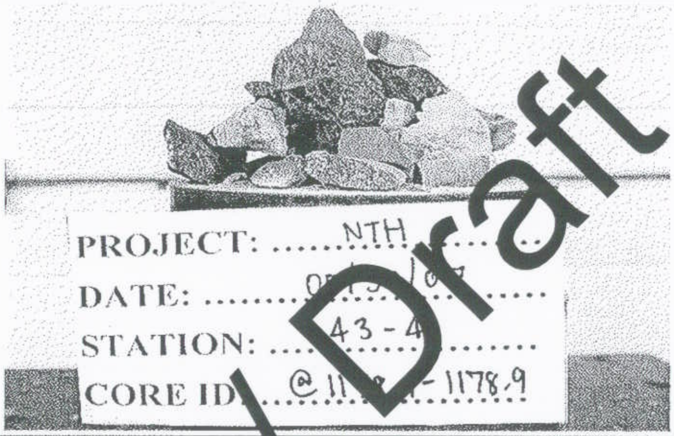
Earth Mechanics Institute

Mining Engineering Department, CSM

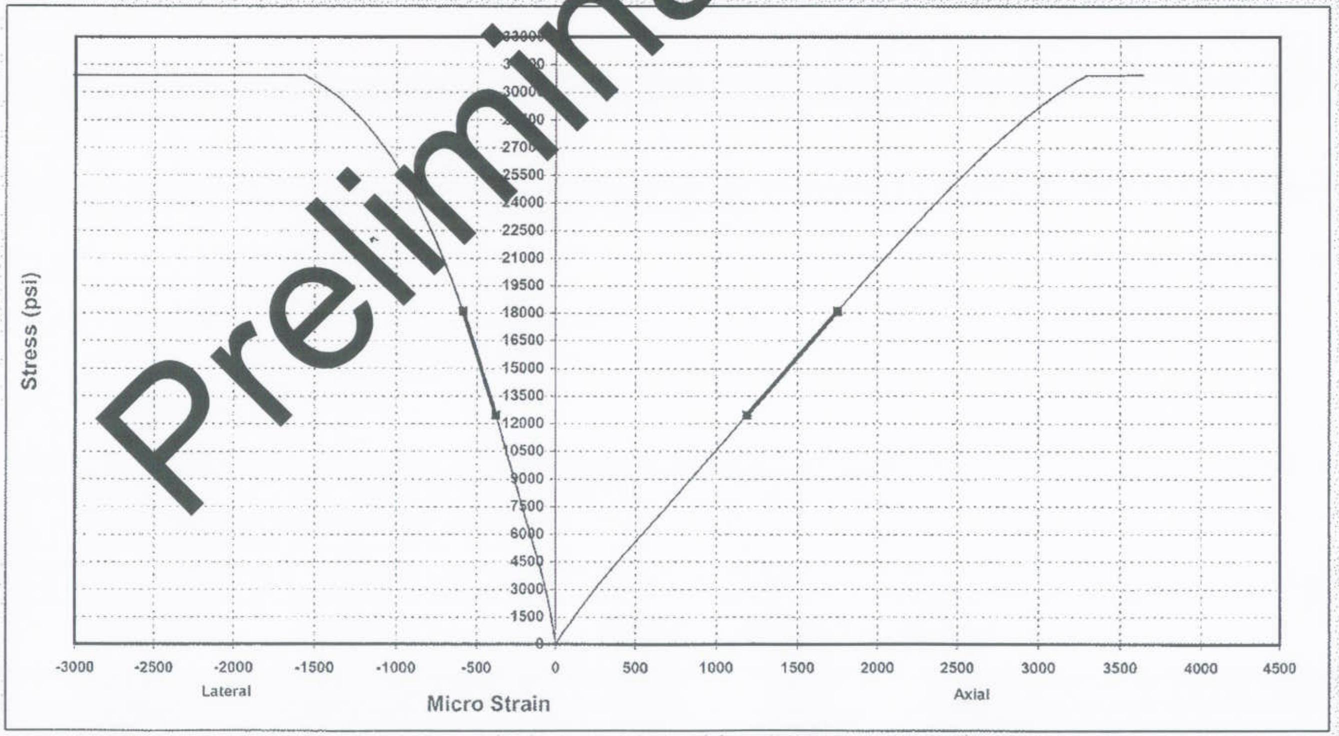
Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Dolomite
Characteristics:	light gray
Core ID:	43-4@1178.1-1178.9
File Name:	43-4@1178.1-1178.9
Test Performed by:	PIPAT
Date Tested:	05/30/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D Ratio	Failure Load		UCS		Failure Mode
in	cm	in	cm		lbs	N	psi	MPa	
4.781	12.14	2.253	5.72	2.12	123,469	[illegible]	30,970	214	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic v	Static E		Static v	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa		ksi	GPa		lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	10,063	69	0.37	183	2.93



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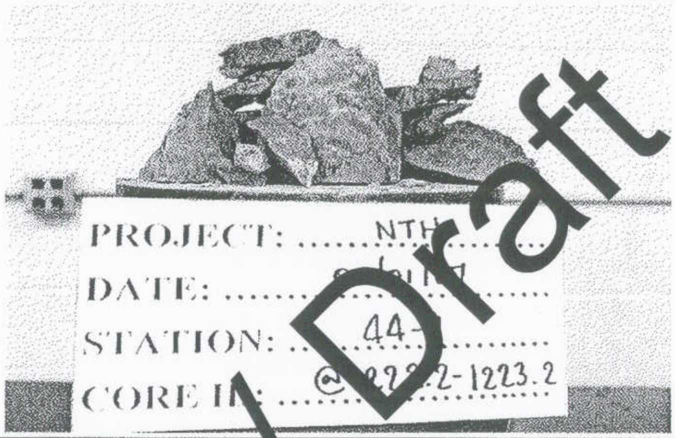
Earth Mechanics Institute

Mining Engineering Department, CSM

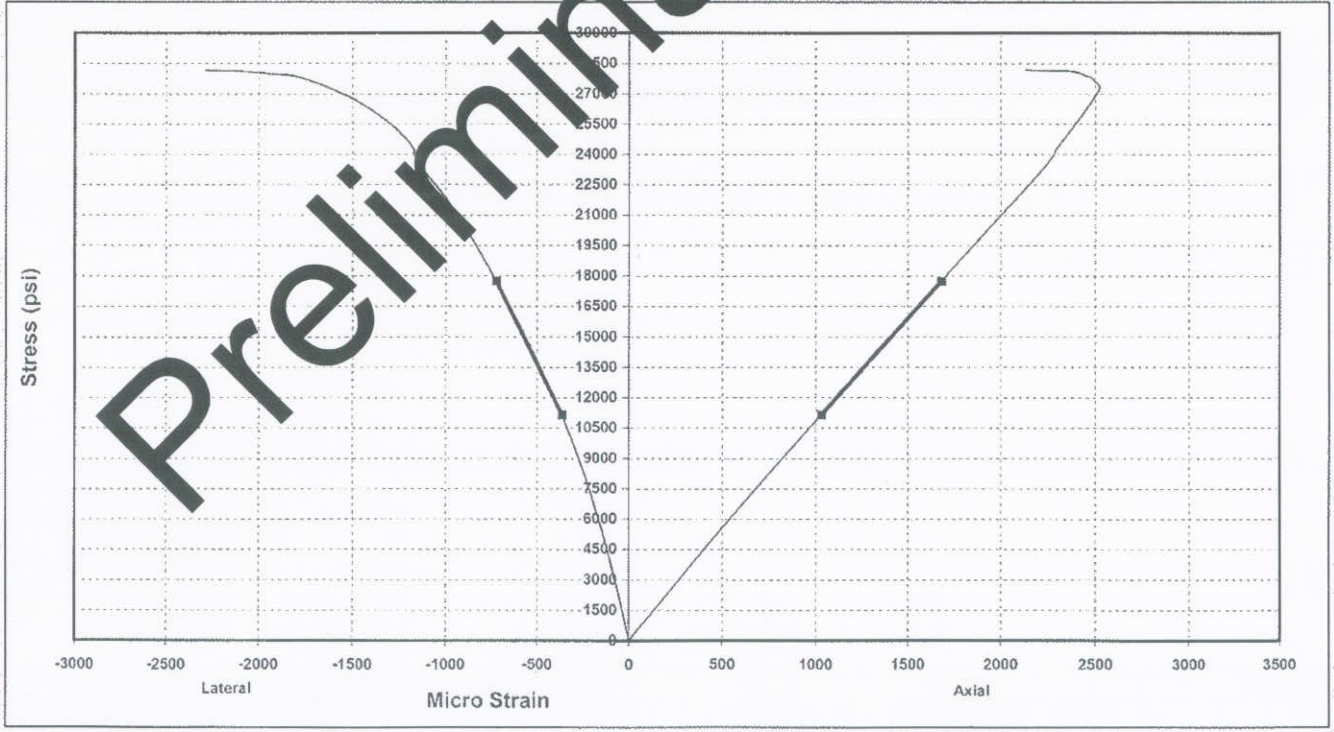
Uniaxial Compressive Strength Test Results (V 3.0)

Project:	DRIC
Location:	Detroit, MI
Rock Type:	Sedimentary
Rock Name:	Dolomite
Characteristics:	brown, porous, dirty texture
Core ID:	44-9@1222.2-1223.2
File Name:	44-9@1222.2-1223.2
Test Performed by:	PIPAT
Date Tested:	06/01/07
Data Reduced by:	mcs
Date Reduced:	06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.804	12.20	2.247	5.71	2.14	111,721	496,957	28,173	194	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	10,141	70	0.55	171	2.74



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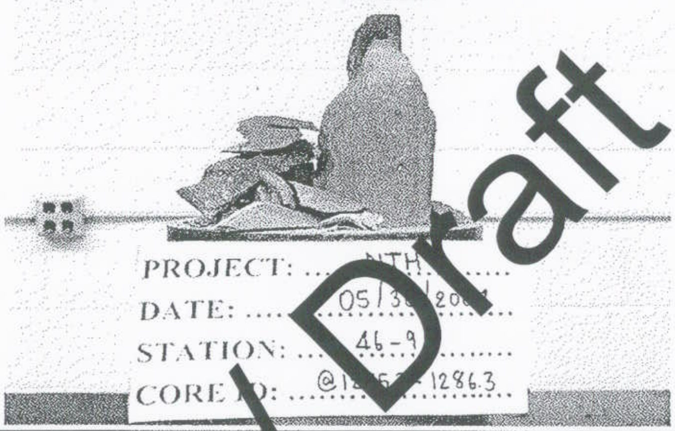
Earth Mechanics Institute

Mining Engineering Department, CSM

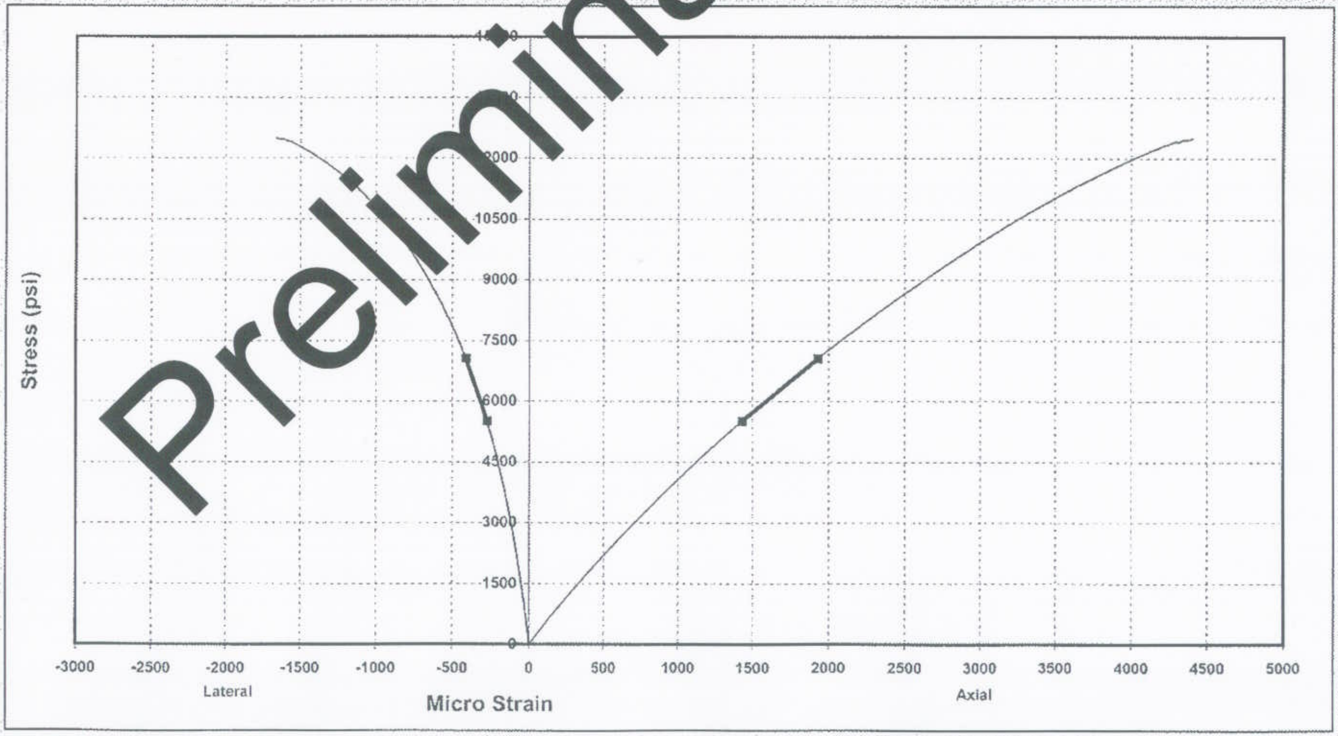
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Dolomite / Salt
Characteristics: dark green/gray
Core ID: 46-9@1285.3-1286.3
File Name: 46-9@1285.3-1286.3
Test Performed by: PIPAT
Date Tested: 05/30/07
Data Reduced by: mcs
Date Reduced: 06/05/07


PROJECT: NTH
DATE: 05/30/2007
STATION: 46-9
CORE ID: @1285.3-1286.3

Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	kN	psi	MPa	Mode
4.777	12.13	2.245	5.70	2.13	49,441	[illegible]19,92	12,490	86	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	ν	ksi	GPa	ν	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	3,106	21	0.27	167	2.67



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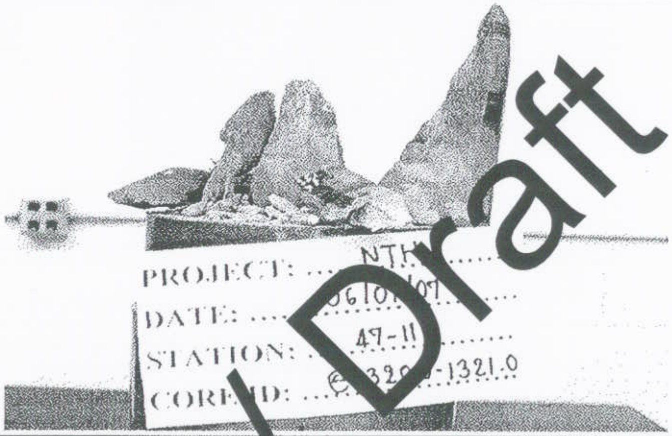
Earth Mechanics Institute

Mining Engineering Department, CSM

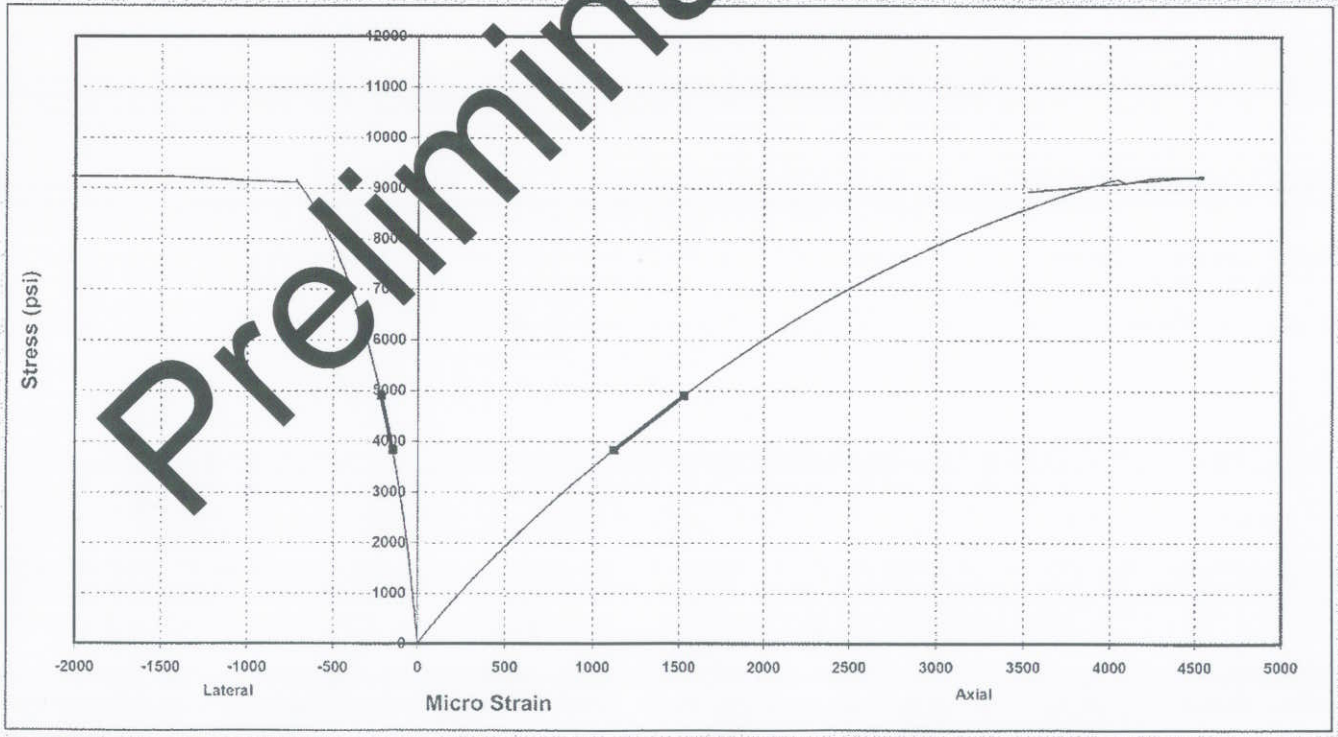
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Shale
Characteristics: dark gray, w/ lenses
Core ID: 47-11@1320.0-1321.0
File Name: 47-11@1320.0-1321.0
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.869	12.37	2.250	5.72	2.16	36,782	163,61	9,251	64	Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	v	ksi	GPa	v	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	2,628	18	0.17	162	2.59



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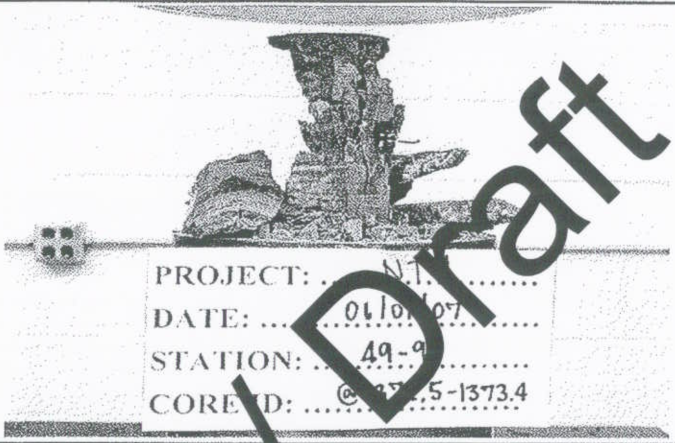
Earth Mechanics Institute

Mining Engineering Department, CSM

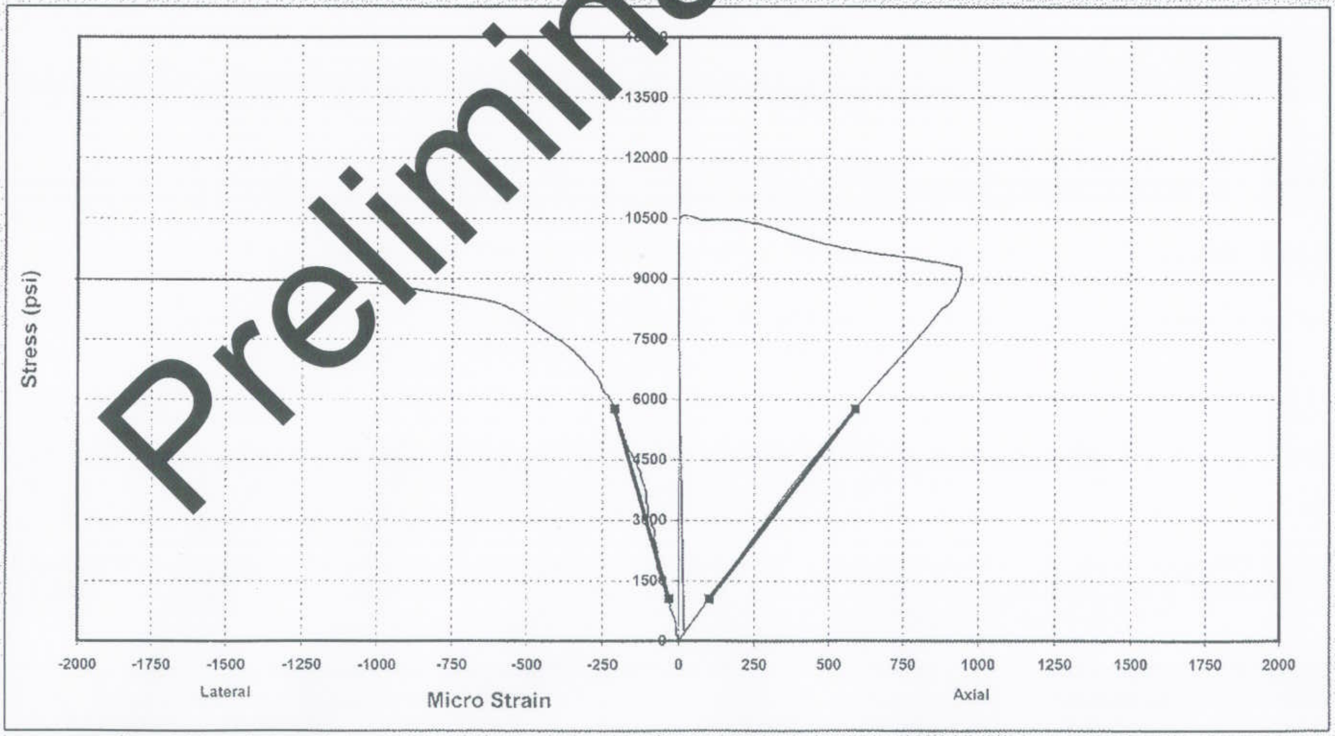
Uniaxial Compressive Strength Test Results (V 3.0)

Project: DRIC
Location: Detroit, MI
Rock Type: Sedimentary
Rock Name: Shaley Dolomite
Characteristics: brown, porous, laminations
Core ID: 49-9@1372.5-1373.4
File Name: 49-9@1372.5-1373.4
Test Performed by: PIPAT
Date Tested: 06/01/07
Data Reduced by: mcs
Date Reduced: 06/05/07



Core Length		Diameter		L/D	Failure Load		UCS		Failure
in	cm	in	cm	Ratio	lbs	N	psi	MPa	Mode
4.469	11.35	2.258	5.73	1.98	41,922	[illegible]6.47	10,473	72	Non-Structural

P-wave		S-wave		Dynamic E		Dynamic	Static E		Static	Density, ρ	
ft/sec	m/sec	ft/sec	m/sec	ksi	GPa	*v*	ksi	GPa	*v*	lb/ft3	g/cm^3
NA	NA	NA	NA	NA	NA	NA	9,656	67	0.37	160	2.57



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Appendix G

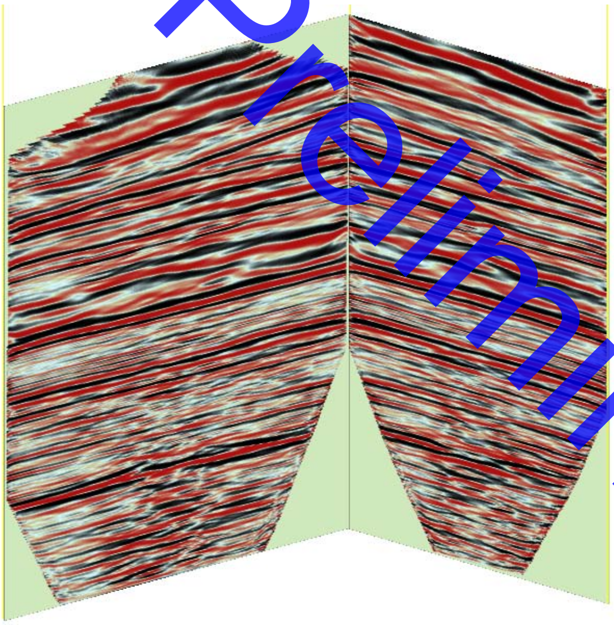
Detroit River International Crossing Study
Preliminary Draft of the Report
Detroit River International Crossing
Cross-well Seismic Imaging

by Roger Turpening and Carol Asiala,
Michigan Technological University
Dated November 9, 2007

Preliminary Draft of the Report
Detroit River International Crossing

Cross-well Seismic Imaging

Roger Turpening
Carol Asiala



Michigan Technological University

November 9, 2007

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Three Dimensional Visualization of Cross-well Seismic Images 39
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X-10 Crossing

Background

Thirteen (13) cross well reflection surveys were acquired in the X-10 area. Because they were somewhat distant from the Mistersky Power Station and because the boreholes were relatively close together the raw data and the processed surveys are excellent. Those images, separately and in selected fence diagrams are given below. First, we will make some general observations about the small segment of Michigan Basin geology seen here and the seismic image of that geology as seen with kilohertz seismic waves.

We are concerned with the salt formations (B-Salt, D-Salt, and F-Salt) of southeastern Michigan therefore the geological column from the top of the A2 Carbonate, at a depth of approximately 1,700ft., to the surface is of interest. (Figure 1)

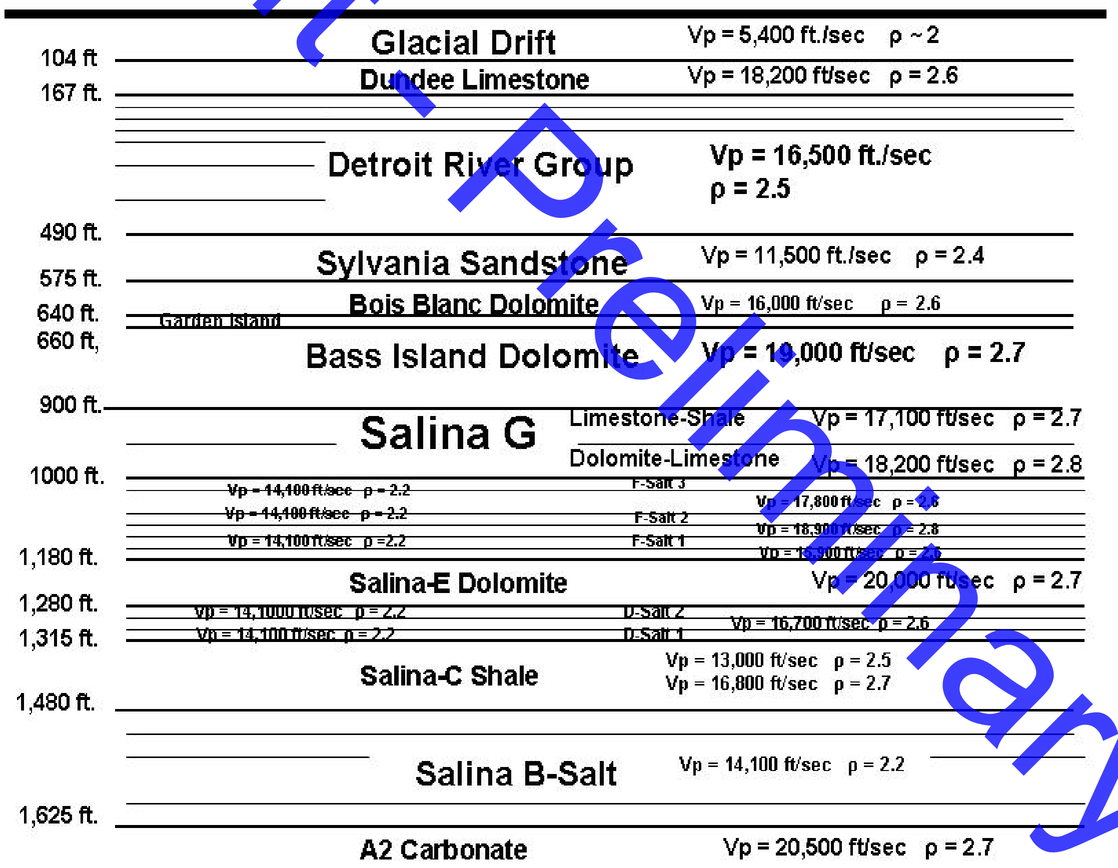


Figure 1 Generalized seismic structure from the A2 Carbonate to the surface, the depths are approximate values that represent the project area not a particular borehole. The only major change in the model occurs when the fourth layer of F-Salt is added to this structure. The compressional wave velocities are averatges over a formation, they are presented here, along with the densities, to highlight the major and minor reflectors.

There are important features in this cross section that should be highlighted now because they are prominent in the seismic images.

Salina B-Salt

Starting at the bottom we see that the velocity and density contrasts at the interface between the A2 Carbonate and the B-Salt are both large therefore the reflection from this interface will be strong. The light lines inside the B-Salt represent the many thin stringers present there. Those stringers in the bottom of the B-Salt are carbonates, and thus good reflectors, while the stringers near the top are composed of shale and therefore are not as strong as reflectors.

Salina C-Shale

With respect to compressional wave velocity both the C-Shale and the G-Shale are divided nearly in half with the base, in each case, being the high velocity region and top lower in velocity. This makes the B-Salt/C-Shale interface a good reflector. In like manner the interface between the two segments of the C-Shale is a good reflector.

Salina D-Salt

The D-Salt is composed of two layers of salt separated by a thick high velocity stringer which all together is thin enough to create a single, large-amplitude, tuned, wavelet. The interface at the top of the D-Salt and bottom of the E-Dolomite is a very large contrast in both velocity and density and is therefore, also, a component in the tuned wavelet. In fact this event is frequently the most prominent reflection in the entire image. The only reflection sometimes stronger is the top of the E-Dolomite

Salina E-Dolomite

The E-Dolomite is the highest velocity formation (20,000ft/sec) in the entire section and thus easily seen when the cross well reflection image is superimposed on the tomographic image. Because of the low-velocity D-Salt the interface at the base of the E-Dolomite is stronger reflector than the top of the E-Dolomite. In places in the X-10 and X-11 areas the E-Dolomite is a monolithic, constant velocity formation however other places two or three, thin, shale layers exist in the E-Dolomite creating internal reflections.

Salina F-Salt

The F-Salt consists of four or five layers of salt with a prominent, thick, stringer between the second and third layers. The material at the base of the F-Salt (just above the E-Dolomite) is frequently a carbonate not salt, this makes the reflection at the top of the E-Dolomite weak, sometimes non-existent. On the full waveform acoustic logs this is represented by a gradual change in velocity from the base of the F-Salt to the E-Dolomite. The high-velocity stringers and the salt layers, here, again create a set of tuned wavelets, therefore one does not see the top and bottom of each individual stringer or salt layer but rather a strong, uniform set of reflections. At the top of the F-Salt, in those areas where the fifth layer of salt exists our seismic images clearly display the G-Shale dipping over this additional layer

Salina G-Shale

The G Shale lies conformably on the F-Salt even when portions of the F-Salt have been dissolved. The fine details of the G-Shale are poorly imaged in this project because the G-Shale lies at a depth of approximately 900 ft. which, places it at mid-depth in the cross-well reflection images. This central location means that the suite of reflections used to image the G –Shale are "wide-angle" reflections, i.e. hit the layer at large angles (in the range of 45^{o}). The phase changes experienced by these reflections distorts the reflection wavelet causing the image of an interface to be distorted. Fortunately, only the inner features of the G-Shale are affected, the upper and lower interfaces of the G-Shale are very good.

Bass Island Dolomite
The Bass Island Dolomite has a high compressional wave velocity creating a strong reflection at the interface with the G-Shale. In the seismic reflection section the Bass Island typically displays a (relatively) low frequency set of wavelets signifying a rather simple internal structure (in acoustic impedance).

Garden Island Formation
The top of the Bass Island Dolomite is identified by the relatively sharp drop in compressional wave velocity that signifies the presence of the Garden Island Formation. This thin (approx. 20+ ft.) formation is clearly seen in the acoustic logs in the project area.

Bois Blanc Dolomite
The Bois Blanc is easily identified on a cross-well seismic section as the relatively thin formation that lies below the Sylvania Sandstone because the Sylvania is so distinctive. Furthermore it has a "high frequency" nature signifying the internal layers inside the Bois Blanc Dolomite.

Sylvania Sandstone
We superimpose the reflection section on the tomogram of compressional wave velocity and because of this the Sylvania Sandstone is instantly identifiable. It is the lowest velocity (10,000 ft./sec to 12,000ft/sec) formation in the project area (neglecting the glacial till) and it rests, sometimes unconformably, on the Bois Blanc Formation. Because it is such a slow formation its upper and lower interfaces are strong reflectors. Thin internal layers can be seen especially a scoured stream channel (hole TB6) at its base, with fine bedding displayed in the channel.

Detroit River Group
The upper portion of the Detroit River Group is identified by a rapidly fluctuating acoustic log (an assemblage of several high velocity (17,000+ ft./sec) layers) overlaying a relatively constant velocity (16,000+ ft/sec) lower section. The Group conformably overlays the Sylvania SS. In this project the Detroit River Group is the shallowest formation imaged. Although of academic interest the Detroit River Group along with many other shallow formations are of little interest to the DRIC project on the U.S. side of the river.

Cross-well Reflection Images
Although complete cross well reflection images will be shown from time to time in this report the primary interest here is with the lower (below 900ft) section. This is because all of the salt layers exist in the lower section and no large cavity "feature" was found in any of those layers on the U.S. side of the Detroit River. The few "features" that were found are so small that they did not even break the first layer above the salt formation in question. Therefore, in the following

sections we will display and discuss the cross-well reflection images of the lower section (approx. 900ft.to 1,700ft.).

The fence diagrams shown below provide the orientation of the boreholes, the cross-well reflection surveys, and the three dimensional orientation of the subsurface formations. Detailed examination of each individual survey is given below.

What is Displayed?

The following figures are displays of the cross well reflection image (wiggly lines of pressure with black fill for one polarity of pressure) superimposed on a tomographic image of compressional wave velocity (in color). This joint display of cross well tomography and reflection images makes the identification of high velocity (E-Dolomite) and low velocity (Sylvania SS) formations easy. This, in turn, quickly fixes the entire image in the interpreter's mind. (This is greatly aided by the fact that the Michigan Basin geology is flat and uncomplicated).

The boreholes used for the seismic sources and receivers are the edges of the image with various logs (gamma ray, acoustic velocity, density) displayed there also, Amongst those logs is a smooth measure of the compressional wave velocity as a function of depth taken from the center of the tomogram. Because the reflection image is in the kilohertz range it is easy to tie the reflectors in the image to the logs on the edges.

When the boreholes are a long distance apart, (e.g. 1,500ft) there are usually gaps in the image along each side at the mid-depth of image (i.e. the 900 ft. region). This is cause by the "wide-angle" reflection problem. As mentioned above, here the phase changes in the reflection wavelet are so large that they distort the wavelet such that it no longer presents an appropriate image of an interface. The image is so poor here that it is not displayed (muted).

The vertical scale on the images is given in ten foot units and the horizontal scale varies as a function of the distance between the boreholes, however, twenty five foot units are readily seen on the horizontal scale. Vertical and horizontal resolution is clearly seen in these images because of the kilohertz frequency content.

What Are We Looking For?

We are looking for cavities in any of the three salt formations. No assumptions are made about how solution mining was conducted, that is, where the fresh water was injected into a salt layer and where in that layer the extraction of brine occurred although it is known that one method of solution mining might produce a "morning glory" shape of cavity

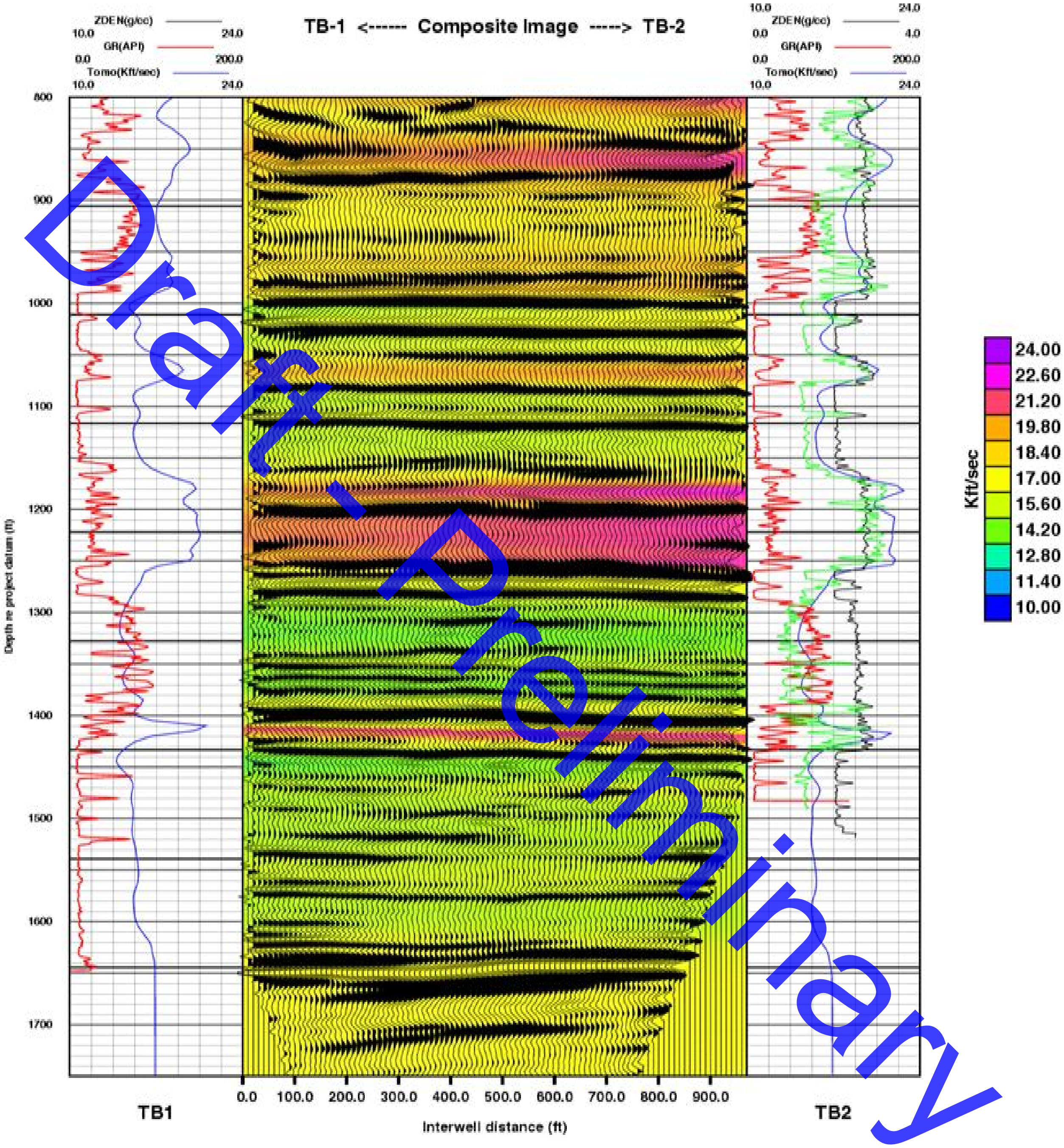
The search uses the stringers that exist in all of the salt layers. Because of the high resolution of these cross-well reflection images and the large number of thin stringers one can search for a zone of broken stringers as an indication of the presence of a cavity. As seen in the following figures stringers are tens of feet apart and high resolution imaging makes them visible. Thus the early development of a cavity a few tens of feet high and on the order of a hundred feet wide will be detected.

If the roof of a cavity collapses allowing the cavity to “propagate upward” into a thick stringer or into the formation above a salt unit the resulting dome shape can be detected. Again, because of the high resolution of the kilohertz reflection images “domes” with heights of a few tens of feet can be detected. Remember, cavities must originate in a salt layer. If a cavity is suspected in an overlying carbonate or shale layer there must be a vertical “pathway” up to that suspect cavity.

This discussion is directed towards very small (tens of feet) cavities and “cavity like features”. Our experience with the cross well seismic imaging of a major collapse structure indicates that one can easily detect a feature that cuts through one or more formations.

Borehole gravity provides a level of protection against false alarms. As seen in the adjoining chapter brine filled cavities of a certain minimum size can be detected at some distance from each borehole. Therefore we need not depend on one technology in our search.

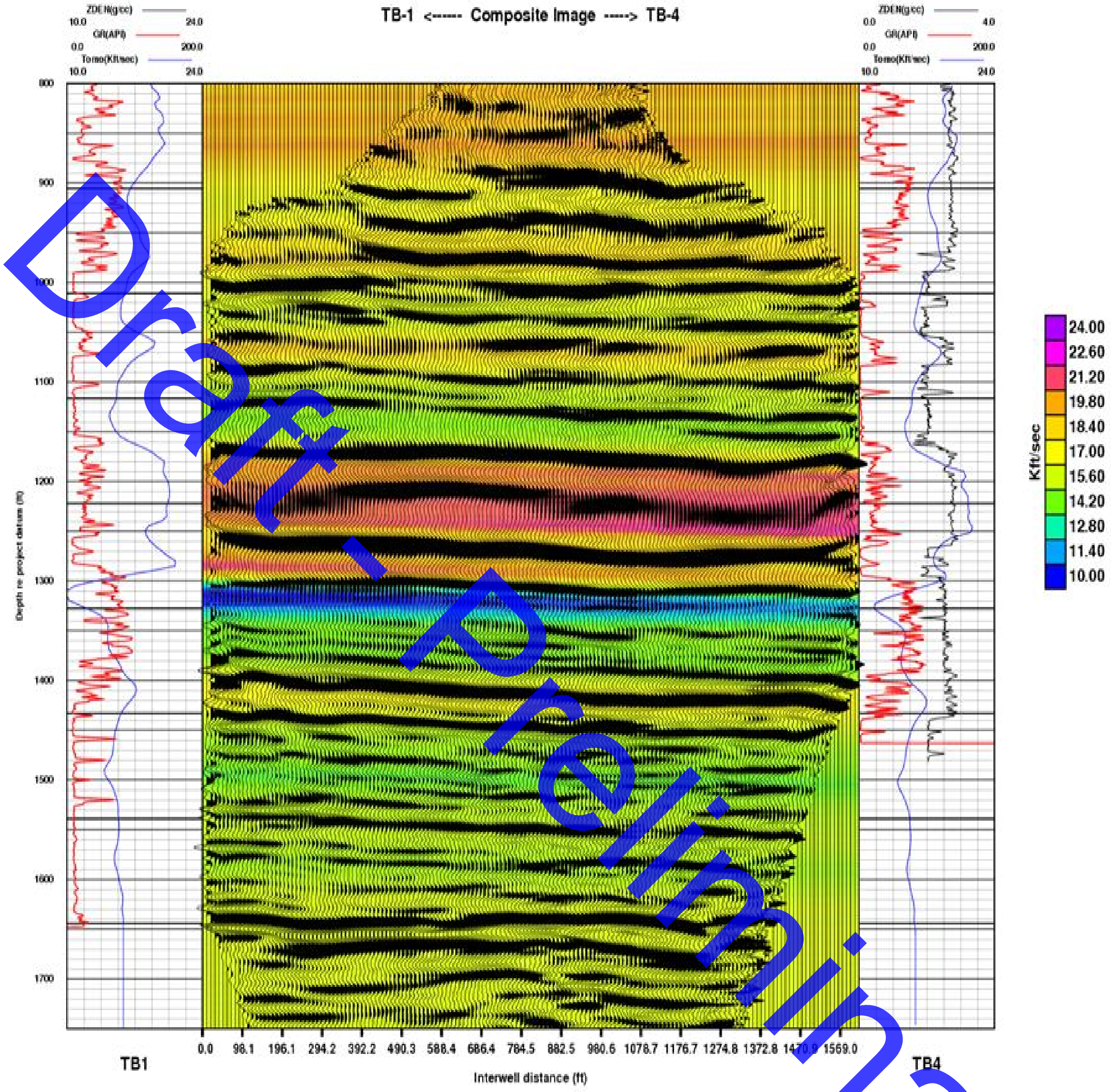
Profile TB1-TB2



This image displays the classic, flat lying formations from the A2 Carbonate at approximately 1,650 ft. to the G-Shale (900ft. to 1,000ft) with a bit of the Bass Island Dolomite seen at the top. In this image every formation lies conformably on the formation below it. No cavity features of any interest exist in any of the salt layers (B-Salt, D-Salt, and F-Salt). The stringers in each of those layers are intact.

The distinct bottom of the E-Dolomite is seen due to the strong velocity contrast between the E-Dolomite and the underlying D-Salt.   The interface at the top of the E-Dolomite is clear and strong and the interior is nearly featureless. Clearly no cavity has broken through this layer so we turn our attention to the F-Salt unit. Here, all of the salt layers and stringer layers are clear and continuous. Near the TB-1 borehole at at depth of 1,050 ft. we do see an interruption in the reflection, however that represents the top of the stringer, as mentioned above a cavity can not originate in a stringer.

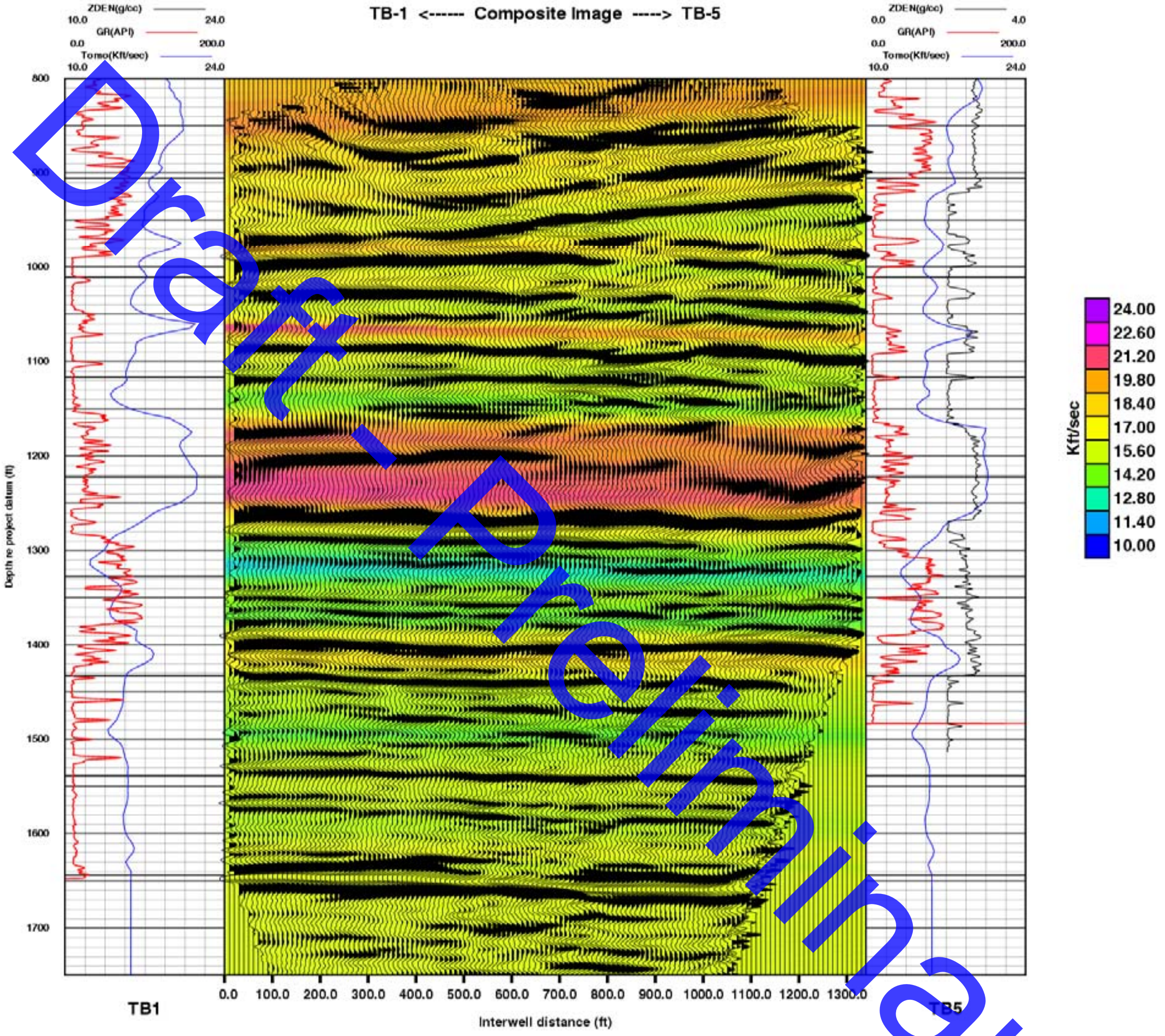
Profile TB1-TB4



The profile TB1 to TB4 is also a simple, nearly flat lying sequence of beds from the A2 Carbonate to the G-Shale. The B-Salt/A2 Carbonate interface is shown, just as it was in image TB1 –TB2, as a strong, nearly horizontal tuned event. In this TB1-TB4 image it is not as clean and clear as it was in the TB1-TB2 image, because the #4 borehole is not very deep causing the loss of fold for deep reflections.

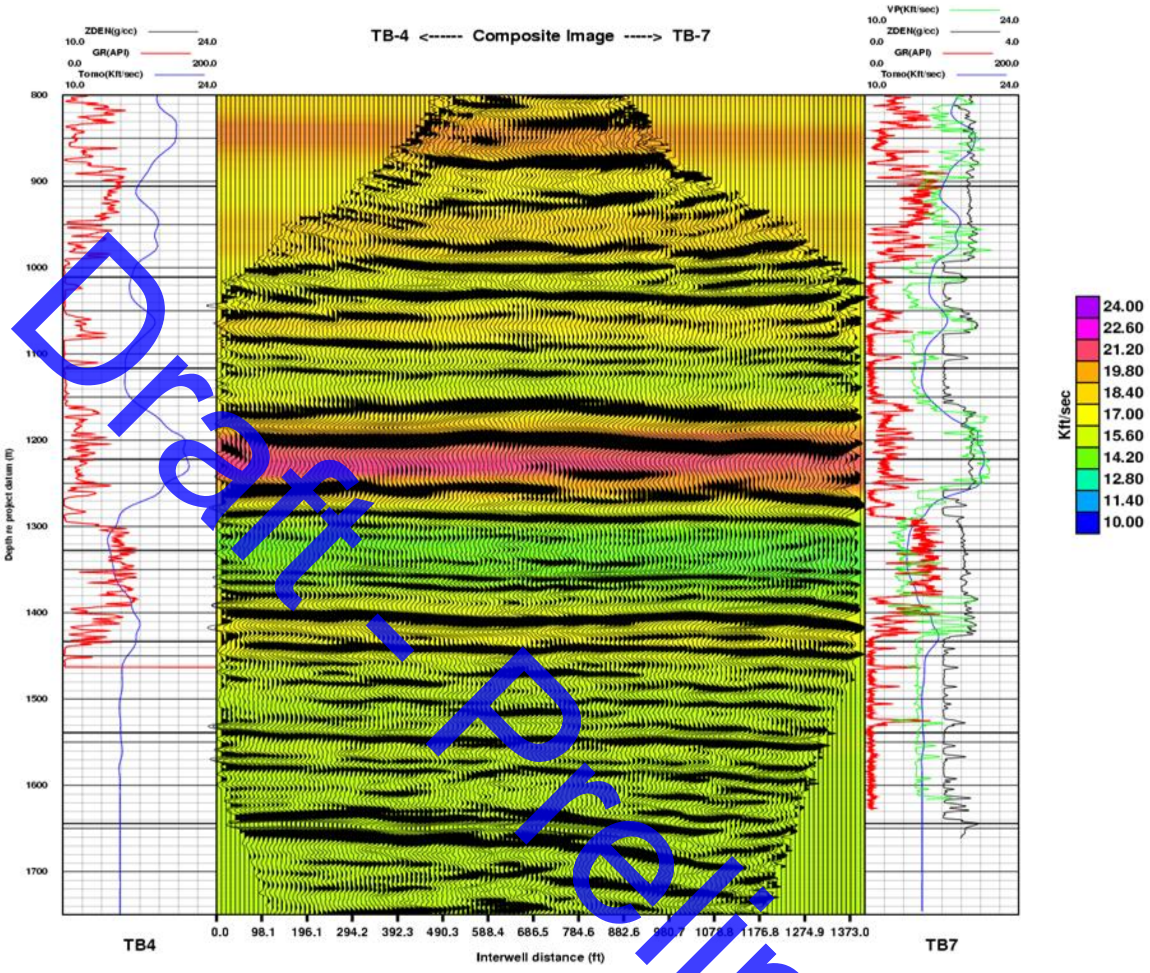
The feature in the top of B-Salt at depth of 1,450 ft. is a plotting artifact denoted by the two vertical lines in this image.

Profile TB1 –TB5



In profile TB1-TB5 we see a feature in the top of the A2 Carbonate at a depth of 1,650ft. in the middle of the image. This violates the rule that cavities must start in salt, furthermore there is no disturbance of the stringers in the B-Salt above that feature. Again, in the top of the C-Shale at a depth of 1,270ft. near the TB 5 borehole we see a feature with no expression in the overlying D-Salt or the E-Dolomite above. Thus, this feature is discarded. In the top of the top of the F-Salt at a depth of 980ft. we suspect a feature at a distance of 800ft from the TB 1 borehole. However, the suspected cavity does not penetrate the wedge of salt above directly above, therefore it is not deemed a threat. Unfortunately it is too far from TB 5 to be tested by borehole gravity.

Profile TB4-TB7

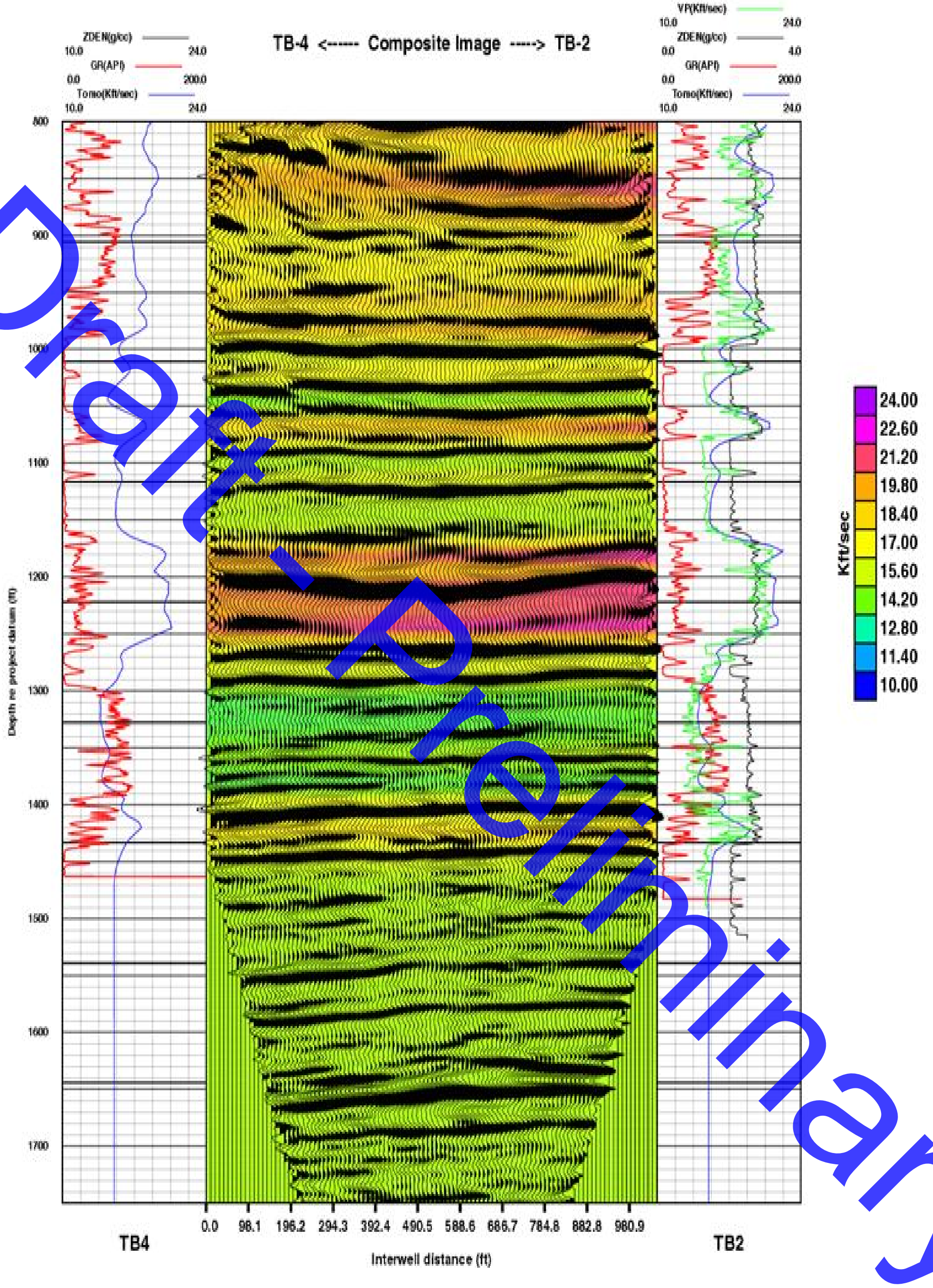


This is a long profile, approx. 1,380 ft. between boreholes TB-4 and TB-7 therefore, as discussed above, portions of the image above the F-Salt have been muted due to the wide-angle problem. However, some migration “smiles” can be seen in the top of the F-Salt (1,000ft) close to TB-4, these artifacts should not be interpreted as a broken interface. Fortunately, these features can be checked against borehole gravity to see if a cavity is masked by the artifacts.

The top of the D-Salt—bottom of the E-Dolomite is irregular and it is possible to interpret the feature as a solution breakthrough, up from the D-Salt. However, the D-Salt is very thin (20ft.) here and we see no solution related feature (e.g. “stem”) in the base. Furthermore, the event inside the E-Dolomite that might be interpreted as the top of the cavity is concave upward, not downward, as the top of a cavity should be shaped.

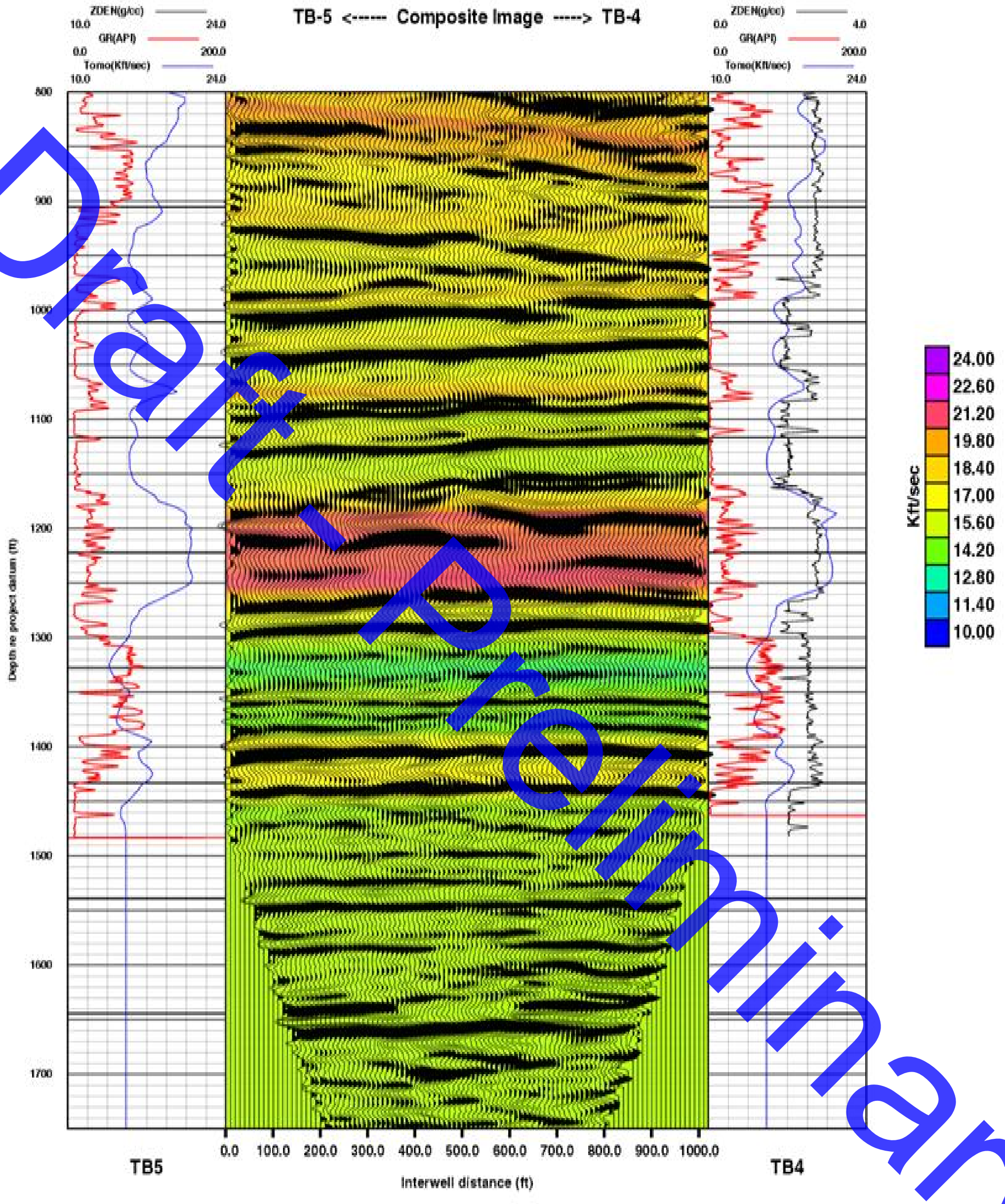
The stringers inside the B-Salt have a low signal to noise ratio and therefore are “wormy” in shape not straight as we see in smaller surveys. Although these low signal to noise ratio features could mask a cavity we see that the top of the B-Salt is solid and continuous, therefore no cavity, should one exist, has broken out of the B-Salt.

Profile TB4 to TB2



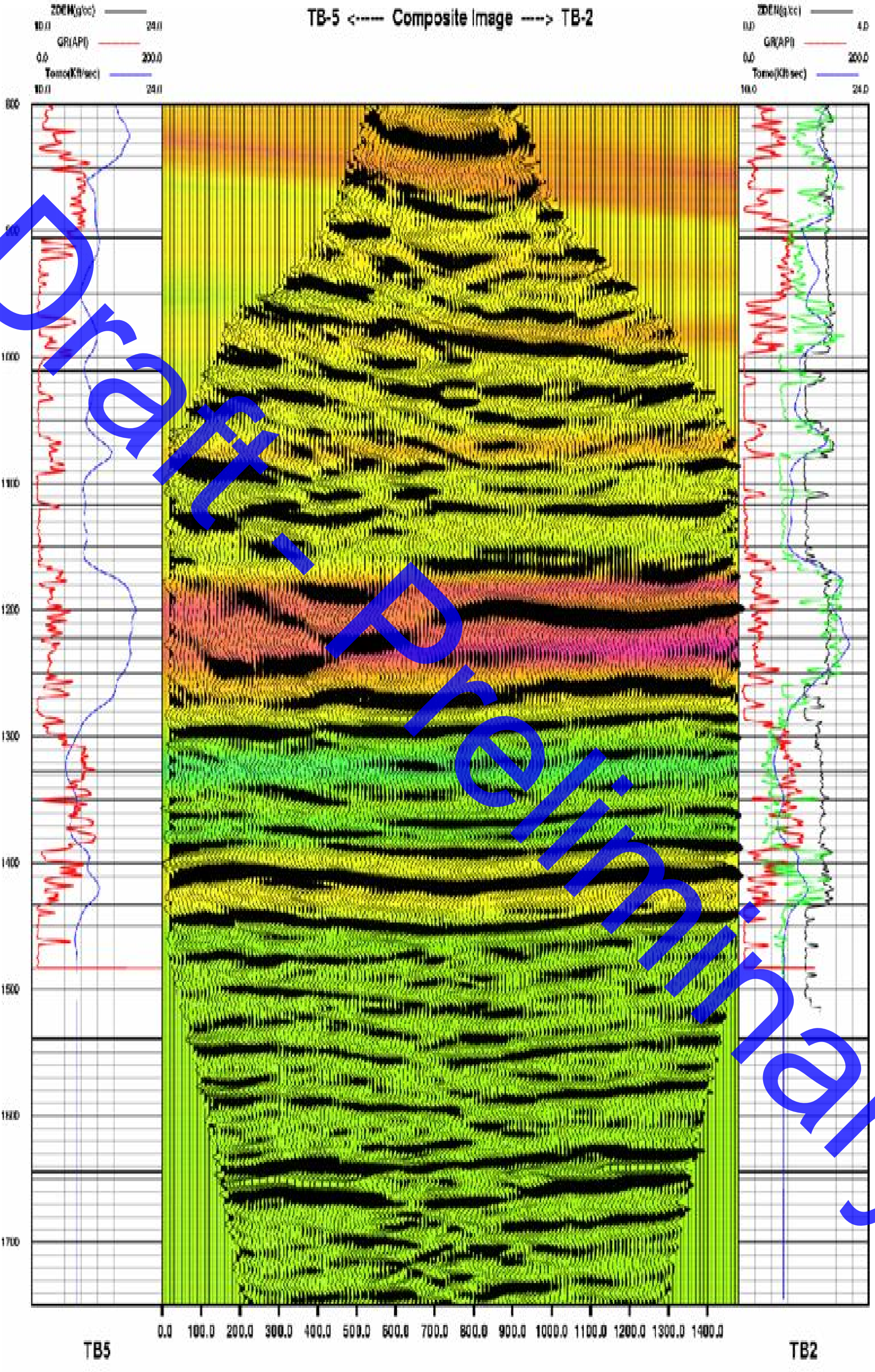
This profile shows a small fault (depth of 1,050 ft.) that offsets just one salt layer (#3) of the F-Salt Formation. It is one of the few images that shows a rather weak bottom interface for the E-Dolomite. But, the two D-Salt layers are solid and continuous. The B-Salt unremarkable with stringers all in place sitting on an A2 Carbonate that is somewhat irregular

Profile TB4 to TB5

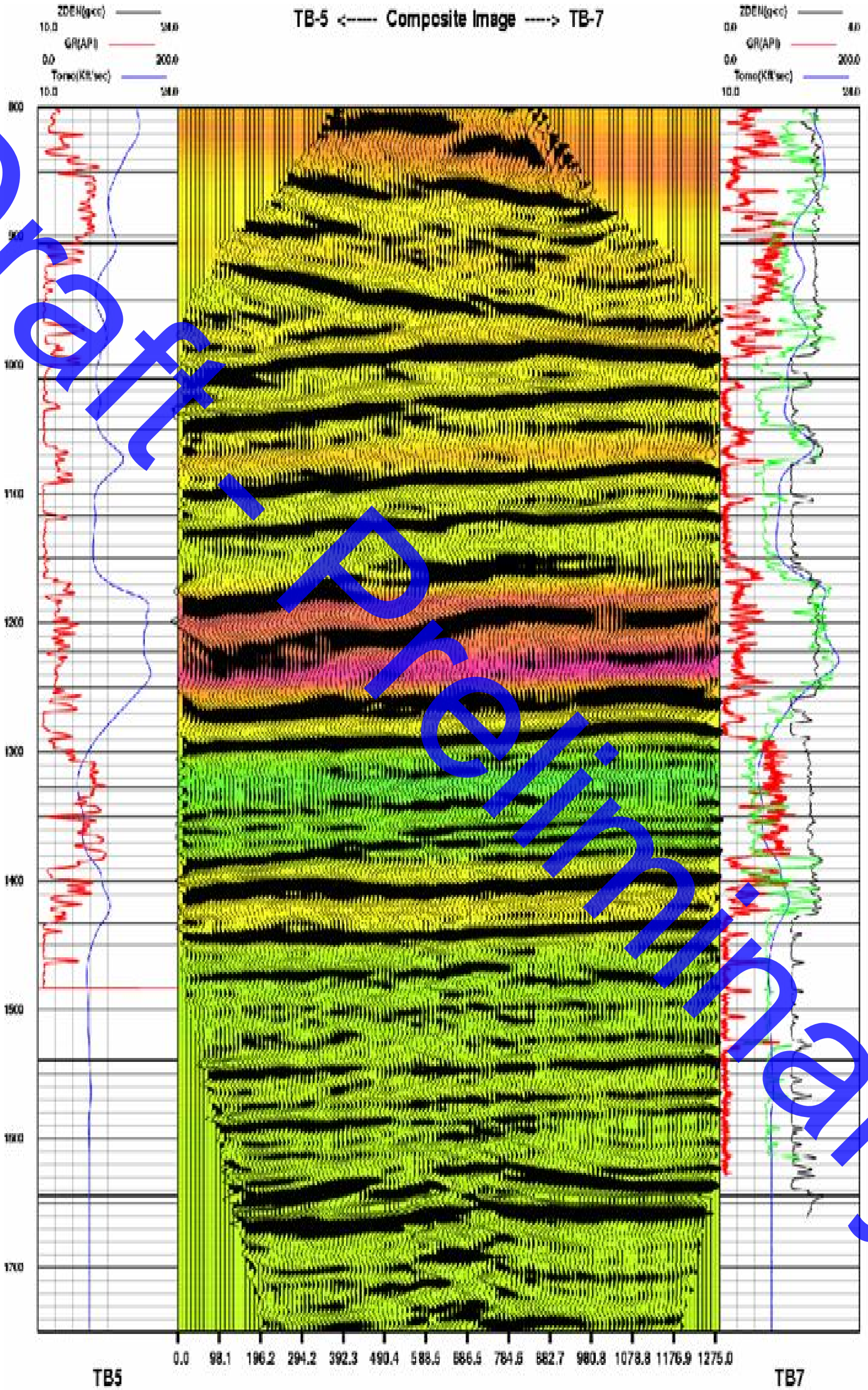


This profile displays the dipping interface of the G-Shale (depth of 920ft). Although some features may be suspect in the F-Salt layers (920ft. to 1,180ft.) it is obvious that the major stringers in the F-Salt are present and continuous. The D-Salt (1,280ft.) contains an minor interface in the center of the image. The B-Salt is unremarkable, and the tuned combination A2 Carbonate has an added

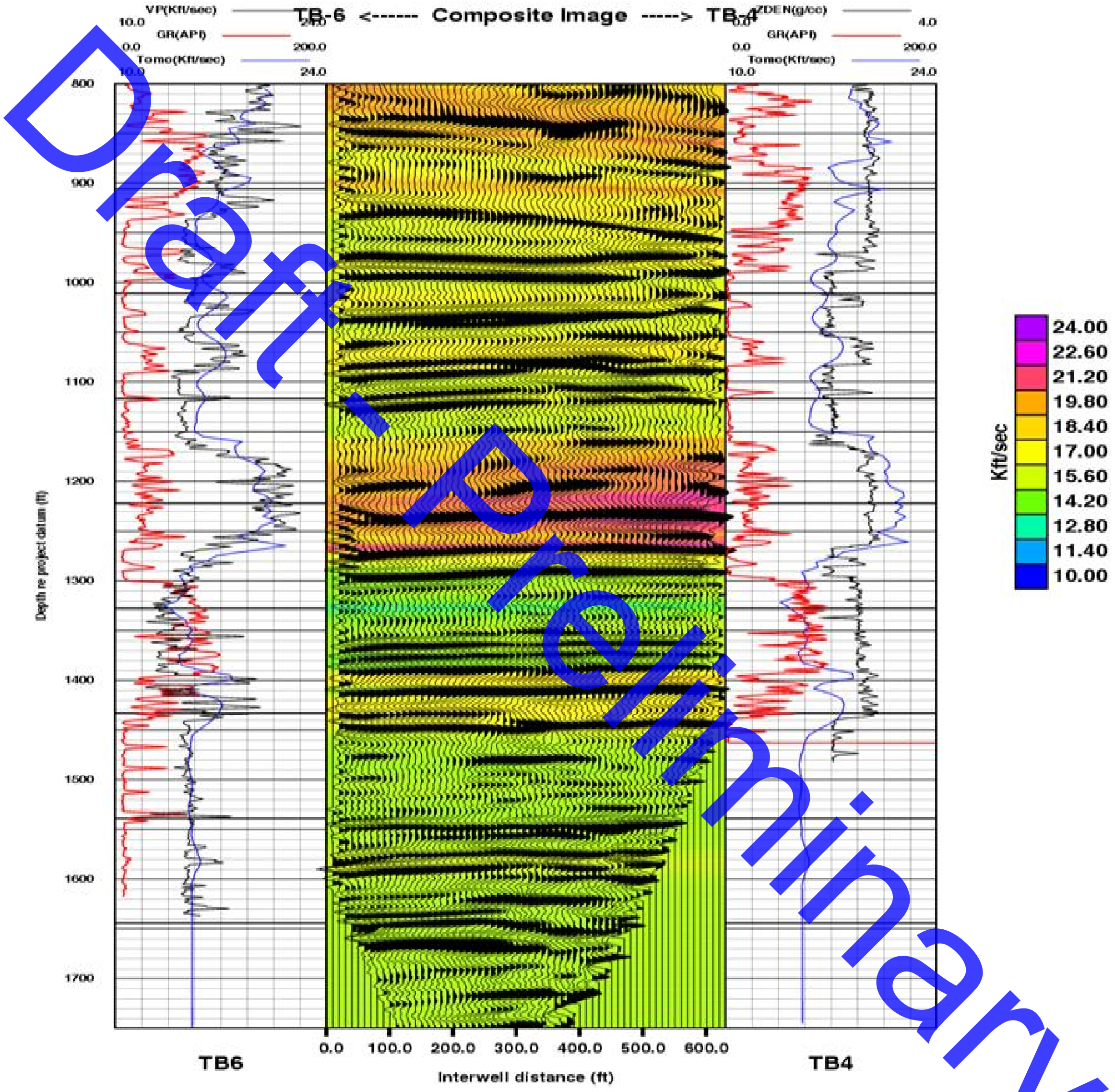
Profile TB5 to TB2



Profile TB5 to TB7

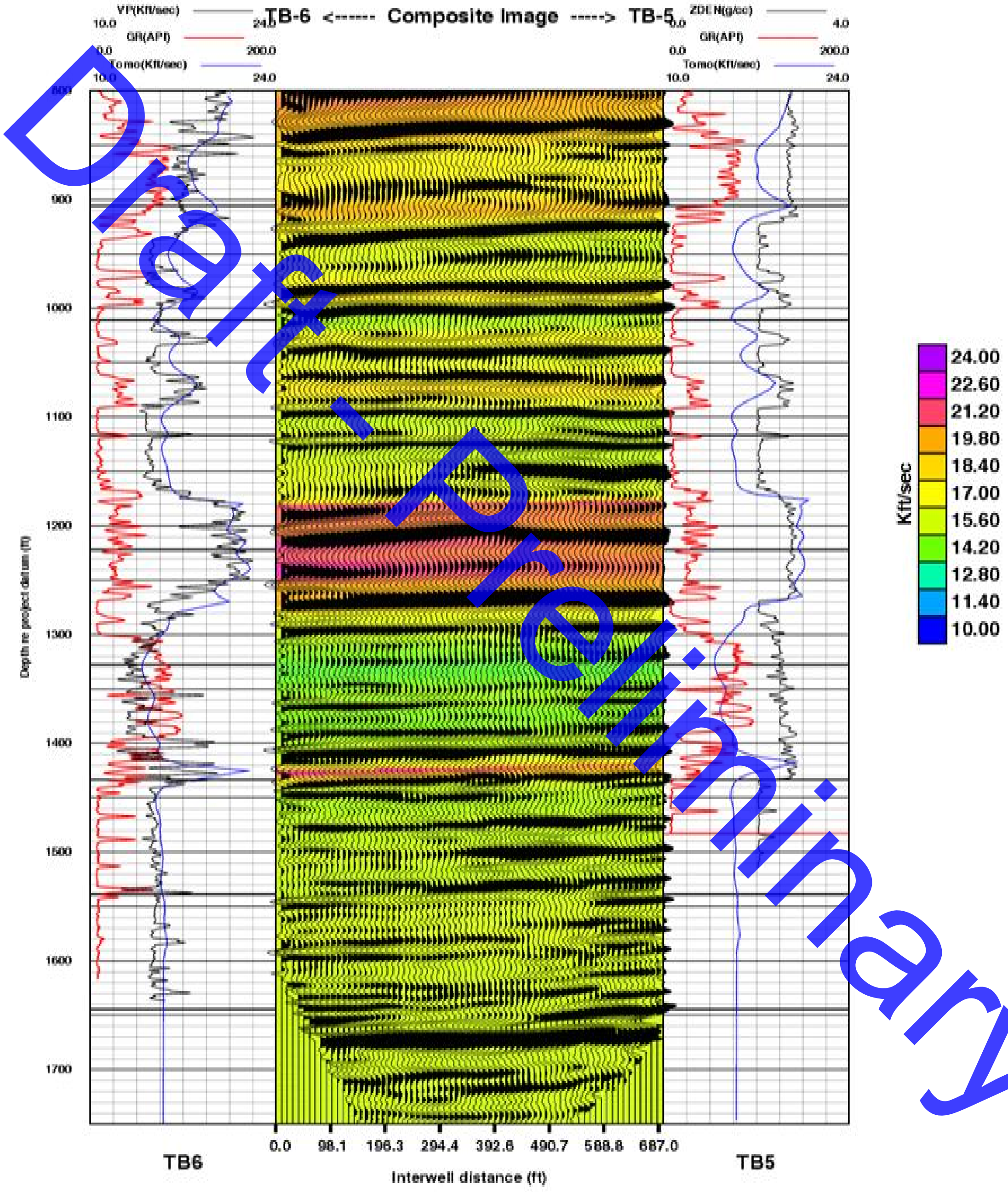


Profile TB6 to TB4

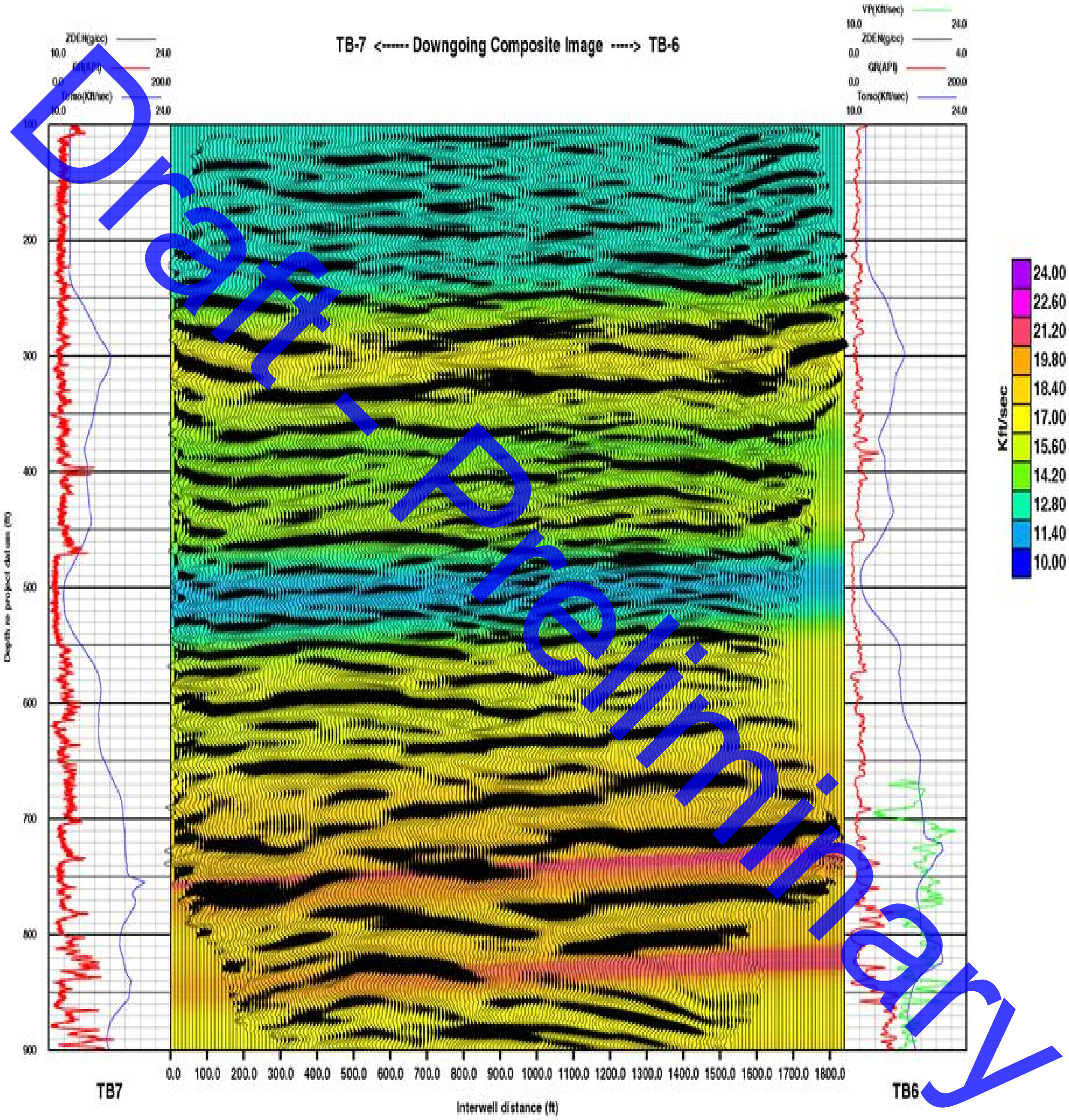


This image displays a "morning glory" feature in the top of the second F-Salt layer (1,010 ft.) a crooked "stem" is seen off center below the dome. This is a very small feature with a height of only 10ft. to 15 ft. Above the F-Salt we see the dipping G-Shale laying on the fifth layer of F-Salt in and near TB 6. The B-Salt displays major, high velocity stringers in the base of the B-Salt and the shaly stringers in the upper portion. The A2 Carbonate is at the base of this image.

Profile TB6 to TB5

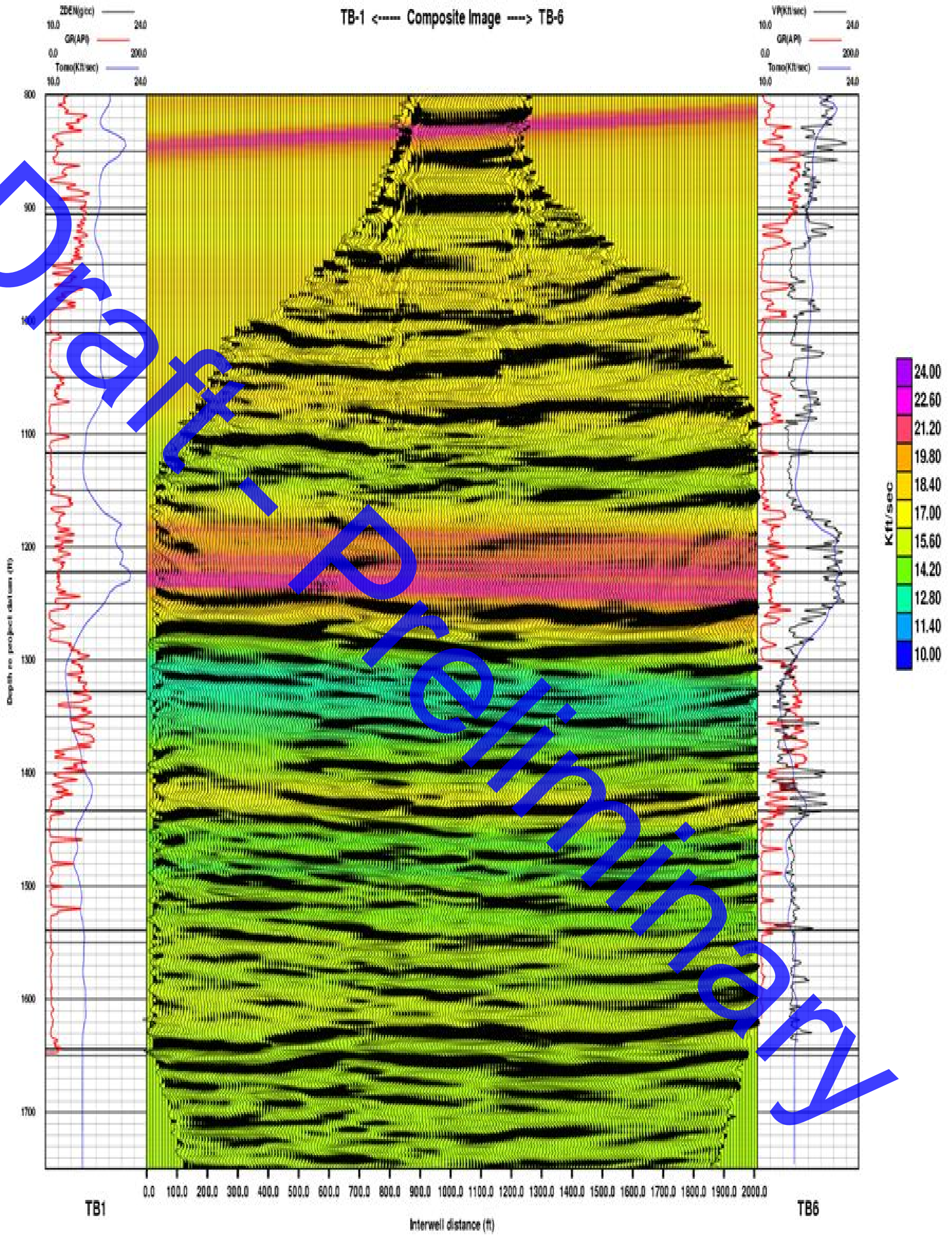


Profile TB7 to TB6



This image is in the processing queue

Profile TB6 to TB1



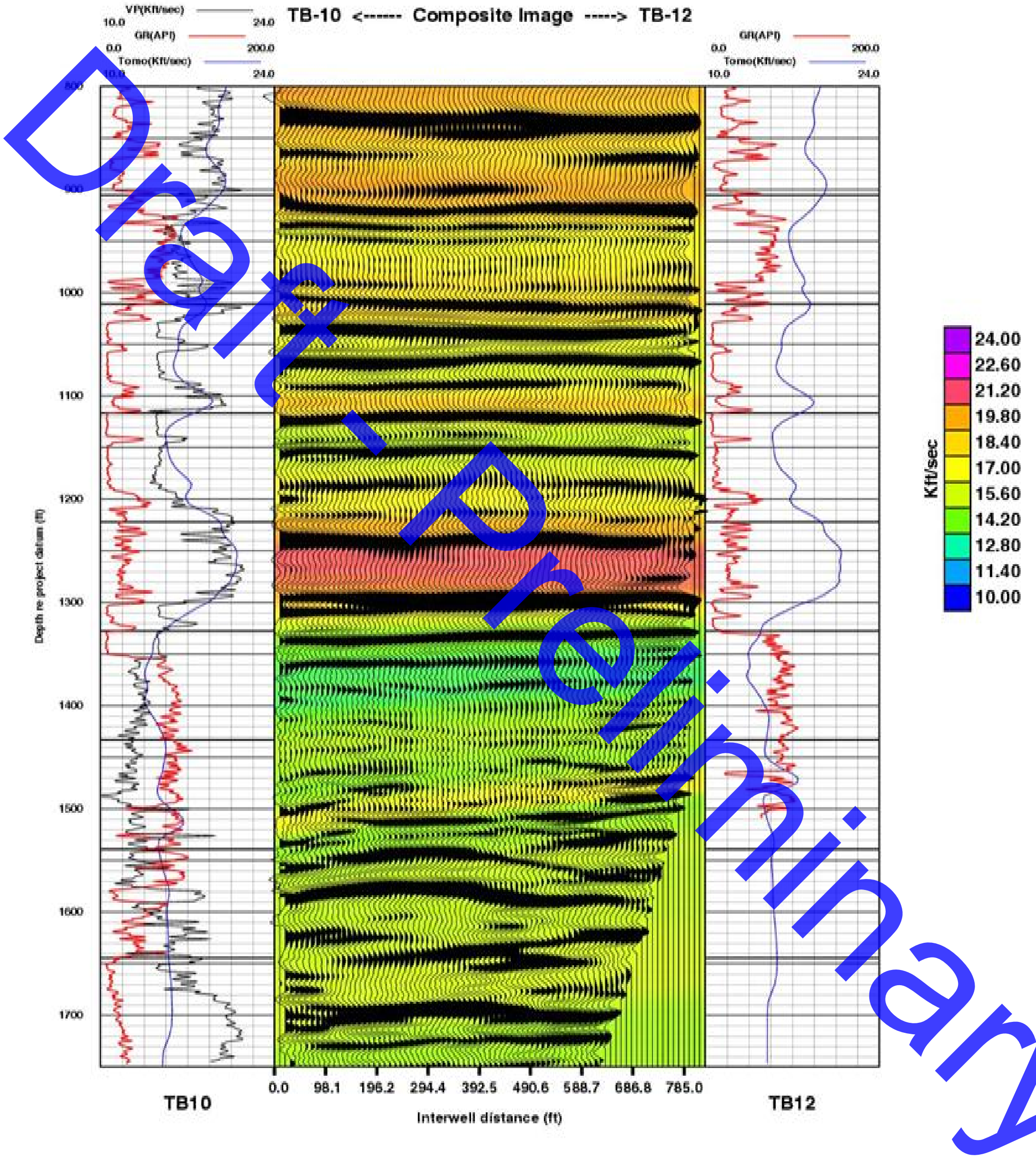
This image is in the processing queue

X-11 Crossing

Background
All of the cross-well surveys in the X-11 crossing area have been acquired. The acquisition was made difficult here due to the proximity of the Mistersky Power Station and the relatively long distance (compared to borehole depth) between boreholes

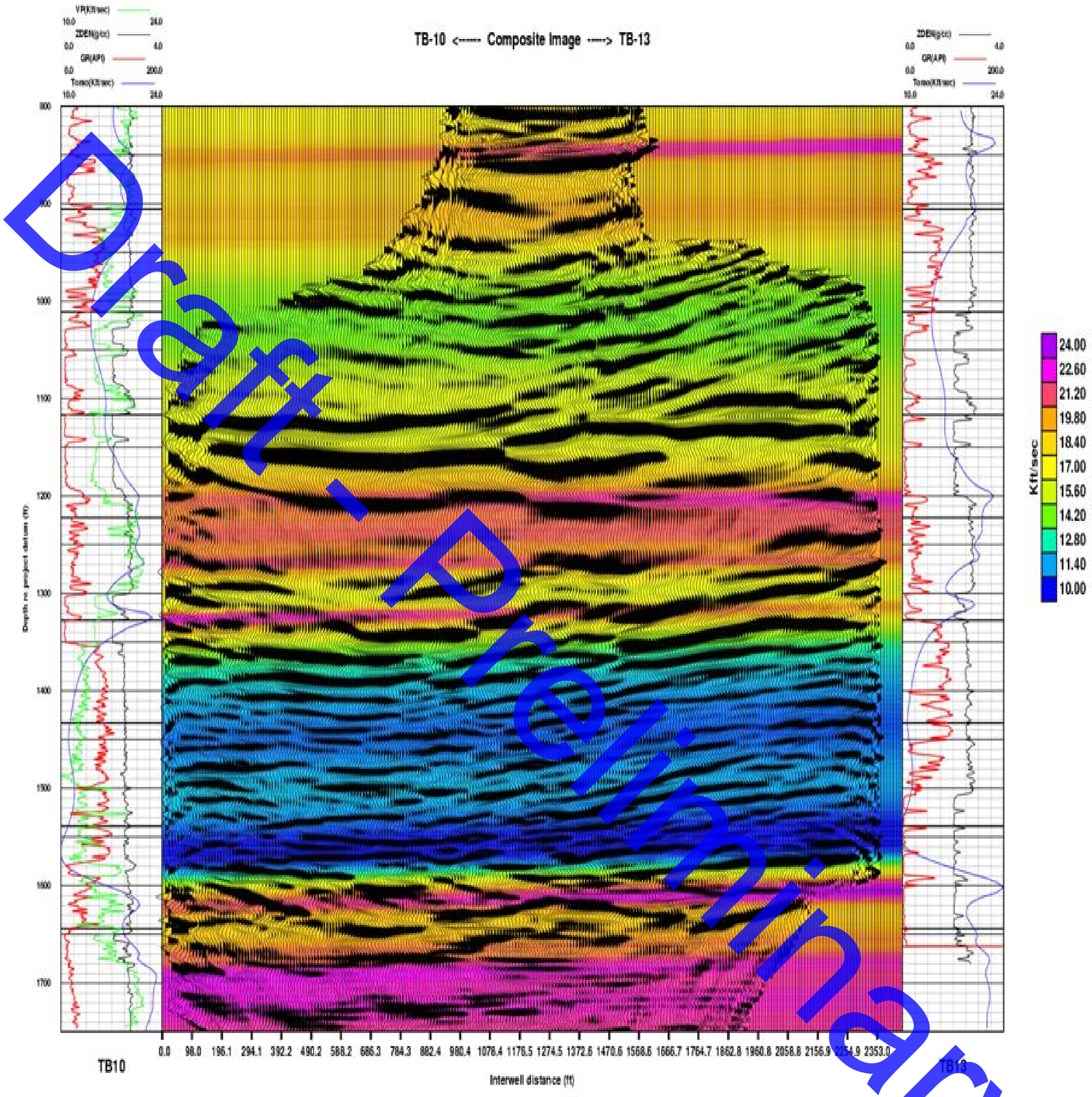
Seismic data processing is an iterative process with continuous interchange between the seismic processing specialist and the seismic interpreter. The first pass of data processing has been completed and the second pass is underway at this time. The images in this processing queue are so marked. No remarks are given for images that are in the processing queue.

Profile TB10 to TB12



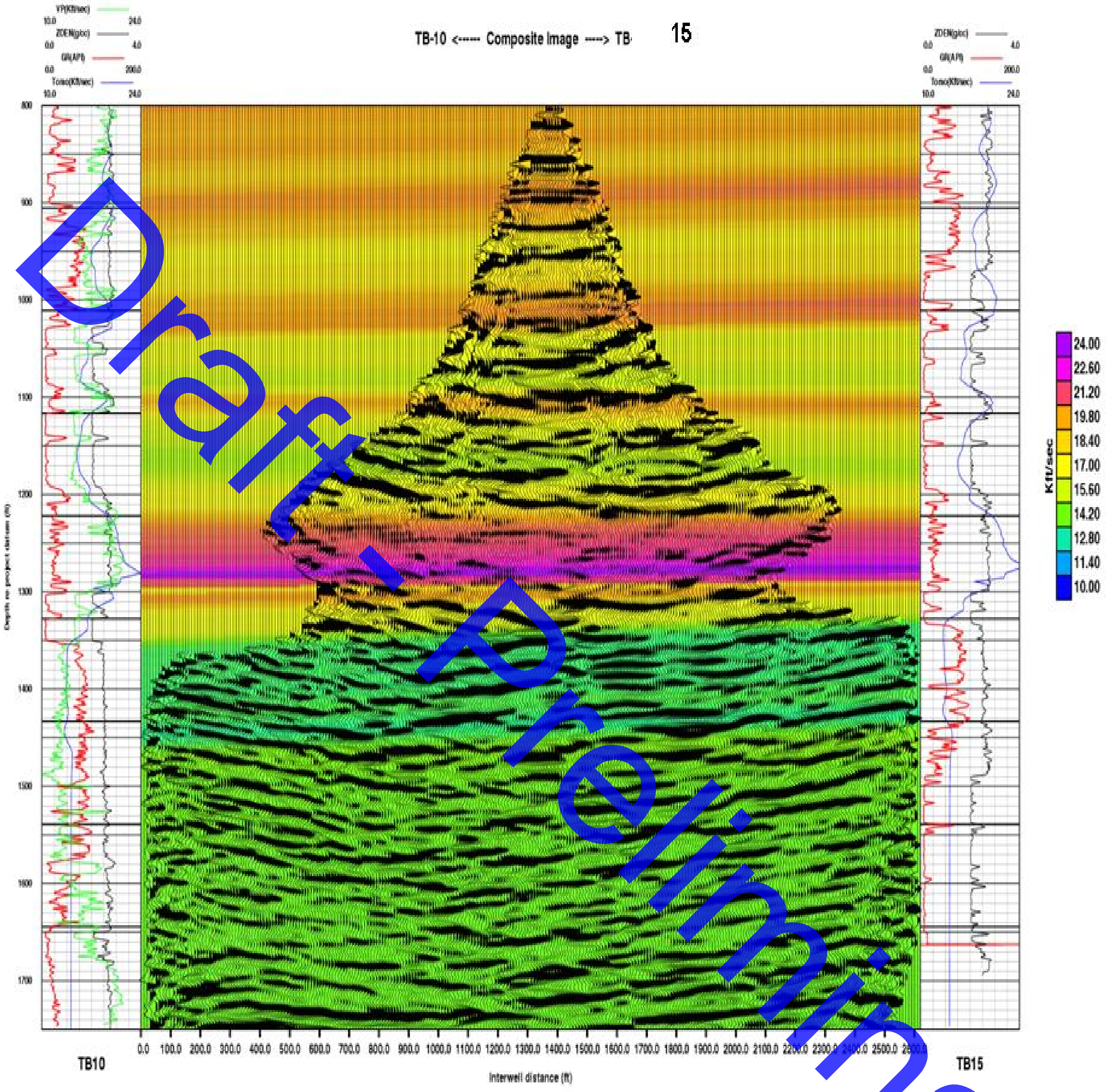
This image shows the complete set of F-Salt reflection events together with the stringers between various F-Salt units. Note two vertical plotting artifacts, these streaks will be removed from the final images. A strong B-Salt reflection is seen even though the B-Salt is only six feet thick near TB 10 and flat between TB 10 and TB 12. The E-Dolomite lies unconformably on the unremarkable D-Salt.

Profile TB10 to TB13

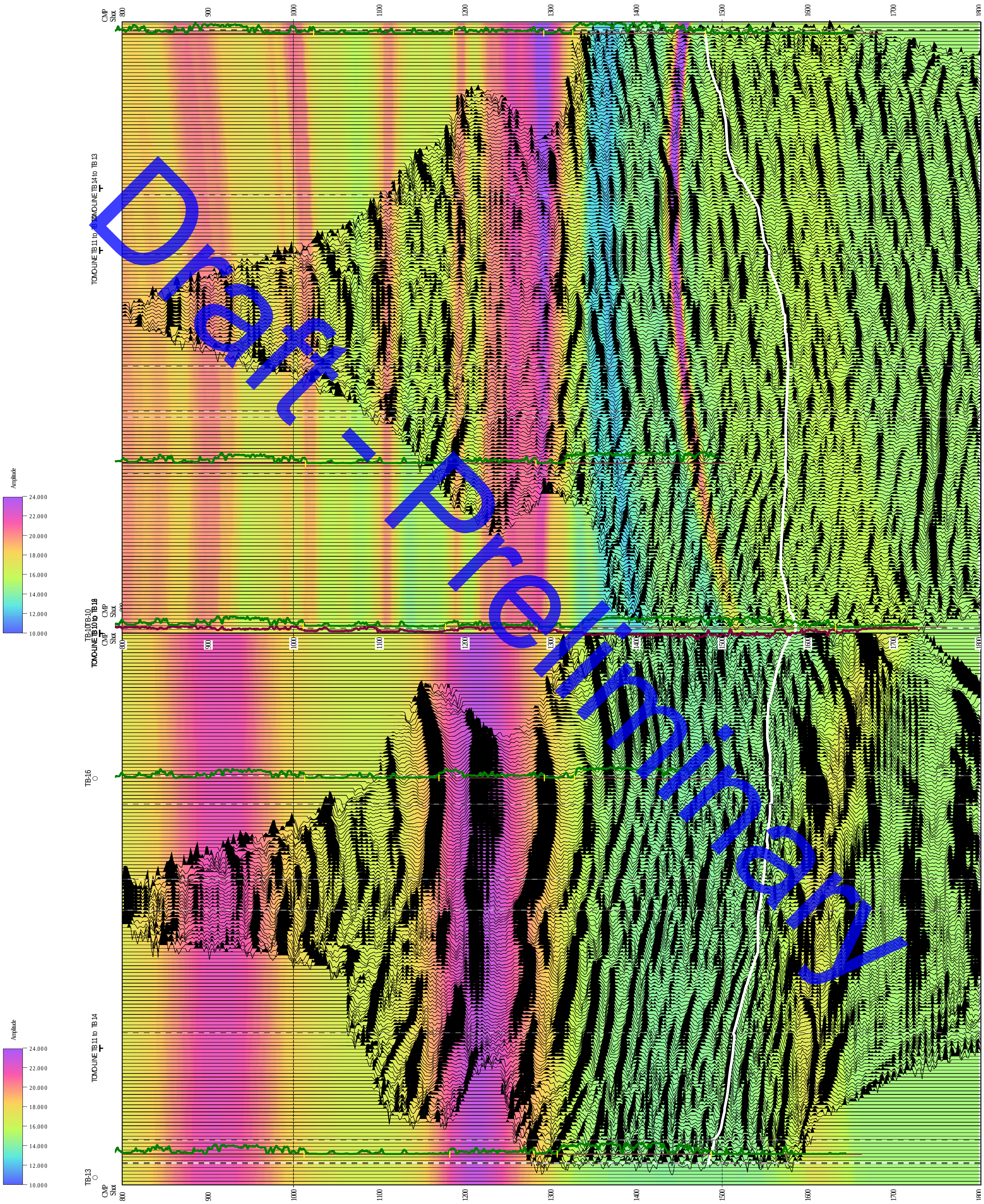


This image is surprisingly good considering the long distance between the boreholes and the electrical noise from the Mistersky Power Plant. The important aspect of this survey is that it connects TB10 which has only 8 ft. of B-Salt to TB13 which penetrated approximately 140 ft. of B-Salt. We can see the top of the thinning B-Salt as it dips gently from TB 13 to TB10. Above that we see individual beds of the C-Shale abutting the B-Salt. Moving upward we see the C-Shale completely overlying the B-Salt. Above the C-Shale we see the D-Salt and then the massive E-Dolomite. The reversed polarity image below of the tie at TB10 between this image and the TB15 to TB10 image provides a better image of the massive E-Dolomite.

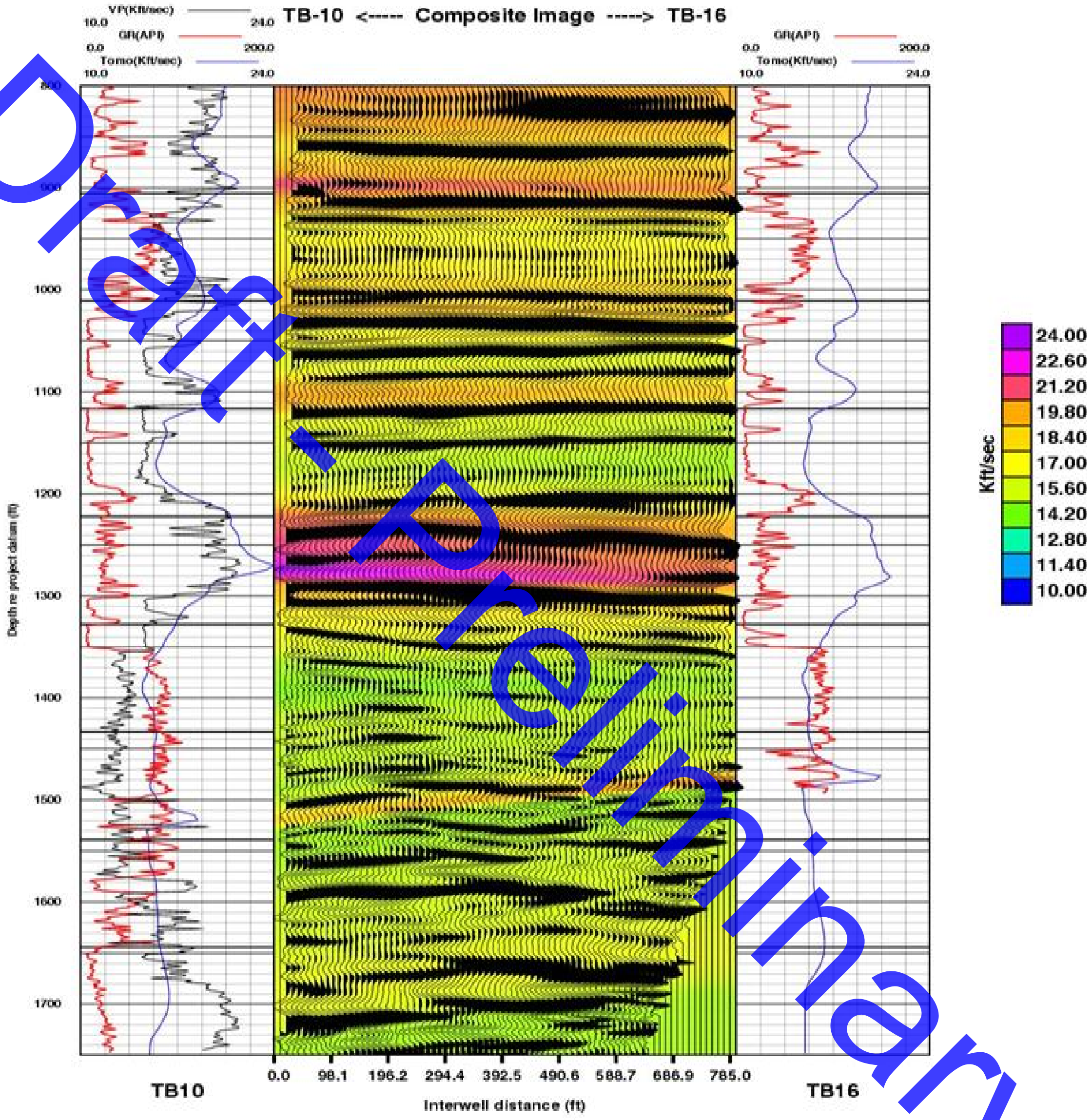
Profile TB10 to TB15



This survey also displays the thinning of the B-Salt from 180 ft thickness in the TB15 borehole to 8 ft. in TB10. The tie between survey TB10 to TB13 and this image at borehole TB10 is shown below. The top of the thinning B-Salt is shown in each image as it approaches the tie at TB10. There the massive E-Dolomite is clearly seen in the TB13 to TB10 image. It is obvious that it has not been broken.

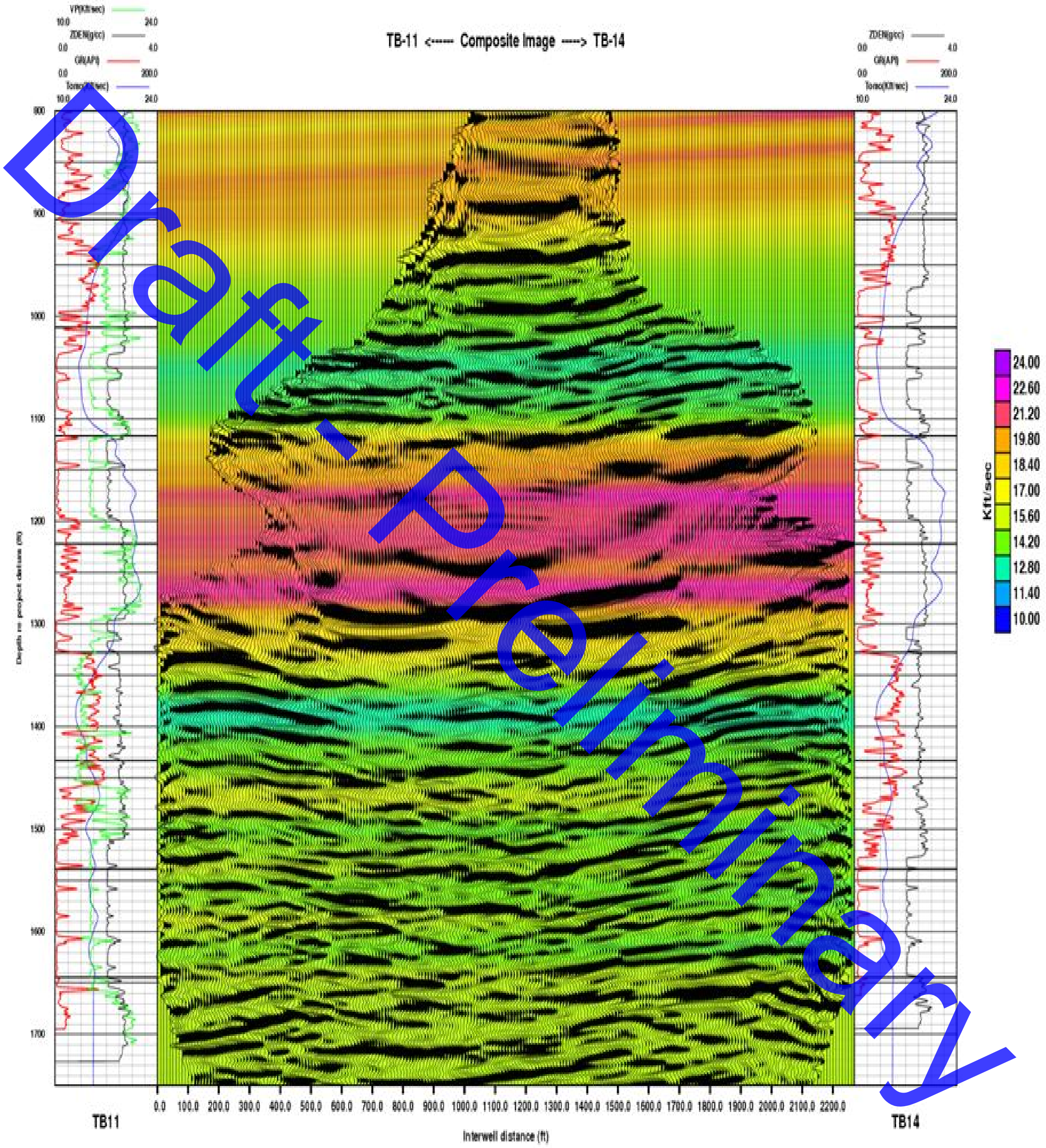

CMP
Shot
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
TOMO-LINE TB 14 to TB 13
TOMO-LINE TB 11 to TB 14
TB-10
TOMO-LINE TB 10 to TB 18
TB-16
TB-13
Amplitude
24.000
22.000
20.000
18.000
16.000
14.000
12.000
10.000

Profile TB10 to TB16



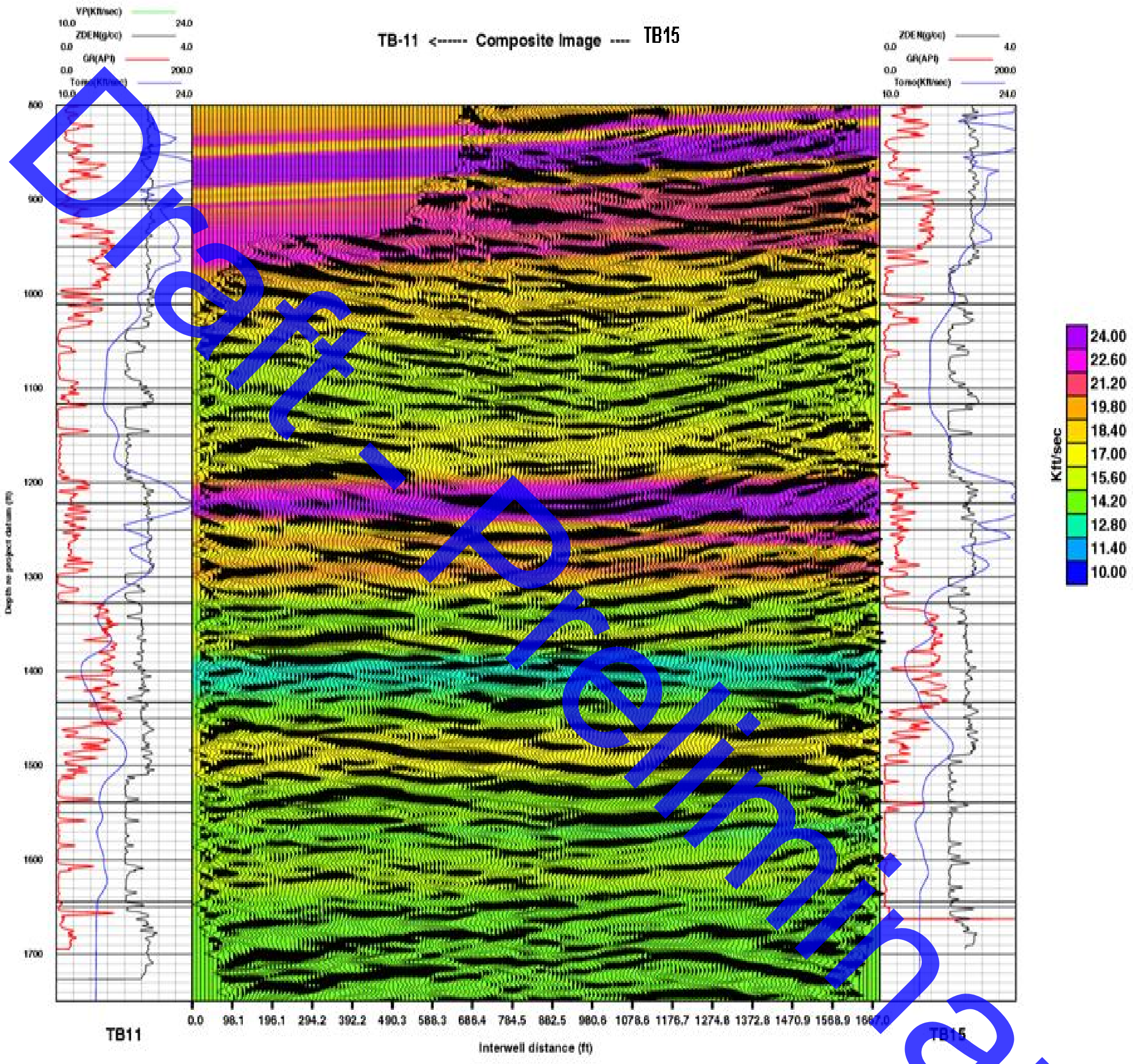
The logs in borehole #10 show eight (8) feet of B-Salt at approximately 1,635 ft. however, the formation is probably broken, the event can not be seen very well here. However, it is constrained between the strong reflection from the high velocity carbonate stringer at approximately 1,580 ft. and the A2 reflection at approximately 1,740 ft. The F-Salt formation is complete with a slightly dipping top and the strong, flat reflection events from all of the stringers, especially the thick stringer at 1,100ft. The D-Salt is clearly seen beneath the E-Dolomite at 1,200ft. with a clear, strong, and continuous top and bottom. The stringer in the D-Salt can be seen in places.

Profile TB11 to TB14



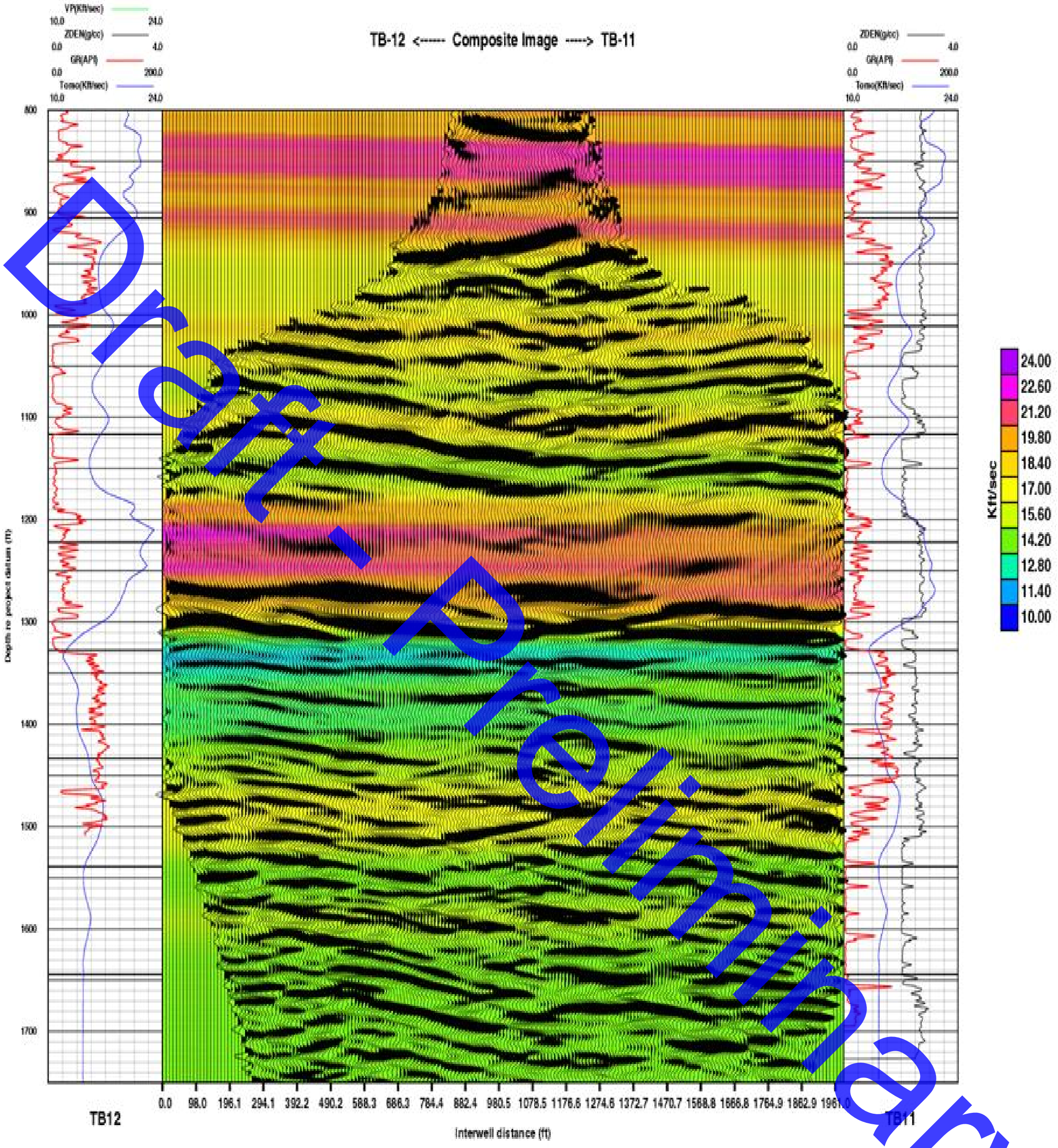
High electrical noise at the site makes this survey difficult to interpret. Because of the high velocities and the low frequency events we can say that the E-Dolomite has not been breached. Note the high velocities (apparently) in the F-Salt. This image will be reprocessed because the high velocities in the F-Salt are not real.

Profile TB11 to TB15



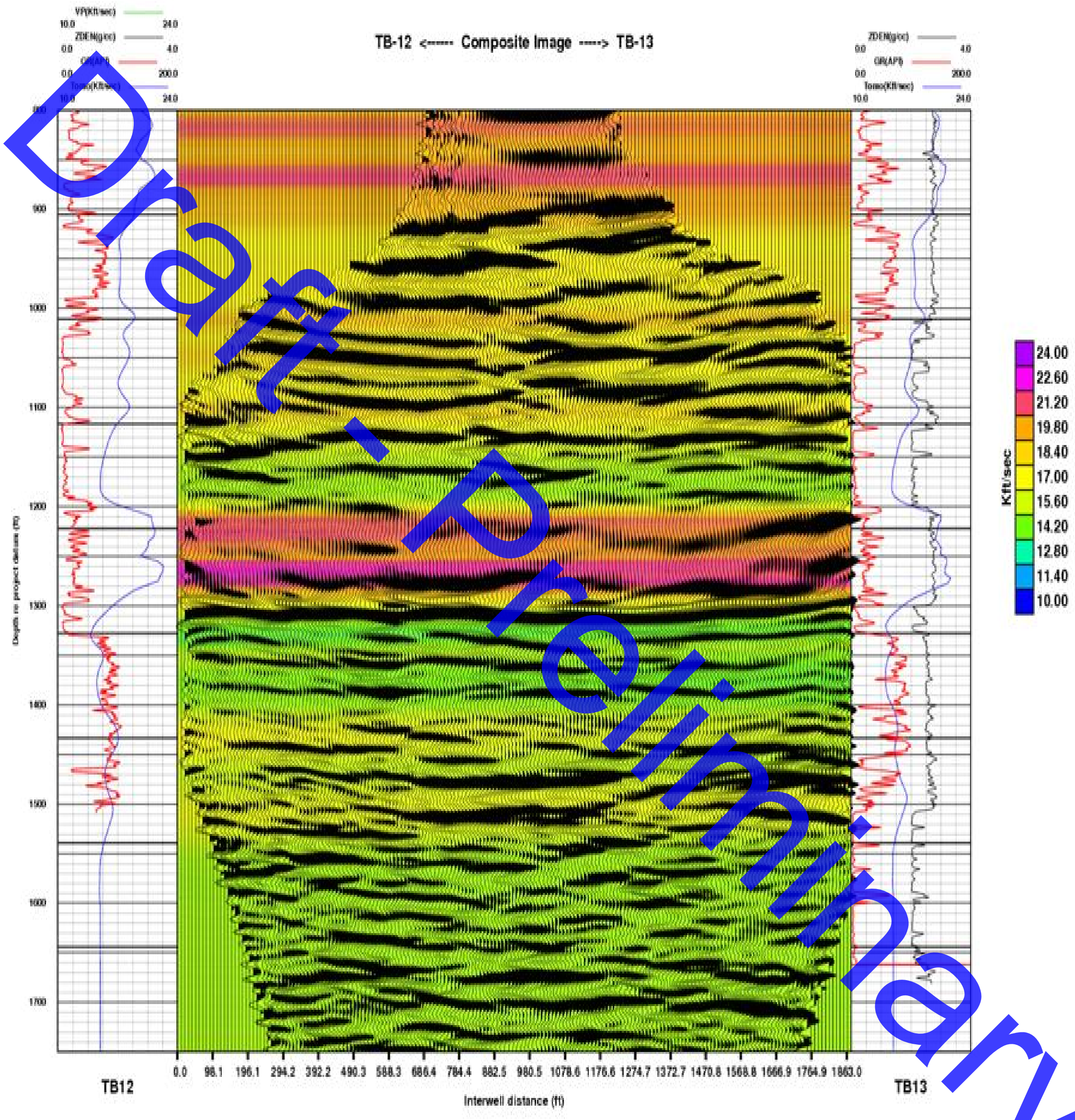
In this image we see the top of the B-Salt fairly clear with the A2 visible at the very bottom of the image. However the extremely high (false) velocities in the E-Dolomite and in the G-Shale and the Bass Island Dolomite distort the migration operation such that the topography on the B-Salt (and other interfaces) is not correct. This image will be reprocessed.

Profile TB12 to TB11



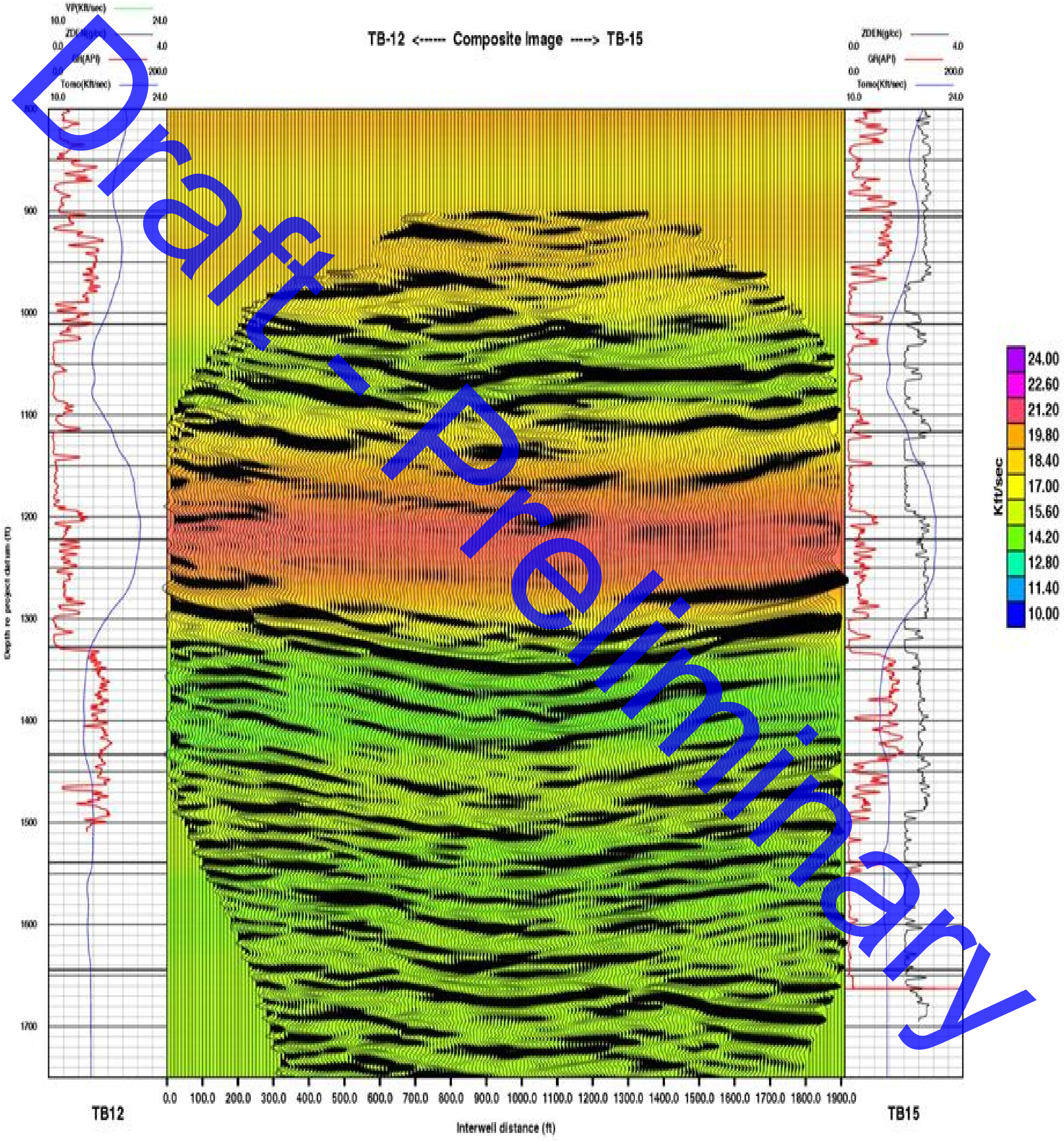
Despite the electrical noise this image shows a solid, continuous, upper C-Shale/D-Salt/E-Dolomite bedding that has not been altered. Although the top of the B-Salt is not clear, it is obvious that the upper C-Shale has not been broken. The “smile” features are data processing artifacts associated with the velocities used in migration.

Profile TB12 to TB13



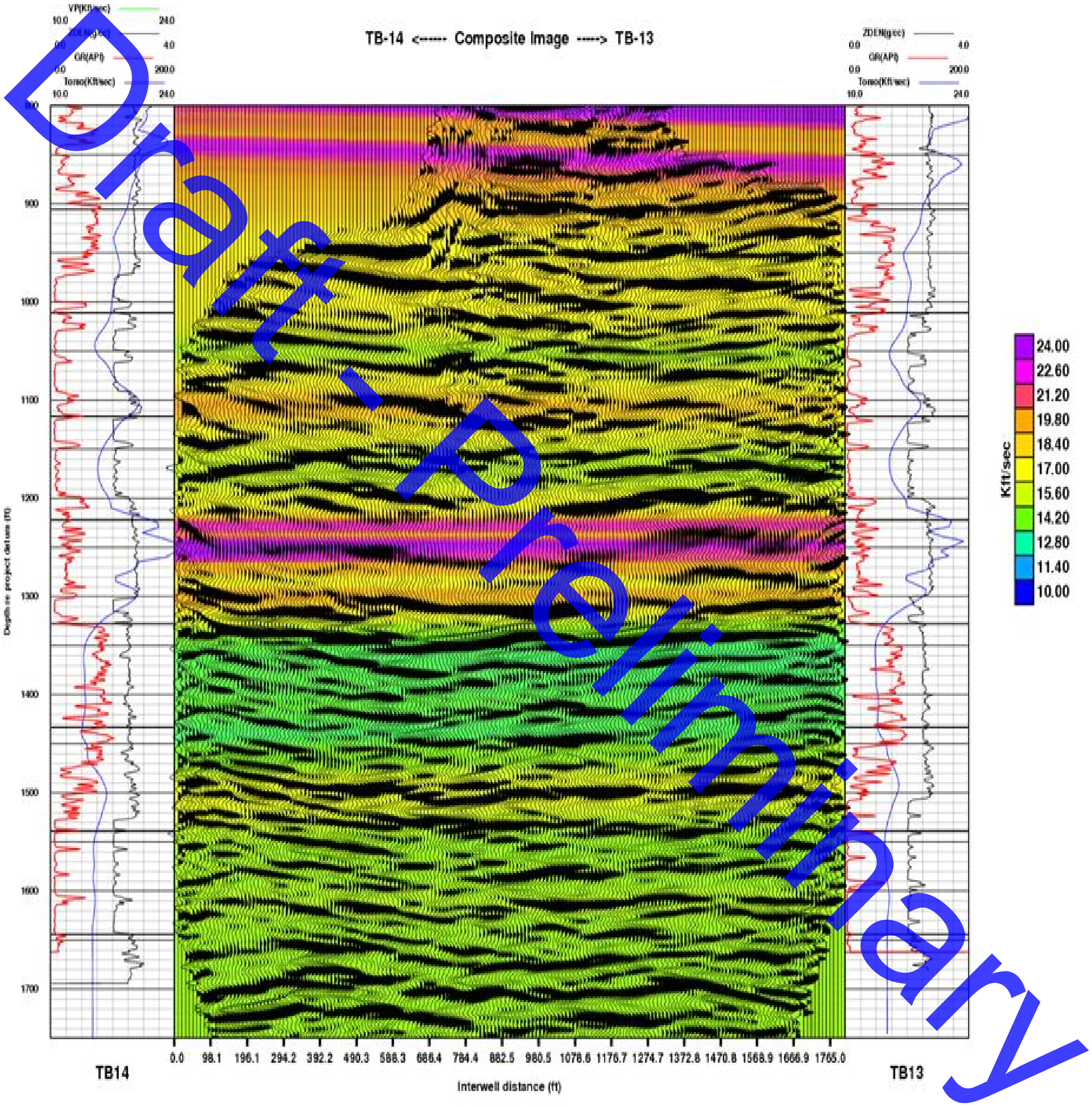
In this survey the D-Salt/E-Dolomite interface is very strong and continuous across the entire image and the C-Shale bedding below is horizontal and unremarkable. The top of the B-Salt/C-Shale reflector complex has small break in the top of its wavelet and a low angle diagonal "branch" that connects this feature with the basal side of the wavelet. In the F-Salt there is a trail of connected, tiny features that are stopped at the top of the F-Salt

Profile TB12 to TB15



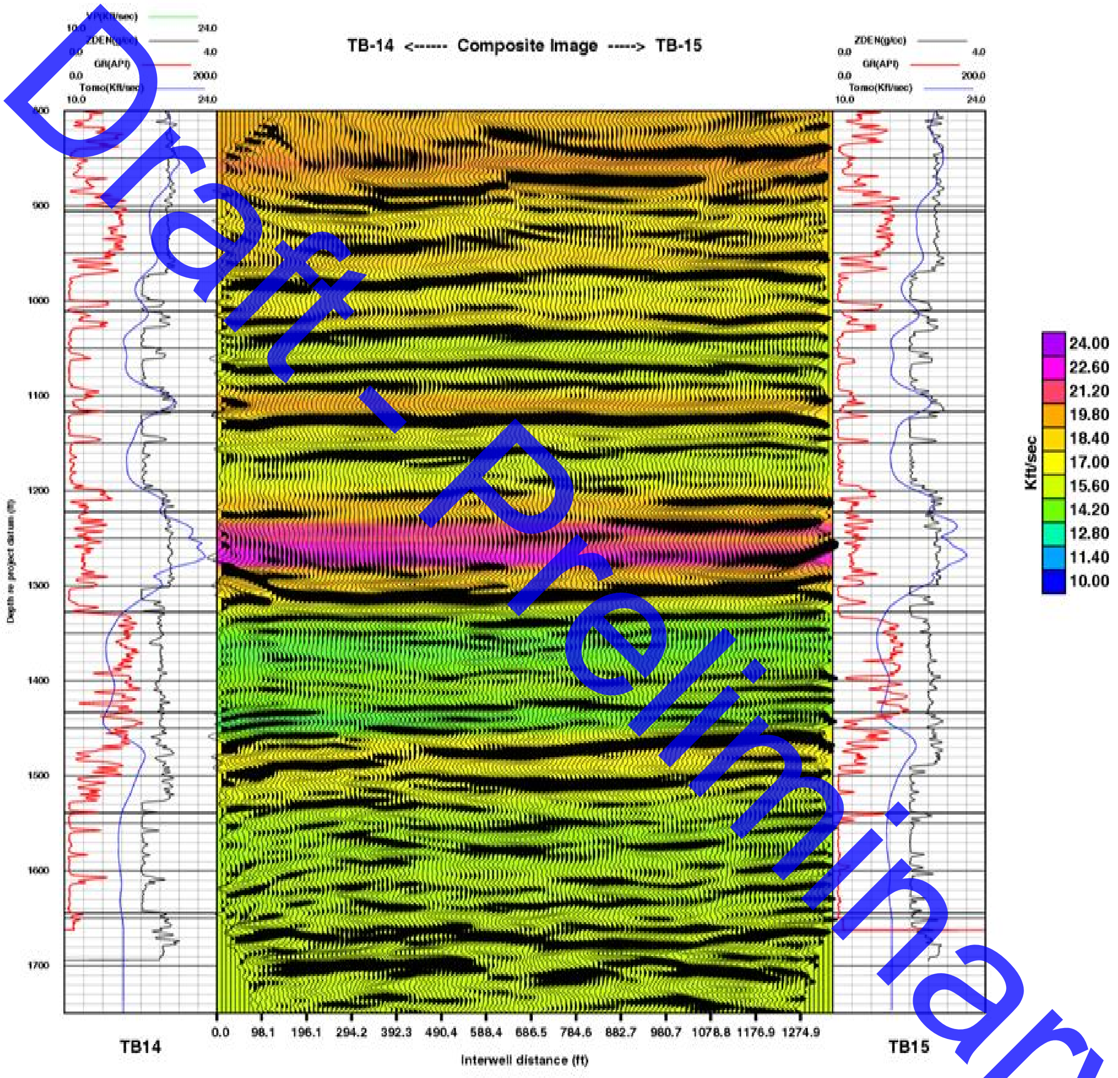
In this survey we see, despite the smile features related to migration, that the D-Salt/E-Dolomite interface continuous across the image. The smile artifact effects the F-Salt interpretation but outside of the smile the stringers in the F-Salt are strong and continuous suggesting that they will probably be continuous across the image when the migration artifacts are corrected in reprocessing.

Profile TB13 to TB14



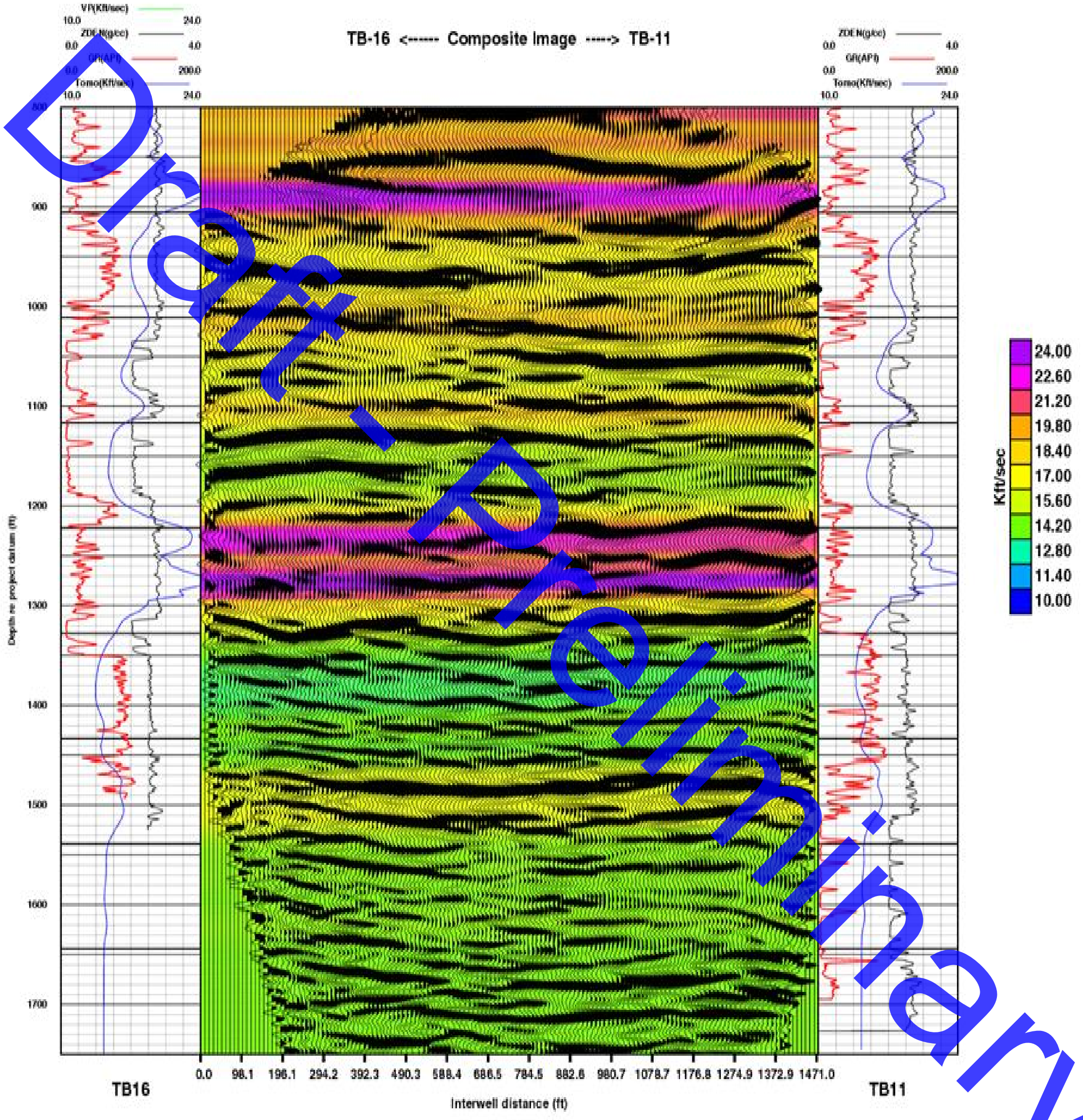
In this image we see a nearly horizontal and continuous reflector at the top of the B-Salt. The C-Shale/D-Salt shows two features that look like low angle “thrust faults” that are probably depositional features. The “mustache” artifact is not real, it is related to the smile feature directly above it, which is, in turn, probably related to the high velocity streak through the E-Dolomite which was used in migration. Vertical banding is seen in the F-Salt which is a plotting artifact

Profile TB14 to TB15



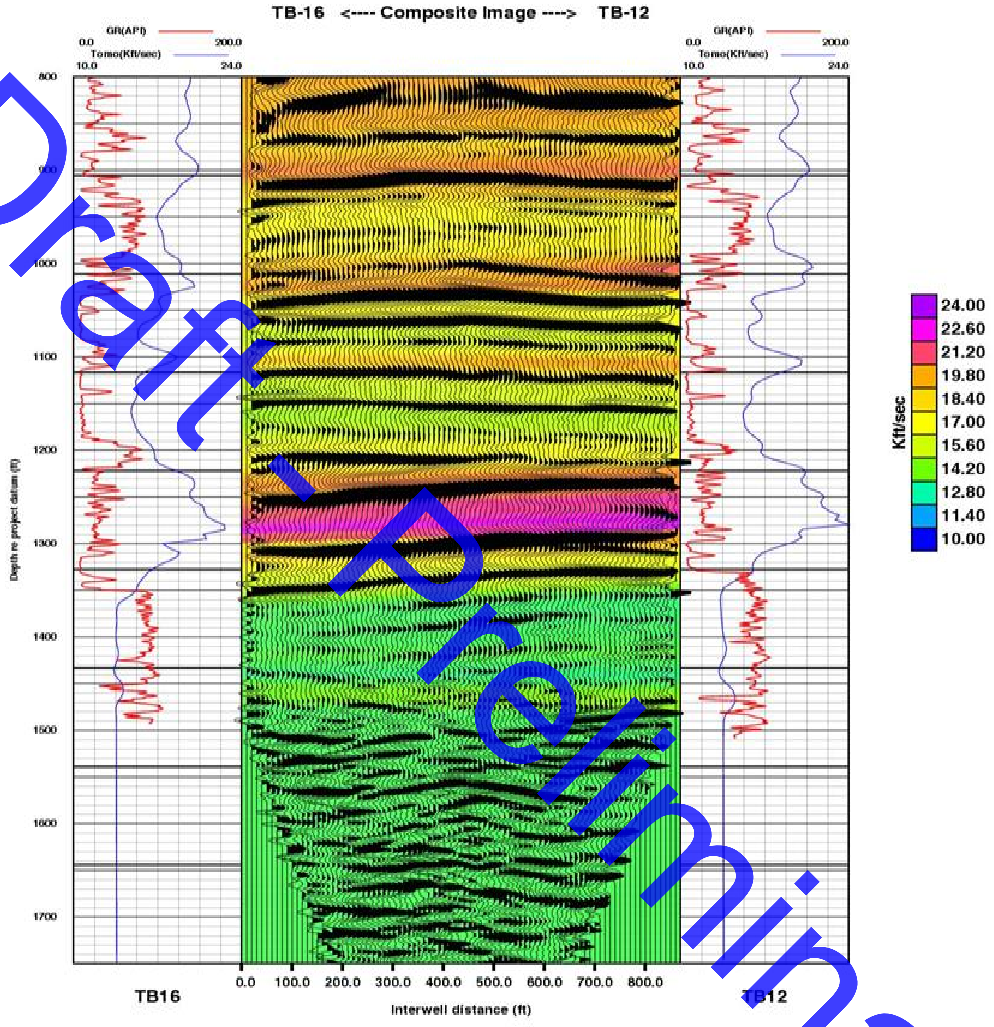
The massive B-Salt/C-Shale reflector is broken by a fault that has very little throw (10ft. -15ft.) and very little extent (approx. 50 ft.). This is a geological feature and not a solution mining Bedding in the C-Shale is essentially horizontal and the D-Salt/E-Dolomite reflector is solid and continuous. The stringers in the F-Salt are all clear, solid and continuous across the entire image. The small "bump" in the top of the F-Salt is probably not real given the "wide angle" artifacts seen above it.

Profile TB16 to TB11



In this image the tops of all of the salt layers are seen, they are continuous, and the bedding beneath the tops is on average, continuous. This means that no vertical disruption, such as a cavity has occurred. Even though one might find a small offset in one interface the one directly above it is solid and continuous. The image will be improved in the reprocessing step which will address the apparent high velocities in the E-Dolomite and G-Shale.

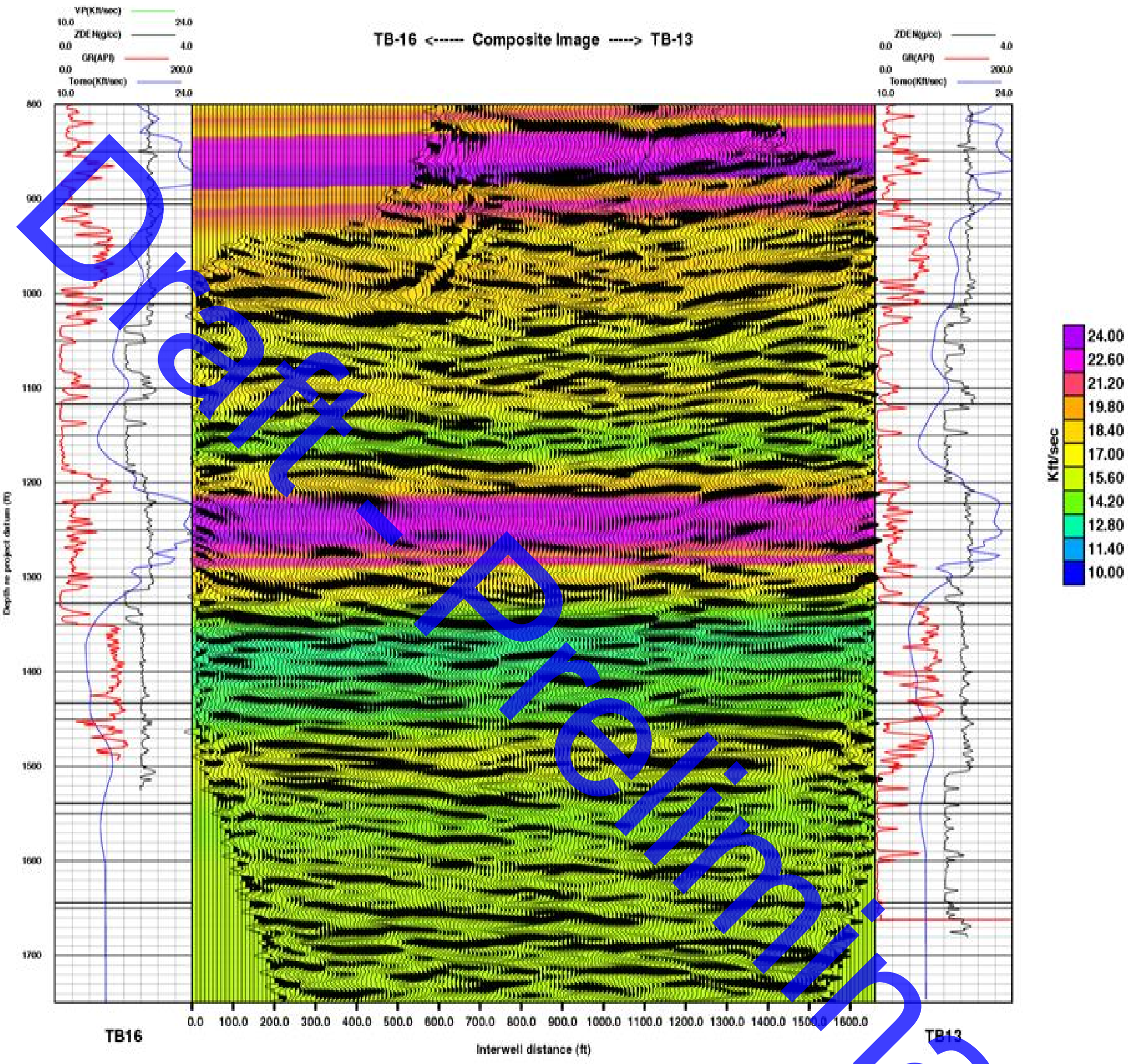
Profile TB16 to TB12



Here we see a clean set of F-Salt layers and associated stringers lying unconformably on the E-Dolomite, which is, in turn, lying unconformably on the D-Salt. The gamma ray log in each borehole shows the two salt formations. In addition the gamma ray logs show strong responses to the C-Shale and the G-Shale. The E-Dolomite displays exceptionally strong upper and lower interfaces

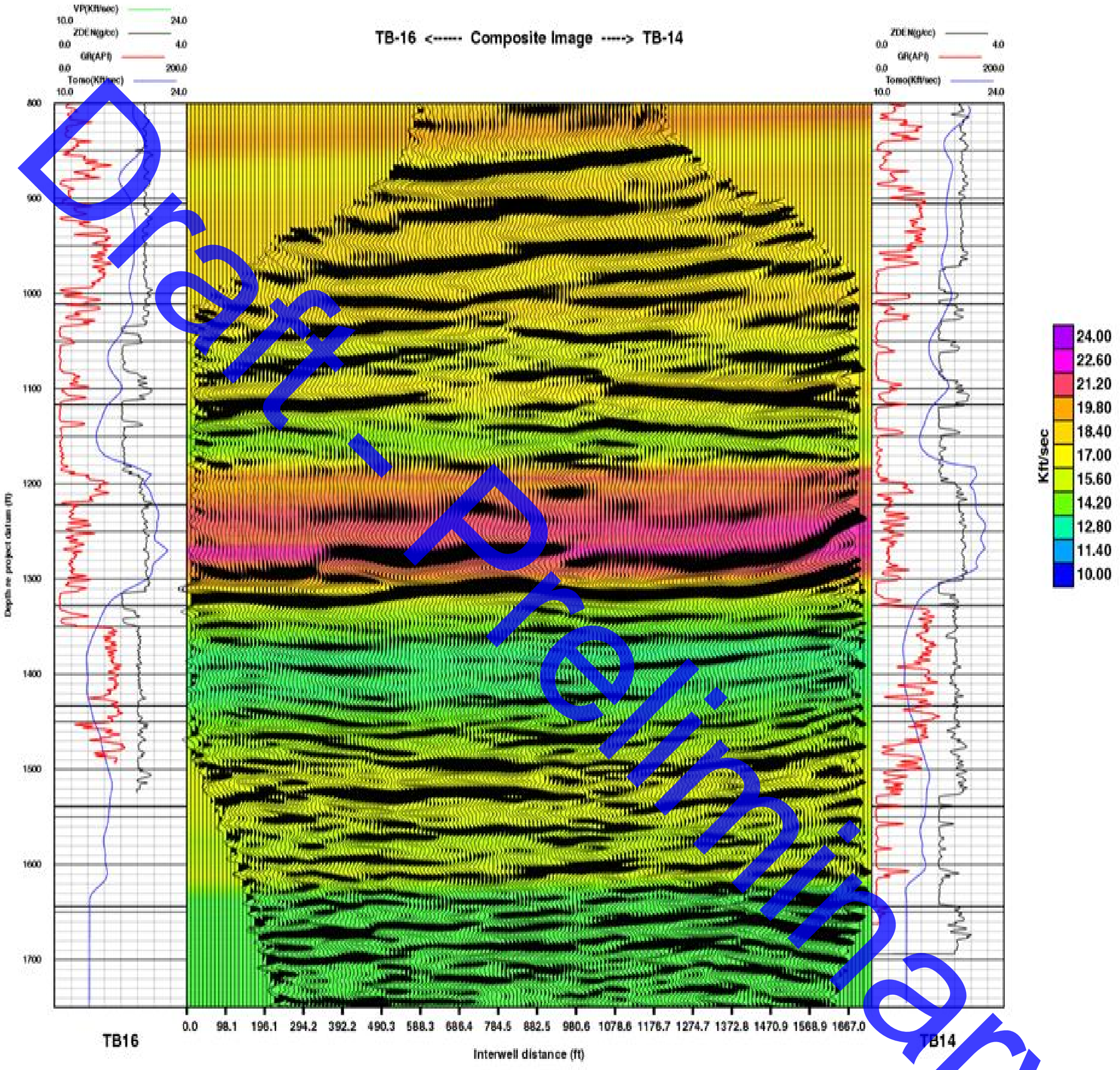
This image is being reprocessed at this time with special emphasis on the zone below 1,500ft.

Profile TB16 to TB13



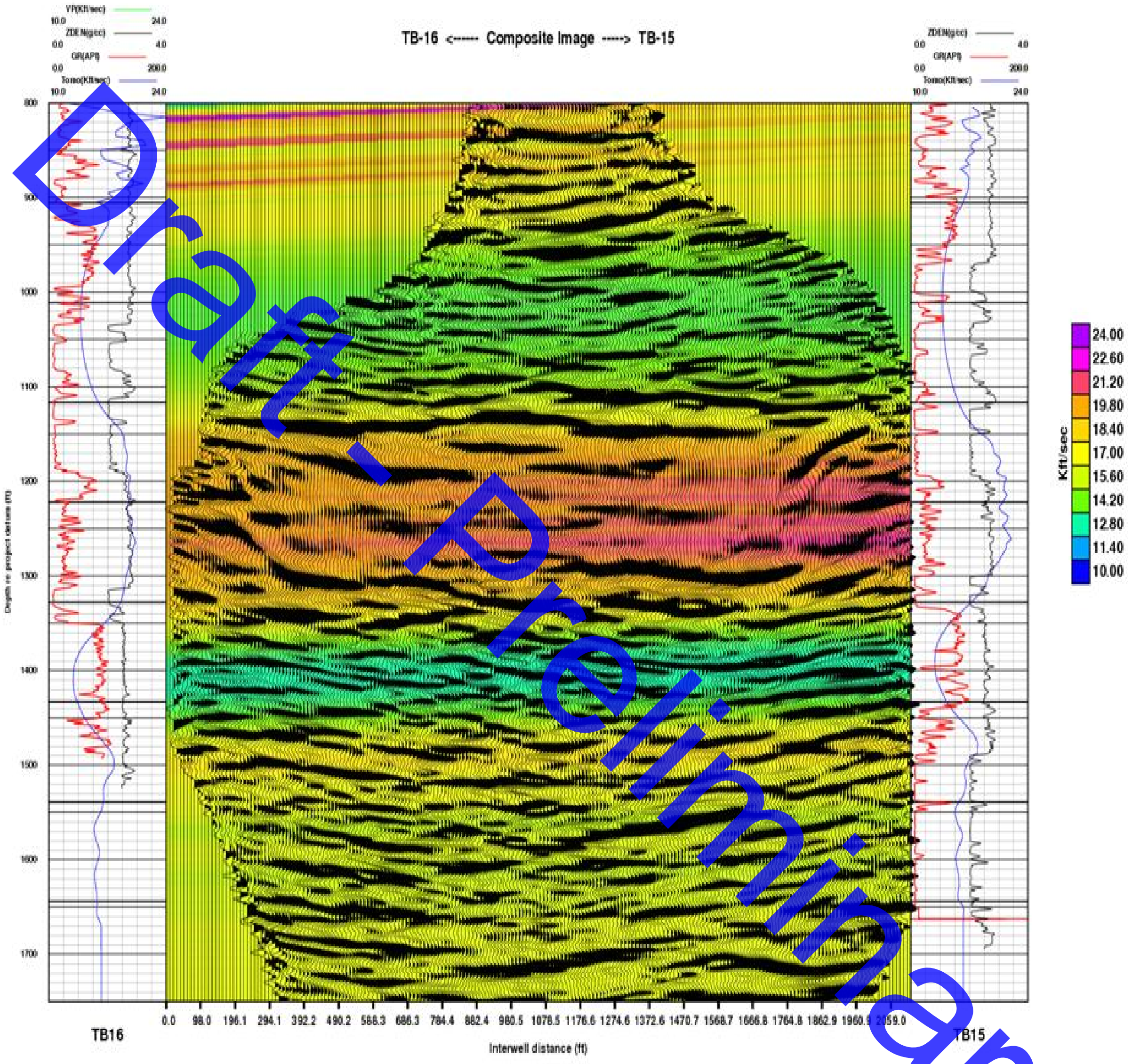
This image displays the horizontal, continuous nature of the structure from A2 Carbonate up through the F-Salt. Although any given interface may show a gap the layers above that point are solid and continuous. Remember the scale of these images, the typical distance between layers in this image is approximately 15ft. to 20ft. Thus, any upward "travel" is stopped within 15ft. or 20ft. The shear wave artifact in the G-Shale will be removed in the next reprocessing step.

Profile TB16 to TB14



The D-Salt/E-Dolomite interface is solid and continuous across the entire image. Moreover, the C-Shale below shows no intrusion from the B-Salt below. The F-Salt does show an offset but the G-Shale above it very massive and continuous.

Profile TB16 to TB15



An indication of the dipping B-Salt dipping from TB15 down to TB16 is seen in the lower portion of this image, which complements the interpretation of a dipping B-Salt from TB13 to TB10. The shear wave artifacts at the base of the F-Salt will be removed in the reprocessing sequence. Even with the artifacts in place one can see that no feature moves vertically through all of the F-Salt layers. A wide feature (approx. 400ft.) of very little vertical extent (approx 10ft. to 15 ft.) exists at a depth of approx. 1,130 ft. at a distance of approximately 980ft from TB10. It must be reexamined after the shear wave artifacts are processed.

Three Dimensional Visualization of Cross-well Seismic Images

In the above figures we have seen that the details of each individual profile can be seen adequately by examining a single reflection image superimposed on the tomographic velocity information with the borehole logs along each side. This however yields no information on the 3-D nature of the geology. In the following figures we explore, using this preliminary draft report, various ways of providing 3-D information on a two-dimensional piece of paper.

Using a seismic interpretation software package (GeoGraphix) we can display “fence diagrams” of any and all of the profiles in the two project areas. Figure 2 shows such a display. We see quickly that this project is blessed with “too much” data, the myriad of profiles defeats the purpose of the “fence diagram” method. (Computer display of this data volume is much better because one can zoom and rotate in three dimensions to focus on an area of interest.) These fence diagrams do not aid the interpretation of flat horizons very much but they are invaluable when viewing dipping formations. In this project the interpretation of the G-Shale overlying the fifth layer of the F-Salt will be greatly aided as will the sloping interface of the B-Salt in the neighborhood of TB10, TB12, and TB16.

Next we take selected profiles, two or three, out of the complete set and display them in black and red. This is far more successful however, it has the limitation that the formation names and logs can not, currently, be displayed simultaneously. To alleviate this problem we next go to the black and white (or black and clear) “wiggle trace display” of the same two or three profiles. This is an excellent display.

Obviously, one could display a many combinations of twenty eight surveys taken two or three at a time. In this preliminary draft report we have chosen three such pairs of surveys as examples of types of graphic display possible. Additionally, we have chosen excellent surveys that are not in the current processing queue for a second iteration of processing.

Profiles TB7 to TB5 to TB4
First, we display these two profiles (Figure 3) in their correct 3-D orientation with that orientation shown in red in the little map between the surveys.

The second, black and white (black and clear), wiggle trace, Figure 4, is a flat layout of the same two profiles. Here the formation names (tops) and selected logs (e.g. gamma ray, density) are given. The prefix Salina is used prior to the names of the B, C, D, E, F, and G formations. The boreholes are shown in yellow. Furthermore, at the top, we indicate where other profiles in the entire data volume, intersect these images.

Profiles TB4 to TB2 to TB1
In the black and clear layout (Figure 6 note that the logs for the intersecting profile (TB7) are shown.

Profiles TB5 to TB6 to TB4
Note, in all of the profiles, how well the separate profiles fit (tie) at each borehole.

Profiles TB6 to TB4 to TB2 to TB1
Three profiles are displayed in Figure 8

Summary

All of the cross-well seismic reflection data has been acquired. All of the profiles have been processed once in coordination with the seismic interpreter. Some profiles, especially in the X-11 area have been returned to the processing queue for a second iteration of processing.

The excellent images that have passed the first processing iteration are being interpreted at this time.

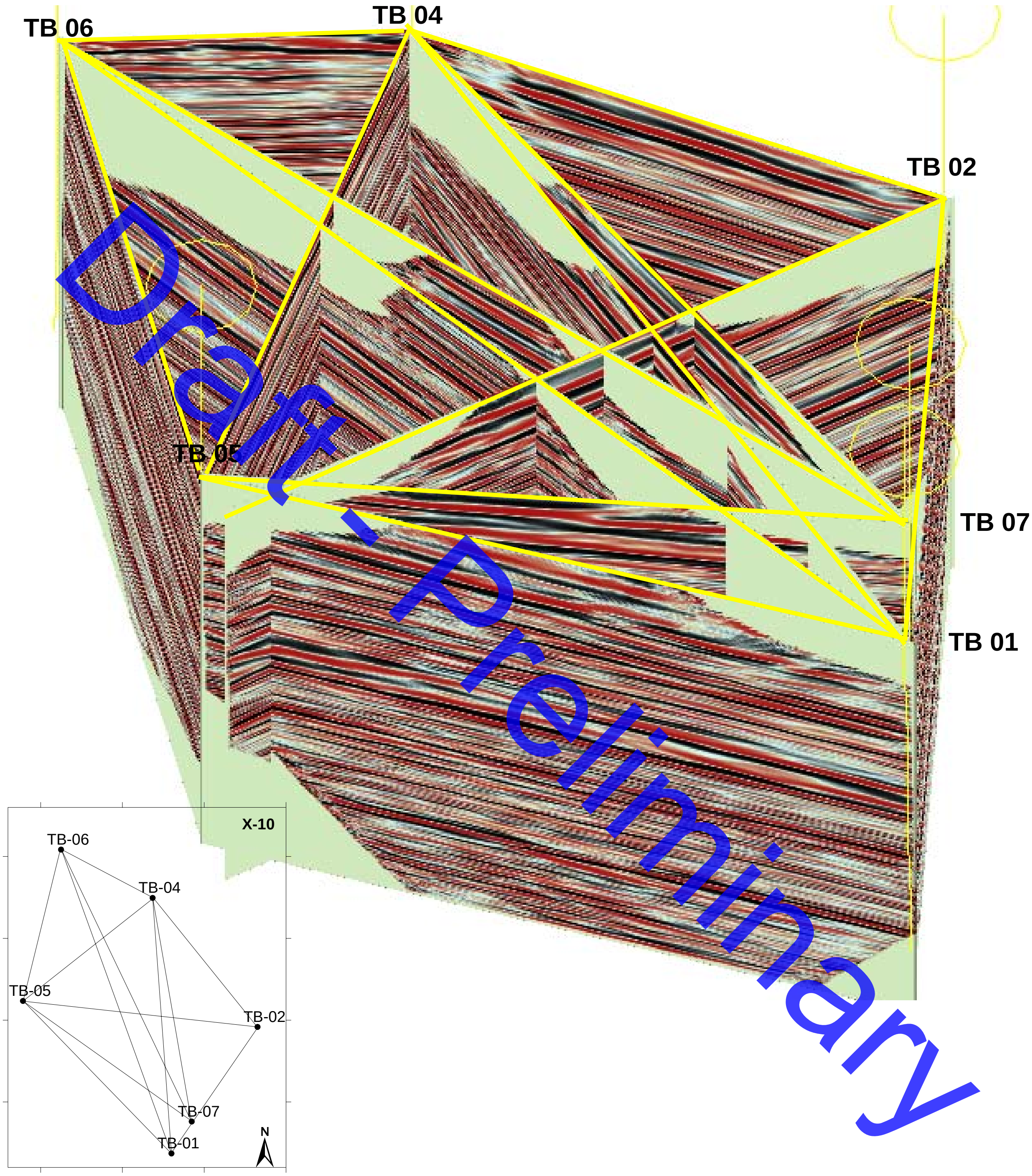


Figure 2. 3D View of all cross-well reflection profiles in X10.

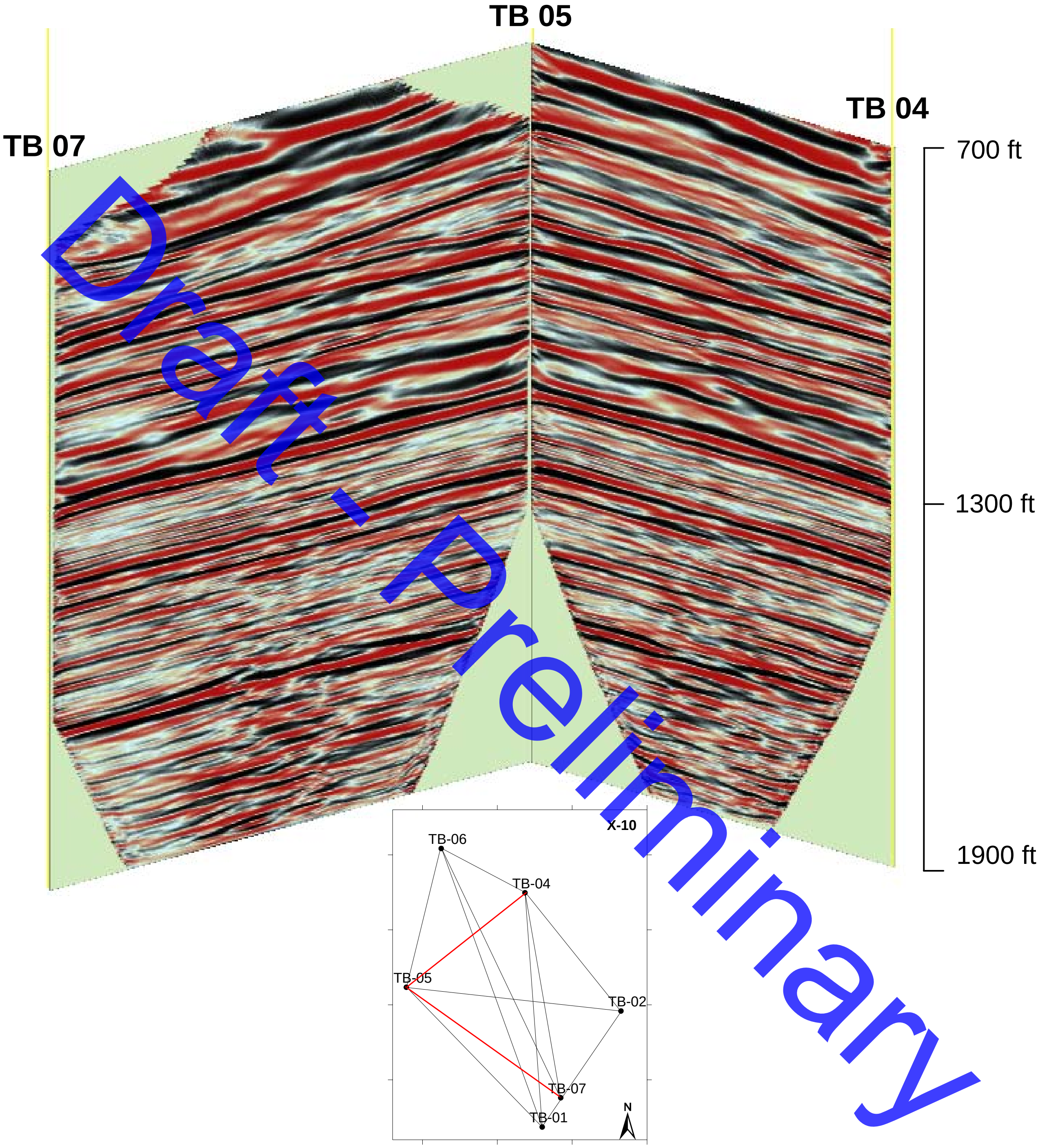


Figure 3. 3D View of Profiles TB07 to TB05 to TB04

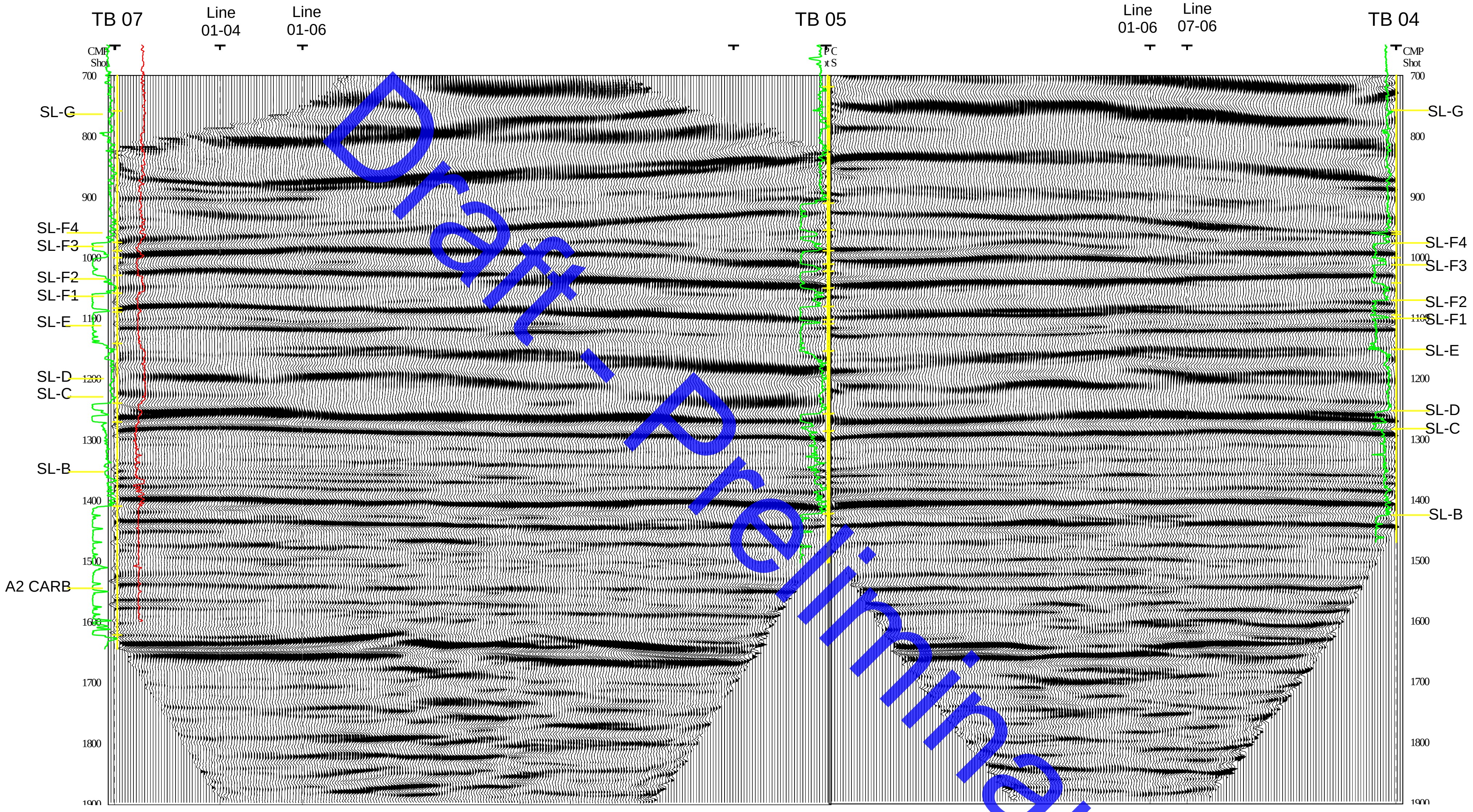


Figure 4. Traces in flat layout of profiles TB07 to TB05 to TB04.

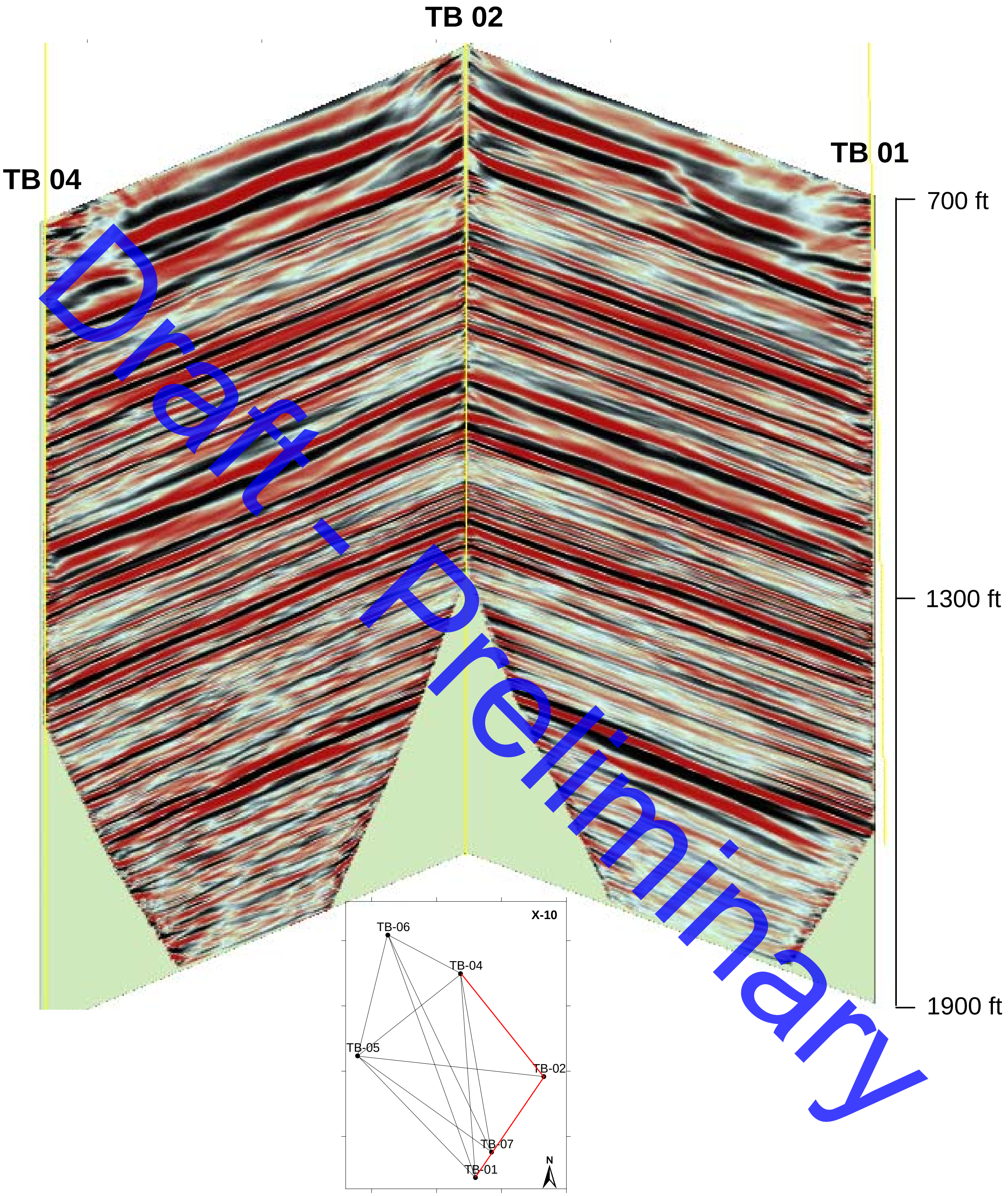


Figure 5. 3D View of Profiles TB04 to TB02 to TB01.

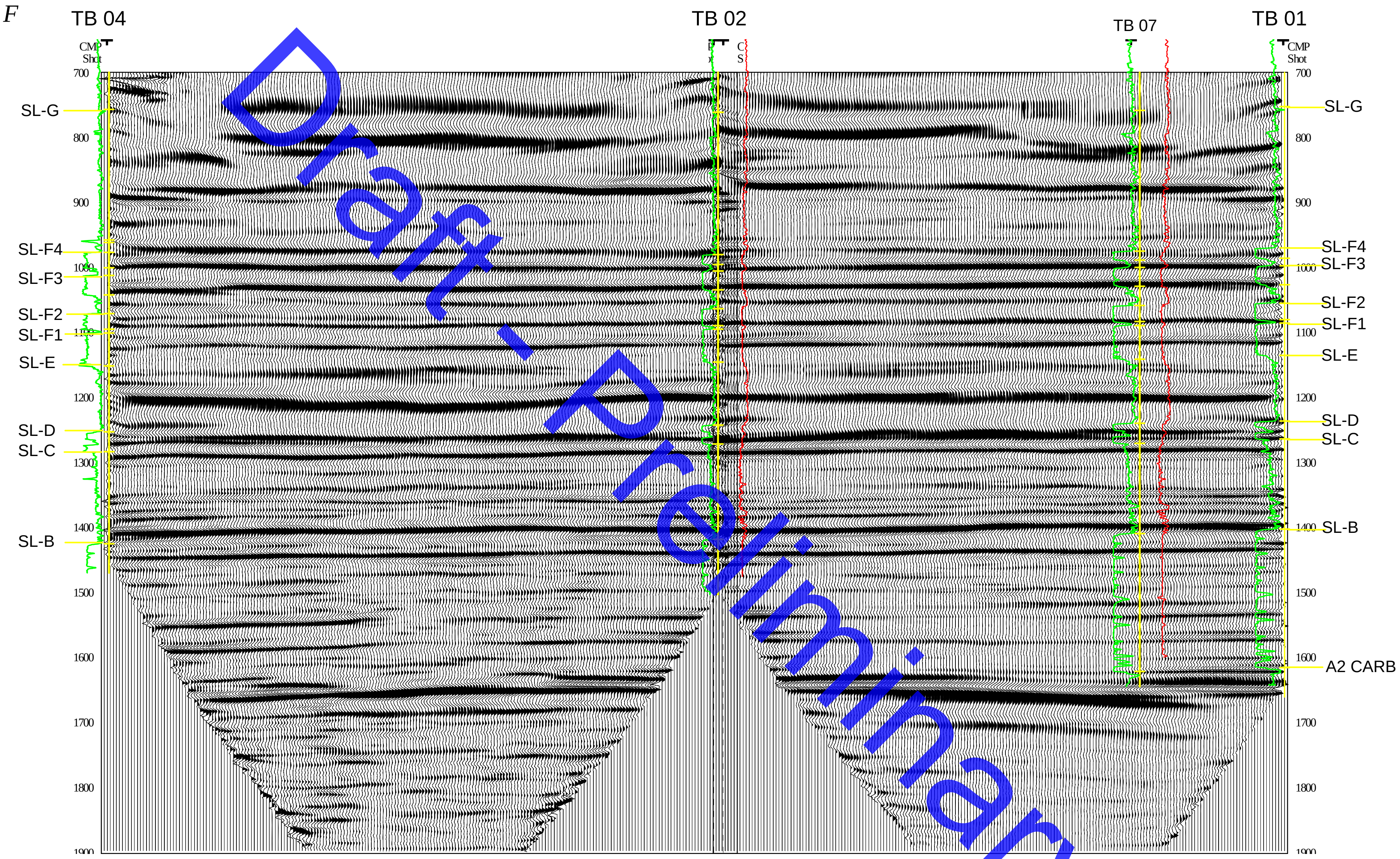


Figure 6   Traces in flat layout of profiles TB4 to TB2 to TB1

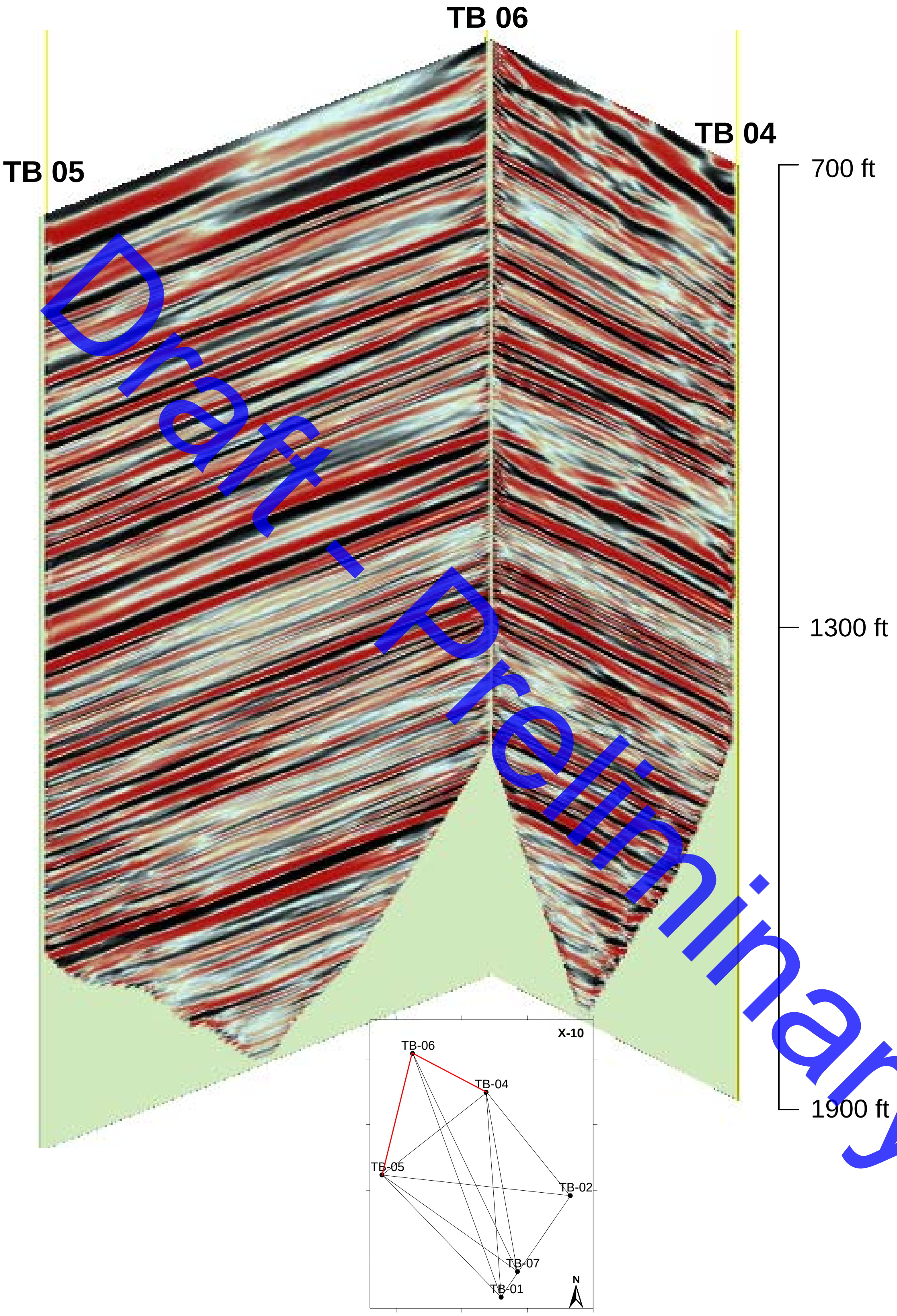


Figure 7. 3D View of Lines TB05 to TB06 to TB04.

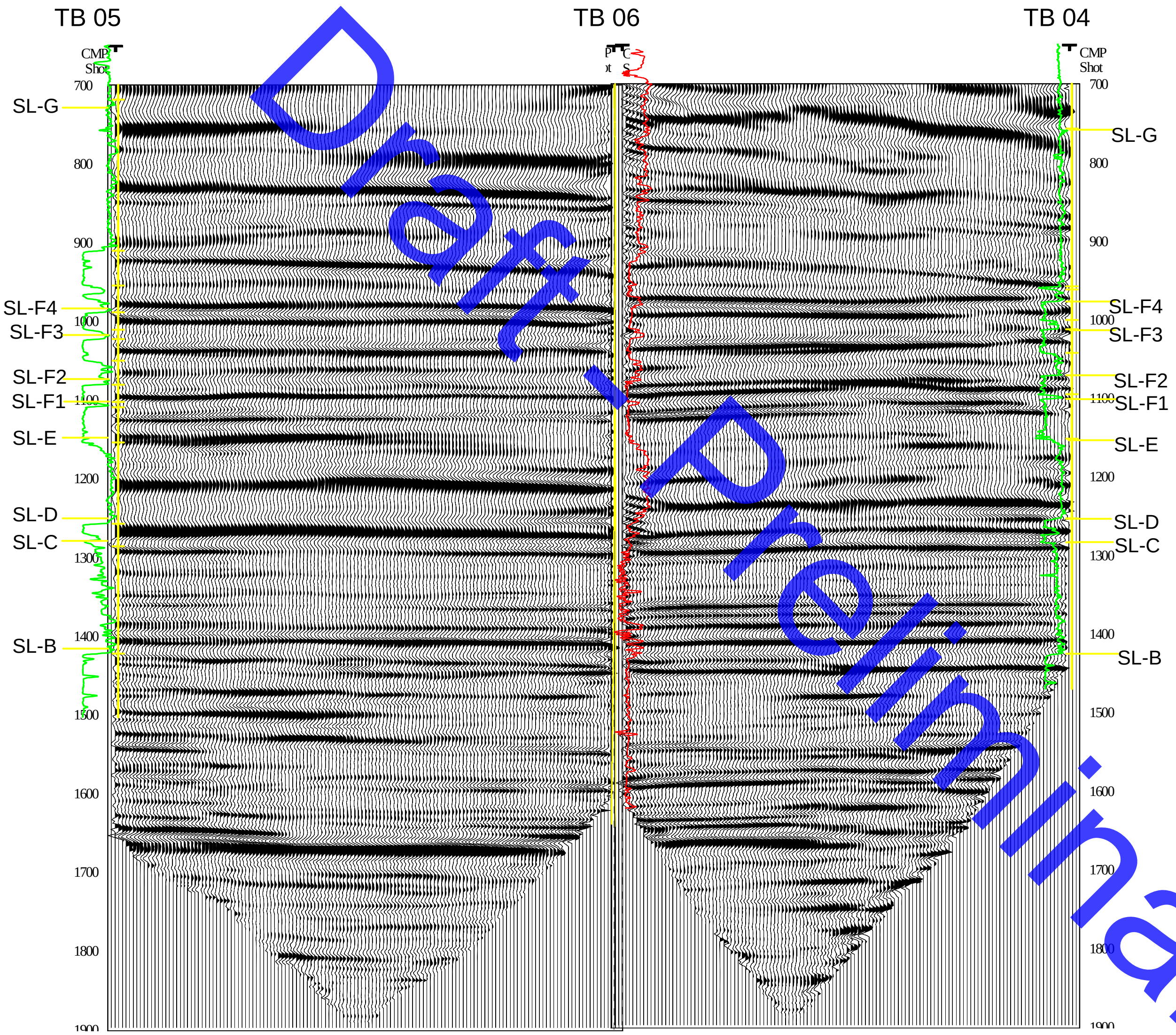


Figure 7. Traces in flat layout of Profiles TB05 to TB06 to TB04.

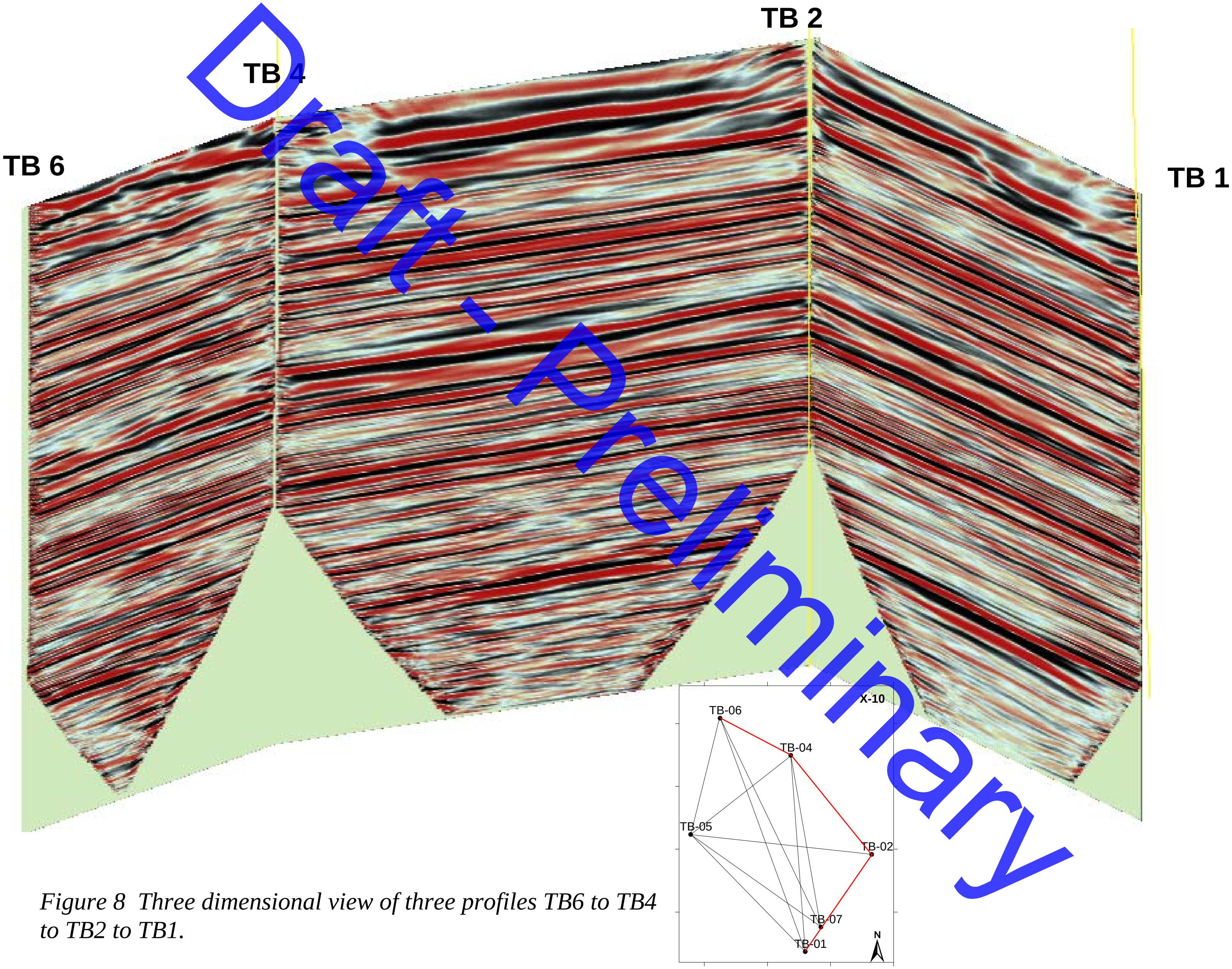


Figure 8 Three dimensional view of three profiles TB6 to TB4 to TB2 to TB1.

Appendix H

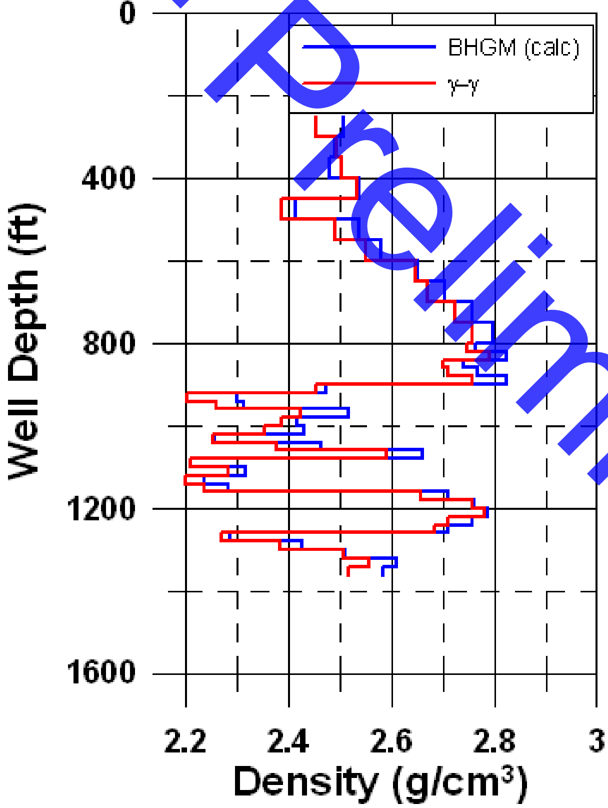
Detroit River International Crossing Study
Preliminary Draft Report
Detroit River International Crossing
Borehole Gravimeter Surveys

by Jimmy F. Diehl,
Michigan Technological University
Dated November 7, 2007

Preliminary Draft Report
Detroit River International Crossing

Borehole Gravimeter Surveys

Dr. Jimmy F. Diehl



Michigan Technological University

November 7, 2007

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Introduction

Microg-LaCoste was contracted by NTH Consultants to conduct borehole gravity meter (BHGM) surveys in X10 and X11 areas of the proposed new Detroit River International Crossing. These surveys were to compliment the crosswell seismic reflection surveys being conducted by Z-Seis, also contracted to NTH. The objective was to determine whether cavities associated with turn-of-the century solution mining of the inter-layered salts of the Silurian Salina Group exist under the X10 and X11 areas and if so their size and number. Solution cavities have a sufficient density contrast with the surrounding salts and anhydrite making them an ideal target for detection using the borehole gravity meter technique. In addition, since gravity and seismic reflection are responding to different physical parameters associated with a cavity, the two methods serve to confirm or negate the findings of one another.

Borehole Gravity Measurements

BHGM surveys can be used to determine subsurface densities over discreet vertical intervals down (up) a drill hole. BHGM is a density logging tool and is the only method that allows direct measurement of density potentially tens to hundreds of feet from the borehole (McCulloh, 1966). BHGM samples a larger volume of rock and is generally not influenced by near-borehole conditions (borehole irregularities, fluid invasion, and drilling mud) thereby giving a density that is more representative of the formation whereas densities determined from standard density logs (Baker Atlas Compensated Z-Densilogs, or gamma-gamma (γ - γ) logs) represent the near-borehole density and are generally more influenced by near-borehole conditions (Beyer, 1983). Gamma-gamma logs are not to be confused with natural gamma logs, which measures natural formation radioactivity. The difference in densities determined by BHGM method and those determined from the gamma-gamma log can be used to infer nearby 3-D structures (solution cavities in the Salina salts) since each method senses a different distance out from the borehole. A practical rule of thumb in BHGM is that 90% of the signal a gravimeter measures is derived from within 5 times the vertical separation between measurements (McColloch, 1966). This assumes that the lithologic units are horizontal and homogeneous; local geology, and in particular the thickness of local density units, also influence the effective radius of investigation of the BHGM. Therefore, large remote bodies with sufficient density contrast should be detected by BHGM to a distance at least equal to or greater than 5x the vertical separation of the measurement interval. And lastly, the precision of the gravity measurement and the uncertainty in the vertical separation between units also determines how easily a density anomaly is recognized. Figure 1 is a schematic of how a solution cavity underlying the proposed DRIC location(s) might appear on a BHGM density log and density difference log. The important point to make here is that the difference between the apparent densities determined by the BHGM measurements which are sensing the solution cavity and the densities determined by gamma-gamma log which are not (gamma-gamma densities are determine by the back scattering of electrons which penetrate no further than about four inches into the formation) gives rise to a negative density or negative apparent density centered at the depth of the solution cavity.

The underlying assumption in computing density from BHGM measurements is that of an earth model made up of a layer cake of horizontal infinite slabs. For such a model, the density of any slab is exactly given by the gravity gradient through that slab; the gradient measured at any point within the slab is constant; and the slabs above and below it have no effect on the gradient within it. The derivation of the density of an infinite slab is shown in Figure 2. This simple assumption serves effectively in a majority of cases and especially for the X10 and X11 panels. Deviation from this assumption arises when 3-D structure is present, but this is easily recognized by plotting density differences (if one has a gamma-gamma density log). Because of the possibility of nearby 3-D structure, the density determined by the BHGM method is generally referred to as an *apparent density* (LaFehr, 1983).

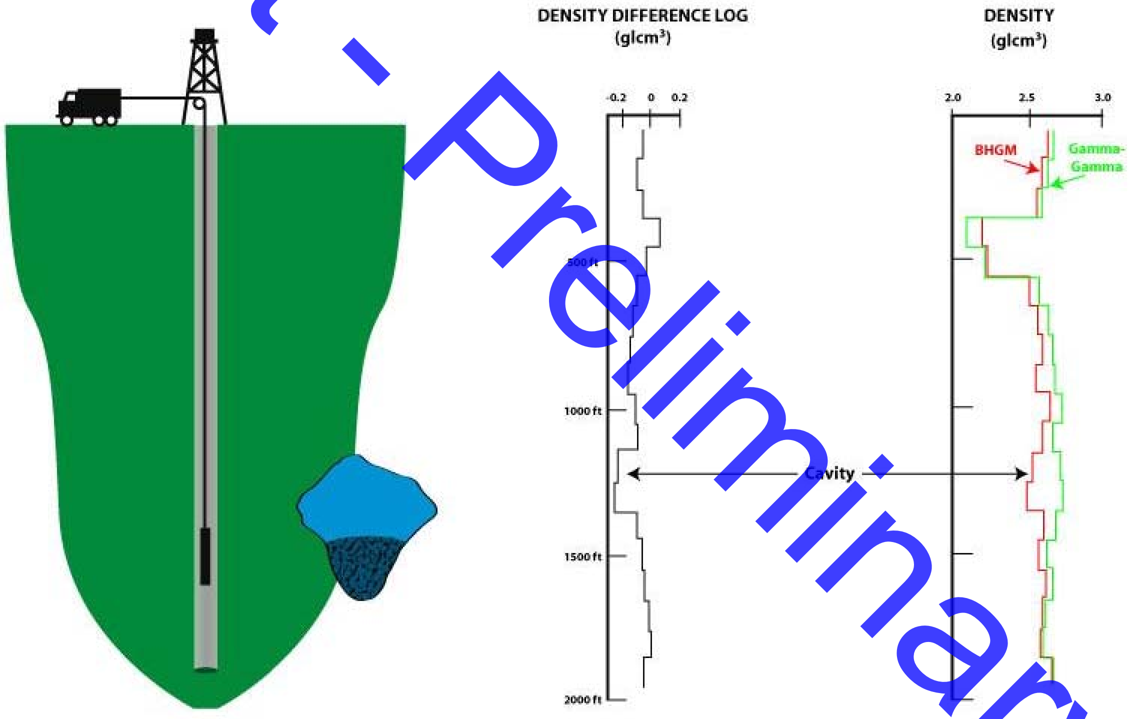
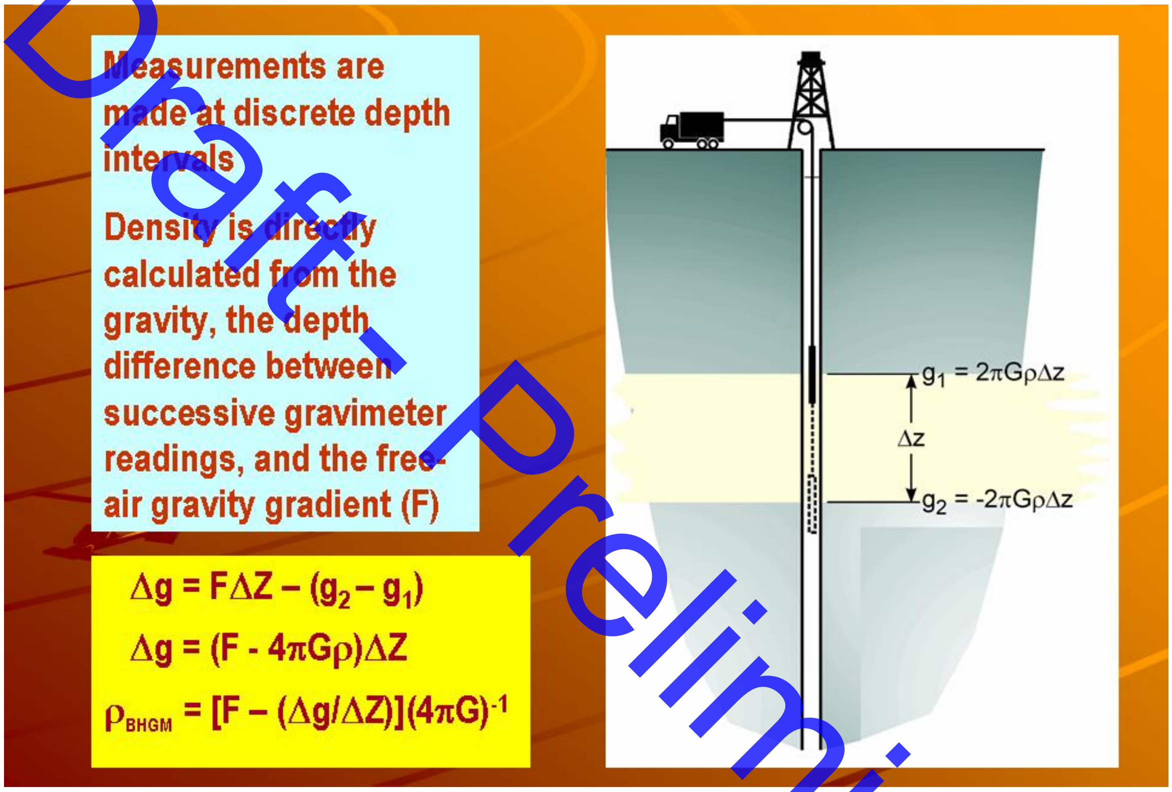


Figure 1. Typical BHGM data from a cavity underlying the propose DRIC site. Note that the BHGM density log shows lower densities than the Gamma-Gamma density. The density difference log (BHGM density log – Gamma-Gamma density log) clearly shows the presence of a cavity (negative difference).

The formula for *apparent density* as shown in Figure 2 is given by the following formula (there are small corrections for latitude and elevation but are not significant for this study):

$$\rho_a = 3.6824 - .03913\ \Delta g/\Delta z \qquad \text{(Equation 1)}$$

where ρ_a is in g/cm^3, Δz is in feet, and Δg is in microgals. The constant density term compensates for Earth's normal vertical gravity gradient.



Measurements are made at discrete depth intervals

Density is directly calculated from the gravity, the depth difference between successive gravimeter readings, and the free-air gravity gradient (F)

$$\Delta g = F\Delta Z - (g_2 - g_1)$$

$$\Delta g = (F - 4\pi G\rho)\Delta Z$$

$$\rho_{BHGM} = [F - (\Delta g/\Delta Z)](4\pi G)^{-1}$$

Figure 2. The apparent density calculation assuming an infinite slab of thickness ΔZ from successive borehole gravity measurements (G is the Universal Gravitational Constant).

Apparent Density Modeling

Synthetic apparent density logs and density difference profiles were generated using the modeling software *Hole-o-grav* distributed by HarbourDom GmbH in order to provide an idea of the magnitude and shape of the apparent density difference profile we could expect from a "morning glory" shaped solution cavity and solution cavities with other geometries. *Hole-o-grav* is a very powerful 3D gravity modeling program designed specifically to model BHGM data. In a previously submitted preliminary draft report, I presented results of modeling a "morning glory" cavity in the B-salt extending upward into the Salina C unit. The second model consist of

3 touching spherical cavities to determine whether we could detect three closely spaced cavities that could link up to form a “morning glory” cavity. For these calculations, we placed three 160 ft diameter cavities entirely in the B salt. Results from the “morning glory” cavity indicated that this type of cavity is detectable but the distance between the borehole and the center of the center has to be less that the diameter of the structure and even then the apparent density uncertainties have to be less than 0.02 g/cm^3. For the 3 spherical cavities, the borehole has to be within 100-150 feet of the geometric center of any one cavity. This estimate is a downward revision from the previous report. I now present two new models of possible subsurface cavities. One of the configurations used is again of the “morning glory” shape but located in the F-salt with the roof extending into the Salina G unit (Fig. 3). The other configuration is that of a circular disk or “hockey puck” (Fig. 4). Both “morning glory” and the “hockey puck” had diameters of ~ 300 ft. The “hockey puck” located entirely in the F-salt had a thickness of ~60 ft. For both models we used a stratigraphy very similar to that of borehole TB1 from the X10 study area (Fig. 5). Figures 6 and 7 illustrate the density difference profiles that result as the ***edge*** of the cavity is moved further from the borehole.

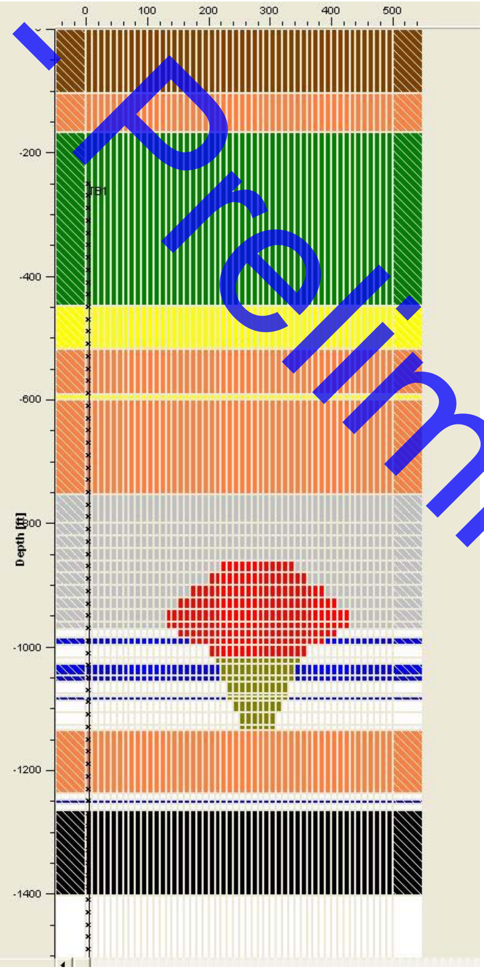


Figure 3. Configuration of “morning glory” cavity in F salt.

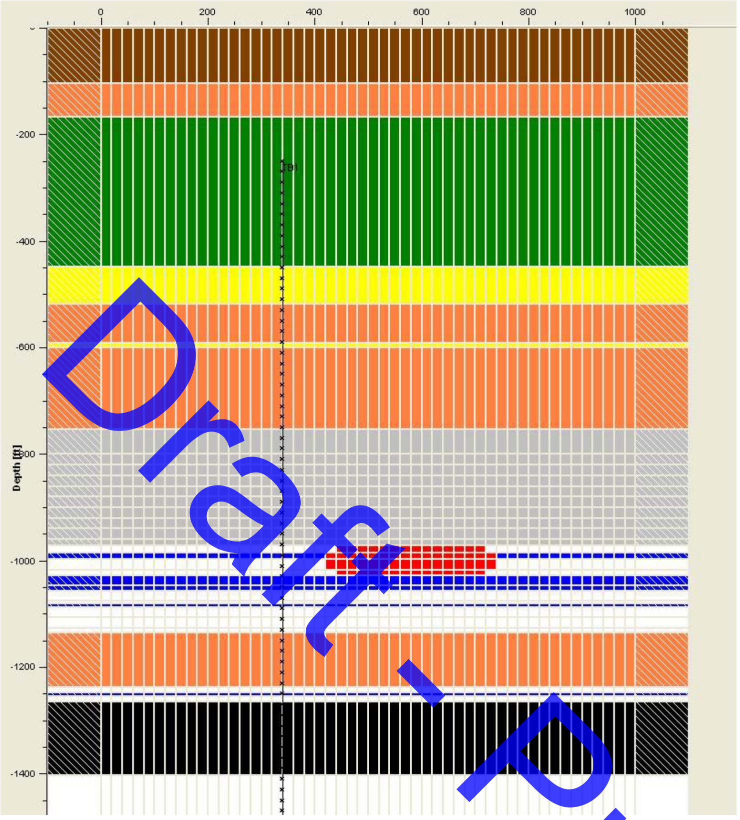
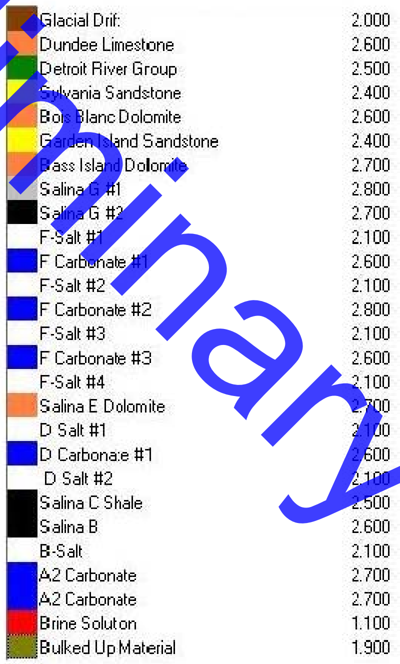


Figure 4. Geometry of a “hockey puck” solution cavity at the top of the F-salt.



🟫	Glacial Drift	2.000
🟧	Dundee Limestone	2.600
🟩	Detroit River Group	2.500
🟨	Sylvania Sandstone	2.400
🟧	Bois Blanc Dolomite	2.600
🟨	Garden Island Sandstone	2.400
🟧	Bass Island Dolomite	2.700
⬜	Salina G #1	2.800
⬛	Salina G #2	2.700
⬜	F-Salt #1	2.100
🟦	F Carbonate #1	2.600
⬜	F-Salt #2	2.100
🟦	F Carbonate #2	2.800
⬜	F-Salt #3	2.100
🟦	F Carbonate #3	2.600
⬜	F-Salt #4	2.100
🟧	Salina E Dolomite	2.700
⬜	D Salt #1	2.100
🟦	D Carbonate #1	2.600
⬜	D Salt #2	2.100
⬛	Salina C Shale	2.500
⬛	Salina B	2.600
⬜	B-Salt	2.100
🟦	A2 Carbonate	2.700
🟦	A2 Carbonate	2.700
🟥	Brine Soluton	1.100
▨	Bulked Up Material	1.900

Figure 5. Formations and densities used in constructing Figures 3 and 4.

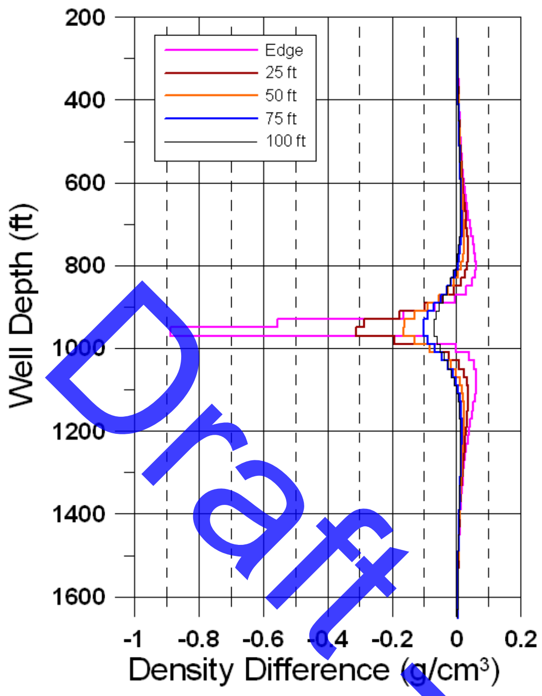


Figure 6. Density difference profile for a 300 ft "morning glory" cavity shown in Figure 3.

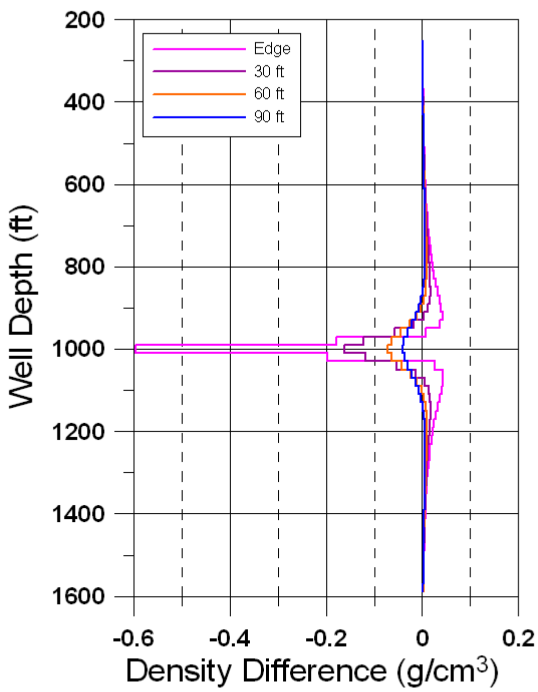


Figure 7. Density difference profile for a 300 ft "hockey puck" cavity shown in Figure 4.

Three important observations can be made from Figures 6 and 7. (1) The apparent density difference anomalies are large (> -0.6 g/cm^3) and easily recognizable when the edge of the cavity is near the borehole. (2) The larger "morning glory" structure has a broader anomaly. (3) As the distance between the edge of the cavity and the borehole increases, the apparent density difference anomaly becomes less but broadens (i.e., a larger number of measurement intervals show a negative density difference). Modeling of 500 ft diameter "morning glory" and "hockey puck" type solution cavities give similar results only the apparent density difference anomalies are larger and there can be detected further from the borehole. In running the above simulations we assume no error in any of the measurements – an unrealistic assumption. If a certain amount of observational error is added in calculating these models, solution cavities close to the borehole can still be detected. However, a "morning glory" cavity whose edge is greater than or equal to a distance equal to 80% of the radius of cavity will not be detectable (60% for a "hockey puck" cavity. Therefore, the modeling results indicate a 300 ft diameter "morning glory" cavity is detectable in a low noise situation as long as the edge of the cavity is less than 120 feet from the borehole.

Data Analysis and Interpretation

Methodology

The BHGM survey data can be found in Appendices A and B and apparent density and density difference plots in Appendices C and D. Explanations of data columns also appear on the cover page for Appendices A and B. In general, from the deepest depth the gravity sonde could penetrate in the borehole (approximate TD) to a depth of 800 ft (700 ft for borehole TB16), gravity measurements were taken every 20 ft. Where the measurement interval was 20 ft, a measurement depth was re-occupied 4 four separate times giving four independent measures of observed gravity at that depth to reduce the uncertainty in our apparent density calculation for a given interval. Appendix E discusses how the uncertainty is calculated. Where the measurement interval was 50 ft, two separate re-occupations of a given interval resulted in two independent determinations of observed gravity at that depth level in the borehole. The average uncertainty in the mean observed gravity for a given borehole ranged from a low of 0.009 mgals (9 microgals) at TB16 to a high of 0.027 mgals (27 microgals) at TB7. In constructing the density (or apparent density) and difference plots shown in Appendices C and D, the gamma-gamma density log was averaged over the same intervals as the BHGM measurements and subtracted from the BHGM densities. However, gamma-gamma density logs tend to underestimate salt density (Black, 1997). Inspection of the gamma-gamma density logs supplied by Baker-Atlas for the X10 and X11 surveys areas indicate salt densities averaging around 2.05 g/cm^3. Pure salt should have a density of 2.16 g/cm^3, higher if the salt is dirty (thin stringers of shale or anhydrite). In order to determine the best density value for the F, D, and B-salts, NTH personnel determined the core density for three representative core segments from the B-salt. Their results are shown in Appendix F. Density values ranged from 2.14 g/cm^3 to 2.16 g/cm^3 to 2.19 g/cm^3. Since, two of the densities were less than or near pure salt and yet were chosen for their dirty appearance (i.e., anhydrite stringers, etc.), I surmise the 2.19 g/cm^3 approaches a more correct value for the density of the salt layers. Hinze et al. (1978) report a borehole density for the B-salt of 2.26 g/cm^3. Averaging the values determined by NTH (excluding the low density value which is likely in error) with that of Hinze et al. (1978) gives a mean of 2.20 g/cm^3. Therefore, if the density in the gamma-gamma log was less than 2.20 g/cm^3, the value was replaced with 2.20 g/cm^3 below averaging the gamma-gamma density log. In determining the apparent densities from the BHGM data (observed gravity), Microg uses a recently developed inversion method, based on work originally presented by MacQueen [1989], which allows stable calculation of interval densities over much closer station spacing than are feasible using the traditional method outlined in the introduction(i.e. using Equation 1). Figure 8 shows the density and density difference plot for borehole TB4 using the borehole densities from Table A2. The most prominent feature of the density difference curve (Fig. 8b) is a rather large swing from positive density differences to negative density differences at the 1000 ft depth in the F-salt. In fact, most of the density difference plots shown in Appendices C and D show a similar pattern of positive-negative density difference swings and most are associated with the F-salt layers or the interval between the F-salt and the overlying Salina G unit. For TB4, the Baker-Atlas caliper log indicates a considerable washout in this depth range, but not all the positive-negative density swings are associated with washouts. However, most are associated with larger uncertainties in observed gravity and all appear to be associated with very large Z-scores. A Z-score as described on the cover pages for Appendices A and B is the standardized measure of misfit from the inversion between the mean of the observed gravity values measured at a particular depth (column 2 of Appendix A and B) and the gravity calculated at that depth from the inversion, i.e. the inversion densities are not fitting the actual measurement data. The inversion technique was designed to handle small sampling intervals such as the 20 ft interval used in this study. After consulting Microg, we surmised that the inversion program was having trouble handling the blocky structure (anhydrite to salt to shale) of the stratigraphy and was giving rise to false density difference swings (noisy data). Therefore, I have recalculated the apparent densities for all boreholes using the actual observed gravity data (column 2 of data tables in Appendix A and

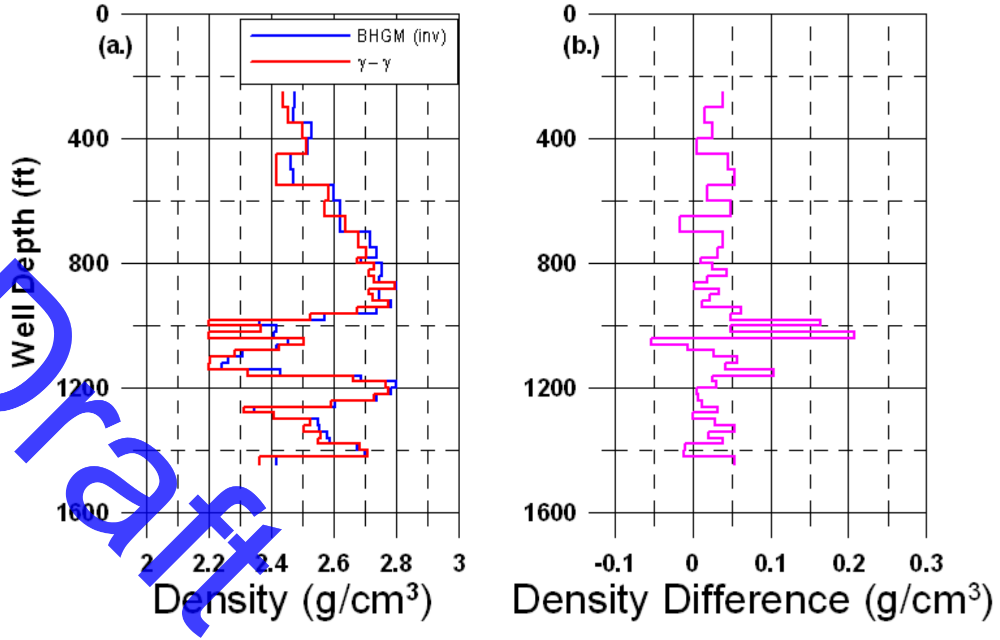


Figure 8. Density and density difference plot for borehole TB4. BHGM (inv) in (a) are the apparent densities determined using the Microg inversion process and is shown in blue while the gamma-gamma densities in (a) are shown in red. Density differences (BHGM – gamma-gamma) are shown in (b).

B) and Equation 1. These borehole densities are labeled "BHGM(calc)" and were used to create a second set of density and density difference plots shown in Appendices C and D. A quick comparison of all the density difference plots shown in Appendices C and D indicates that in almost every case the density difference plots calculated from density data using Equation 1 and the observed gravity is much less noisy except for boreholes TB7 and TB10, which are extremely noisy regardless of the method used to calculate apparent densities from the borehole data. Data from TB7 and TB10 were reprocessed by Microg, but the data could not be improved over the original. In summary, the Microg inversion technique used to get apparent densities is probably not the correct method for calculating apparent density because of the blocky nature of the stratigraphy that underlies the X10 and X11 areas (MacQueen, personal communication, 2007).

Interpretation

The BHGM, γ - γ, and density difference plots shown in this section of the report are the "(c)" and "(d)" plots shown in Appendices C and D except that the density difference plots now have a standardized scale (-0.2 g/cm^3 to 0.2 g/cm^3). Again, the BHGM densities shown in the "(a)" figures below have been calculated using Equation 1 and are not the inversion densities reported by Microg in the data tables in Appendices A and B.

X10 Survey Area

TB1: Figure 10 shows the BHGM, γ - γ, and density difference results from borehole TB1. Data quality is excellent with the average uncertainty in the means of the observed gravity at each level being 0.010 mgals. The data display an overall positive density difference except for a small negative density difference between 1420 and 1460 ft levels in the B-salt. Interestingly, this negative density difference appears to correlate with a prominent up-

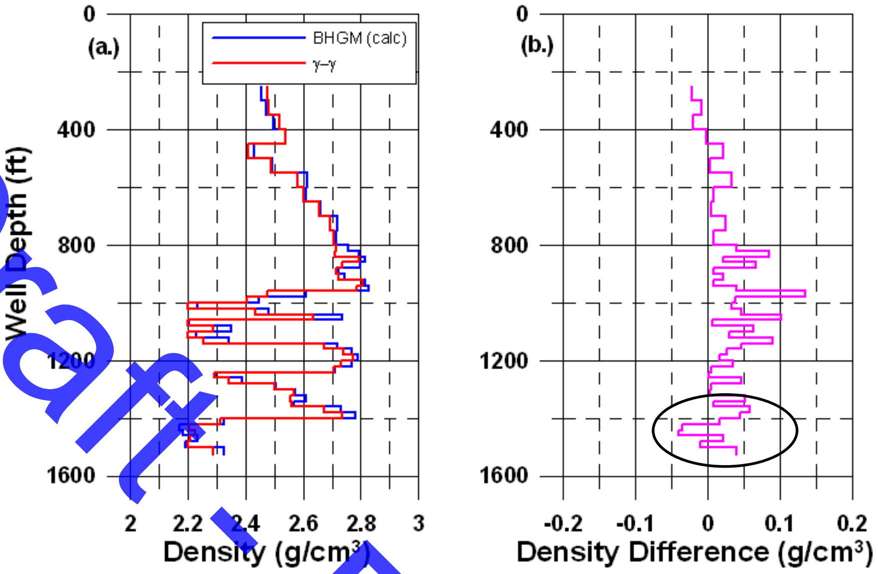


Figure 9. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB1. Oval highlights negative density difference

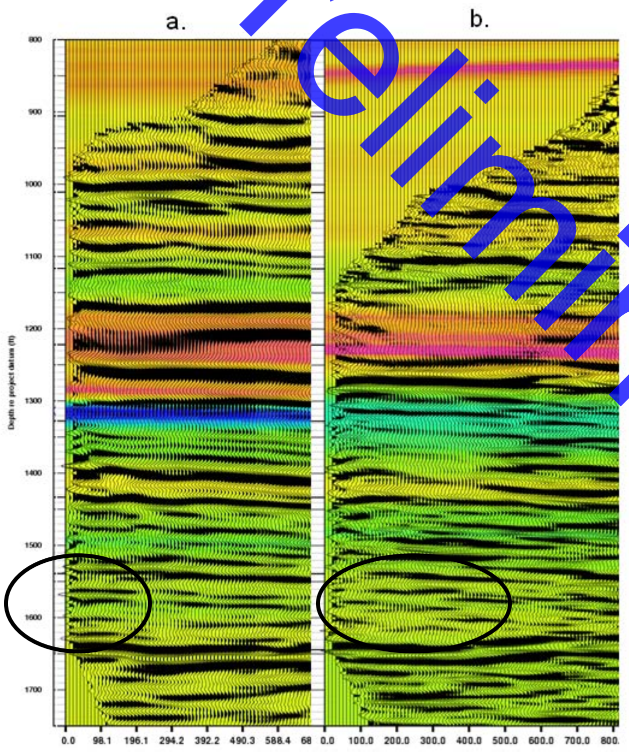


Figure 10. Cross-well seismic reflection data from (a) TB1 to TB4 and from (b) TB1 to TB6. TB1 is located at the 0.0. Circles show the up warped reflections near 1400 ft depth.

warping of a the reflector near the 1400 ft depth on the cross-well seismic reflection data from (a) TB1 to TB4 and from (b) TB1 to TB6 (Fig. 10). However, this negative density difference is only -0.04 g/cm^3 – just above the noise level. The uncertainty in the determined density values for the 1400-1420 and the 1420-1440 ft interval are less than ± 0.01 g/cm^3 so this anomaly could be significant. We have modeled this negative difference using *Hole-o-grav*. The results suggest that the negative density difference outlined in Figure 9b is consistent with a 20 foot thick low-density zone ($\Delta\rho = -1.1$ g/cm^3) in the B-salt whose dimensions are 150 x 250 ft, i.e. elliptical in shape approximately 30 ft from the borehole. However, other geometric shapes and density contrasts are possible given the non-uniqueness of the gravity method. For instance, increasing the thickness of the elliptical disk would decrease the x-y dimensions of the disk, but the thickness is rather constrained by the density difference data. Another solution would be to increase the cross-sectional area of the disk, keep the thickness the same while reducing the density contrast of the feature with respect to its surroundings. Interestingly enough, if the density of the B-salt is 2.16 g/cm^3, then this density difference anomaly disappears, and conversely, the anomaly becomes larger if the density of the salt is higher. The exact nature of this negative density difference anomaly is unknown, but is consistent with a brine-filled zone in the B-salt. However, given the small magnitude of the anomaly we may be looking at noise as the shape of the anomaly doesn't quite match that expected from model studies. Therefore, this anomaly should be viewed with caution and is considered interesting but probably not significant.

TB4: Figure 11 shows the BHGM, γ - γ, and density difference results from borehole TB4. Data quality is excellent with the average uncertainty in the means of the observed gravity at each level being 0.0120 mgals. Except for three 20 ft intervals which have very small negative density differences (<-0.02 g/cm^3), all the density differences are positive and most are less than 0.05 g/cm^3. These small negative density anomalies are not consistent with the presence of a "morning glory" or "hockey puck" solution cavities.

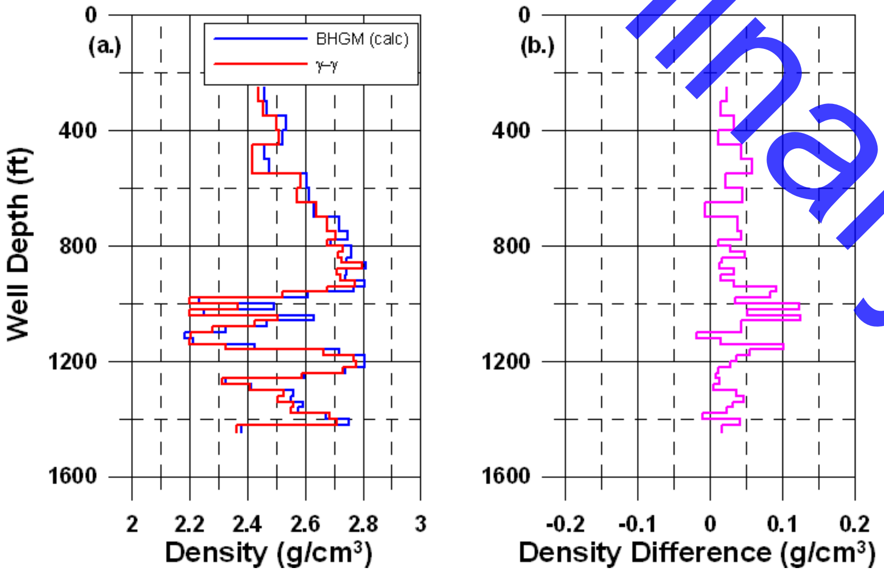


Figure11. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB4.

Figure 12 shows an interesting interpretation of cross-well data from TB4 to TB6 submitted by NTH Consultants, to myself and Dr. Roger Turpening showing a series of inter-connected “morning glory” cavities/structures next to borehole TB4. These “morning glory” cavities range from 200 to 300 feet in diameter (assuming a circular “morning glory” in plan view). Since the density difference plot from TB4 (Fig. 11b) shows no significant negative density difference zones between 800 and 1200 ft that one would expect to be associated with the proposed cavities shown in Figure 12. A 300 ft “morning glory” solution cavity whose edge is next to the borehole should give rise to a large negative density difference as shown in Figure 6, but none are seen. Therefore, it is highly unlikely that the proposed cavities exist. Solution cavities of either the “hockey puck” or “morning glory” and of reasonable size edging on the borehole should be easily recognized from BHGM data. This makes BHGM an excellent check on cross-well reflection interpretation at the borehole.

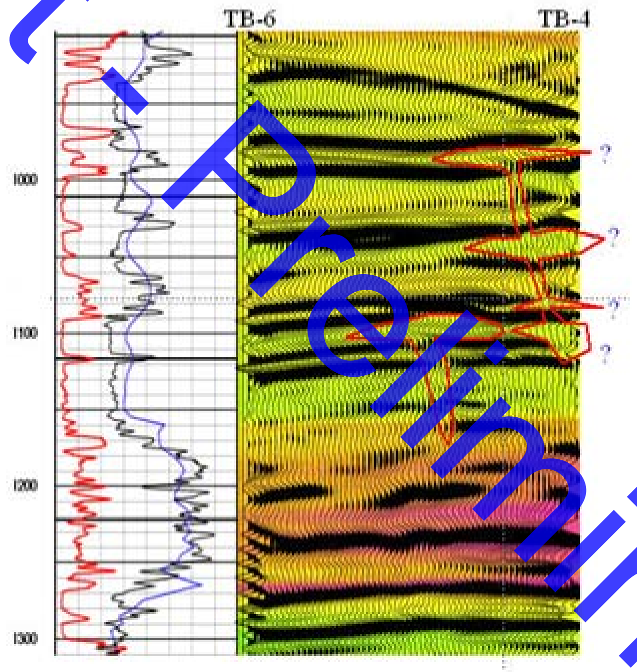


Figure 12. Cross-well seismic reflection data from TB6 to TB4 with possible solution cavities outlined. Notice the density difference plot from borehole TB4 (Fig. 11b) does not show the negative density differences expected for a large “morning glory” type structure. Distance between boreholes TB4 and TB6 is 620 ft.

TB5: Figure 13 shows the BHGM, γ - γ, and density difference results from borehole TB5. Data quality is excellent with the average uncertainty in the means of the observed gravity at each level being 0.0130 mgals. The lack of significant negative density differences like those shown in Figures 6 and 7 again indicates that within the sensing range of the borehole gravimeter no significant solution cavities are present.

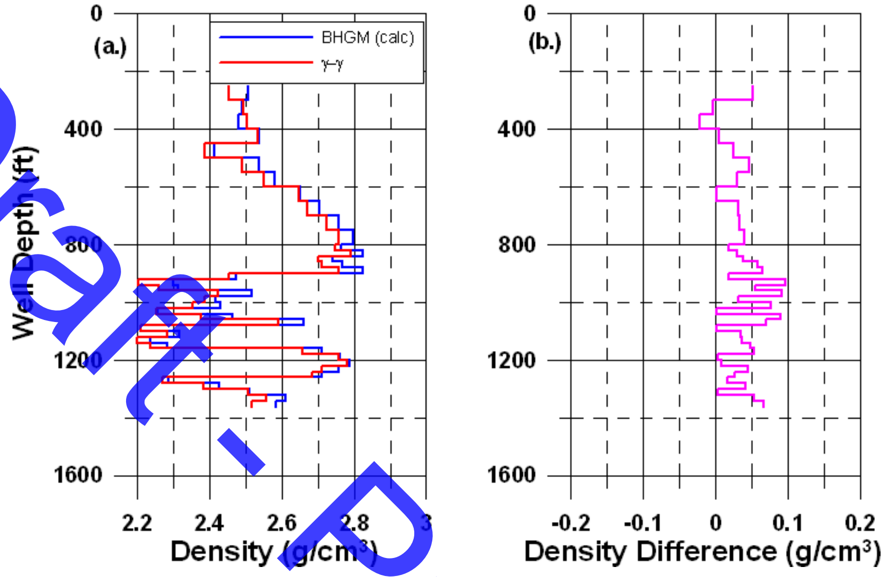


Figure13. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB5.

TB7: Figure 14 shows the BHGM, γ - γ, and density difference results from borehole TB7.

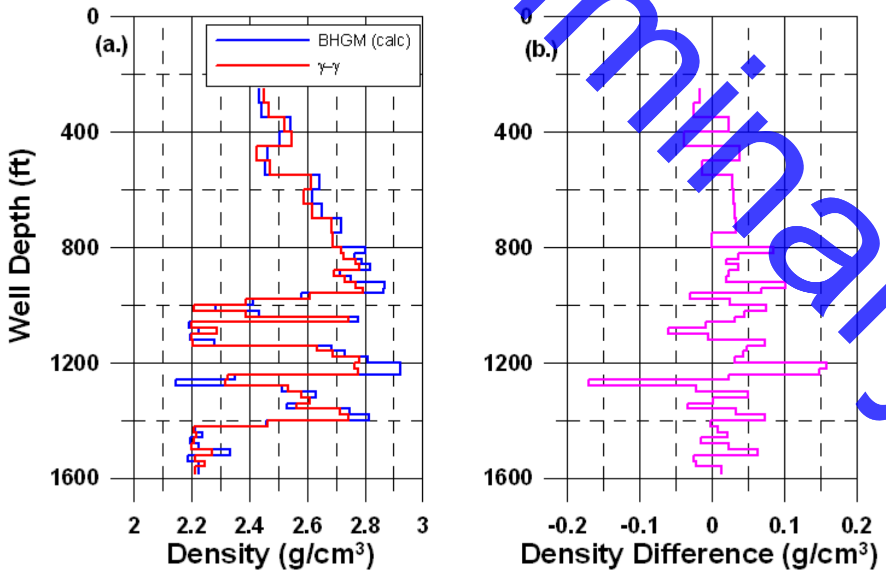


Figure14. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB7.

Unlike boreholes TB1, TB4, and TB5 for the X-10 survey area, the data from TB7 is very noisy and is reflected in the fact that the average uncertainty in the means of the observed gravity at each level is over twice the value (0.027 mgals) of the other boreholes in X-10. This borehole had significant washout problems in the F and D-salts (see Baker Atlas caliper log for this hole) and this definitely contributes to the overall noisiness of the gravity data. The large swing from positive to negative density differences between 1200 and 1280 foot levels (Fig. 14b) can not be considered real as the average uncertainty in BHGM density over this interval is 0.07 g/cm^3 – a magnitude that is a significant portion of the density anomalies over this interval. The negative density difference anomaly associated with the 1000 to 1020 ft interval is also probably associated with a prominent washout at this level as indicated by the Baker Atlas caliper log. Therefore, I see no evidence in these noisy data that would suggest the presence of a solution cavity within the sensing range of the gravimeter.

X11 Survey Area

TB10: Figure 15 shows the BHGM, γ - γ, and density difference results from borehole TB10. Like borehole TB7, the data from TB10 are noisy. The average uncertainty in the means of the observed gravity is 0.023 mgals – slightly less the results from TB7. The exact cause is unknown, but TB10 was the first borehole logged by Microg and perhaps a longer shake down period after arrival at the hole was needed before gravity measurements were undertaken. The rapid swings from positive to negative density difference shown in Figure 15b have no similarity to the density different plots shown in Figures 6 and 7 from our model studies on "morning glory" and "hockey puck" solution cavities. These back and forth swings can not be reproduced with any reasonable geologic model in *Hole-o-grav*. Therefore, a statement on presence or absence of a solution cavity within the sensing range of the gravimeter from this data cannot be unequivocally made.

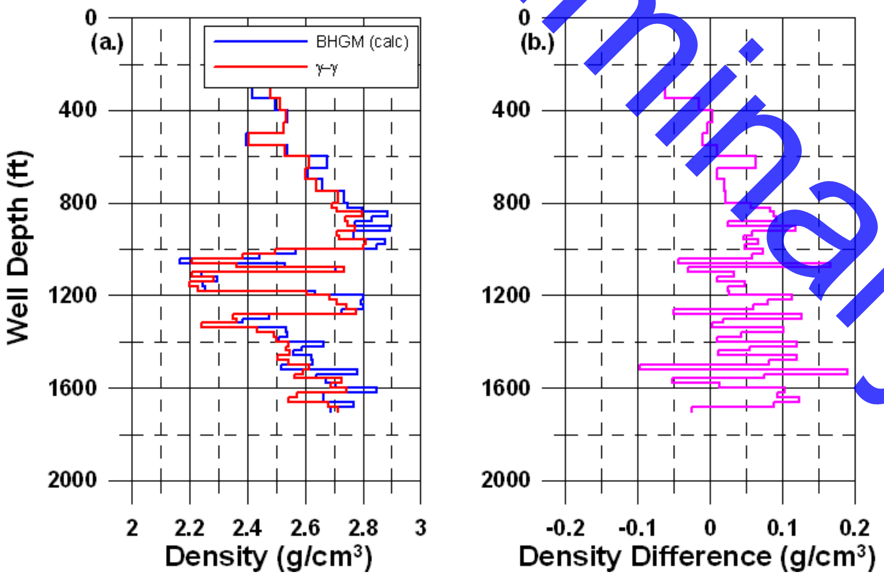


Figure15. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB10.

TB12: Figure 16 shows the BHGM, γ - γ, and density difference results from borehole TB12. The data quality is reasonable with the average uncertainty in the means of the observed gravity being 0.016 mgals. The negative density difference between 1100 and 1160 ft levels (circled on Fig. 16b) appears to be associated with a washout in the F-salt as indicated by the Baker Atlas caliper log. But since the density difference swings back to a positive density difference between 1100 – 1120 ft levels, this anomaly is not consider significant as it does not match the density difference pattern one would expect from a "morning glory" or "hockey puck" solution cavity (Figs. 6 and 7) and may just be experimental error. In addition, there is no evidence from crosswell reflection data (TB12 to TB16 and TB10 to TB12) indicating a solution cavity at 1100 ft depth. No significance can be attributed to the negative density difference between 1400 and 1460 ft levels as the uncertainty in the BHGM density is ±0.03 g/cm^3 which makes this difference barely significant. Again, there is no evidence in these data that would suggest the presence of a solution cavity within the sensing range of the gravimeter.

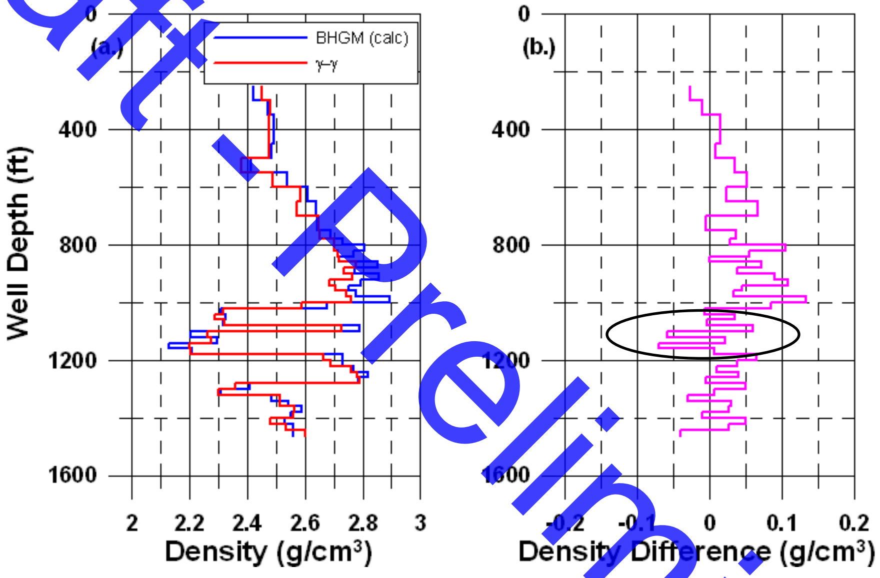


Figure16. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB12. Circle highlights negative density difference zone discussed in text.

TB14: Figure 17 shows the BHGM, γ - γ, and density difference results from borehole TB14. The data are similar in quality to TB12 with the average uncertainty in the means of the observed gravity also being 0.016 mgals. However, nothing significant in terms of a density difference anomaly stands out in these data (Fig. 17b). The overall positive aspect of the density difference data may be due to borehole rugosity as the caliper log for this borehole indicates a fair degree of rugosity. Borehole rugosity can cause the densities determined by gamma-gamma method to be too low resulting in positive density difference between the BHGM density and the γ - γ. This may be the cause of the predominance of positive density differences at most of the boreholes. Once again, like borehole TB12, there is no evidence from the data that would suggest the presence of a solution cavity within the sensing range of the gravimeter.

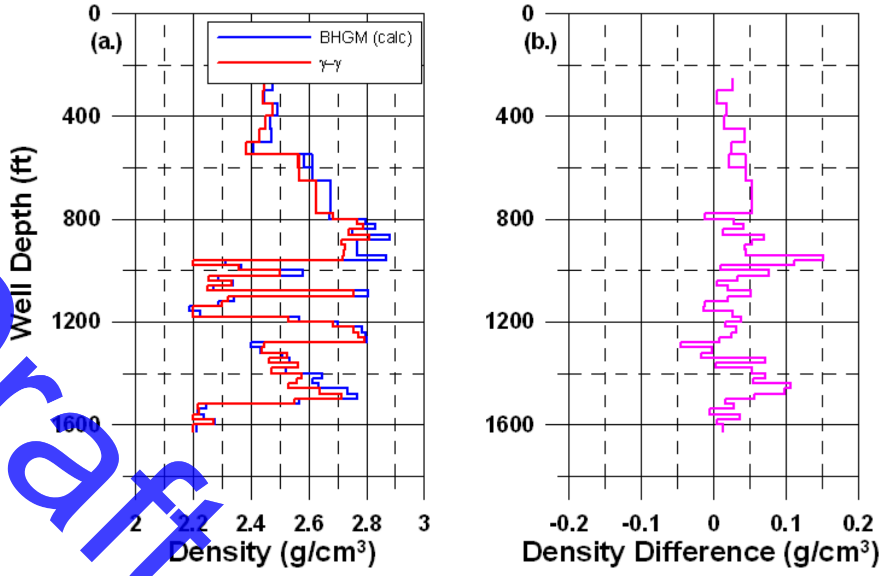


Figure17. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB14.

TB15: Figure 18 shows the BHGM, γ - γ, and density difference results from borehole TB15. Overall, the data are of good quality with the average uncertainty in the means of the observed gravity also being 0.011 mgals. The density difference plot (Fig. 18b) shows mainly positive density difference anomalies and almost no negative density differences and what is present is not significant. Therefore, there is no evidence from the data that would suggest the presence of a solution cavity within the sensing range of the gravimeter.

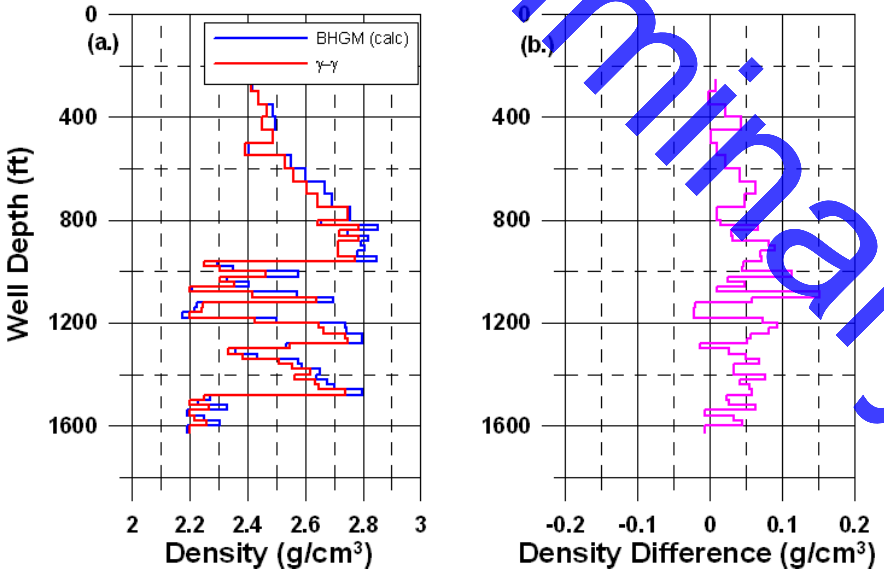


Figure18. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB15.

TB16: Figure 19 shows the BHGM, γ - γ, and density difference results from borehole TB16. Overall, the data have the lowest average uncertainty (0.009 mgals) in the means of the observed gravity of all the BHGM data collected from the 9 boreholes from the two survey area and yet.

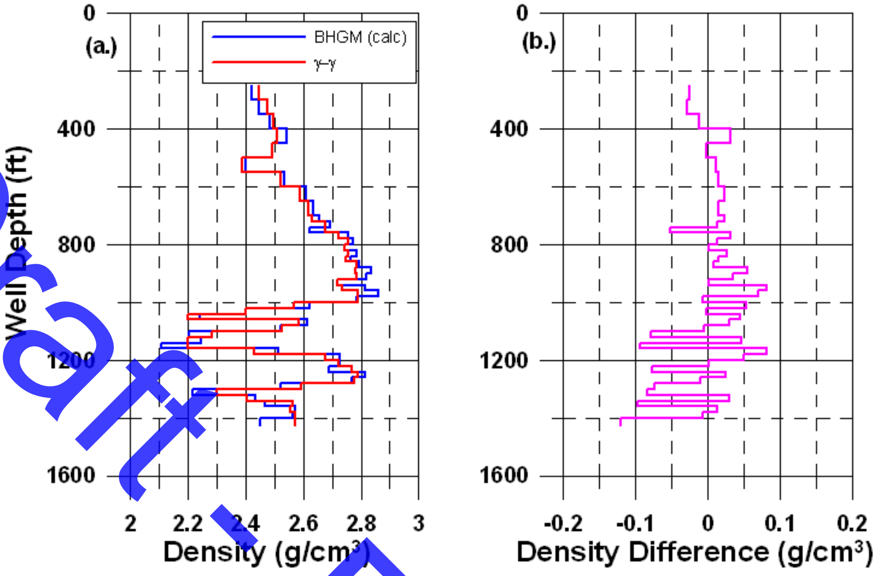


Figure19. Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB16.

the data appear to be very noisy (back and forth swings on the density difference plot – Fig. 19b). The exact cause is unknown but may be associated with the use of a 20 ft measurement interval. Small station spacing can produce poor results using Equation 1 (MacQueen, 1989), but 4 repeat measurements should have minimized the error. Nevertheless, I have recalculated the borehole densities from 700 ft down to the bottom of the hole (1420 ft) using a 40 ft interval. The results are shown in Figure 20. Interestingly enough, the density difference data shown in Figure 20b, especially below 1100 ft, are significantly less noisy than those shown in Figure 19b. More importantly, the 40 ft interval data (Fig. 20b) appears to define a negative density difference near the bottom of the borehole which is not as easily seen from the 20 ft interval data shown in Figure 19b. The negative density differences occur in the Salina E, D, and C units. Once again, the gamma-gamma densities shown in Figure 20a assume a salt density of 2.2 g/cm^3 (as discussed in **Methodology** section). Had I used a density of 2.16 g/cm^3 for salt, the negative density anomaly associated the D-salt (1300-1340 ft interval) disappears. The negative density differences in the Salina E are very small (<0.038 g/cm^3) and are not consider significant. However, the negative density differences that occur in the top of the Salina C are intriguing but only occur over to 40 ft intervals before we run out of data. Modeling this negative density difference anomaly with *Hole-o-grav* indicates that the anomaly is most probably associated with a 40 ft salt lens very near the borehole (<25 ft) and not a brine filled solution cavity. This is supported by the density logs ran in the other X-11 (e.g. TB11) boreholes by Baker-Atlas that indicate the presence of low density zones (2.10 to 2.20 g/cm^3) at various levels in the Salina C, i.e. thin interbedded salt layers in the Salina C.

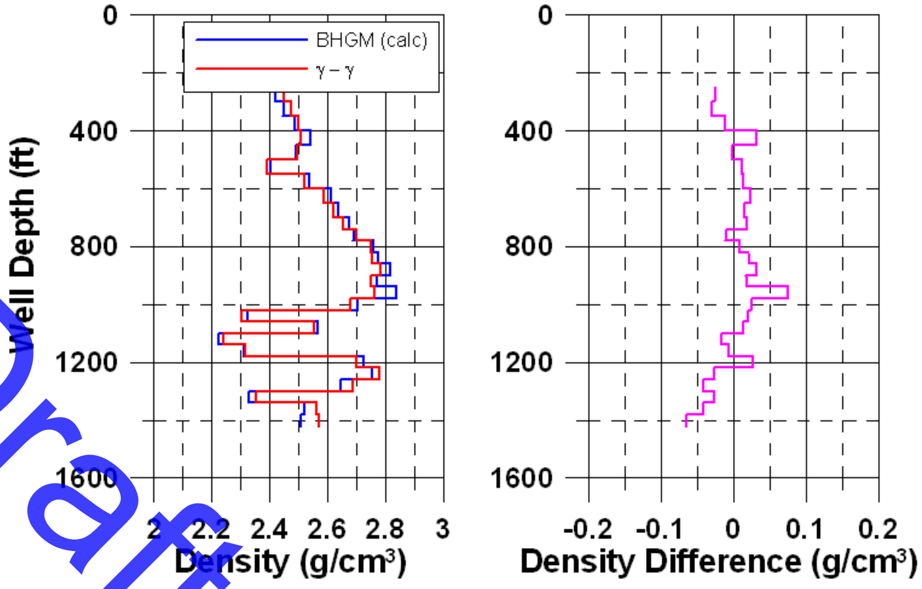


Figure 20. **Apparent density and γ - γ density plot (a), and density difference plots (b) for borehole TB16 using a 40ft interval instead of a 20 ft interval to calculated borehole gravity below 700 ft.**

Summary

- Apparent density modeling exercises using *Hole-o-grav* indicate under ideal conditions (low ambient noise) that a 300ft diameter "morning glory" solution cavity can be detected with BHGM if the edge of these cavities are less than 120 ft from the borehole and 90 ft or less for the "hockey puck" cavity.

- The Microg inversion process of calculating apparent density values from the observed gravity values measured with the borehole gravimeter appears to have some difficulty handling the blocky structure of the stratigraphy (thin layers with large density variation from layer to layer) that underlies the X10 and X11 survey areas. The process appears to create artificial swings in the density difference plots shown in Appendices C and D. Using Equation 1 to recalculate the apparent densities produces density difference plots that show less variation.

- All density difference plots presented in this report whether calculated using apparent densities form the Microg inversion algorithm or by Equation 1 tend to be skewed toward positive density differences, i.e. the densities from the gamma-gamma density log are lower than the apparent density calculated form the BHGM data. This positive skewness is probably the result of borehole rugosity which cause the densities recorded by the gamma-gamma tool to underestimated (Black, 1997).

- The density difference plots from all boreholes show little or no similarity in shape or magnitude to the density difference plots for the "morning glory" (Fig. 3) and "hockey puck" (Fig. 4) cavities shown in Figures 6 and 7. Therefore, the BHGM data indicate no significant density anomalies within the sensing range of the method.

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Appendix A: Borehole Gravity Data for the X10 Survey Area

Explanation of data columns in tables:

Station depth (ft) = depth below ground surface where gravity reading was taken. Four repeated measurements were taken where station interval was 20 ft and two repeated measurement where station interval was 50 ft.

Observed gravity (mgal) = The mean observed gravity reading at each depth based on an average of 4 where the station interval was 20 ft or 2 readings where station interval was 50 ft. 1 mgal = 1 x 10^{-5} m/sec^2.

Calculated gravity (mgal) = Observed gravity calculated from the Microg inversion densities.

Gravity uncertainty (mgal) = Standard deviation of the observed gravity reading shown in column 2.

Z-score = The standardized measure of misfit from the inversion between the mean of the gravity observations at a particular depth (column 2) and the gravity calculated at that depth from the inversion, ie. $Z(d) = \dfrac{g_{mean}(d) - g_{inv}(d)}{\sigma_g\ (d)}$

where Z(d) is the Z-score at depth, d, the mean of the gravity observations at d is g_{mean} (d), the gravity calculated by the inversion is g_{inv} (d), and the standard deviation of the observed gravity at d is σ_g (d).

Inversion density (g/cm^3) = the best-fit density using Microg-LaCoste inversion method based on a damped least-squares method for closely spaced gravity readings.

Density uncertainty (g/cm^3) = The one-sigma standard deviation of the inversion densities.

Table A1: Borehole gravity data for Well TB1.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty (g/cm^3)
250	3710.836	3710.842	0.008	-0.80	2.457	0.004
300	3712.404	3712.404	0.008	0.00	2.471	0.006
350	3713.950	3713.947	0.016	0.20	2.498	0.009
400	3715.464	3715.457	0.022	0.30	2.527	0.009
450	3716.924	3716.930	0.011	-0.60	2.434	0.006
500	3718.523	3718.522	0.005	0.20	2.491	0.004
550	3720.043	3720.041	0.005	0.40	2.609	0.005
600	3721.408	3721.408	0.008	0.00	2.606	0.004
650	3722.780	3722.780	0.000	0.00	2.659	0.002
700	3724.085	3724.084	0.004	0.10	2.713	0.002
750	3725.319	3725.319	0.001	0.00	2.714	0.002
800	3726.555	3726.553	0.004	0.40	2.753	0.008
820	3727.029	3727.027	0.011	0.20	2.791	0.010
840	3727.483	3727.481	0.013	0.20	2.809	0.009
860	3727.926	3727.926	0.005	-0.10	2.792	0.008
880	3728.377	3728.379	0.010	-0.20	2.730	0.010
900	3728.867	3728.864	0.014	0.20	2.748	0.011
920	3729.347	3729.341	0.012	0.50	2.799	0.009
940	3729.791	3729.791	0.003	0.00	2.793	0.008
960	3730.229	3730.244	0.010	-1.60	2.569	0.010
980	3730.776	3730.811	0.025	-1.40	2.493	0.010
1000	3731.408	3731.417	0.008	-1.20	2.279	0.010
1020	3732.149	3732.133	0.011	1.40	2.451	0.009
1040	3732.763	3732.761	0.004	0.50	2.658	0.009
1060	3733.247	3733.283	0.012	-3.20	2.282	0.010
1080	3734.001	3733.998	0.009	0.30	2.336	0.011
1100	3734.682	3734.685	0.023	-0.10	2.318	0.011
1120	3735.424	3735.381	0.032	1.30	2.389	0.010
1140	3736.108	3736.041	0.026	2.60	2.596	0.011
1160	3736.601	3736.595	0.007	0.80	2.752	0.007
1180	3737.069	3737.069	0.004	0.10	2.784	0.007
1200	3737.525	3737.527	0.007	-0.30	2.734	0.010
1220	3737.992	3738.010	0.023	-0.80	2.662	0.011
1240	3738.489	3738.530	0.014	-2.90	2.377	0.010
1260	3739.198	3739.197	0.008	0.10	2.390	0.008
1280	3739.859	3739.856	0.007	0.40	2.502	0.007
1300	3740.460	3740.458	0.007	0.30	2.570	0.009
1320	3741.027	3741.025	0.010	0.20	2.597	0.009
1340	3741.576	3741.578	0.012	-0.20	2.572	0.008
1360	3742.145	3742.145	0.001	0.10	2.727	0.001
1380	3742.632	3742.632	0.001	0.00	2.741	0.007
1400	3743.093	3743.112	0.011	-1.70	2.357	0.008
1420	3743.785	3743.788	0.005	-0.70	2.179	0.010
1440	3744.557	3744.555	0.016	0.10	2.183	0.010

Table A1 (con't.)

1460	3745.323	3745.320	0.010	0.20	2.222	0.010
1480	3746.064	3746.065	0.010	-0.10	2.205	0.009
1500	3746.826	3746.819	0.008	0.80	2.329	0.009
1520	3747.518	3747.510	0.008	0.90		

Table A2: Borehole gravity data for Well TB4.

Station Depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density(g/cm^3)	Density uncertainty (g/cm^3)
250	3711.220	3711.244	0.009	-2.60	2.477	0.006
300	3712.781	3712.781	0.010	0.00	2.470	0.005
350	3714.330	3714.326	0.011	0.30	2.529	0.007
400	3715.795	3715.796	0.020	-0.10	2.517	0.007
450	3717.277	3717.282	0.015	-0.30	2.464	0.008
500	3718.837	3718.834	0.024	0.10	2.472	0.007
550	3720.378	3720.377	0.002	0.30	2.602	0.003
600	3721.755	3721.754	0.006	0.10	2.620	0.007
650	3723.118	3723.108	0.051	0.20	2.622	0.007
700	3724.462	3724.459	0.008	0.50	2.717	0.005
750	3725.695	3725.688	0.011	0.60	2.737	0.007
780	3726.411	3726.411	0.012	0.00	2.687	0.009
800	3726.919	3726.918	0.002	0.20	2.755	0.004
820	3727.391	3727.391	0.004	0.00	2.757	0.005
840	3727.862	3727.862	0.004	0.00	2.748	0.006
860	3728.341	3728.338	0.007	0.40	2.799	0.007
880	3728.787	3728.789	0.006	-0.30	2.746	0.007
900	3729.266	3729.266	0.007	0.00	2.746	0.008
920	3729.748	3729.743	0.011	0.50	2.786	0.009
940	3730.195	3730.200	0.010	-0.50	2.739	0.009
960	3730.663	3730.680	0.013	-1.40	2.573	0.009
980	3731.212	3731.246	0.012	-2.80	2.365	0.009
1000	3731.952	3731.918	0.026	1.30	2.419	0.009
1020	3732.560	3732.563	0.016	-0.20	2.407	0.008
1040	3733.291	3733.213	0.038	2.00	2.454	0.008
1060	3733.828	3733.840	0.018	-0.70	2.419	0.009
1080	3734.449	3734.483	0.017	-2.00	2.309	0.008
1100	3735.143	3735.185	0.032	-1.30	2.261	0.008
1120	3735.908	3735.910	0.011	-0.20	2.242	0.009
1140	3736.658	3736.645	0.008	1.60	2.429	0.008
1160	3737.300	3737.285	0.007	2.10	2.690	0.006
1180	3737.792	3737.791	0.004	0.30	2.799	0.005
1200	3738.240	3738.241	0.006	-0.10	2.783	0.008
1220	3738.688	3738.699	0.017	-0.60	2.738	0.009
1240	3739.169	3739.180	0.009	-1.30	2.604	0.008
1260	3739.723	3739.730	0.005	-1.40	2.345	0.007
1280	3740.416	3740.413	0.006	0.50	2.410	0.006
1300	3741.064	3741.062	0.004	0.60	2.553	0.004
1320	3741.637	3741.637	0.003	0.00	2.557	0.008
1340	3742.216	3742.210	0.014	0.40	2.582	0.009
1360	3742.773	3742.772	0.009	0.10	2.590	0.009
1380	3743.339	3743.330	0.011	0.80	2.675	0.008
1400	3743.855	3743.843	0.020	0.60	2.700	0.008
1420	3744.330	3744.344	0.008	-1.90	2.417	0.009

Table A2 (con’t.)

1440	3744.996	3744.990	0.011	0.60		

Table A3: Borehole gravity data for Well TB5.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty (g/cm^3)
250	3711.139	3711.139	0.001	-0.40	2.500	0.007
300	3712.641	3712.646	0.088	-0.10	2.490	0.006
350	3714.164	3714.166	0.062	0.00	2.481	0.008
400	3715.698	3715.697	0.005	0.20	2.531	0.005
450	3717.160	3717.165	0.008	-0.70	2.416	0.005
500	3718.782	3718.780	0.006	0.40	2.532	0.003
550	3720.246	3720.246	0.002	0.10	2.582	0.005
600	3721.654	3721.648	0.010	0.60	2.646	0.006
650	3722.973	3722.969	0.008	0.50	2.709	0.008
700	3724.223	3724.208	0.025	0.60	2.743	0.008
750	3725.405	3725.405	0.006	0.10	2.796	0.002
800	3726.534	3726.533	0.003	0.30	2.772	0.008
820	3727.003	3726.997	0.013	0.40	2.798	0.009
840	3727.442	3727.448	0.011	-0.50	2.750	0.008
860	3727.923	3727.923	0.002	0.00	2.763	0.005
880	3728.390	3728.391	0.005	0.00	2.756	0.008
900	3728.829	3728.864	0.013	-2.70	2.509	0.009
920	3729.447	3729.462	0.010	-1.60	2.356	0.008
940	3730.153	3730.139	0.039	0.40	2.366	0.008
960	3730.852	3730.809	0.028	1.50	2.429	0.009
980	3731.448	3731.450	0.016	-0.10	2.416	0.009
1000	3732.094	3732.095	0.010	-0.10	2.407	0.009
1020	3732.734	3732.745	0.011	-1.10	2.283	0.008
1040	3733.463	3733.459	0.004	0.90	2.475	0.007
1060	3734.085	3734.075	0.011	1.00	2.623	0.007
1080	3734.607	3734.615	0.005	-1.90	2.227	0.005
1100	3735.359	3735.357	0.005	0.30	2.310	0.006
1120	3736.056	3736.058	0.005	-0.40	2.240	0.005
1140	3736.795	3736.794	0.004	0.20	2.317	0.006
1160	3737.509	3737.491	0.007	2.70	2.676	0.007
1180	3738.006	3738.004	0.005	0.50	2.758	0.008
1200	3738.477	3738.475	0.011	0.20	2.781	0.008
1220	3738.934	3738.934	0.005	-0.20	2.750	0.007
1240	3739.407	3739.410	0.009	-0.30	2.704	0.007
1260	3739.904	3739.908	0.003	-1.30	2.303	0.006
1280	3740.617	3740.611	0.007	0.90	2.424	0.007
1300	3741.259	3741.254	0.007	0.70	2.524	0.009
1320	3741.857	3741.845	0.016	0.80	2.566	0.009
1340	3742.405	3742.414	0.012	-0.80	2.496	0.010
1360	3742.966	3743.019	0.027	-2.00		

Table A4: Borehole gravity data for Well TB7.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty (g/cm^3)
250	2551.760	2551.761	0.004	-0.40	2.436	0.012
299.9	2553.353	2553.347	0.039	0.20	2.440	0.013
350	2554.939	2554.933	0.013	0.40	2.537	0.010
400	2556.392	2556.394	0.018	-0.10	2.501	0.012
450	2557.894	2557.900	0.027	-0.20	2.466	0.012
500	2559.452	2559.452	0.009	0.10	2.479	0.012
550	2561.018	2560.985	0.026	1.20	2.616	0.014
600	2562.347	2562.344	0.027	0.10	2.620	0.014
650	2563.707	2563.699	0.034	0.20	2.644	0.012
700	2565.024	2565.020	0.012	0.30	2.712	0.009
750	2566.256	2566.257	0.017	0.00	2.692	0.008
800	2567.526	2567.518	0.011	0.70	2.778	0.013
820	2567.976	2567.979	0.044	-0.10	2.771	0.013
840	2568.445	2568.443	0.018	0.10	2.784	0.014
860	2568.902	2568.901	0.011	0.10	2.801	0.014
880	2569.343	2569.350	0.018	-0.40	2.750	0.015
900	2569.837	2569.825	0.028	0.40	2.786	0.012
920	2570.312	2570.282	0.062	0.50	2.806	0.013
940	2570.728	2570.728	0.014	0.00	2.803	0.014
960	2571.147	2571.177	0.019	-1.50	2.602	0.014
980	2571.710	2571.727	0.016	-1.10	2.435	0.013
1000	2572.358	2572.363	0.011	-0.50	2.313	0.013
1020	2573.073	2573.061	0.017	0.70	2.452	0.014
1040	2573.711	2573.689	0.018	1.20	2.612	0.015
1060	2574.174	2574.235	0.022	-2.80	2.299	0.014
1080	2574.936	2574.941	0.018	-0.30	2.233	0.011
1100	2575.680	2575.680	0.005	-0.10	2.196	0.007
1120	2576.440	2576.439	0.005	0.20	2.295	0.008
1140	2577.157	2577.146	0.010	1.00	2.661	0.008
1160	2577.667	2577.667	0.004	0.10	2.733	0.008
1180	2578.153	2578.151	0.008	0.20	2.803	0.007
1200	2578.598	2578.599	0.002	-0.10	2.736	0.012
1220	2578.987	2579.081	0.078	-1.20	2.695	0.010
1240	2579.375	2579.583	0.097	-2.10	2.557	0.012
1260	2580.056	2580.158	0.045	-2.30	2.427	0.012
1280	2580.840	2580.798	0.062	0.70	2.451	0.014
1300	2581.438	2581.426	0.014	0.90	2.601	0.015
1320	2581.976	2581.977	0.022	-0.10	2.591	0.014
1340	2582.524	2582.534	0.041	-0.20	2.574	0.014
1360	2583.113	2583.099	0.016	0.90	2.705	0.014
1380	2583.591	2583.597	0.012	-0.50	2.569	0.013
1400	2584.034	2584.165	0.068	-1.90	2.479	0.010
1420	2584.658	2584.779	0.067	-1.80	2.411	0.012

Table A4 (con't.)

1440	2585.408	2585.427	0.018	-1.00	2.268	0.015
1460	2586.145	2586.149	0.017	-0.20	2.224	0.014
1480	2586.905	2586.893	0.045	0.30	2.235	0.013
1500	2587.650	2587.632	0.027	0.60	2.290	0.015
1520	2588.338	2588.342	0.018	-0.30	2.225	0.014
1540	2589.102	2589.086	0.041	0.40	2.245	0.014
1560	2589.847	2589.820	0.020	1.40	2.368	0.014
1580	2590.592	2590.491	0.064	1.60		

Appendix B: Borehole Gravity Data for the X11 Survey Area

Explanation of data columns in tables:

Station depth (ft) = depth below ground surface where gravity reading was taken. Four repeated measurements were taken where station interval was 20 ft and two repeated measurement where station interval was 50 ft.

Observed gravity (mgal) = The mean observed gravity reading at each depth based on an average of 4 where the station interval was 20 ft or 2 readings where station interval was 50 ft. 1 mgal = 1 x 10^{-5} m/sec^2.

Calculated gravity (mgal) = Observed gravity calculated from the Microg inversion densities.

Gravity uncertainty (mgal) = Standard deviation of the observed gravity reading shown in column 2.

Z-score = The standardized measure of misfit from the inversion between the mean of the gravity observations at a particular depth (column 2) and the gravity calculated at that depth from the inversion, ie. $Z(d) = \frac{g_{mean}(d) - g_{inv}(d)}{\sigma_g (d)}$

where Z(d) is the Z-score at depth, d, the mean of the gravity observations at d is g_{mean} (d), the gravity calculated by the inversion is g_{inv} (d), and the standard deviation of the observed gravity at d is σ_g (d).

Inversion density (g/cm^3) = the best-fit density using Microg-LaCoste inversion method based on a damped least-squares method for closely spaced gravity readings.

Density uncertainty (g/cm^3) = The one-sigma standard deviation of the inversion densities.

Table B1: Borehole gravity data for Well TB10.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty(g/cm^3)
300	3717.178	3717.228	0.015	-3.30	2.460	0.010
350	3718.793	3718.786	0.017	0.30	2.500	0.011
400	3720.305	3720.294	0.029	0.40	2.524	0.012
450	3721.768	3721.770	0.018	-0.10	2.511	0.011
500.1	3723.249	3723.264	0.021	-0.70	2.438	0.012
550	3724.889	3724.849	0.030	1.30	2.526	0.012
600	3726.350	3726.323	0.021	1.30	2.652	0.010
650	3727.635	3727.636	0.008	-0.10	2.612	0.007
700	3729.004	3729.001	0.012	0.30	2.657	0.007
750	3730.311	3730.307	0.010	0.50	2.759	0.008
800	3731.519	3731.483	0.029	1.20	2.745	0.011
820	3731.997	3731.961	0.055	0.70	2.769	0.011
840	3732.450	3732.426	0.028	0.90	2.833	0.013
860	3732.857	3732.859	0.019	-0.10	2.822	0.013
880	3733.293	3733.297	0.017	-0.20	2.796	0.013
900	3733.759	3733.749	0.021	0.50	2.851	0.012
920	3734.163	3734.172	0.015	-0.60	2.785	0.012
940	3734.630	3734.630	0.020	0.00	2.788	0.012
960	3735.098	3735.085	0.023	0.50	2.848	0.012
980	3735.509	3735.511	0.009	-0.10	2.819	0.010
1000	3735.935	3735.950	0.010	-1.50	2.580	0.011
1020	3736.504	3736.512	0.013	-0.70	2.442	0.011
1040	3737.137	3737.145	0.011	-0.80	2.319	0.011
1060	3737.911	3737.840	0.045	1.60	2.423	0.011
1080	3738.499	3738.483	0.013	1.20	2.576	0.012
1100	3738.998	3739.047	0.022	-2.20	2.326	0.012
1120	3739.734	3739.738	0.015	-0.30	2.292	0.013
1140	3740.443	3740.448	0.029	-0.20	2.275	0.012
1160	3741.176	3741.166	0.029	0.30	2.296	0.012
1180	3741.905	3741.873	0.014	2.30	2.636	0.012
1200	3742.441	3742.407	0.024	1.40	2.736	0.012
1220	3742.892	3742.890	0.010	0.20	2.776	0.012
1240	3743.347	3743.352	0.013	-0.40	2.725	0.011
1260	3743.797	3743.839	0.051	-0.80	2.690	0.010
1280	3744.285	3744.345	0.026	-2.30	2.541	0.013
1300	3744.901	3744.927	0.019	-1.40	2.415	0.013
1320	3745.565	3745.574	0.016	-0.50	2.359	0.012
1340	3746.300	3746.249	0.029	1.80	2.461	0.012
1360	3746.886	3746.872	0.021	0.70	2.518	0.013
1380	3747.471	3747.465	0.019	0.30	2.552	0.012
1399.9	3748.067	3748.039	0.027	1.00	2.600	0.012
1420	3748.591	3748.594	0.020	-0.20	2.588	0.013
1440	3749.149	3749.153	0.022	-0.20	2.574	0.013

Table B1 (con’t.)

1460	3749.723	3749.717	0.020	0.30	2.613	0.012
1480	3750.264	3750.262	0.027	0.10	2.616	0.012
1500	3750.804	3750.806	0.021	-0.10	2.610	0.012
1520	3751.400	3751.353	0.048	1.00	2.679	0.011
1540	3751.860	3751.865	0.038	-0.10	2.671	0.011
1560	3752.393	3752.381	0.039	0.30	2.686	0.012
1580	3752.909	3752.889	0.044	0.50	2.716	0.011
1600	3753.409	3753.382	0.048	0.60	2.735	0.010
1620	3753.836	3753.865	0.045	-0.60	2.710	0.012
1640	3754.356	3754.360	0.017	-0.20	2.677	0.012
1660	3754.876	3754.873	0.011	0.30	2.731	0.012
1680	3755.344	3755.358	0.016	-0.80	2.643	0.013
1700	3755.852	3755.888	0.018	-2.00		

Table B2: Borehole gravity data from Well TB12.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty(g/cm^3)
250	3714.073	3714.075	0.003	-0.7	2.422	0.002
300	3715.683	3715.682	0.002	0.1	2.472	0.008
350	3717.231	3717.226	0.016	0.3	2.485	0.008
400	3718.752	3718.752	0.005	0.0	2.490	0.003
450	3720.272	3720.272	0.001	0.0	2.480	0.001
500	3721.805	3721.805	0.001	0.0	2.412	0.002
550	3723.425	3723.424	0.003	0.3	2.549	0.009
600	3724.885	3724.869	0.020	0.8	2.608	0.010
650	3726.257	3726.238	0.042	0.5	2.624	0.010
700	3727.589	3727.586	0.016	0.2	2.639	0.007
750	3728.915	3728.915	0.002	0.1	2.695	0.005
780	3729.676	3729.671	0.007	0.7	2.751	0.009
800	3730.163	3730.145	0.038	0.5	2.767	0.009
820	3730.611	3730.612	0.022	0.0	2.764	0.011
840	3731.078	3731.08	0.009	-0.2	2.740	0.010
860	3731.57	3731.56	0.014	0.7	2.821	0.010
880	3731.995	3731.999	0.012	-0.3	2.789	0.011
900	3732.459	3732.454	0.014	0.4	2.821	0.011
920	3732.881	3732.893	0.036	-0.3	2.795	0.010
940	3733.336	3733.344	0.029	-0.3	2.778	0.010
960	3733.811	3733.805	0.029	0.2	2.785	0.010
980	3734.273	3734.262	0.037	0.3	2.812	0.011
1000	3734.676	3734.706	0.015	-2.0	2.593	0.011
1020	3735.191	3735.262	0.022	-3.3	2.404	0.010
1040	3735.892	3735.914	0.033	-0.6	2.355	0.010
1060	3736.586	3736.591	0.018	-0.3	2.334	0.010
1080	3737.284	3737.279	0.005	1.0	2.748	0.006
1100	3737.741	3737.755	0.006	-2.4	2.229	0.006
1120	3738.497	3738.497	0.004	0.1	2.283	0.006
1140	3739.205	3739.21	0.007	-0.6	2.150	0.008
1160	3739.998	3739.992	0.010	0.6	2.288	0.010
1180	3740.75	3740.704	0.012	3.8	2.677	0.011
1200	3741.237	3741.216	0.025	0.8	2.719	0.010
1220	3741.724	3741.707	0.028	0.6	2.758	0.010
1240	3742.191	3742.178	0.021	0.6	2.792	0.010
1260	3742.632	3742.632	0.004	-0.1	2.770	0.006
1280	3743.09	3743.097	0.005	-1.3	2.401	0.010
1300	3743.741	3743.751	0.023	-0.4	2.377	0.010
1320	3744.443	3744.417	0.020	1.3	2.458	0.011
1340	3745.055	3745.041	0.017	0.8	2.536	0.011
1360	3745.638	3745.626	0.025	0.5	2.560	0.010
1380	3746.196	3746.198	0.019	-0.1	2.552	0.011
1400	3746.774	3746.775	0.010	-0.1	2.533	0.009
1420	3747.362	3747.361	0.007	0.1	2.551	0.009

Table B2 (con't.)

1440	3747.936	3747.938	0.010	-0.1	2.532	0.012
1460	3748.51	3748.524	0.033	-0.4		

Table B3: Borehole gravity data for Well TB14.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty(g/cm^3)
250	3713.600	3713.611	0.010	-1.10	2.477	0.008
300	3715.143	3715.145	0.013	-0.10	2.452	0.010
350	3716.721	3716.713	0.021	0.40	2.482	0.011
400	3718.239	3718.244	0.032	-0.10	2.469	0.011
450	3719.789	3719.789	0.010	0.00	2.465	0.011
500	3721.335	3721.339	0.026	-0.20	2.448	0.012
550	3722.966	3722.916	0.028	1.80	2.567	0.011
600	3724.367	3724.338	0.044	0.70	2.592	0.011
650	3725.730	3725.728	0.005	0.20	2.674	0.004
700	3727.011	3727.010	0.004	0.10	2.693	0.003
750	3728.274	3728.273	0.004	0.30	2.742	0.008
780	3728.990	3728.992	0.016	-0.20	2.684	0.011
800	3729.507	3729.500	0.010	0.60	2.784	0.011
820	3729.959	3729.957	0.010	0.20	2.815	0.012
840	3730.394	3730.400	0.028	-0.20	2.786	0.012
860	3730.870	3730.857	0.025	0.50	2.815	0.010
880	3731.279	3731.299	0.046	-0.40	2.795	0.011
900	3731.747	3731.750	0.015	-0.20	2.764	0.011
920	3732.214	3732.218	0.010	-0.40	2.704	0.012
940	3732.682	3732.718	0.031	-1.10	2.646	0.010
960	3733.098	3733.246	0.042	-3.60	2.512	0.010
980	3733.798	3733.843	0.038	-1.20	2.463	0.011
1000	3734.470	3734.464	0.014	0.40	2.507	0.012
1020	3735.034	3735.063	0.017	-1.70	2.344	0.011
1040	3735.746	3735.746	0.006	0.00	2.339	0.009
1060	3736.432	3736.432	0.009	0.00	2.340	0.010
1080	3737.154	3737.116	0.013	3.00	2.697	0.010
1100	3737.602	3737.619	0.009	-1.90	2.350	0.011
1120	3738.286	3738.298	0.018	-0.70	2.288	0.011
1140	3738.999	3739.010	0.017	-0.60	2.209	0.011
1160	3739.762	3739.761	0.009	0.10	2.231	0.007
1180	3740.506	3740.501	0.005	0.90	2.564	0.007
1200	3741.076	3741.072	0.006	0.60	2.701	0.009
1220	3741.578	3741.573	0.010	0.50	2.772	0.009
1240	3742.036	3742.036	0.006	0.10	2.788	0.008
1260	3742.488	3742.492	0.009	-0.40	2.692	0.011
1280	3742.939	3742.997	0.022	-2.70	2.503	0.011
1300	3743.593	3743.598	0.012	-0.40	2.451	0.011
1320	3744.230	3744.226	0.014	0.20	2.504	0.010
1340	3744.830	3744.827	0.014	0.20	2.529	0.010
1360	3745.417	3745.416	0.008	0.10	2.558	0.011
1380	3745.988	3745.989	0.014	-0.10	2.550	0.012
1400	3746.580	3746.566	0.021	0.70	2.620	0.012
1420	3747.109	3747.108	0.022	0.00	2.621	0.012

Table B3 (con't.)

1440	3747.654	3747.649	0.020	0.30	2.642	0.012
1460	3748.189	3748.180	0.014	0.70	2.716	0.011
1480	3748.673	3748.673	0.012	0.00	2.715	0.011
1500	3749.140	3749.166	0.017	-1.50	2.572	0.011
1520	3749.710	3749.732	0.011	-2.00	2.285	0.009
1540	3750.444	3750.445	0.004	-0.10	2.219	0.006
1560	3751.192	3751.192	0.005	0.10	2.236	0.006
1580	3751.930	3751.930	0.004	0.10	2.274	0.006
1600	3752.648	3752.648	0.005	-0.10	2.228	0.007
1620	3753.398	3753.391	0.007	1.10		

Table B4: Borehole gravity data for Well TB15.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty(g/cm^3)
250	3713.053	3713.053	0.001	-0.10	2.426	0.001
300	3714.667	3714.667	0.001	0.00	2.439	0.007
350	3716.257	3716.252	0.020	0.30	2.483	0.009
400	3717.783	3717.781	0.015	0.10	2.491	0.010
450	3719.299	3719.300	0.022	-0.10	2.482	0.010
500	3720.825	3720.831	0.013	-0.40	2.413	0.008
550	3722.458	3722.449	0.011	0.80	2.543	0.006
600	3723.901	3723.901	0.003	0.10	2.599	0.005
650	3725.284	3725.280	0.009	0.40	2.665	0.007
700	3726.579	3726.578	0.010	0.20	2.690	0.006
750	3727.843	3727.842	0.006	0.20	2.755	0.003
800	3729.024	3729.024	0.004	0.10	2.672	0.008
820	3729.548	3729.540	0.009	0.90	2.826	0.009
840	3729.973	3729.976	0.010	-0.30	2.753	0.008
860	3730.451	3730.450	0.006	0.30	2.810	0.008
880	3730.893	3730.894	0.007	-0.10	2.790	0.010
900	3731.347	3731.348	0.017	-0.10	2.777	0.011
920	3731.795	3731.810	0.031	-0.50	2.752	0.010
940	3732.255	3732.284	0.026	-1.10	2.686	0.011
960	3732.682	3732.791	0.033	-3.40	2.495	0.011
980	3733.391	3733.397	0.008	-0.70	2.376	0.010
1000	3734.072	3734.063	0.011	0.80	2.487	0.011
1020	3734.637	3734.672	0.028	-1.20	2.390	0.011
1040	3735.328	3735.331	0.020	-0.20	2.378	0.012
1060	3735.981	3735.997	0.024	-0.70	2.302	0.012
1080	3736.733	3736.701	0.015	2.20	2.517	0.011
1100	3737.301	3737.296	0.008	0.60	2.626	0.010
1120	3737.805	3737.833	0.012	-2.30	2.278	0.009
1140	3738.549	3738.551	0.007	-0.30	2.217	0.010
1160	3739.297	3739.297	0.013	0.00	2.212	0.010
1180	3740.066	3740.048	0.009	2.00	2.526	0.011
1200	3740.670	3740.638	0.015	2.10	2.676	0.010
1220	3741.151	3741.150	0.004	0.20	2.747	0.007
1240	3741.630	3741.628	0.007	0.20	2.789	0.009
1260	3742.083	3742.083	0.008	0.00	2.778	0.009
1280	3742.535	3742.544	0.010	-0.90	2.545	0.007
1300	3743.122	3743.124	0.004	-0.50	2.370	0.008
1320	3743.797	3743.794	0.012	0.30	2.428	0.008
1340	3744.435	3744.434	0.004	0.40	2.572	0.005
1360	3745.000	3745.000	0.005	0.00	2.590	0.005
1380	3745.558	3745.557	0.004	0.20	2.650	0.005
1400	3746.084	3746.084	0.004	0.00	2.637	0.005
1420	3746.617	3746.617	0.004	0.10	2.677	0.007
1440	3747.131	3747.130	0.007	0.10	2.699	0.009

Table B4 (con’t.)

1460	3747.632	3747.631	0.010	0.10	2.717	0.010
1480	3748.084	3748.123	0.014	-2.90	2.340	0.010
1500	3748.804	3748.808	0.008	-0.40	2.262	0.010
1520	3749.547	3749.532	0.028	0.50	2.295	0.010
1540	3750.237	3750.240	0.008	-0.40	2.201	0.009
1560	3750.998	3750.996	0.008	0.30	2.249	0.009
1580	3751.730	3751.727	0.010	0.20	2.296	0.007
1600	3752.434	3752.434	0.003	-0.20	2.220	0.008
1620	3753.195	3753.181	0.009	1.60		

Table B5: Borehole gravity data for Well TB16.

Station depth (ft)	Observed gravity (mgal)	Calculated gravity (mgal)	Gravity uncertainty (mgal)	Z-score	Inversion density (g/cm^3)	Density uncertainty(g/cm^3)
250	3714.651	3714.654	0.003	-0.90	2.422	0.002
300	3716.261	3716.261	0.001	0.00	2.451	0.007
350	3717.839	3717.831	0.023	0.40	2.477	0.007
400	3719.368	3719.368	0.001	0.00	2.539	0.002
450	3720.825	3720.826	0.003	-0.10	2.489	0.003
500	3722.346	3722.347	0.004	-0.30	2.403	0.004
550	3723.981	3723.978	0.005	0.60	2.531	0.003
600	3725.446	3725.446	0.000	0.00	2.613	0.007
650	3726.814	3726.809	0.016	0.30	2.631	0.007
700	3728.152	3728.149	0.007	0.30	2.650	0.008
720	3728.677	3728.675	0.007	0.30	2.685	0.007
740	3729.183	3729.184	0.006	-0.20	2.651	0.009
760	3729.724	3729.709	0.016	0.90	2.730	0.009
780	3730.198	3730.195	0.010	0.30	2.757	0.009
800	3730.664	3730.667	0.020	-0.10	2.750	0.009
820	3731.143	3731.142	0.006	0.10	2.777	0.008
840	3731.602	3731.603	0.010	-0.10	2.766	0.008
860	3732.072	3732.070	0.006	0.20	2.796	0.008
880	3732.526	3732.522	0.018	0.20	2.823	0.008
900	3732.959	3732.960	0.007	-0.10	2.803	0.009
920	3733.401	3733.408	0.011	-0.60	2.749	0.009
940	3733.893	3733.884	0.015	0.60	2.805	0.009
960	3734.336	3734.330	0.016	0.40	2.825	0.009
980	3734.756	3734.768	0.015	-0.80	2.776	0.009
1000	3735.215	3735.230	0.010	-1.50	2.609	0.009
1020	3735.757	3735.777	0.010	-2.00	2.422	0.008
1040	3736.412	3736.420	0.009	-0.90	2.268	0.006
1060	3737.147	3737.142	0.004	1.30	2.578	0.008
1080	3737.693	3737.705	0.018	-0.60	2.529	0.008
1100	3738.286	3738.293	0.005	-1.50	2.221	0.008
1120	3739.041	3739.039	0.012	0.20	2.237	0.008
1140	3739.775	3739.777	0.005	-0.40	2.159	0.007
1160	3740.580	3740.554	0.011	2.40	2.481	0.008
1180	3741.177	3741.167	0.007	1.60	2.706	0.006
1200	3741.666	3741.665	0.004	0.10	2.718	0.007
1220	3742.155	3742.157	0.008	-0.20	2.694	0.007
1240	3742.662	3742.661	0.004	0.40	2.801	0.006
1260	3743.106	3743.110	0.007	-0.70	2.696	0.009
1280	3743.573	3743.613	0.013	-3.20	2.458	0.008
1300	3744.166	3744.238	0.033	-2.20	2.361	0.008
1320	3744.914	3744.913	0.005	0.40	2.431	0.005
1340	3745.551	3745.551	0.002	0.10	2.470	0.005
1360	3746.172	3746.170	0.007	0.40	2.563	0.005
1380	3746.740	3746.740	0.003	0.00	2.564	0.003

Table B5 (con't.)

1400	3747.311	3747.311	0.001	-0.10	2.495	0.010
1420	3747.940	3747.917	0.026	0.90		

Appendix C: Apparent Density from BHGM, Gamma-Gamma Density, and Density Difference Plots for the X10 Survey Area

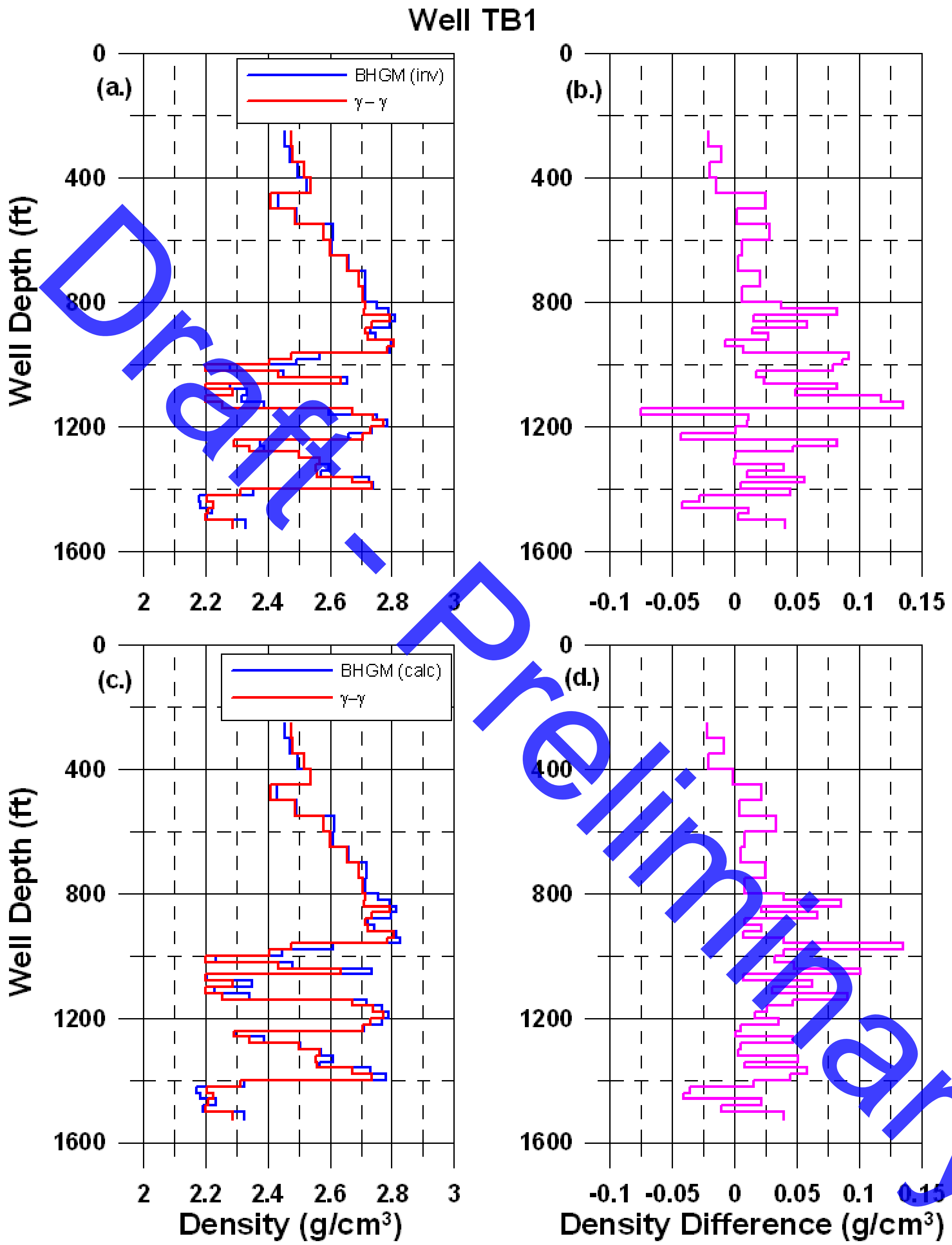


Figure C1. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB1. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

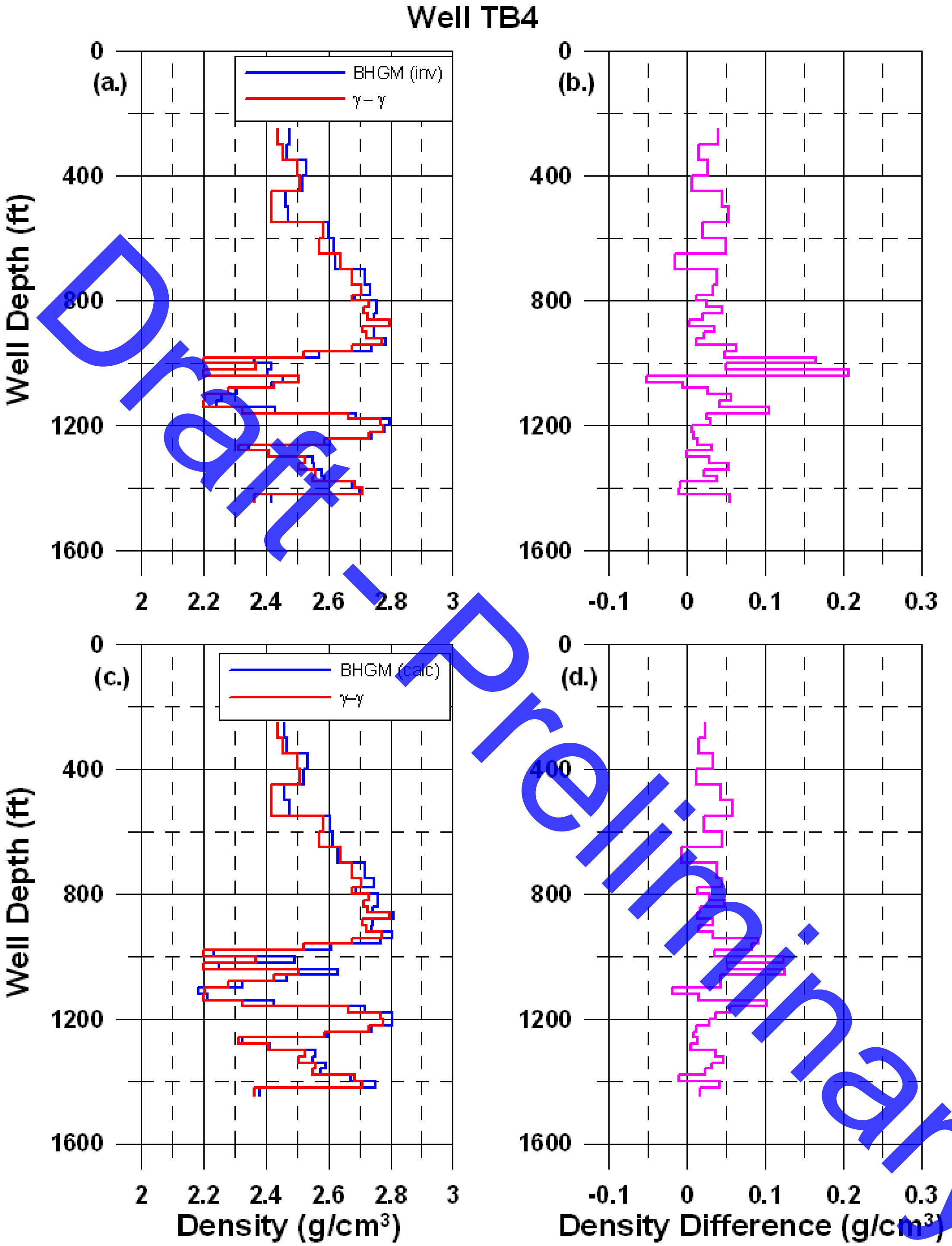


Figure C2. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB4. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

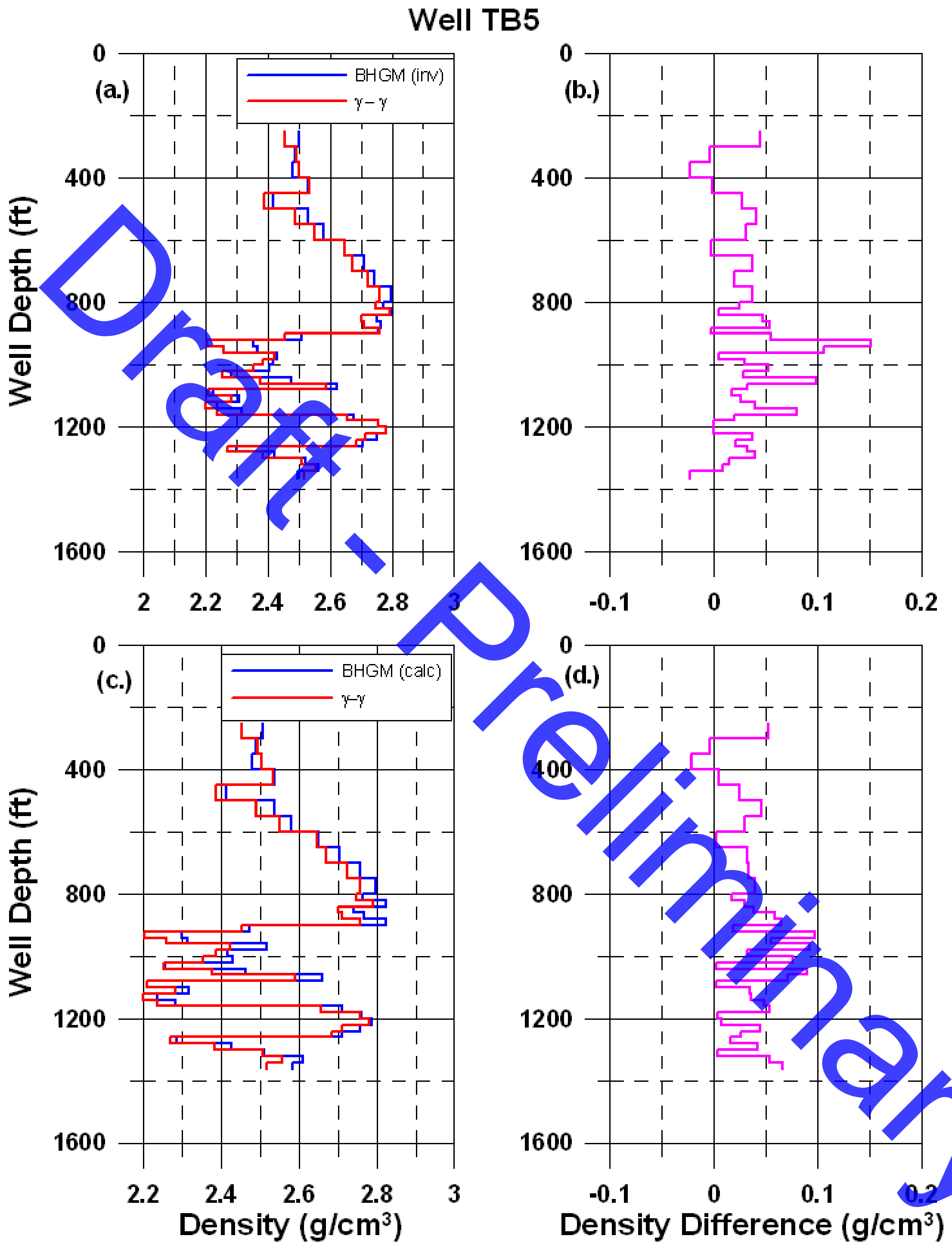


Figure C3. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB5. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

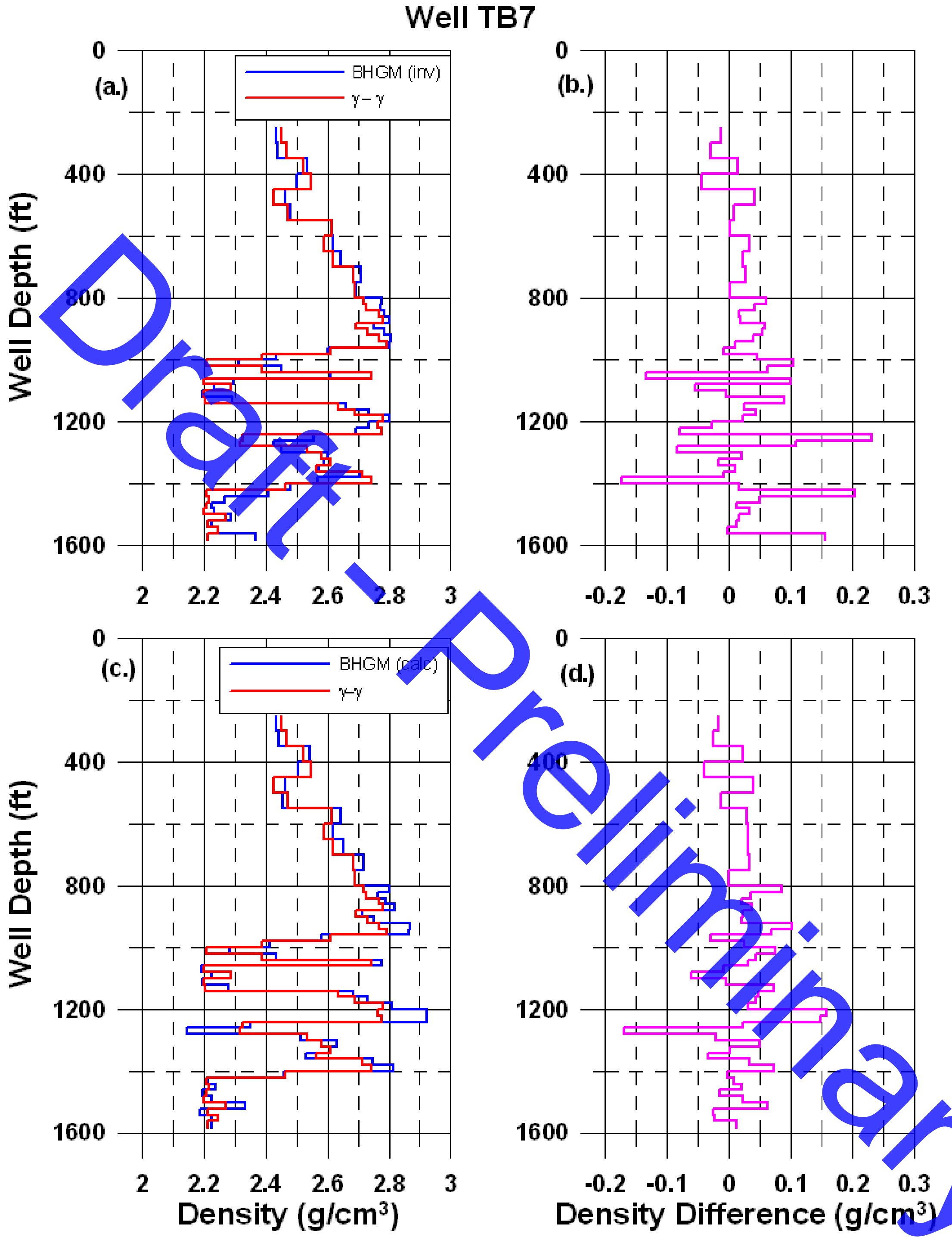


Figure C4. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB7. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

Appendix D: Apparent Density from BHGM, Gamma-Gamma Density, and Density Difference Plots for the X11 Survey Area

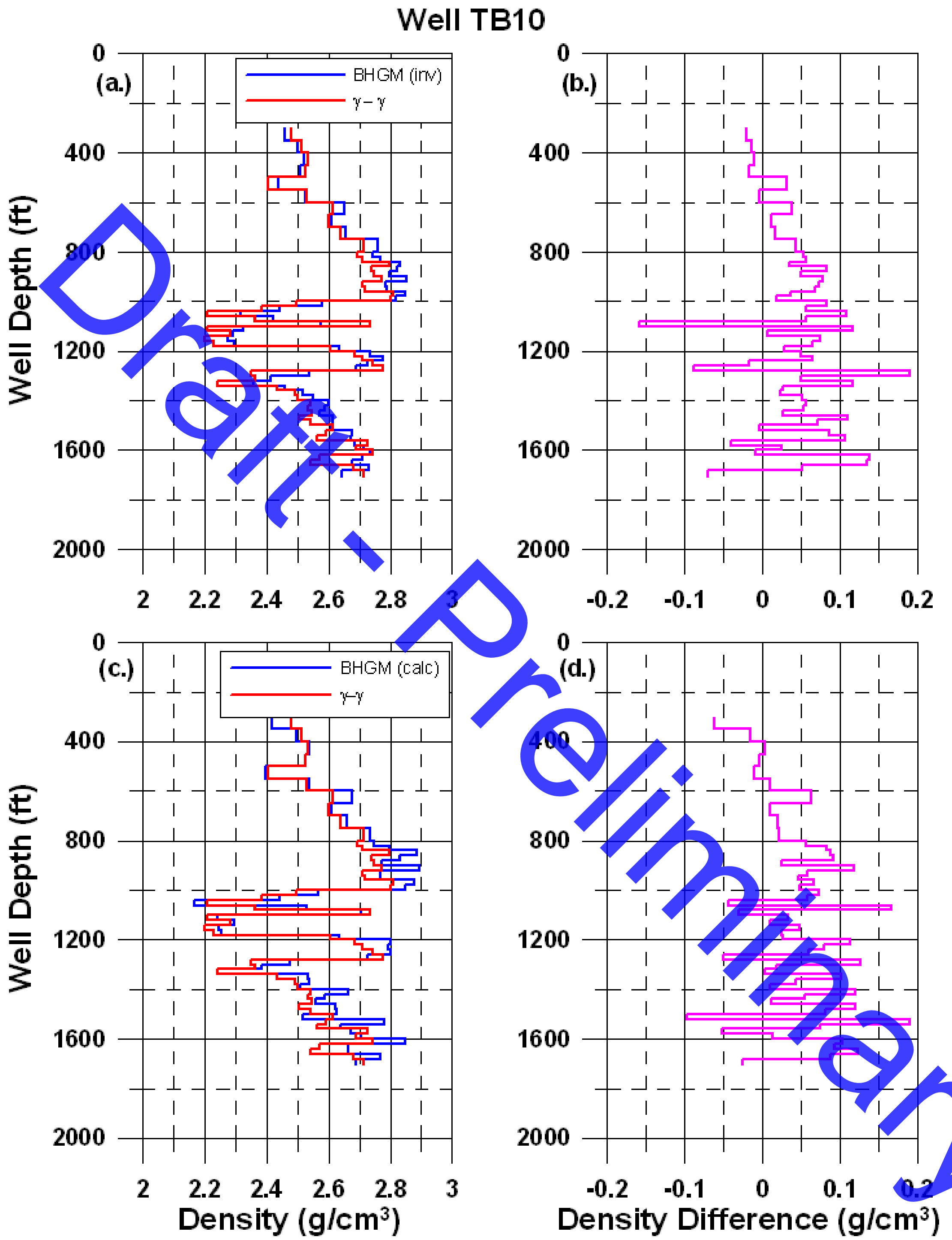


Figure D1. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB10. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

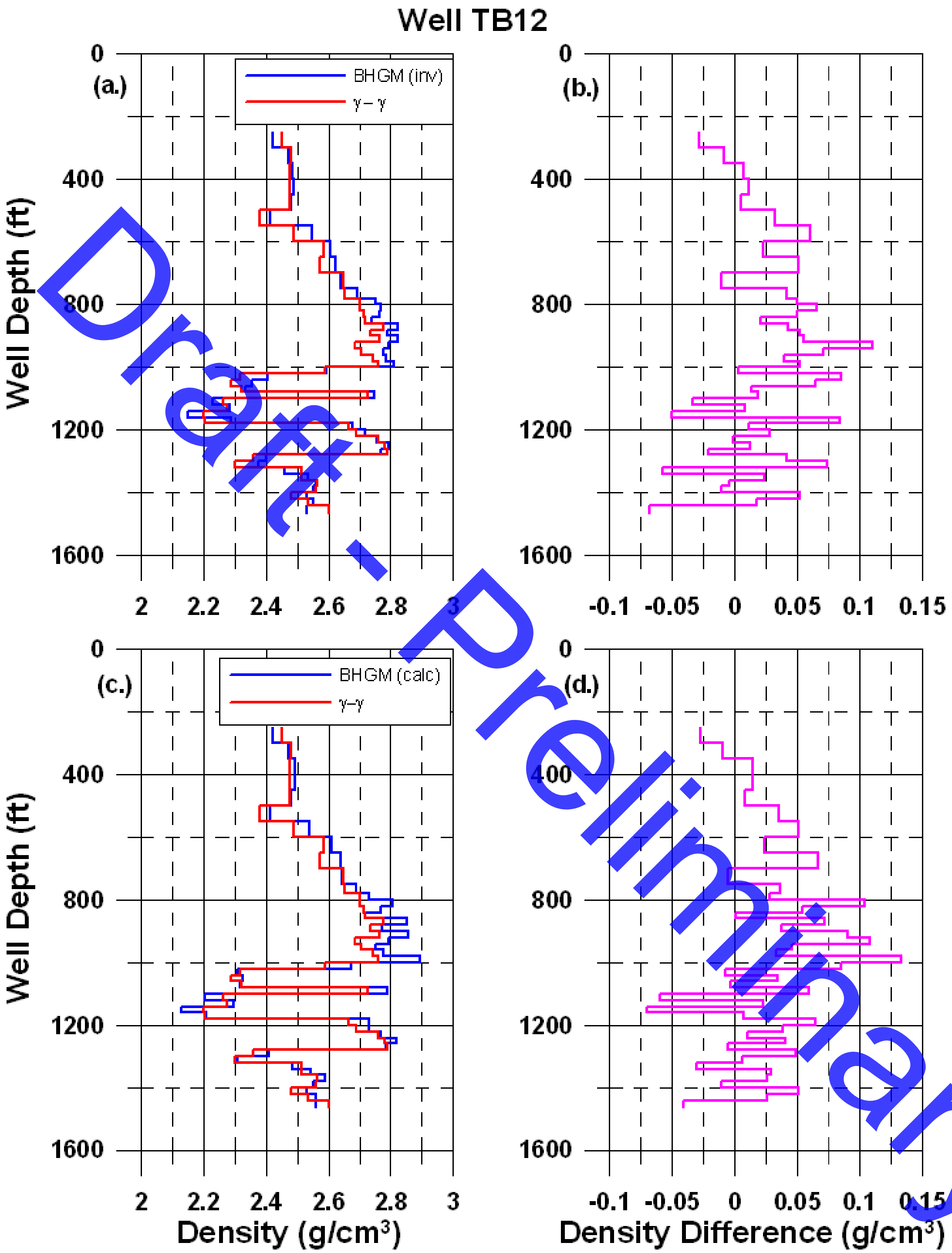


Figure D2. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB12. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

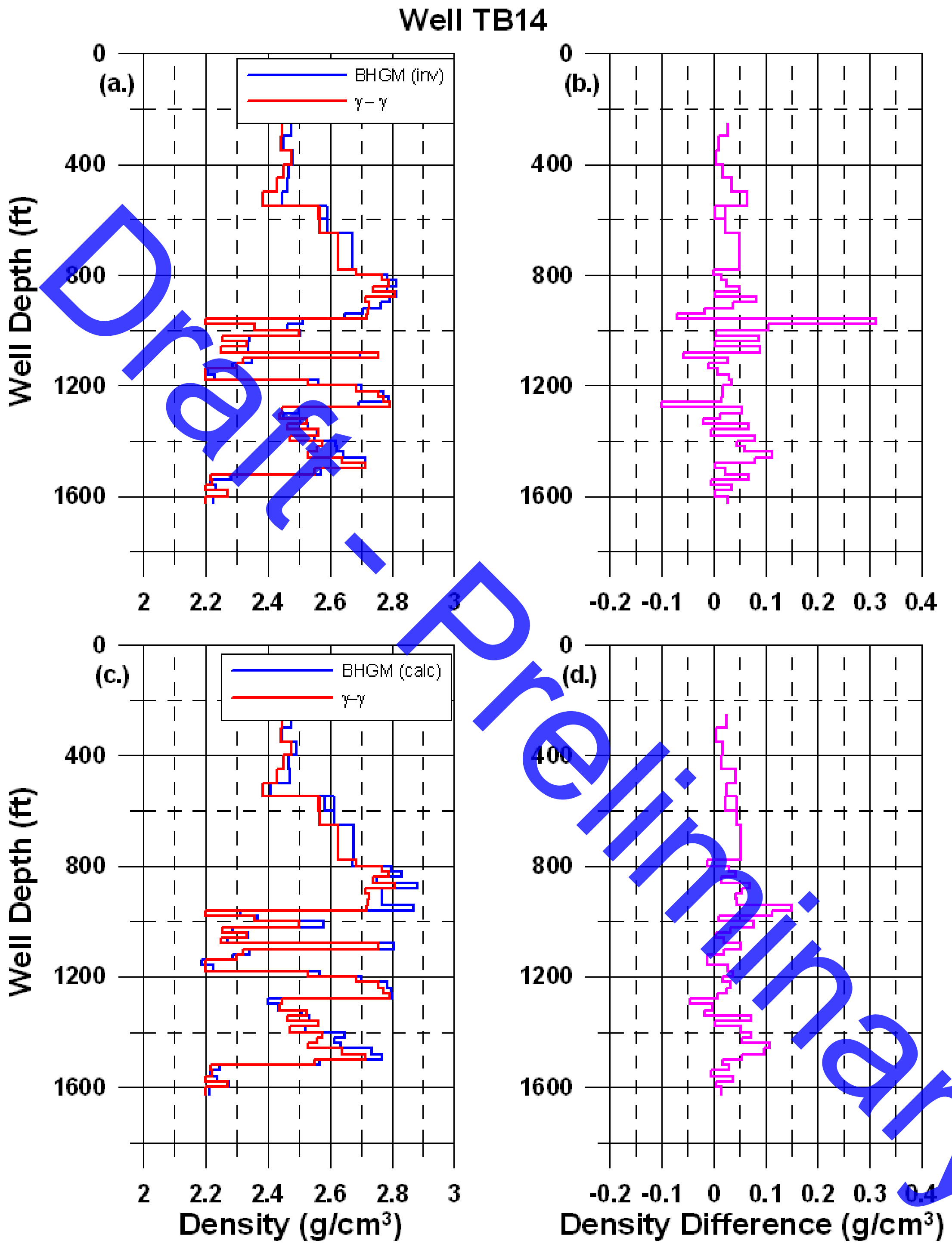


Figure D3. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB14. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

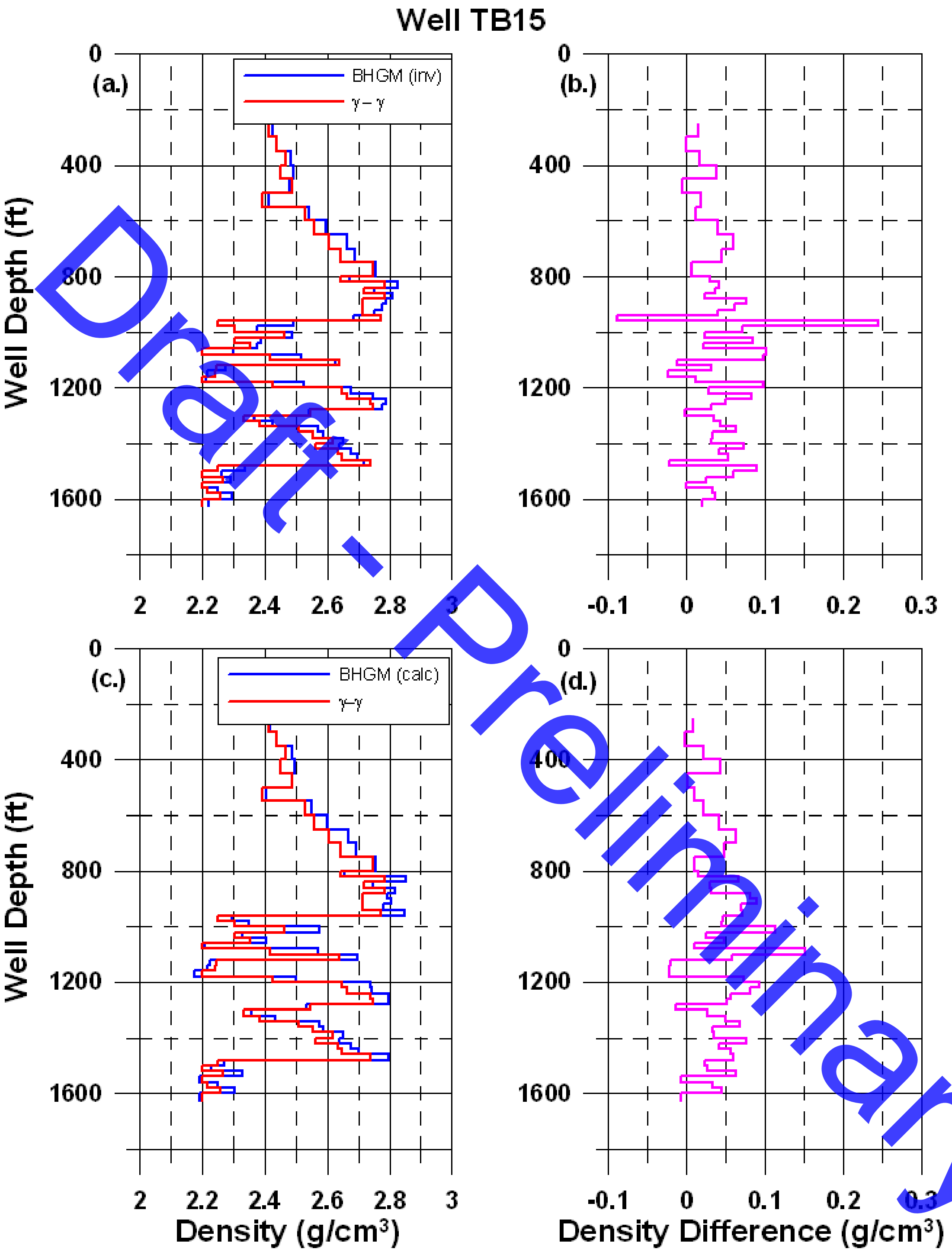


Figure D4. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB15. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

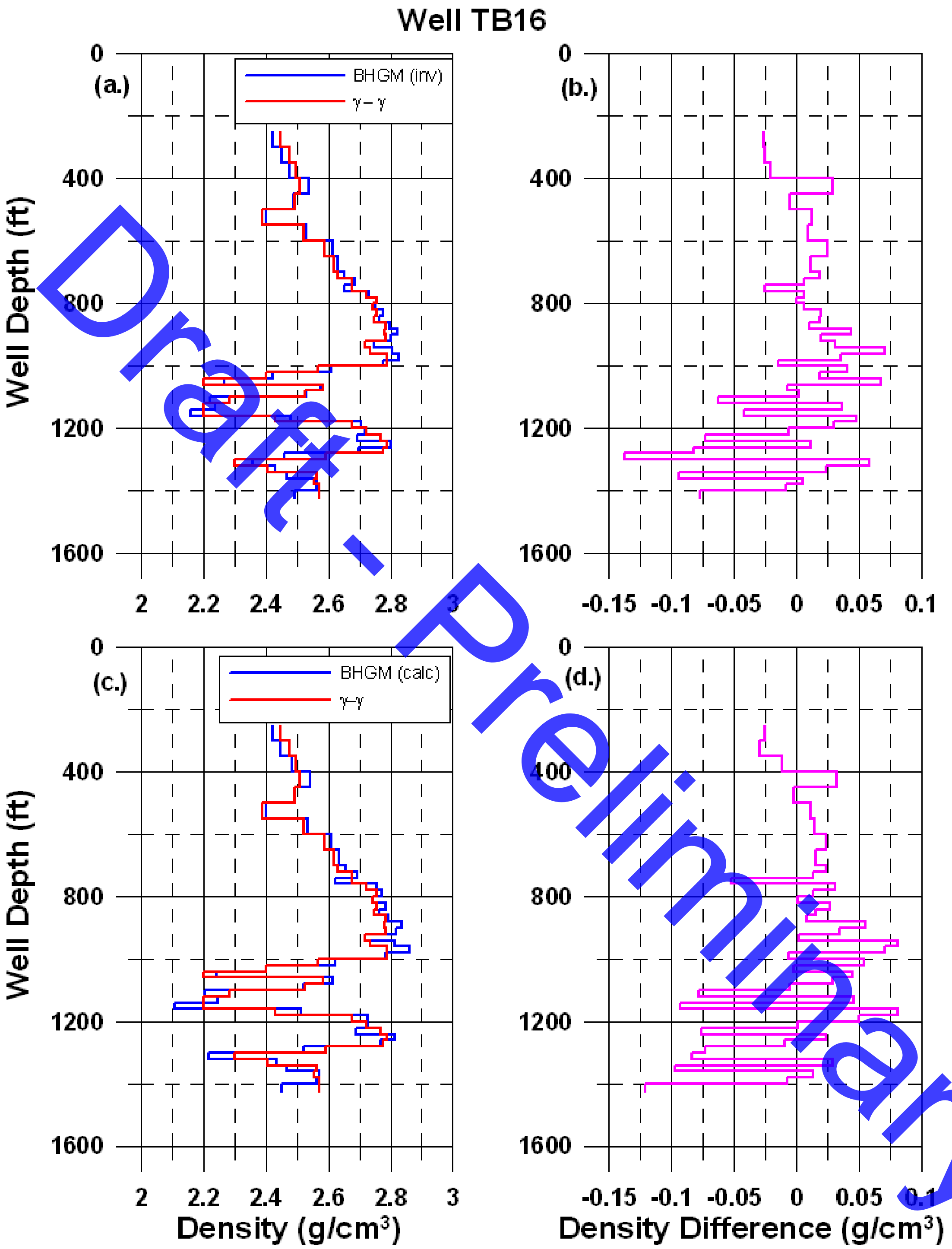


Figure D5. Apparent density and γ - γ density plots (a,c), and their corresponding density difference plots (b,d) for Well TB16. In (a) the apparent was calculated using the Microg inversion method (BHGM (inv)) and in (c.) the apparent density was calculated using the difference in observed gravity shown in the second column of Table A1 (BHGM (calc)).

Appendix E: Data Uncertainty

In interpreting the significance of negative and positive apparent density difference, one must evaluate the uncertainty in data. Assuming errors in the measurement of depth and the calibration of the borehole gravimeter are negligible, then the error in an apparent density ($\Delta\rho_a$) calculation in BHGM is controlled by (1) the uncertainty or precision of the gravity measurement (Δg), and (2) by the length of the vertical interval (Δz) between measurement and its uncertainty. The error in the apparent density ($\Delta\rho_a$) is found by taking the square root of the sum of the squares of the partial derivatives of Equation 1 and dividing by the number of measurements taken at a given level, i.e.

$$\delta\rho_A = \sqrt{\frac{(0.03913\delta\Delta g)^2 + ((3.68237 - \rho_B)\delta\Delta z)^2}{N\Delta z^2}}$$

where $\delta\Delta g$ is the error in the gravity differential, $\delta\Delta z$ is the error in the depth differential, and N is the number of repeated measurements at a measurement level.

Apparent density uncertainties shown in Appendices A and B show uncertainties associated with the Microg inversion process to be ~0.01 g/cm^3. However, as discussed in the text of this report, I have chosen to use Equation 1 to determine apparent densities for the different boreholes (the (c.) figure of Appendices C and D). As seen in Appendices A and B, uncertainty in observed gravity ranges from 1 to 97 microgals (0.001 to 0.097 mgal). These uncertainties translate to uncertainties of 0.001 to 0.095 g/cm^3 in the apparent density calculations. More importantly, to detect subsurface cavities whose size is of the order of 200-300 ft in diameter we should be able to resolve apparent density differences on the order of 0.01 - 0.02 g/cm^3 (difference between BHGM apparent density and Gamma-Gamma density). Table E1 below show the magnitude of the uncertainty in apparent density as a function of uncertainty in observed gravity for $\Delta z = 20$ (N = 4) and $\Delta z = 50$ ft (N = 2) where the error in $\Delta z = .08$ ft, a reasonable value for this study.

Table E1: Apparent density uncertainties.

	Δ = 20 ft	Δ =50 ft
Observed gravity uncertainty (mgal)	ρ_a uncertainty (g/cm^3)	ρ_a uncertainty (g/cm^3)
.005	.005	.003
.010	.010	.006
.015	.014	.008
.020	.020	.011
.025	.025	.014
.030	.029	.017
.035	.034	.019
.040	.039	.022
.045	.044	.025
.050	.049	.028
.055	.054	.030

Table E1 (con't.)

.060	.059	.033
.065	.064	.036
.070	.068	.039
.075	.073	.042
.080	.078	.044
.090	.088	.050

Appendix F: Rock Core Densities of B-salt from TB7

Table F1: Tabulation of Rock Core Density

Project Name:	Detroit River International Crossing Study						
Project Number:	15-050014-12						
Test Boring:	TB-7		Test Boring:	TB-7		Test Boring:	TB-7
Run:	51-11		Run:	52-5		Run:	52-6
Depth	1438.1-1441.0		Depth	1450.6-1453.3		Depth	1453.3-1456.3
Diameter (in)	3.941		Diameter	3.932		Diameter	3.940
	3.946			3.902			3.940
	3.960			3.930			3.934
	3.961			3.919			3.924
	3.955			3.930			3.936
	3.950			3.938			3.948
	3.953						3.944
	3.956						3.936
	3.965						3.955
	3.971						3.964
Average Diameter (in)	3.9558		Average Diameter (in)	3.925167		Average Diameter (in)	3.9421
Average Area (sq in)	12.29018		Average Area (sq in)	12.10057		Average Area (sq in)	12.2052
Length (in)	34.375		Length (in)	19.25		Length (in)	35.0625
Volume (cu ft)	0.244488		Volume (cu ft)	0.134801		Volume (cu ft)	0.247653
Weight (lbs)	32.587		Weight (lbs)	18.413		Weight (lbs)	33.365
Density (pcf)	133.2868		Density (pcf)	136.5941		Density (pcf)	134.7247
Density (g/cc)	2.14		Density (g/cc)	2.19		Density (g/cc)	2.16

Appendix I

Detroit River International Crossing Study
Stability of Solution Caverns in Salt
Rock Mechanics Investigation for Proposed Detroit River International Crossing

by Edward J. Cording
Dated October 2007

Stability of Solution Caverns in Salt

Rock Mechanics Investigation

for

Proposed Detroit River International Crossing

Prepared for NTH Consultants

October, 2007

Edward J. Cording

Savoy, IL 61874

1 Introduction and Summary

Presented in this report is an evaluation of the potential for instability or surface impacts from potential solution caverns at proposed Crossing Sites X-10 and X-11 on the Detroit side of the Detroit River International Crossing. Geologic conditions at the site were obtained from borehole geophysical logs and from core samples. Cross-well investigations provided information on the absence, or existence and geometry, of solution features at the site.

Prior to the field investigations at the two sites, available information on solution mining activity and surface subsidence and sinkhole formation in the Detroit-Windsor area was reviewed (Cording, May 27, 2006). Defined in the report were the horizontal stand-off distances at the ground surface from the edge of collapsed solution caverns beyond which there is no significant surface settlement.

In a second rock mechanics report (Cording, Dec 2006), a forward modeling effort was conducted prior to exploration at Sites X-10 and X-11 in order to evaluate the sizes of solution caverns that would be stable. The evaluation was based on the observed behavior of existing solution caverns in the salt formations in the Detroit-Windsor area, as well as on the results of a series of three-dimensional distinct element analyses for a brine-filled solution cavern with its roof located in the overlying bedded and jointed rock. Parametric analyses were conducted for cavern widths ranging from 100 to 500 ft and for a range of bedding plane spacings, vertical joint spacings, and rock stiffnesses. The results showed that brine-filled caverns with roofs of 100- to 300-ft-diameter would stabilize against the thicker rock layers present above the salt, and would not continue to propagate upward and would not cause any settlement or sinkhole formation in the rock conditions anticipated at Sites X-10 and X-11.

A primary objective of the forward modeling effort was to provide information on the size of caverns that were of concern for stability and therefore needed to be detected with the planned cross-well seismic analyses. Based on the results of the analyses it was anticipated that the cross-well investigation would be able to detect caverns that were much smaller than any cavern that would be potentially, or actually, unstable. It was recommended that the cross-well program be designed to sense caverns with widths greater than 100 ft.

The exploration program at proposed Crossing Sites X-10 and X-11 consisted of drilled rotary borings, downhole geophysical logging, core sampling, and cross-well seismic investigations. The results have shown that solution activity at the sites is either absent or very limited. The investigation confirms that the sites are not underlain by a brine-field with interconnecting solution caverns or galleries that could collapse, propagate,-and cause surface subsidence or sinkholes. The cross-well profiles did not show evidence of any large solution caverns. There were two cases in which there was evidence of small potential solution caverns, one with dimensions of 120 ft wide by 20 ft high, and one with dimensions of 170 ft by 10 to 20 ft high.

In Section 4 of this report, the three-dimensional distinct element method has been used to analyze the roof stability of a solution cavern with the geometry identified in the cross-well investigation and with the rock properties obtained from the borings and core samples at Sites X-10 and X-11. The results confirm that the maximum-sized solution cavern (120 ft to 170 ft in width) that could be present at the site will develop a stable roof in the bedded deposits above the salt and progressive roof collapse and propagation of a chimney toward the surface will not occur. In addition, the bulking analysis conducted in Section 5 of the report shows that, even if progressive roof collapse did occur, bulking of the rubble would fill the void and arrest the collapse zone well before it would approach the top of rock or cause surface settlement.

2. Investigation of Solution Caverns at Sites X-10 and X-11.

The field investigations show that solution activity at proposed Crossing Sites X-10 and X-11 is either absent or very limited. None of the borings at the X-10 and X-11 sites showed any evidence of cavities or solution features in or above the salt horizons, The cross-well investigation confirms that the sites are not underlain by a brine-field with interconnecting solution caverns that could collapse, propagate upward and cause surface subsidence or sinkholes. (In the Detroit-Windsor area, surface subsidence and sinkhole formation has only occurred above brinefields containing a series of wells, with pumping between wells forming large, interconnected caverns).

The results of the cross-well seismic profiles were used to establish the maximum size and geometry of potential solution features at the site. The borings for the cross-well seismic profiles, in combination with Vertical Seismic Profiling (VSP) profiles, and the 300-foot “clear zone” around the proposed primary bridge elements were laid out so that there would be no shadow zones in which a cavern greater than approximately 100 ft in width could be located.

The cross-well profiles did not show evidence of any large solution caverns. There were two cases in which there was evidence of small potential solution caverns.

One cross-well profile (BD, TB-6 to TB-4) revealed the possibility of a cavern in the F2 Salt Unit.. From the profile, the maximum size of the cavern is estimated to be 120 ft wide and 20 ft high. The BD profile also showed evidence of a narrower zone of solutioning below the cavern, which appears to be consistent with the morning glory shape that develops during solutioning within a single well. The location of the cavern on the profile is close to the possible location of a pre-existing salt well (Franklin-Swift Salt) identified by NTH in reviewing the history of Sites X-10 and X-11. According to available historical records, the Franklin-Swift

Salt company drilled the initial well in 1901 and produced approximately 73, 618, 53,939, and 16,662 barrels of brine in 1902 through 1904, respectively. Such a volume.is consistent with a small cavern having characteristics estimated from the BD cross-well profile.

The other case involves a small potential cavity in the top of the B-Salt adjacent to the TB-1 well, approximately 100 feet from TB-1 in the TB-1 to TB-6 and TB-1 to TB-4 profiles. From the cross-well profiles, the cavity is estimated to form a lens 170 ft in diameter and approximately 10 to 20 ft high, at the top of the B salt, with no evidence of solution features above or below the lens. The characteristics of the feature identified in the cross-well profile do not provide strong evidence that it is a solution cavity. The location of the feature is more than several hundred feet from any known salt producing well. Further, for wells operated in the early 1900's, brine was usually circulated along the well bore through several of the salt units, so that solution features were formed at multiple depths in F,D, and B Salt Units, whereas the cross-well profiles near the TB-1 well only indicate a thin lens in the B Salt. Additionally, the geophysical data indicates that the density within the potential cavity is greater than that of brine, as might be expected for a rubble-filled cavern. However, if the cavern were filled with rubble, the cross-well profiles should show that the cavern roof had broken up into the overlying bedded deposits, at least several tens of feet, rather than being limited to a thin lens at the top of the B Salt Unit.

In Section 3 below, the experience with existing caverns is assessed and used as a benchmark for evaluating the stability of the potential solution caverns at Sites X-10 and X-11 (Section 3)

The roof stability of the two features identified in the cross-well profiles has been analyzed, assuming that the features are open, brine-filled solution caverns. In Section 4, the results of a three-dimensional distinct element analysis (3DEC) are presented for solution caverns with widths of 125 ft and 175 ft, having roofs located in bedded deposits above the F2 and B Salt Units, respectively. Rock properties used in the analysis were determined from borings and core samples obtained at Sites X-10 and X-11. The analysis results are consistent with the observed behavior of existing solution caverns in the Detroit-Windsor area.

3. Stability of Existing Solution Caverns in Detroit-Windsor Area

Two types of solution caverns in the Detroit-Windsor area are described below: Case1, modern solution caverns in which a substantial thickness of salt is left above the cavern roof and, Case 2, solution caverns in which the roof is at the top of the salt, in bedded shale or dolomite (Case II). Roof stability is quite different for the two cases: For Case I, the internal pressure in the salt supports the cavern roof and has a stabilizing effect, whereas, for a roof consisting of rock layers containing joints (Case II), the brine pressure or gas pressure acts on all sides of potentially unstable rock blocks and rock layers in the roof so that the pressure does not aid stability. However, the buoyant effect of the brine does reduce the effective weight of the rock blocks and rock layers in the roof which improves stability compared to caverns which are not fluid-filled or which contain fluids (such as LPG) with lower densities.

3.1 Case I. Stable solution caverns with roofs in the B Salt.

In recent years, stable solution caverns 500 to 600 ft wide have been mined in the B salt, in the Detroit/Windsor area, leaving a roof of 50 to 100 ft of salt above the cavern. The cavern dimensions are monitored using sonar profiling. The roof of salt acts as confinement for the brine allowing the internal pressure of the brine in the cavern to support the salt and prevent collapse of the salt and the bedded deposits above the salt. This is the condition existing in modern brinefields where the location and volume of the solution caverns are measured and controlled. Surface settlements are small and can be predicted using elastic theory.

3.2 Case II. Caverns with roofs in bedded deposits at the top of the salt.

Early Caverns. In the Detroit-Windsor area in the early 1900's and through at least the early 1970's the solution zones created around the wells were not controlled or measured and therefore the extent and location of the solution zones in a given well, and between wells, was not mapped. It is known that, in many of the wells, fresh water was being injected through the annulus between the outer casing and inner casing and the outer casing was terminated in or near the upper salts (F & D Units). Therefore, solution activity was greatest in the upper salts where the fresh water was being injected. Further, water with the lowest brine content will sit on the top of the concentrated brine so that solutioning is most active at the contact between the top of the salt and overlying shale and dolomite layers. Solutioning also tends to extend laterally along and beneath thin shale and anhydrite layers. Thus, it is concluded that most of the older solution caverns extend to the top of the salt layers and have roofs that consist of bedded deposits such as dolomite and shale, as well as interbedded layers of anhydrite and salt.

For caverns with their roofs in the bedded deposits above the salt, the brine pressure acts along the rock joints (including horizontal joints along bedding planes) as well as on the surface of the cavern so that the brine does not provide a confining pressure to the rock on the cavern surface but only provides a buoyant force that reduces the weight of the rock blocks.

At Sites X-10 and X-11 on the Detroit side of the river, the NTH review of the history and ownership at the sites does not indicate any evidence of major brine field development beyond the Zug Island brinefield, although properties on portions of the sites were owned by salt companies in the early 1900's, and isolated wells may have been drilled. According to available records, the Franklin-Swift Salt company drilled an initial well in 1901 and produced approximately 73,618 barrels, 53,939 barrels, and 16,662 barrels of brine in 1902, 1903 and 1904, respectively.

Interconnection of wells began in about 1915 at the Wyandotte, Michigan brinefield and 1920 at the Sandwich, Ontario brinefield. At Sites X-10 and X-11, It is likely that any solution wells, if present, were operated as single wells. Much of the brine was likely to have been extracted from salt in the shallower F and D units, even though some wells in the early 1900's were drilled deeper. Evidence from Sandwich and Wyandotte indicates that early wells were drilled into the B salt and some solutioning of the B salt took place.

Recent Caverns. Data from sonar profiling of BP solution caverns used for storage of LPG at Windsor have been made available to the DRIC project. In one of the caverns, sonar surveys in 1972 showed that a 350 x 500-ft-wide cavern in the salt had its roof in bedded deposits at the top of the B Salt at a depth of 1360 ft. By 1980 the roof had broken up through interbedded shale, salt, and anhydrite above the top of the B salt forming a roof at a depth of 1280 ft that was approximately 100 to 150 ft wide. In 2002, the sonar survey showed that the cavern roof had not broken above the 1280 ft depth, but the flat part of the roof had widened to 350 ft. In this case, the bedded rock in the roof progressively slabbed and broke up 80 ft above the original roof, forming a pile of debris that raised the floor elevation approximately 20 to 30 ft. Part of the mechanism of fallout in the roof was likely related to solutioning of salt layers and vertical salt seams located in the bedded deposits above the roof, which created void space and also destabilized adjacent shale layers. Core samples obtained in bore hole TB-7 on the Detroit side of the river showed that vertical salt seams up to 4 in. thick were present over a height of 69 feet above the top of the B salt. If similar conditions exist above the roof of the BP cavern in Windsor, it would lead to the conclusion that additional solutioning along the vertical seams of salt may have been responsible for the loosening and fallout of roof slabs and the 80 ft break up of the roof. . Slabbing and progressive roof collapse should be expected in thin-bedded, weak rock, particularly when salt seams or interbeds are present. The roof will stabilize when a massive, thick bedded layer is encountered. The thickness of the bed required to stop the progressive failure is related to the cavern width.

The roof stability of a cavern filled with LPG is lower than the same-sized cavern filled with brine, because the density of the LPG is lower than that of brine. Further, rapid cycling of pressures in the cavern during extraction/insertion of LPG can cause differential pore pressures to develop in the roof that will affect local stability of the rock slabs and blocks in the roof. Thus, the experience with the 350-ft-wide LPG cavern provides a conservative estimate of stable spans for brine-filled caverns where the roof of the cavern intersects overlying bedded deposits.

It is concluded that stable spans are in excess of 300 ft for solution caverns with their roof in bedded deposits above the salt horizons.

3.3 Progression of failure above solution caverns.

In the Detroit-Windsor area, surface impacts from solution mining, in the form of large settlement sags and sinkholes, have occurred only in older brinefields after solution caverns became interconnected between wells and brine was being produced by pumping across the brinefield, between injection and recovery wells. For the brinefields developed in the Detroit-Windsor area prior to 1970, there was little control on the size and location, vertically and laterally, of the solution zones. Major surface impacts occurred in three of the major brinefields during solution mining, or within a few years after solution mining activities had ceased. Surface subsidence developed in the Wyandotte brinefield and both surface subsidence and large sinkholes developed in the Pt. Hennepin, and Sandwich fields

In order for large settlement sags and sinkholes to form, a series of events must occur, beginning with local roof failures above the solution caverns and continuing with progressive chimneying of collapse zones through the overlying bedded rock toward the surface. The overlying rock layers sag not only as a result of the loss of support above the voids formed by solution caverns and collapse zones but also as a result of compression of the salt pillars remaining between multiple solution caverns. The surface sags that developed at the North and Central galleries at Point Hennepin, at Sandwich, and at Wyandotte, Michigan extended over the full area of the brinefields, indicating that extraction ratios were high enough to cause high stresses in the intervening salt pillars, with consequent compression or collapse of the pillars.

The following four conditions summarize the range of behavior of solution caverns, from individual stable caverns to multiple caverns in brine fields with large surface subsidence and sinkholes:

a. **Cavern span is small enough that there is no loosening, overbreak or collapse in the bedded deposits above the roof.** The thickness of the beds in the immediate roof largely determines the span that will be stable. The 3DEC analysis has been used to estimate the stable cavern spans for different bedding thicknesses and joint spacings.

b. **Cavern roof is stable against a thicker bed.** Local overbreak and fallout of blocks occur in the roof of the cavern where rock is thinly bedded and shaley or where spans reach distances that allow sag and tension in the immediate roof. Loosening and fallout of blocks progresses above the roof until a thicker bed is encountered. Often, a stepped (corbelled or arched) roof surface forms. The roof may stabilize or blocks may continue to fall out, widening the roof until a flat roof is again formed. Loosening and fallout of blocks progresses

above the roof until a thicker bed is encountered. Cavern span is related to thickness of the bed and can be analyzed as in Case 1.
As shown in the three-dimensional distinct element analyses in Section 4 of this report, 120-ft- to 170-ft-wide brine-filled solution caverns in the salt will be stable with bedding thicknesses of 2 to 3 ft in the roof of the cavern.

c. **Bulking arrests collapse zone.** As above, but cavern span is large enough that roof does not stabilize against thicker beds. Progressive collapse zone continues upward until bulking of the rubble fills the void and arrests further upward movement. As noted in b, above, the roof of the 120- to 170-ft solution caverns will be stable so that progressive failure and chimneying will not occur. However, as shown in Section 5 of this report, if progressive roof collapse were to occur, bulking of the rubble would fill the void and arrest the collapse zone well before it would approach the top of rock.

d. **Collapse zone progresses to surface.** As above, but bulking is not sufficient to arrest the collapse zone. The collapse zone continues to extend upward through shallower rock layers until a sinkhole forms. This condition will not occur for solution features existing at proposed crossing Sites X-10 and X-11. In Section 5, Table 5.1 indicates that cavern dimensions of the order of 300 to 800 ft are required to allow the collapse zone to extend to the surface. In the Detroit-Windsor Area, the sinkholes only formed after significant surface sags had developed over most of the area of the brinefield. At Sites X-10 and X-11, on the Detroit side of the river, there is no evidence of significant solutioning extending across the site and no evidence of the presence of a brine field with interconnected solution caverns that could cause surface sags and sinkholes to develop.

4. Distinct Element Analyses of Cavern Roof Stability

Three-dimensional distinct element analyses of roof stability of solution caverns have been performed using the computer program 3DEC. The analyses were conducted under the writer's direction by Dr. Joung Min Oh, who is experienced in developing constitutive models for three-dimensional distinct element numerical analyses and in conducting analyses and applying the results to rock engineering projects.

The method allows modeling of a three-dimensional rock mass containing rock blocks bounded by joints and bedding planes. The rock blocks are deformable and their contact surfaces are assigned strength and stiffnesses equivalent to the properties of rock joints and bedding planes. The blocks are capable of large displacements, including sliding, separating, and falling..

The model consists of a single solution cavern located within a salt layer having no rock joints or bedding planes. The roof of the cavern is located at the top of the salt, against rock layers with horizontal bedding planes and vertical joints. The cavern shape in plan is square. This produces some conservatism in the results, since a square cavern of a given width will have a lower factor of safety against roof failure than a circular cavern having the same width.

The analyses provide information on the initiation of fallouts in the roof and the stabilization that occurs for the bedding thicknesses and joint spacings existing in the rock above the salt units.

The pressure and density of the brine were modeled in the solution cavern, as well as along the vertical joints and horizontal bedding joints in the bedded deposits above the salt. Thus, in the immediate roof of the cavern, brine pressures act on the bedding joints above the rock slab as well as on the surface of the cavern roof so that the pressures on both sides of the rock slab are nearly balanced and the internal pressure is not effective in holding up the rock slab. However, both in the field and in the numerical model, the density of the brine creates a buoyant effect that reduces the effective weight of rock slabs in the roof, thereby improving stability from that of a cavern that has no internal fluid pressure.

Forward modeling analyses were conducted prior to the field investigations, and post field investigation modeling was conducted using rock properties and cavern dimensions obtained from the field data.

4.1 Forward modeling with Distinct Element Method, May 2006

4.1.1 Forward modeling assumptions

Prior to the field investigation, a parametric study was conducted using 3DEC for a range of solution cavern widths. Four cavern widths were evaluated: 100, 300, 400, and 500 ft.

The analyses were conducted using a cavern depth equivalent to the depth of the B salt, but similar results were expected for the shallower D and F salt layers.

Parameters for the base case included the following:

Joint and bedding strength:

Bedding, first 20 ft above roof: shale, $\phi_{\text{peak}} = 25^{\circ}$, $\phi_{\text{residual}} = 20^{\circ}$.

Vertical joints and bedding above 20 ft: $\phi_{\text{peak}} = 40^{\circ}$, $\phi_{\text{residual}} = 35^{\circ}$.

Young's modulus of rock above the cavern roof:

$E = 2.5 \text{ x}10^{8}$ psf $= 1.7 \text{ x } 10^{6}$ psi

Joint stiffness:

$K_n = 1.7\text{x}10^{8}$ psf/ft

The Young's modulus of the rock above the cavern roof represents the stiffness of the rock and any other fractures located between the joints that are modeled in the program.

Cases were run using different joint and bedding plane spacings. Continuous vertical joint spacings were 50 ft and 25 ft in both directions. Bedding plane spacings above the roof of the solution cavern were typically 2, 5, and 10 ft. The lateral earth pressure coefficient, K_o, which is the ratio of in-situ lateral stress to vertical stress, was usually assumed to be 1, some cases were run with $K_o = 2$.

4.1.2 Summary of forward modeling results.

In Table 4.1 the extent of the failure zone is summarized, "Y" indicating fallout of rock and large displacement, "N" indicating a stable roof with small displacements, "SL" indicating some loosening without fallout.

Table 4.1 Summary of forward modeling analyses of cavern roof stability

Case	Cavern width,ft	Bedding spacing, ft		Joint spacing, ft	Other	Extent of failure: (**Y**es, **Sl**ight, **N**o) max displacement, ft		
		0-50' above roof	50-100' above roof			Roof	20 ft above roof	50 ft above roof
3	300	2	10	50	E = 1/3 E_{base}	Y	Y 5'	N 0.5'
3	100	2	10	50		Y	Y 3.5'	N 0.1'
3	500	2	10	50		Y	Y	Y
4 Sec BB	300	2	5	50		N 0.6'	N 0.5'	N 0.2'
4 Sec AA	300	2	5	50		SL 1.2'	N 0.5'	N 0.2'
5	300	5	10	25		SL 1.9'	N 0.4'	N 0.3'
5	100	5	10	25		SL 1'	N 0.05'	N 0.03'
5	400	5	10	25	K_o = 2 ϕ_{shale}= 35/30	N 0.8'	N 0.7'	N 0.5'
8	500	20, 30	50	25		N 0.7'	N 0.7'	N 0.4'
9	300	2	10	25		Y	Y 14'	SL1.1'
9	400	2	10	25	K_o = 2 ϕ_{shale}= 35/30	Y	Y 7.8'	SL1.3'

In summary, the forward modeling analyses showed that the 100- and 300-ft-diameter caverns were stable, but, for the 2-ft bedding plane spacing, some blocks loosened and fell out of the roof. For the 5-ft bedding plane spacing, there was no fallout of blocks for the 100-ft-diameter cavern, and only local fallout for the 300-ft-diameter cavern.

4.2 Modeling of observed site conditions at Sites X-10 and X-11

4.2.1 Observed site conditions

The field investigations, including drilling, core samples, downhole geophysical logging, and cross-well seismic investigations, have provided extensive information on the rock characteristics and the presence, or absence of solutioning and solution caverns at the site.

From drilling records and downhole geophysics, there is no evidence of open solution features in any of the drill holes placed at Sites X-10 and X-11. (Drilling of additional solution wells during operation of the old Windsor brinefield in the Detroit-Windsor area showed the presence of open voids in all the additional wells, which were drilled approximately 500 ft from existing wells.

The cross-well profiles did not show evidence of large or interconnected solution caverns at either the X-10 or X-11 sites. At two locations, the profiles showed evidence of possible solution features which were 10 to 20 ft thick. The features were 120 and 170 ft in with, at the top of the F2 and B salts, respectively. These are the cavern widths that have been modeled in the 3DEC analyses conducted after completion of the field investigation.

4.2.2 Geologic profile

Extensive information on the distribution and properties of rock formations across the sites was obtained from downhole geophysical logging of all borings and from the cross-well profiles. Core samples retrieved from two borings have provided information on joint and bedding plane spacings and properties and on rock strength and stiffness. Core was obtained from the full length of boring TB 7 and from selected zones in boring TB 11. The properties of the rock above the salt layers were of particular interest for evaluating stability of the solution cavern roof.

Table 4.2 summarizes the geologic profile from Boring TB 7 and Table 4.3 shows the profile in the Salina Formation, which includes the salt units, below a depth of 877 ft in Boring TB 7.

Table 4.2 Summary, Core Boring TB-7

Depth, ft	Unit	
	Soil	
95.3	DUNDEE LIMESTONE	
140	DETROIT RIVER GROUP: Lucas	
380	Amherstberg	
455	SYLVANIA SANDSTONE (Detroit River Group)	
523.1	BOIS BLANC	
601	GARDEN ISLAND SANDSTONE	
606	BASS ISLANDS	
877	SALINA GROUP	
	Groups G through A	

Table 4.3 Salina Formation, Core Boring TB-7

Depth, ft	SALINA FORMATION	Salt Thickness
877	SALINA G UNIT	
877	Shale	
882	Dolomitic Shale	
908	Shale	
930.4	Shaley Dolomite, Dolomite	
967.1	Anhydritic Dolomite	
970.6	Shale	
978.5	SALINA F UNIT	
978.5	F4 Halite	F4:10’
989	Dolomite	
1003	F3 Halite	F3: 29’
1031.8	Dolomite	
1061.6	F2 Halite	F2: 20’
1082	Dolomite	
1091.3	F1 Halite	F1: 50’
1142	SALINA E UNIT	
1142	Dolomite	
1171	Shaley Dolomite, Dolomite	
1201	Shaley Dolomite	
1206.3	Dolomite	
1242	SALINA D UNIT	D: 10’
1242	D Halite	
1252	Interbedded Salt and Dolomite	
1259.7	Dolomite, Shaley Dolomite	
1270	SALINA C UNIT	
1270	Shaley Dolomite	
1291	Shale and Shaley Dolomite	
1320	Halite and Dolomitic Shale	
1351	Shaley Dolomite, vertical salt seams	
1376.4	Dolomitic Shale	
1378	Shaley Dolomite	
1392.2	Dolomite, Shaley Dolomite	
1393.6	Dolomite	
1410.6	SALINA B UNIT	
1410.6	Dolomite, Shaley Dolomite	
1413	B Halite, occasional shaley dolomite stringers	B: >57’
(1426, 1447)	1 to 2’ Shaley Dolomite seams	
1470.5	End core boring	

4.2.3 Properties of rock and bedding above salt layers

Bedding plane thickness Core was placed in 3-ft-long boxes. From my inspection of all the core and the photographs of the core, it is concluded that in the rock above the salt units, breaks along bedding planes were typically 1 to 3 ft apart, with some shorter pieces (3 ft is the maximum length of the boxes in which the core is stored). RQD values and core recovery were near 100%. Some of the breaks were pre-existing bedding plane joints, some were caused by drilling and by placement in the 3-ft-long boxes. It is concluded that bed thicknesses of 3 ft or more are present close to the top of the salt units.

F Salt. Four to six layers of F salt were identified from the downhole geophysical logging. In Borehole TB-7, layers F1 through F4 were present, as shown in Table 4.3 Roof conditions above the F2 salt consisted of 30 ft of a fine grained to amorphous dolomite, laminated bedding, with occasional anhydrite nodules. Breaks along bedding were typically in the range of 1 to 3 ft, with some 6 in. pieces of core.

D Salt. Two to three layers of D Salt were identified in the downhole geophysical logging: In borehole TB-7, layers D3 and D2 were present. Roof conditions above the D-Salt typically consisted of approximately 100 feet of amorphous to fine grained dolomite, laminated to massive bedding, with occasional anhydrite interbedding. Breaks along bedding were typically in the range of 1 to 3 ft.

B Salt. The roof above the B Salt consists of dolomite and shaley dolomite. Vertical veins of red-orange halite extended 69 feet above the top of the B salt, from a depth of 1411 ft to a depth of 1342 ft.

4.2.4 Rock stiffness

Unconfined compression tests (Earth Mechanics Institute, Colorado School of Mines, June 5, 2007) provided information on the Young's Modulus of the intact rock. The range is 2.6 to 11.1 million psi, and most of the results are between 4 and 7 million psi.

4.2.5 Rock joints

In Core boring TB -7, steeply dipping joints were absent over almost the entire core run below the bottom of the Amherstburg Formation of the Detroit River Group from a depth of 455 ft to the bottom of the hole at 1471 ft. Steeply dipping joints were also absent in the sections cored in Boring TB-11. The exception was at one location in boring TB-7, at a depth of 580 to 590 ft in the Bois Blanc Formation, where a very irregular near-vertical joint was present. The irregularity indicates that the joint has very high shear strength and dilatancy. (Dilatancy is the tendency of a rock joint surface to ride up over irregularities as it is sheared, which contributes to joint shear strength and causes interlocking of joints.)

It is not possible to obtain an accurate measurement of the spacing of near-vertical joints from vertical core holes. However, the absence of all but the flat-lying bedding joints over 1000 vertical ft of core leads to the conclusion that high-angle joints are widely spaced. Assuming that the high-angle joints have a vertical spacing in the core of approximately 500 ft and that they have a dip within 5 to10 degrees of vertical, then the horizontal spacing would be on the order of 40 to 80 ft: (1/6 to 1/12) x 500 ft = 40 to 80 ft).

4.3 Model assumptions (post-field investigation)

The 3DEC analyses were performed using the cavern widths determined from the cross-well investigation and rock properties determined from the core borings and lab testing. The cavern was assumed filled with brine and bedding and vertical joint planes were also assumed to have fluid pressures equivalent to those of a head of brine.

Rock properties and geometry selected for the base cases were as follows:

Cavern width:	120 and 125 ft	175 ft
Depth to cavern roof:	1100 ft	1400 ft
Vertical joint spacing:	25 ft and 40 ft	
Bedding spacing:	1, 2, 3, and 4 ft, as shown on profiles	
Young's Modulus of rock:	$E_{rock} = 4 \times 10^6$ psi	
Young's Modulus of salt:	$E_{salt} = 1 \times 10^6$ psi	
Vertical joint normal stiffness:	$K_n = 1.7 \times 10^8$ psf/ft	
Vertical joint shear stiffness:	$K_s = 1.7 \times 10^7$ psf/ft	
Vertical joint friction angle:	peak: 45^o, residual: 35^o,	
Bedding joint normal stiffness:	$K_n = 1.7 \times 10^7$ psf/ft	
Bedding joint shear stiffness	$K_s = 1.7 \times 10^6$ psf/ft	
Bedding friction angle:	peak: 35^o, residual: 30^o,	
Lateral earth pressure coefficient:	$K_o = 1$, $K_o = 2$	

In several analyses, one of the rock properties was changed from the base case, as indicated in the summary for that case.

Results of the roof stability analyses are presented in the figures in Appendices A and B. They show that 120-ft- and 170-ft-wide solution caverns may have local roof failures when beds are 1 to 2 ft thick. The roof will stabilize against layers when their thickness reaches 2 to 3 ft. The thinner 2-ft beds are stable when vertical joints are irregular and have high dilatancy or are non persistent and offset between layers.

The core information shows that beds of 2 to at least 3 ft thickness exist above the F, D, and B salt units at the site. Vertical joints are widely spaced and irregular. It is therefore concluded that any solution caverns present in the X-10 and X-11 sites will stabilize against a thick-bedded roof layer and not be subject to progressive failure and collapse and chimneying above a solution cavern in the salt.

Seismic effects during earthquakes will not have a significant effect on roof stability. For the Detroit area, maximum horizontal accelerations are 6% g for a 2% probability at 500 years. (USGS, 2005) and vertical accelerations would be smaller. Thus, applying the vertical acceleration in a pseudo-static analysis would result in only a small increase in the weight of the blocks in the roof, a parameter variation less significant than other parameter variations used in the analyses.

5. Evaluation of Caving and Bulking Above a Solution Cavern.

From the field investigation, the review of the behavior of existing solution caverns in the Detroit-Windsor area, and the analyses of roof stability, it is concluded that solutioning at the X-10 and X-11 sites is limited or absent, and any potential solution features that could be present, whether detected or whether smaller than the detection capabilities of the cross-well surveys, will be stable with only local roof collapse and will not propagate toward the surface and will not cause any surface subsidence or sinkholes.

However, another way to evaluate the potential impacts of solution caverns at the X-10 and X-11 sites is to assess the maximum distance a caved zone could extend above a solution cavern, assuming that the roofs above the caved zone do not stabilize. In this case, as caving progresses, the caved rock will fall into the cavern and bulk --- form a pile of rubble whose volume is greater than the in-place volume of the rock. If the bulked rubble fills the cavern as caving proceeds, it will support the roof and arrest further caving and upward chimneying.

In order for a sinkhole to form at the surface, a chimney must advance from the level of the solution cavern to the surface. The cavern must be wide enough and high enough that the bulked rubble does not fill the chimney and arrest the collapse before the chimney reaches the top of rock.

As described in this section, for the small potential cavern volumes and large depth to the salt at the X-11 and X-12 sites, bulking would arrest the progression of the chimney long before it approached the top of rock, so that there would be no subsidence or sinkhole formation.

5.1 Observed sinkholes in Detroit-Windsor area.

The sinkholes that formed at the surface above the old brinefield at Sandwich (Windsor) had dimensions of 350 x 450 ft. Above the Central Gallery brinefield at Point Hennepin (Grosse Ile) the sinkhole width was 150 x 450 ft with a satellite sinkhole 200 ft in diameter. At the North Gallery, a sinkhole 100 ft in diameter and 100 ft deep formed. At Point Hennepin, the soil cover over the rock is thin, so that the sinkhole width at the surface is likely to be close to its width near the top of rock.

In order for chimneying to progress through thick-bedded zones in the rock formations at the site, it is expected that chimney spans would have to be well in excess of 100 ft. Table 5.1 summarizes relationships between the size of the solution cavern and the size of the chimney, for low and high bulking factors. It is assumed that bulked material can fill the full volume of the solution cavern and chimney and that the solution cavern and the chimney are cylindrical. If the solution caverns have a morning glory shape, consistent with well development in the early 1900s, then the height of the solution cavern would be several times larger than the height shown for a cylinder in order to create a cavern of the same volume. Table 5.1 shows that solution caverns with cylinder heights of 75 to 100 ft (equivalent to a total height of approximately 225 to 300 ft for several morning glory shaped caverns) would have to be in the range of 300 ft to 800 ft wide to accommodate the bulked collapse material coming from a 200 to 300-ft-wide chimney.

Table 5.1 Solution cavern size related to bulking of collapsed rock and chimney propagation

	Bulking Factor		Bulking Factor		Bulking Factor		Bulking Factor	
	1.2	1.5	1.2	1.5	1.2	1.5	1.2	1.5
Chimney Height	1000 ft		1000 ft		1000 ft		1000 ft	
Chimney Width	200 ft		300 ft		200 ft		300 ft	
Cavern Height	100 ft (cylinder), ~ 300 ft (morning glory)				75 ft (cylinder) ~ 225 ft (morning glory)			
Cavern Width	283’	447’	424’	670’	327’	516’	490’	775’

The sinkholes that formed at Sandwich and Point Hennepin were located in brinefields in which solution caverns were interconnected between several wells. Over the years, in the original brinefield at Sandwich, drilling of additional wells 500 ft from existing wells encountered voids, indicating that widespread solutioning extending 500 ft from wells had already occurred. It is possible that the sinkholes were the result of collapse above several large solution caverns, or above a solution cavern with large solution channels extending to caverns in adjacent wells.

5.2 Potential for Chimneying of 120- to 170-ft-wide caverns.

In Tables, 5.2 and 5.3, the cavern dimensions are those that were estimated from the cross-well surveys. The tables show the chimney heights that would develop before bulking would fill the small caverns with rubble and arrest further caving.. In both cases, it is assumed that the cavern roof is not thick enough to stop progression of the caving. In actual fact, the evidence from analysis and the experience with existing solution caverns shows that the roofs of chimneys ranging from 80 to 170 ft in width will stabilize against thicker beds in the shales and dolomites existing above the salt beds. Thus, the bulking analysis does not indicate the conditions that have or will occur for these small caverns. Rather, it provides an added degree of conservatism in the evaluation of the potential for surface subsidence and sinkhole formation for small caverns of the dimensions indicated from the cross-well investigations.

Table 5.2 summarizes the height that a chimney would propagate from a 120-ft-wide cavern, for different cavern heights. The 120-ft-width and 20-ft height of the cavern were estimated from the cross well profile BD, and is the approximate thickness of the F2 salt unit at that location. Other cavern heights are also shown in the table and indicate that bulking would arrest the collapse, if no stable roof formed above the cavern.

Table 5.2 Height of collapse zone, in ft
for a 120-ft-wide cavern, assuming roof is not stable

Chimney Width		120 ft (same as cavern)		80 ft*	
Cavern Ht, ft	Bulking Factor	1.2	1.5	1.2	1.5
10		**50**	**20**	**113**	**45**
20**		**100**	**40**	**225**	**90**
40		200	80	450	180
60		300	120	675	270
80		400	160	900	360
100		500	200	1125	450

*Note: The roof of an 80-ft-wide chimney will be more stable than the roof of a 120-ft wide chimney and therefore less likely to propagate upward. However, in this bulking analysis it is assumed that the roofs are not stable. The smaller-diameter chimney will have to propagate further upward in order for the bulked rubble to fill the 120-ft-wide cavern.

**Estimated height of 120-ft cavern, from cross well results.

For the geometry estimated from cross-well profile BD (cavern width: 120 ft and cavern height of 20 ft), the chimney height for a 120-ft-wide chimney is 40 to 100 ft for a bulking factor of 1.5 to 1.2, respectively. The chimney height for an 80-ft-wide chimney is 90 to 225 ft for a bulking factor of 1.5 and 1.2, respectively.

In Table 5.3, the chimney heights are analyzed for a 170-ft-wide cavern, which was estimated from cross-well profiles to be located at the top of the B salt and to be 10 to 20 ft thick. The ratios of cavern width to chimney width and the bulking factors were the same as those used in Table 5.2. The resulting chimney heights for the 170-ft-wide cavern are the same as those that were obtained for the 120-ft- wide cavern.

Table 5.3 Height of collapse zone, in ft
for a 170-ft-wide cavern, assuming roof is not stable

Chimney Width		170 ft (same as cavern)		113 ft	
Cavern Ht, ft	Bulking Factor	1.2	1.5	1.2	1.5
10**		**50**	**20**	**113**	**45**
20**		**100**	**40**	**225**	**90**
40		200	80	450	180

**Estimated range of heights of 170-ft cavern, from cross well results.

The tables demonstrate the fact that even if a chimney roof did not stabilize against a thick bed in the roof, bulking would arrest progressive caving and chimneying long before it could reach the surface and form a sinkhole.

6. Evaluation of stand-off distances

6.1 Stand-off distance from edge of a brine field

The stand-off distance at the ground surface, beyond which settlements from cavern or mine collapse are insignificant, can be described in terms of an angle of draw, which is the vertical angle from the edge of the cavern at depth to the edge of the settlement sag or trough at the ground surface. The edge of the settlement sag or trough can be defined as the location where settlements are less than some minimum value, such as 0.05 times the maximum settlement.

The angle of draw in rock will be less than that observed for tunnels in soil. In the Cording, May, 2006 report, information from mine and cavern subsidence was summarized. All the cases in rock at depth resulted in angles of draw less than 15 degrees. The design curves from the Subsidence Engineers handbook give an angle of draw less than 15 degrees, for the edge of the subsidence zone defined by a settlement of 0.05 times the maximum settlement. From the cases described in the May, 2006 report, it is concluded that an angle of draw of 15 degrees can be used to estimate of the potential extent of surface subsidence beyond the edge of the outer solution caverns formed in brine fields with interconnected wells in the Detroit area, or beyond the edge of caverns excavated in a room and pillar mine. At this distance, settlement slopes are estimated to be less than 2 to 5 x 10^{-4} (1/5000 to 1/2000).

In the Detroit area, sink holes formed near the center of the subsidence zone, well within the boundaries of the brine fields. Thus, the angle of draw defining the boundaries for subsidence in a brinefield provides a conservative limit for any sink hole formation.

6.2 Stand-off distance from a single cavern

6.2.1 Cavern with high depth/diameter ratio

For individual solution caverns in the Detroit area, the depth to the cavern will be greater than the cavern width, and three-dimensional effects will cause the angle of draw to be smaller and the lateral extent of any subsidence sag beyond the cavern to be narrower than given in Section 6.1, should subsidence occur.

For caverns with widths of 120 to 170 ft, located at depths of 1100 ft to 1400 ft, respectively, the depth to diameter ratio is 9, a very high value. If the cavern were to result in surface effects, the angle of draw would be approximately vertical in the rock, and a sink hole at the top of rock would be directly above the cavern and within the cavern perimeter. However, as noted in Sections 4 and 5, and in Section 6.2.2 below, the stability of the roof will prevent significant caving. The bulking of rock, if a cave were to develop, would arrest the caving process at depth so that surface settlement or a sinkhole could not develop.

6.2.2 Stable cavern roof or caving cavern with sufficient bulking to fill cavern volume and arrest further caving.

Taking the stability of the individual solution cavern into account will provide a more realistic view of the potential for impacts at the surface. The potential for surface impacts is negligible for individual, smaller solution caverns.

The roofs of the 120-ft-diameter by 20-ft- high cavern and the 170-ft-diameter by 10- to 20-ft-high cavern will stabilize against a roof layer and there will be no measurable settlement at the surface. If the cavern were to cave up, the caving would only proceed a short distance above the cavern roof. There would be no measurable settlement at the ground surface for this case. The angle of draw and the stand-off distance would not apply to this case and surface facilities and facilities founded at the top of rock directly above the cavern would not be subject to significant settlement.

7. Summary and Conclusions

7.1 Solution caverns in the Detroit-Windsor area.

Dimensions of stable solution caverns can be evaluated from the experience with solution caverns in the Detroit-Windsor area.

Brine is being produced at Windsor from solution caverns located within the B salt, with widths of 500 to 600 ft. Solutioning is controlled and cavern dimensions are monitored so that approximately 50 to 100 ft of salt is retained above the cavern roofs. Galleries are being developed so that the long axis of the solution caverns is much greater than 500 to 600 ft.

For caverns with roofs located at the top of the salt, smaller spans are required to minimize the potential for collapse. One example in the Windsor area is an LPG cavern in the B salt which had its roof at the top of the B salt, in contact with the overlying rock. Between 1972 and 1980, the roof broke up an additional 80 ft forming a 150-ft-wide flat roof. Between 1980 and 2002, continuing fallouts caused the flat roof to widen to 350 ft, which was the approximate width of the solution cavern, but the roof did not break up above the flat roof.

Core from TB-7 on the Detroit side of the river shows the presence of vertical salt seams several inches thick extending 69 ft above the top of the B salt. Similar conditions may be present above the B salt at the LPG cavern site in Windsor. Additional solutioning along these seams would have reduced the confinement in the roof and allowed the rock layers between the seams to fall out. The LPG provides less buoyancy than brine, and therefore the 350-ft-wide LPG cavern provides a conservative (low) estimate of stable widths for brine-filled caverns.

Based on the experience in the Detroit/Windsor area and the forward modeling analyses with the three-dimensional distinct element method, it is concluded that brine-filled caverns intersecting the bedded deposits at the top of the F, D or B salt units will be stable with dimensions of the order of 100 to 300 ft. Local roof fallout will occur where thin bedded layers less than a foot or two in thickness are present. The extent of roof fallout and collapse will depend on bedding plane spacing as well as rock jointing. Solution caverns of this size in the F, D or B salt units will not form sinkholes at the surface and will not cause significant surface subsidence.

7.2 Chimneying and formation of surface subsidence and sinkholes.

The width of solution caverns or groups of solution caverns that will allow chimneying to extend to the surface and sinkholes to form at the surface are likely to be significantly wider than 300 ft, perhaps in the range of 500 to 800 ft. The solution caverns must also have significant vertical extent in the salts of the

F, D, and/or B units. The total vertical height of morning glory shaped caverns would have to be in excess of 200 ft in order to accommodate the bulked collapse debris and permit the collapse to reach the surface and form a sinkhole.

Sinkholes in the Detroit/Windsor area have only formed in areas where multiple wells were developed and production was between injection and recovery wells, with little control of cavern location or size. The sinkholes developed after subsidence of several feet had occurred and shortly after the time, or within a few years of the time, that solution mining activities had ceased.

At Sites X-10 and X-11 on the Detroit side of the river, the NTH review of the history and ownership at the sites does not indicate any evidence of major brine field development beyond the Zug Island brinefield, although properties on portions of the sites were owned by salt companies in the early 1900's. The borings, downhole geophysical logging, and cross-well profiles at Sites X-10 and X-11 also show that major solutioning did not occur.

Interconnection of solution zones between wells began in about 1915 at the Wyandotte, Michigan brinefield and 1920 at the Sandwich brinefield. At Sites X10 and X11, It is likely that any solution wells, if present, were operated as single wells. Much of the brine was likely to have been extracted from salt in the shallower F and D units, even though wells in the early 1900's were drilled deeper. Evidence from Sandwich and Wyandotte indicates that early wells were drilled into the B Salt and some solutioning of the B Salt took place.

7.3 Field investigations and analyses of conditions at Sites X-10 and X-11

The exploration program at Sites X-10 and X-11 consisted of borings, downhole geophysical logging, core sampling and cross-well investigations. The results have shown that solution activity at the sites is either absent or very limited. The investigation confirms that the sites are not underlain by brine-field galleries with interconnecting solution caverns that could collapse, propagate and cause surface subsidence or sinkholes. None of the cross-well profiles showed any evidence of solution caverns, except in the cases previously mentioned.

In Section 4 of this report, the three dimensional distinct element method was used to analyze the roof stability of solution caverns with the geometry identified in the cross-well investigation and with the rock properties obtained from the borings and core samples at Sites X-10 and X-11. The results confirm that the maximum-sized solution caverns (120 ft to 170 ft in width) identified in the cross-well investigation will develop stable roofs in the bedded deposits above the salt and progressive roof collapse and propagation of a chimney toward the surface will not occur. In addition, the bulking analysis conducted in Section 5 of the report shows that, even if progressive roof collapse did occur for 20-ft high caverns, bulking of the rubble would fill the void and arrest the collapse zone well before it would approach the top of rock or cause any surface settlement.

The field investigation confirms that solution features at Crossing Sites X-10 and X-11 are limited. There is no evidence of a brinefield with interconnected solution caverns and there are no large solution caverns. The experience in the Detroit-Windsor area, and the analysis results show that the two features identified in the cross-well profiles as potential caverns are small enough that their roofs will stabilize against thicker beds in the rock above the salt. Further, the cross-well data indicates that the features are only 10 to 20 ft high, so that, even if the roof were unstable and progressive chimneying were to occur, it would be arrested by bulking of the rubble and would not continue toward the surface. It is concluded that potential solution features identified at Crossing Sites X-10 and X-11 will not cause subsidence or sinkholes at the ground surface or in the upper rock formations.

Appendix A: Distinct element analyses of stability of bedded roofs above 125-ft-wide solution cavern for base cases

See attachment

Appendix B.1: Summary figures. Distinct element analyses of stability of 120- -ft-wide solution caverns with roofs in bedded rock with continuous vertical joints

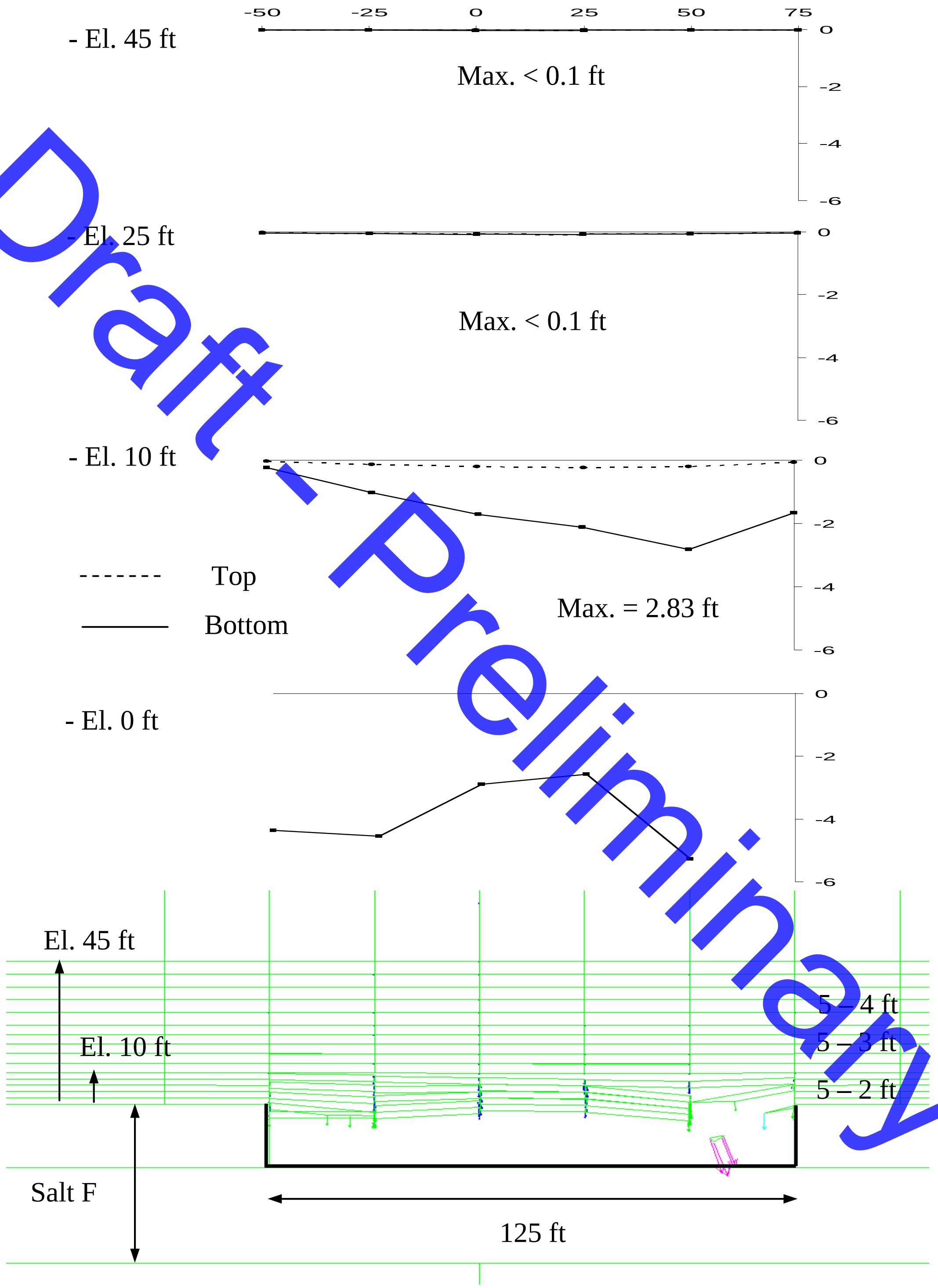


Figure 1. Vertical displacements, Case 1: 125 ft wide:

Spaced @ 25-ft, 2-ft bedding (Base Case)

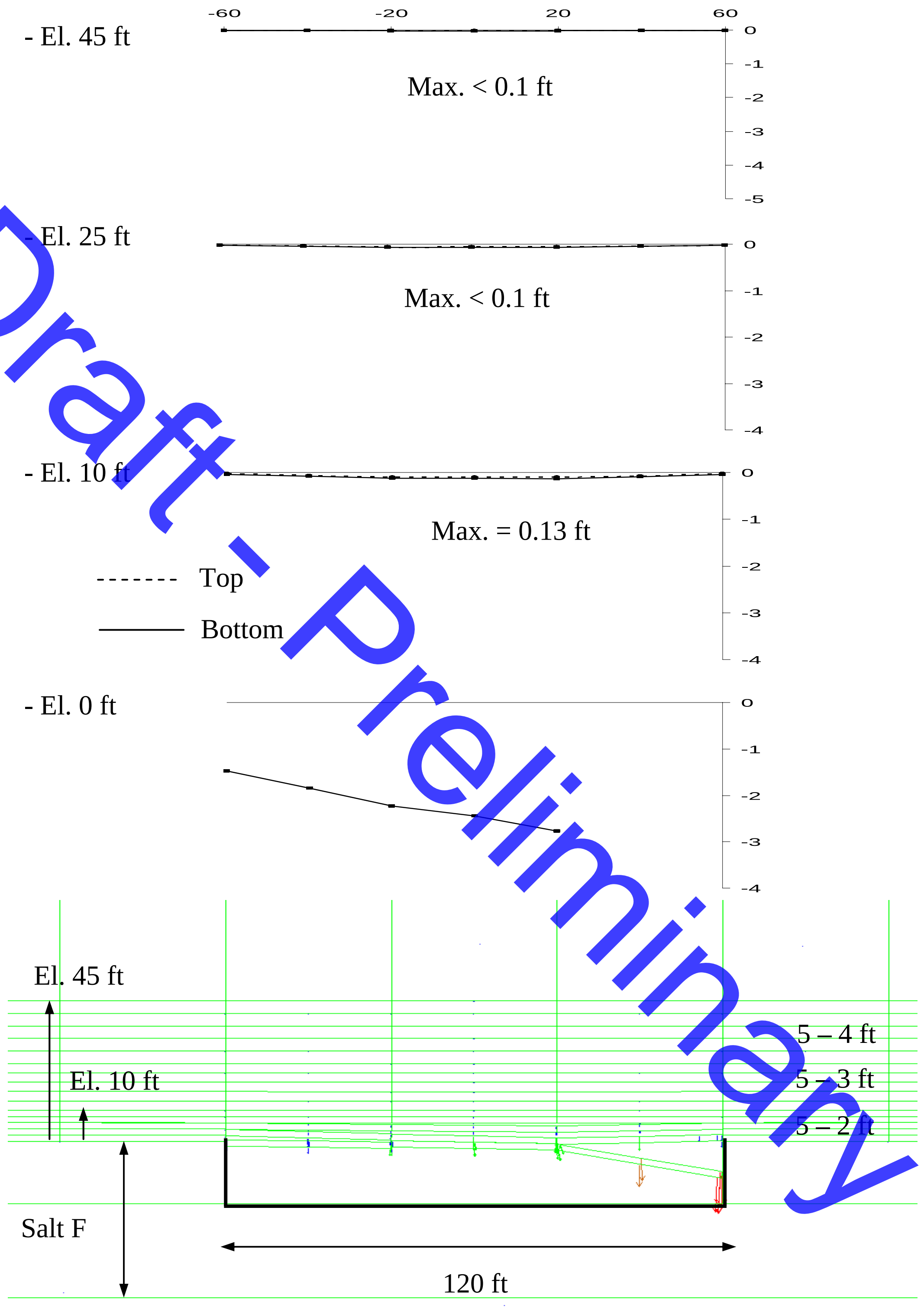


Figure 2. Vertical displacements, Case 2: 120 ft wide:

Spaced @ 40-ft, 2-ft bedding

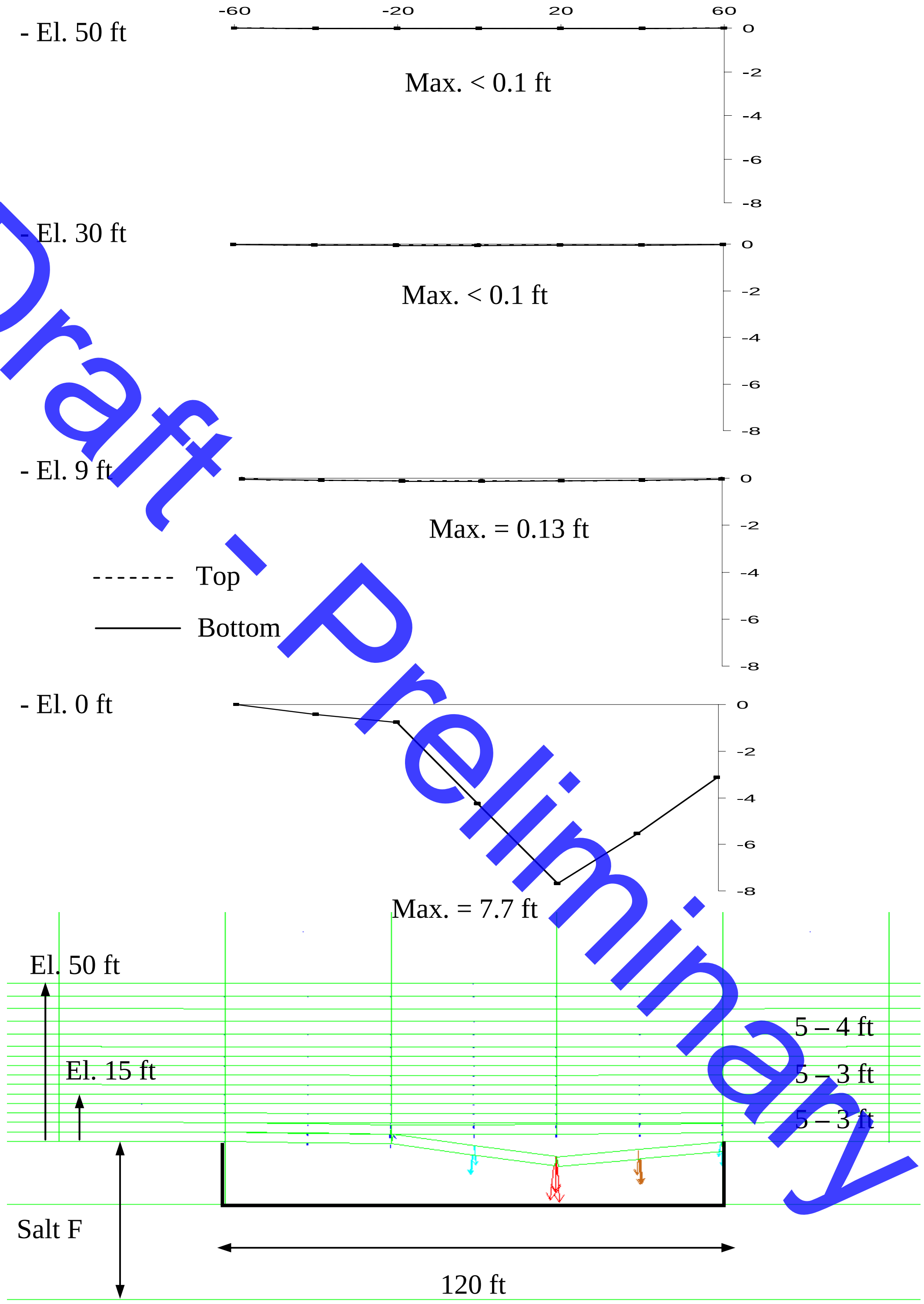


Figure 2-2. Vertical displacements, Case 2-2: 120 ft wide:

Spaced @ 40-ft, 3ft beds bottom and beneath 4 ft beds

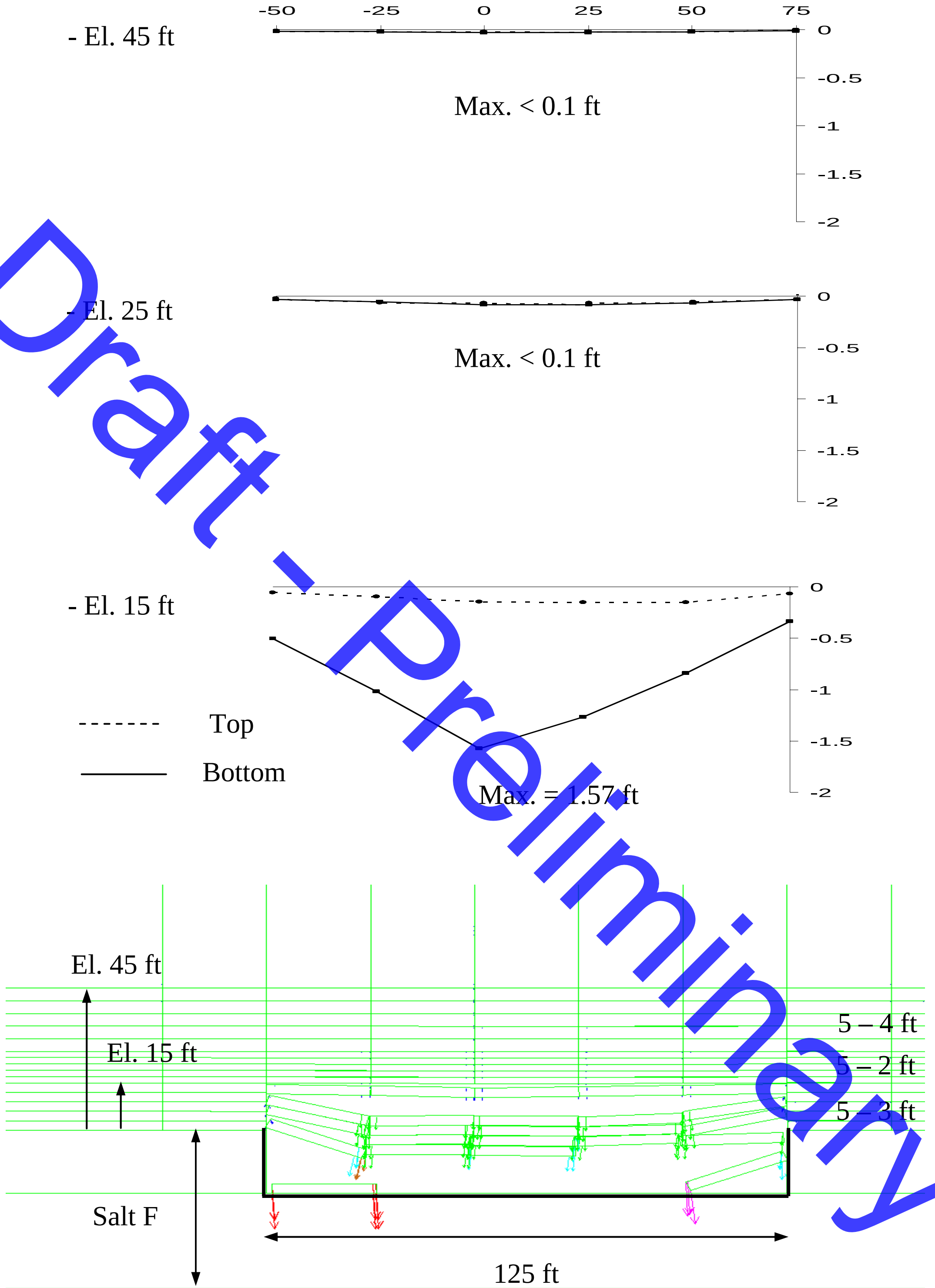


Figure 3. Vertical displacements, Case 3: 125 ft wide:

Spaced @ 25-ft, 3 ft beds beneath 2 ft beds th 4 ft beds

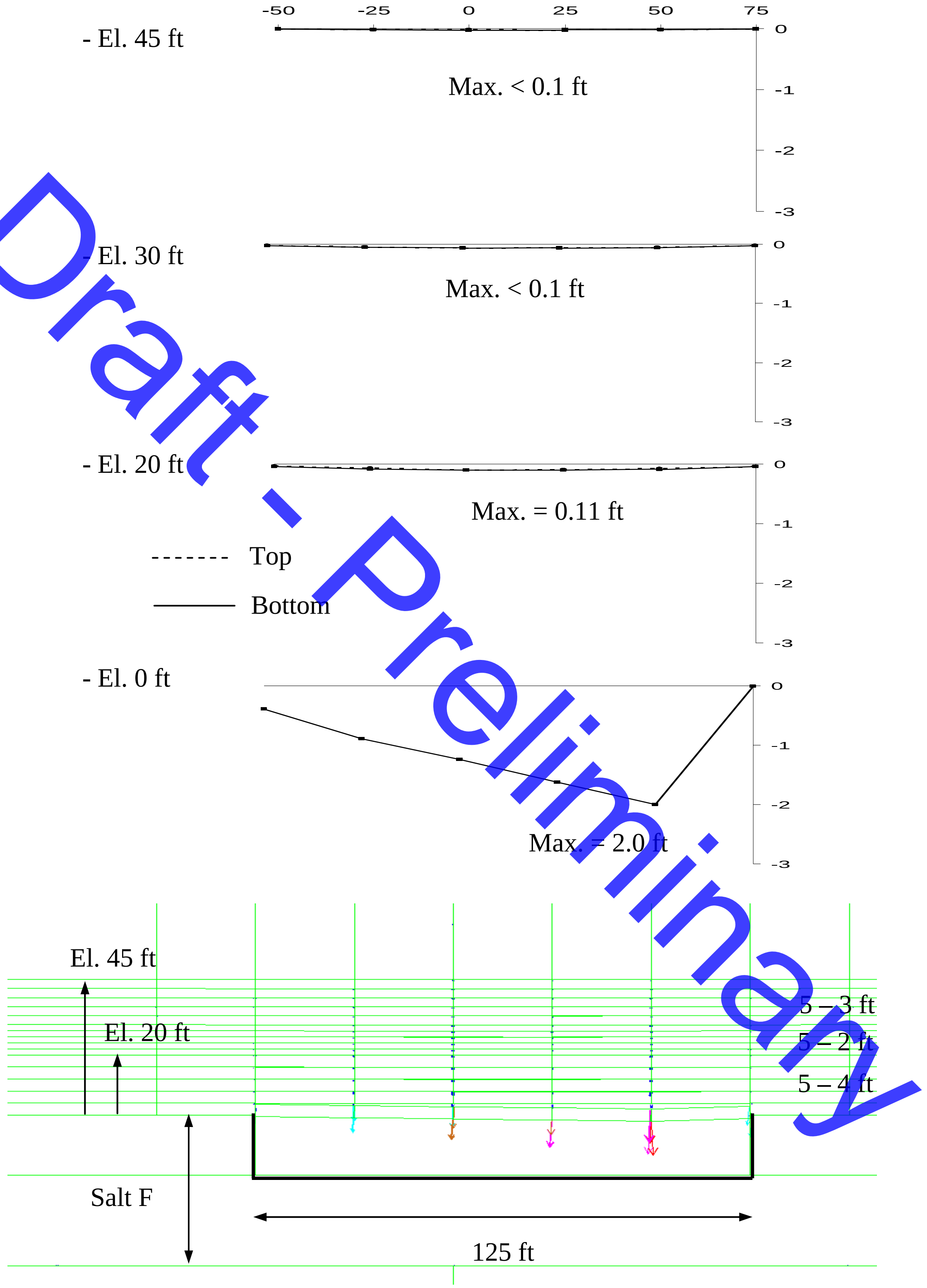


Figure 3-2. Vertical displacements, Case 3-2: 125 ft wide:

Spaced @ 25-ft, 4-ft bedding

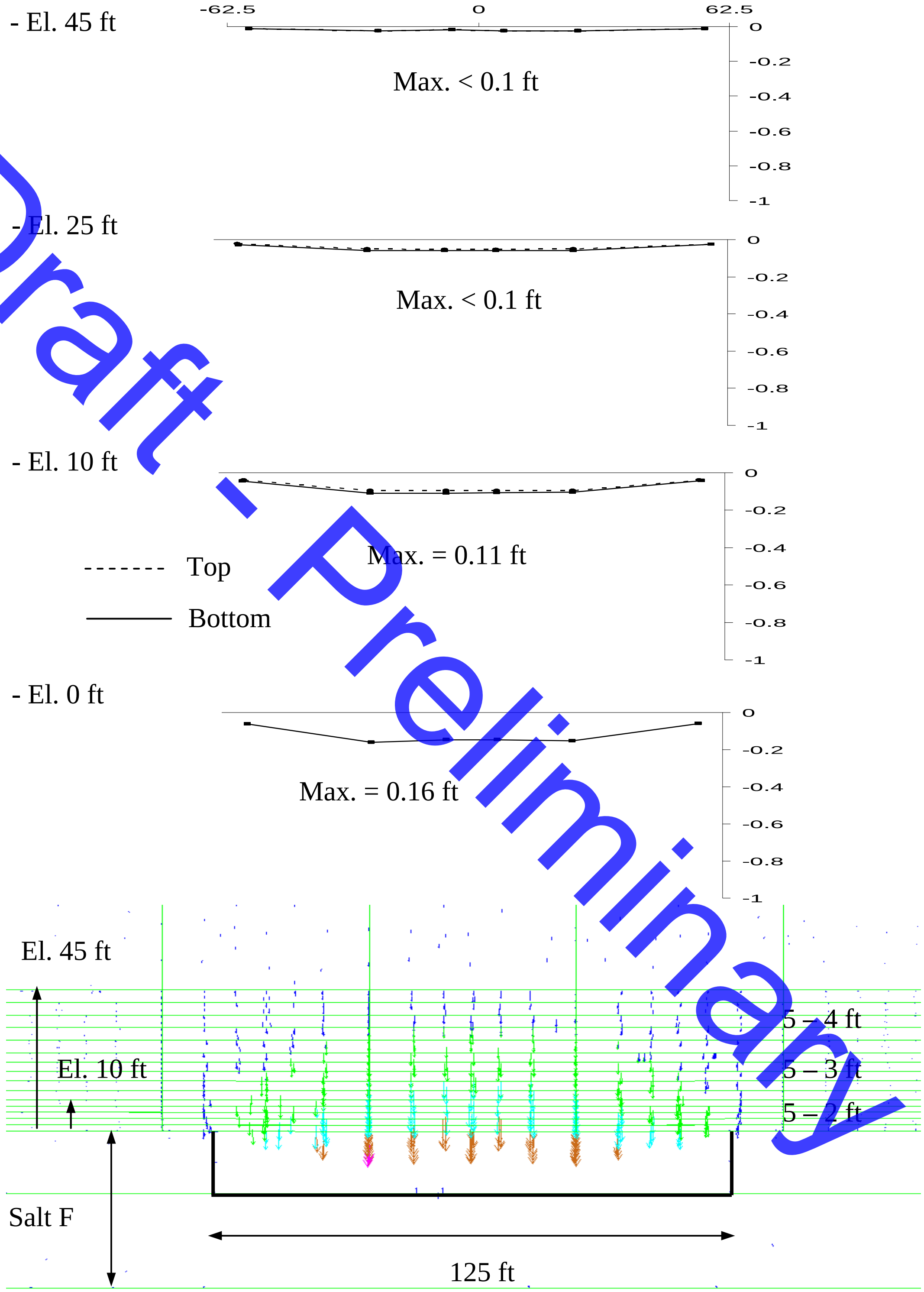


Figure 3-3. Vertical displacements, Case 3-3: 125 ft wide:

Spaced @ 50-ft, 2-ft bedding

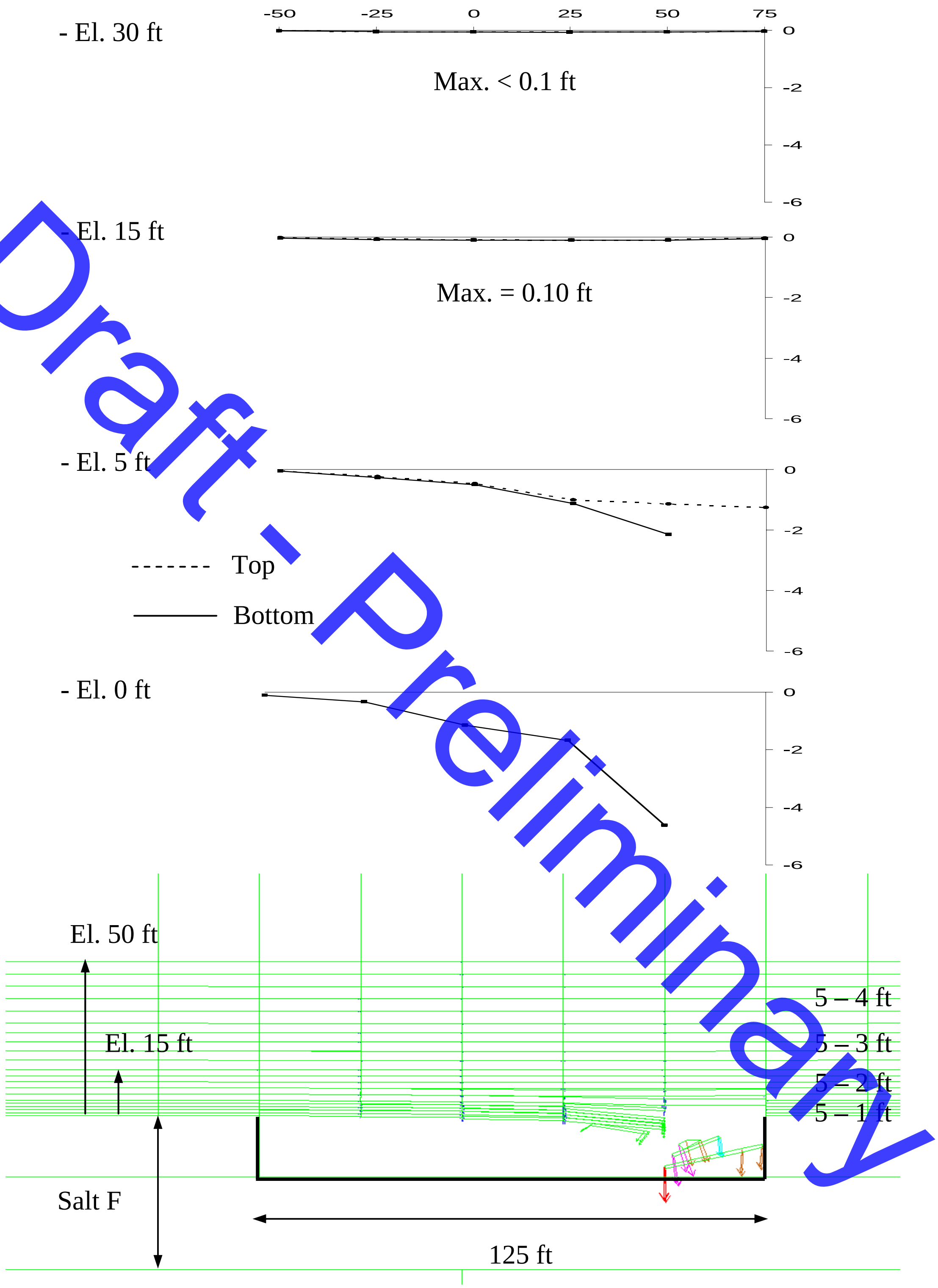


Figure 4. Vertical displacements, Case 4: 125 ft wide:

Spaced @ 25-ft, 5-1 ft beds at bottom

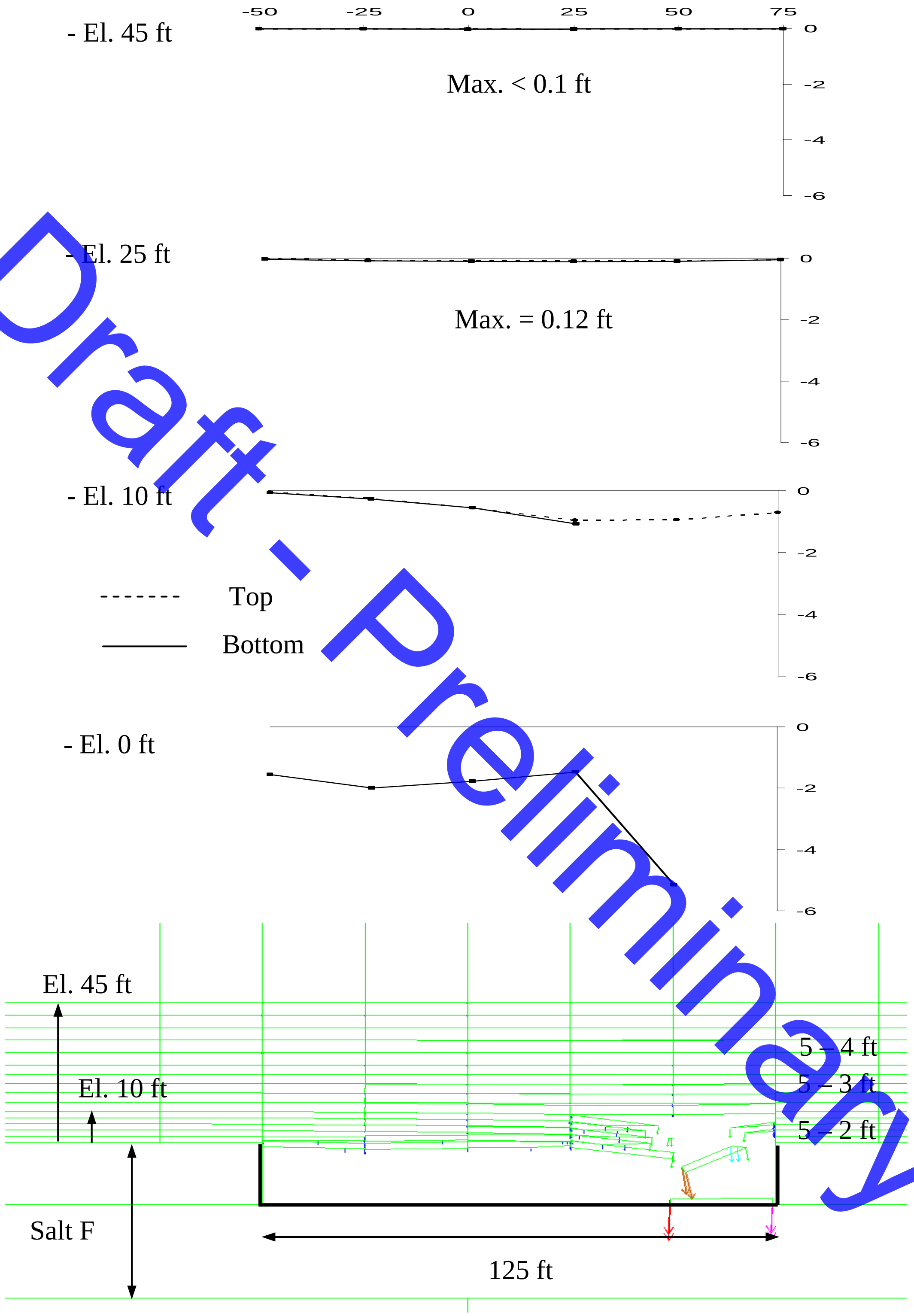


Figure 5. Vertical displacements, Case 5: 125 ft wide:

Spaced @ 25-ft, 2-ft bedding, E = 2×10^6 psi

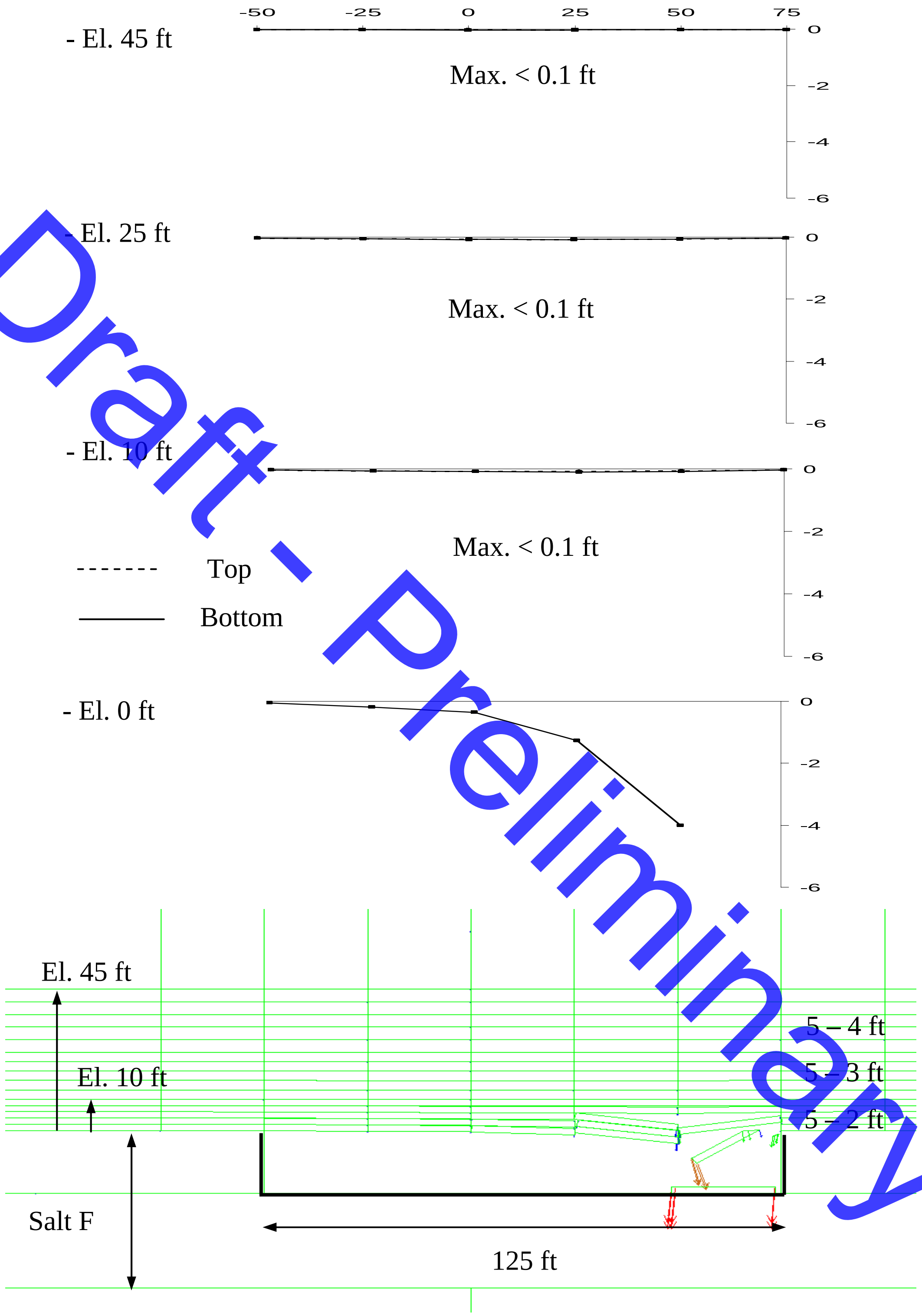


Figure 6. Vertical displacements, Case 6: 125 ft wide:

Spaced @ 25-ft, 2-ft bedding, K_0 = 2.0

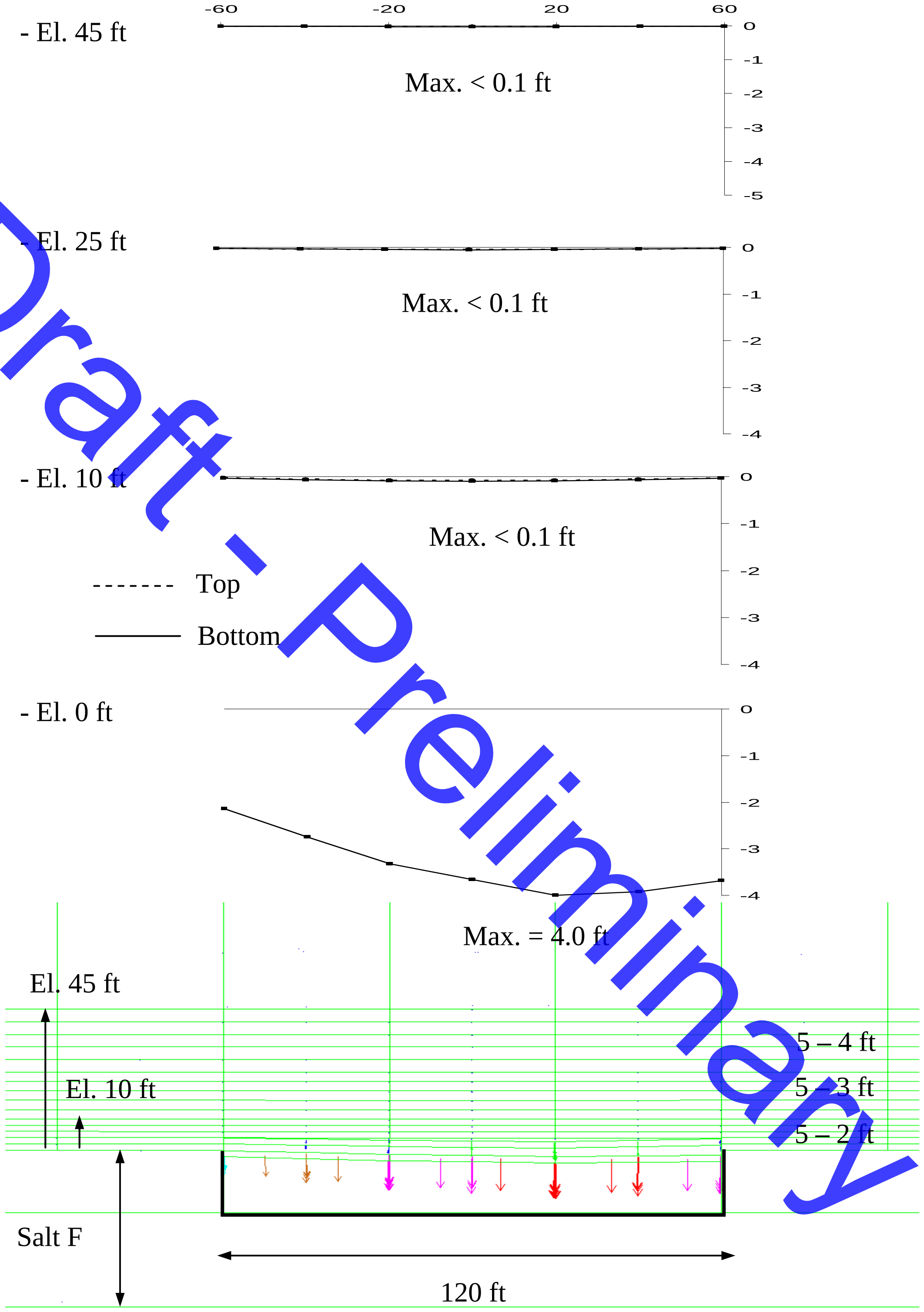


Figure 7. Vertical displacements, Case 7: 120 ft wide:

Spaced @ 40-ft, 2-ft bedding, $K_0 = 2.0$

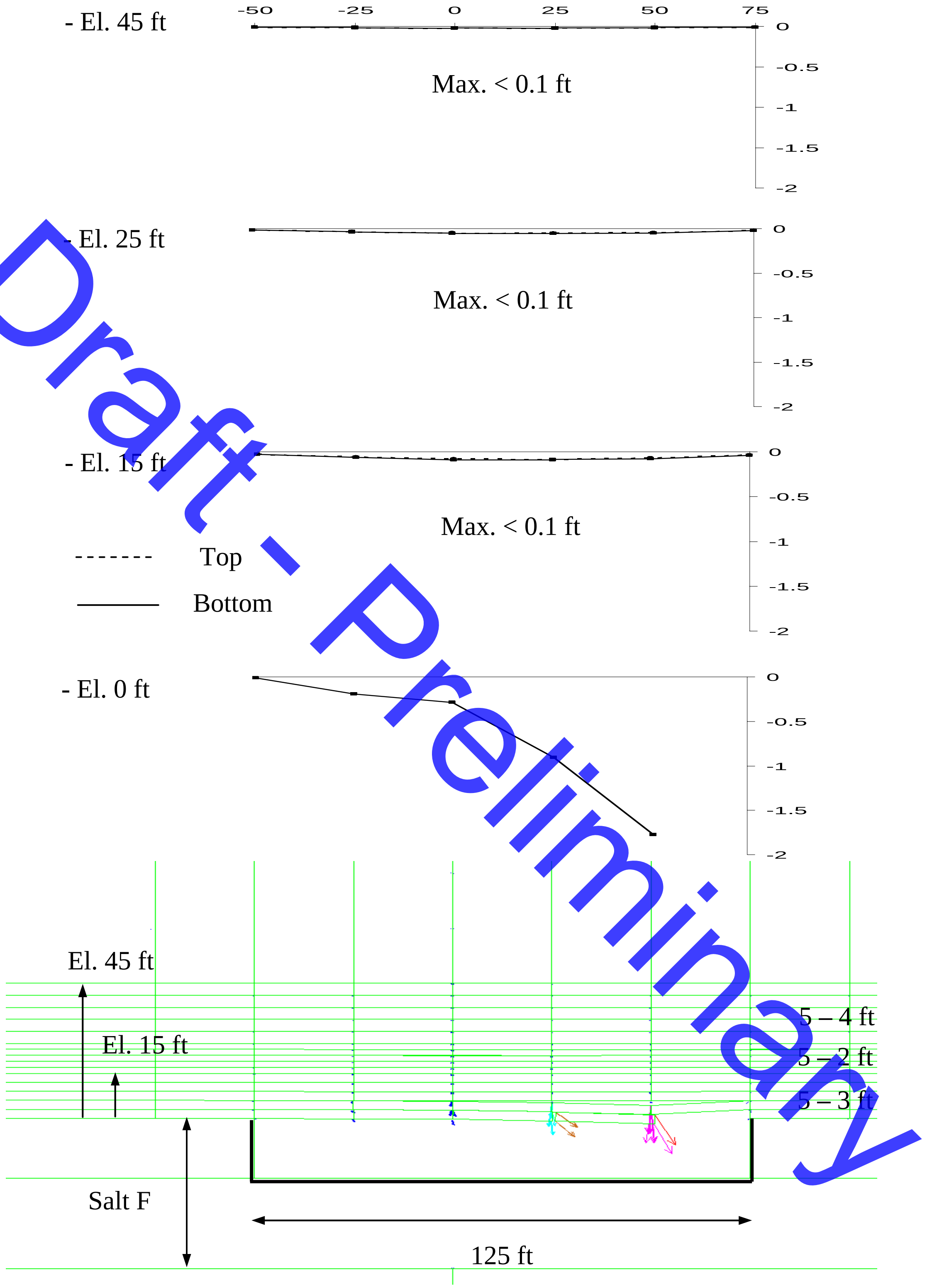


Figure 8. Vertical displacements, Case 8: 125 ft wide:

Spaced @ 25-ft, 3 ft beds beneath 2 ft beds, $K_0 = 2.0$

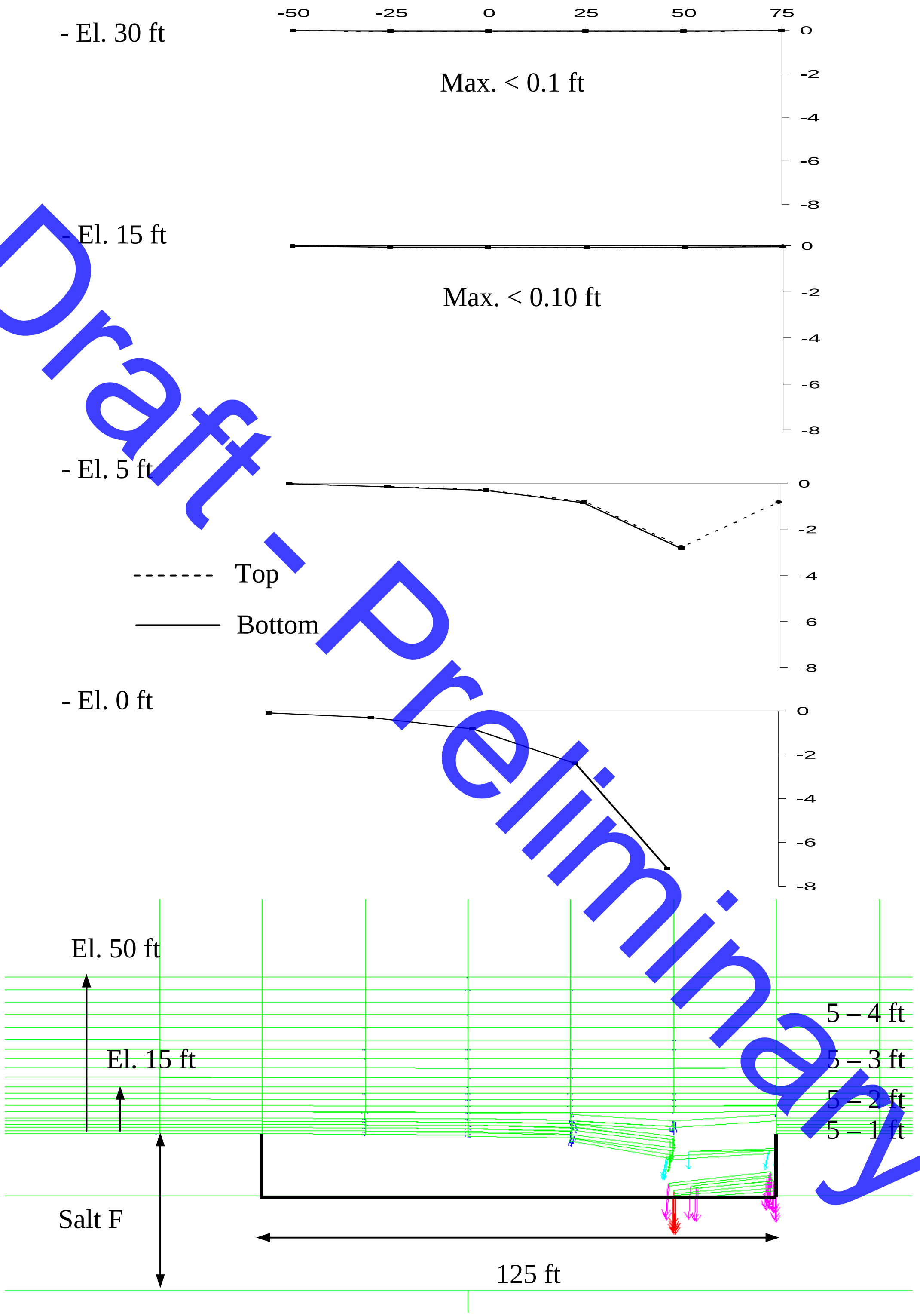


Figure 9. Vertical displacements, Case 9: 125 ft wide:

Spaced @ 25-ft, 5-1 ft beds at bottom, K_0 = 2.0

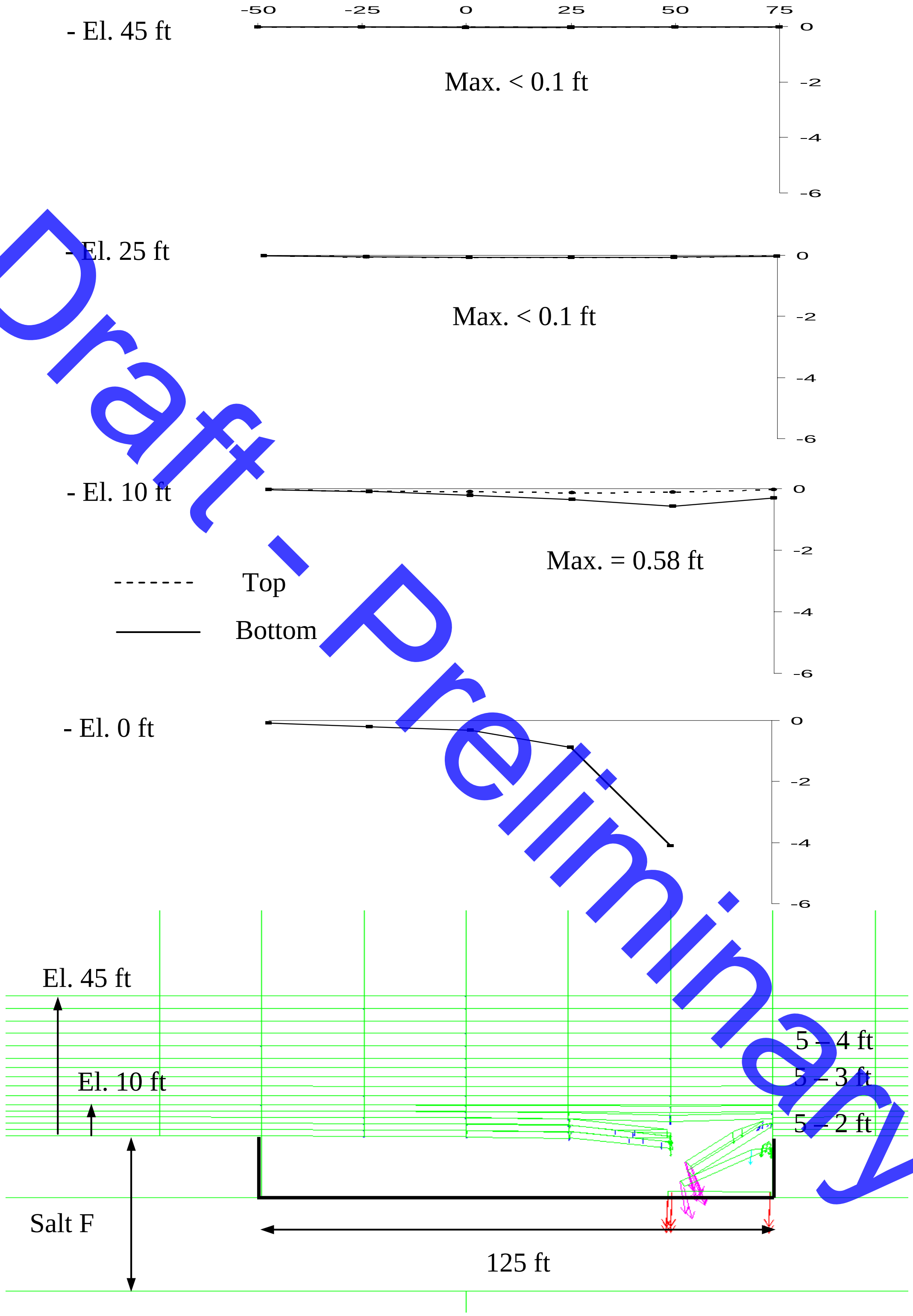


Figure 10. Vertical displacements, Case 10: 125 ft wide:

Spaced @ 25-ft, 2-ft bedding, E = 2×10^6 psi, K_0 = 2.0

Appendix B.2: Summary figures. Distinct element analyses of stability of 120- and 170-ft-wide solution caverns with roofs in bedded rock with offset vertical joints

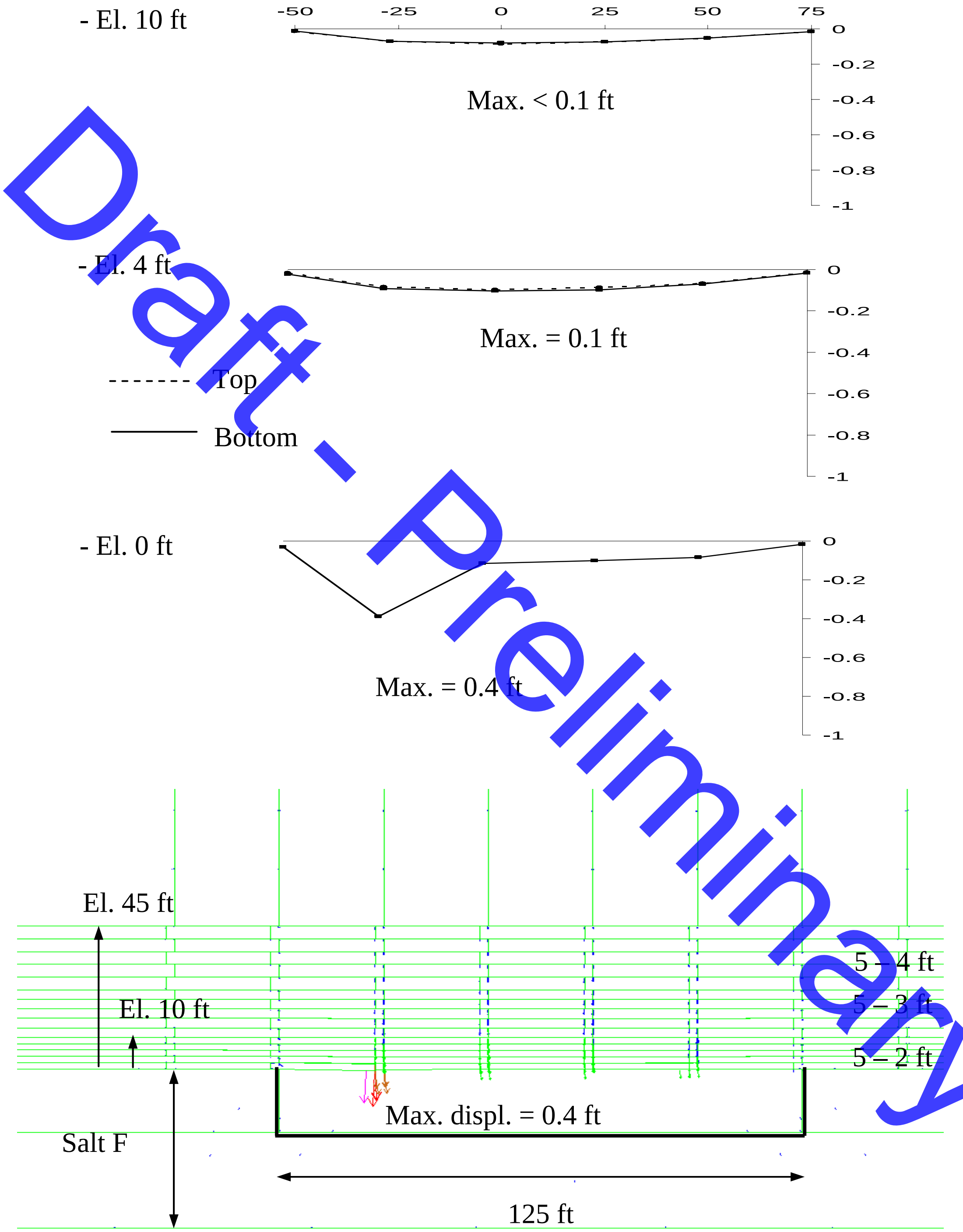


Figure 1. Vertical displacements, Case A: 125 ft wide:

Vertical joints offset 2 ft and spaced @ 25-ft, 2-ft bedding

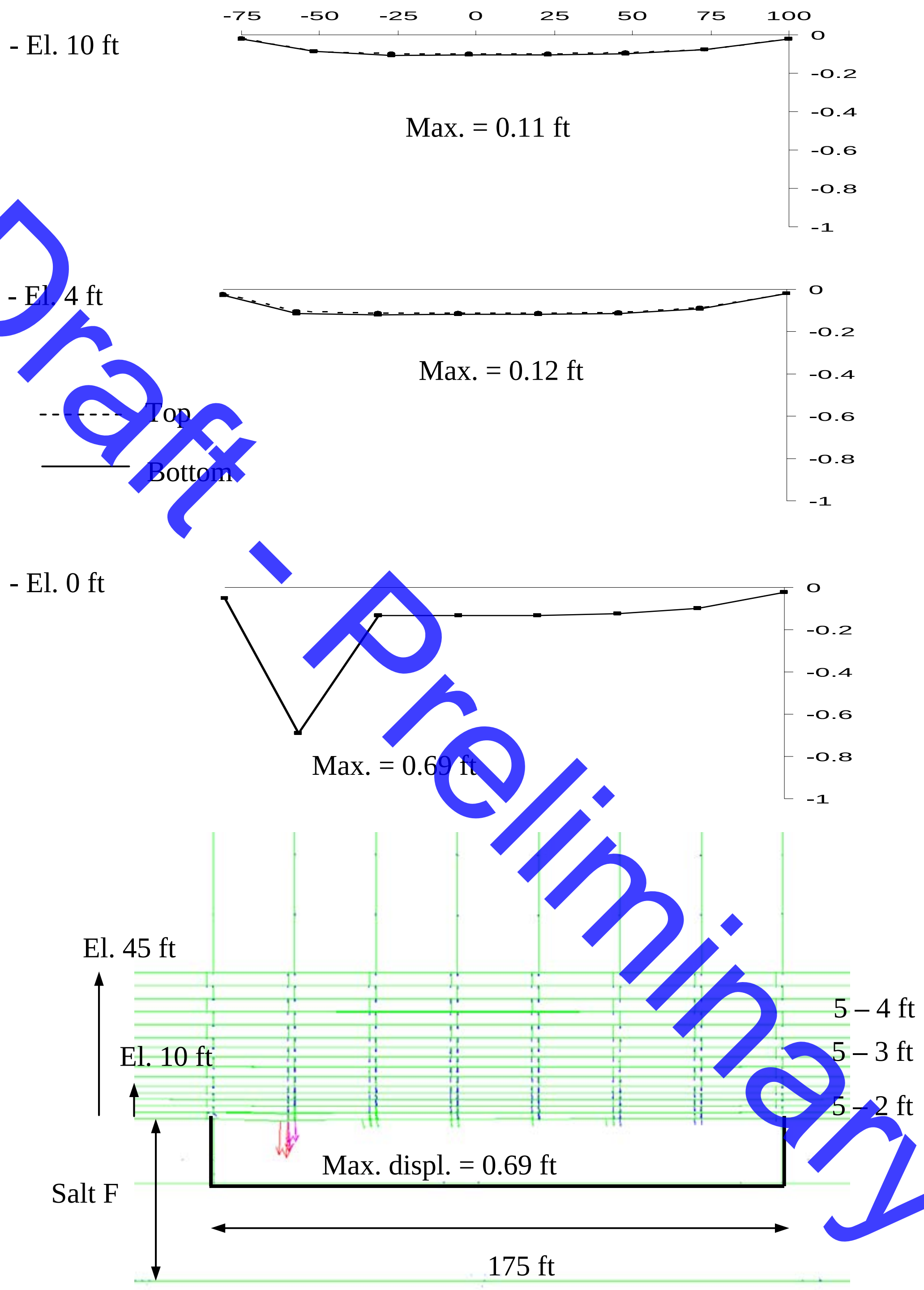


Figure 2 Vertical displacements, Case B, 175 ft wide

Vertical joints offset 2 ft and spaced @ 25-ft, 2-ft bedding

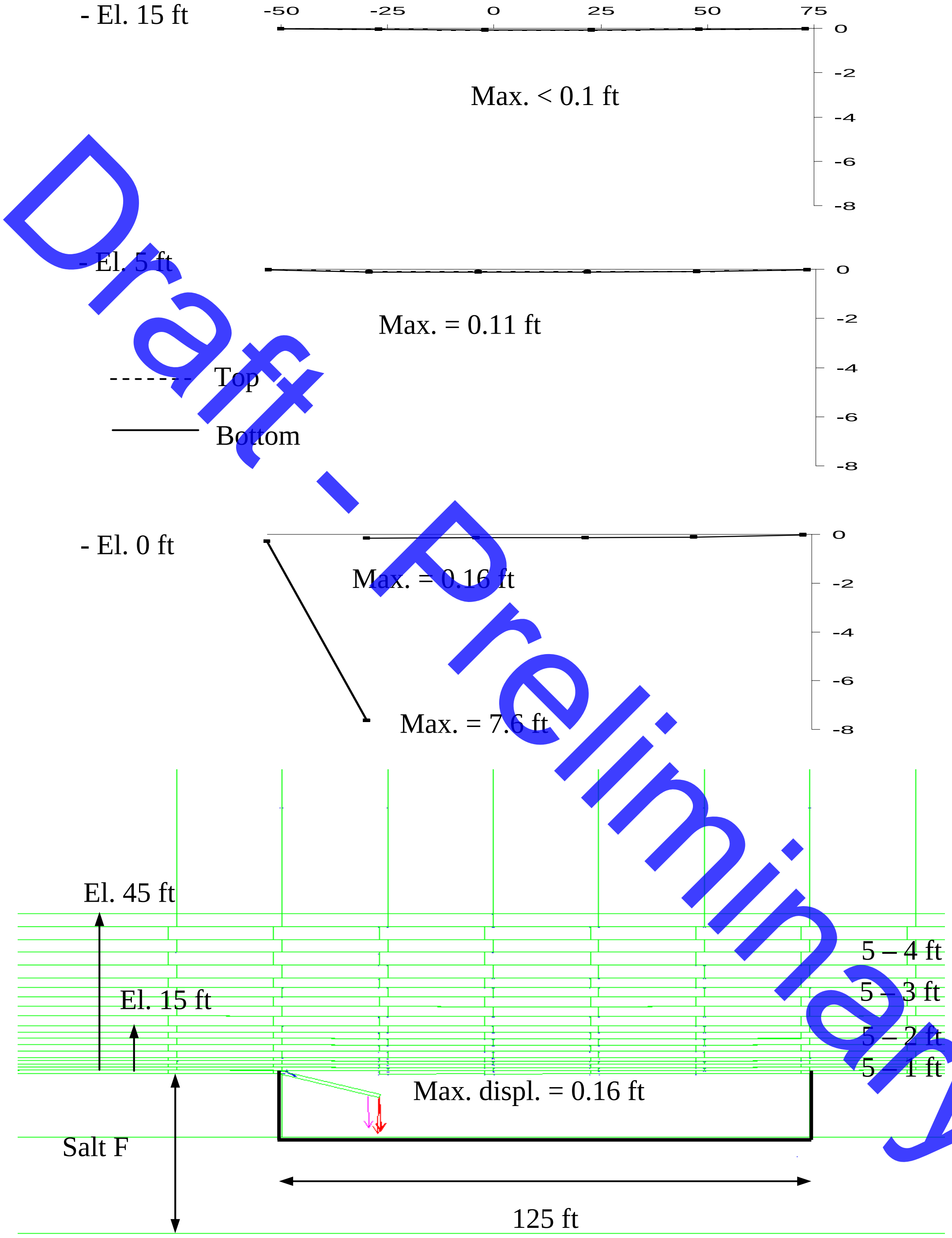


Figure 3. Vertical displacements, Case C, 125 ft wide
Vertical joints offset 2 ft and spaced @ 25 ft, 5-1 ft beds at bottom

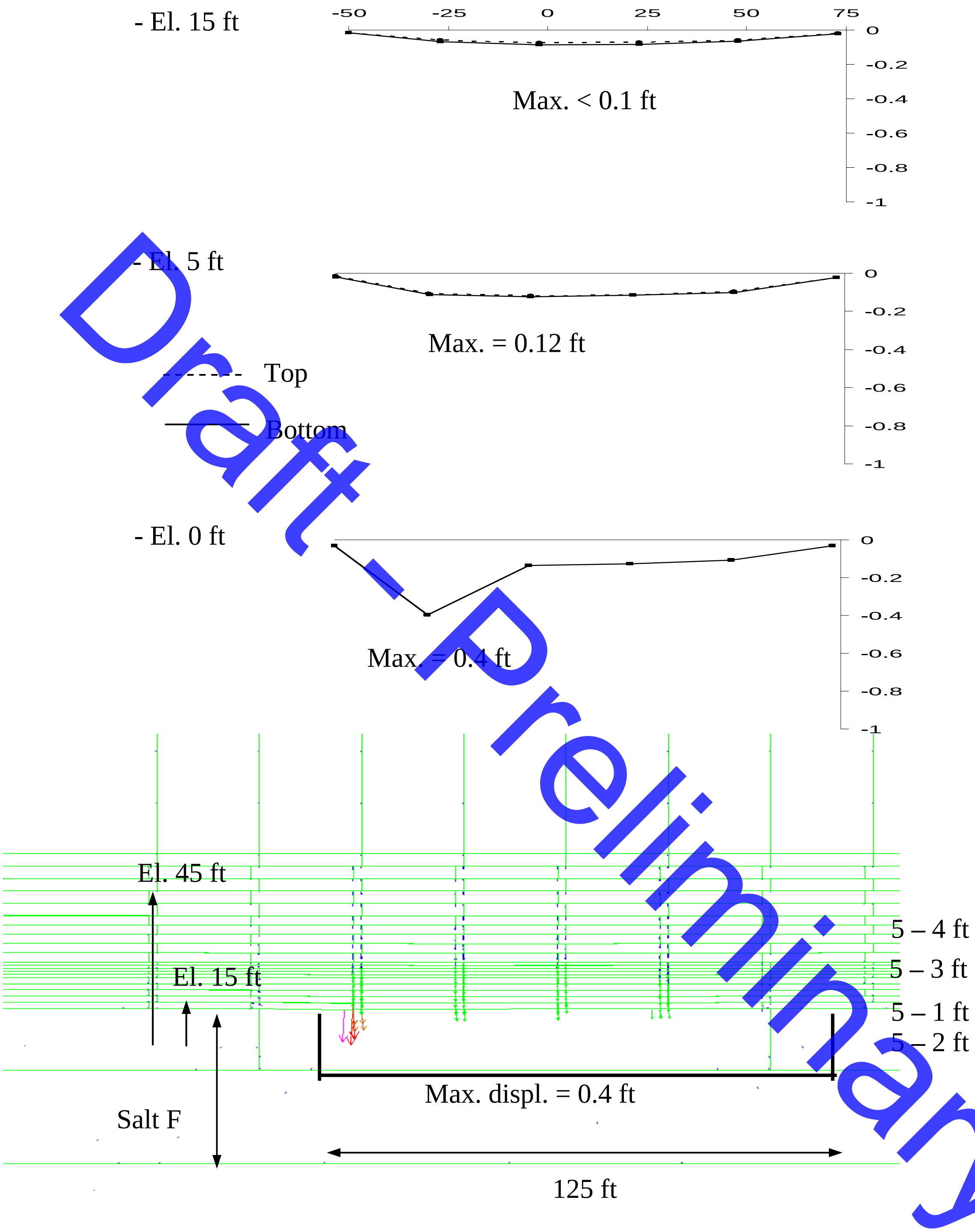


Figure 4. Vertical displacements, Case D 125 ft wide
Vertical joints offset 2 ft and spaced @ 25 ft, 5-1 ft beds above 5-2 ft beds

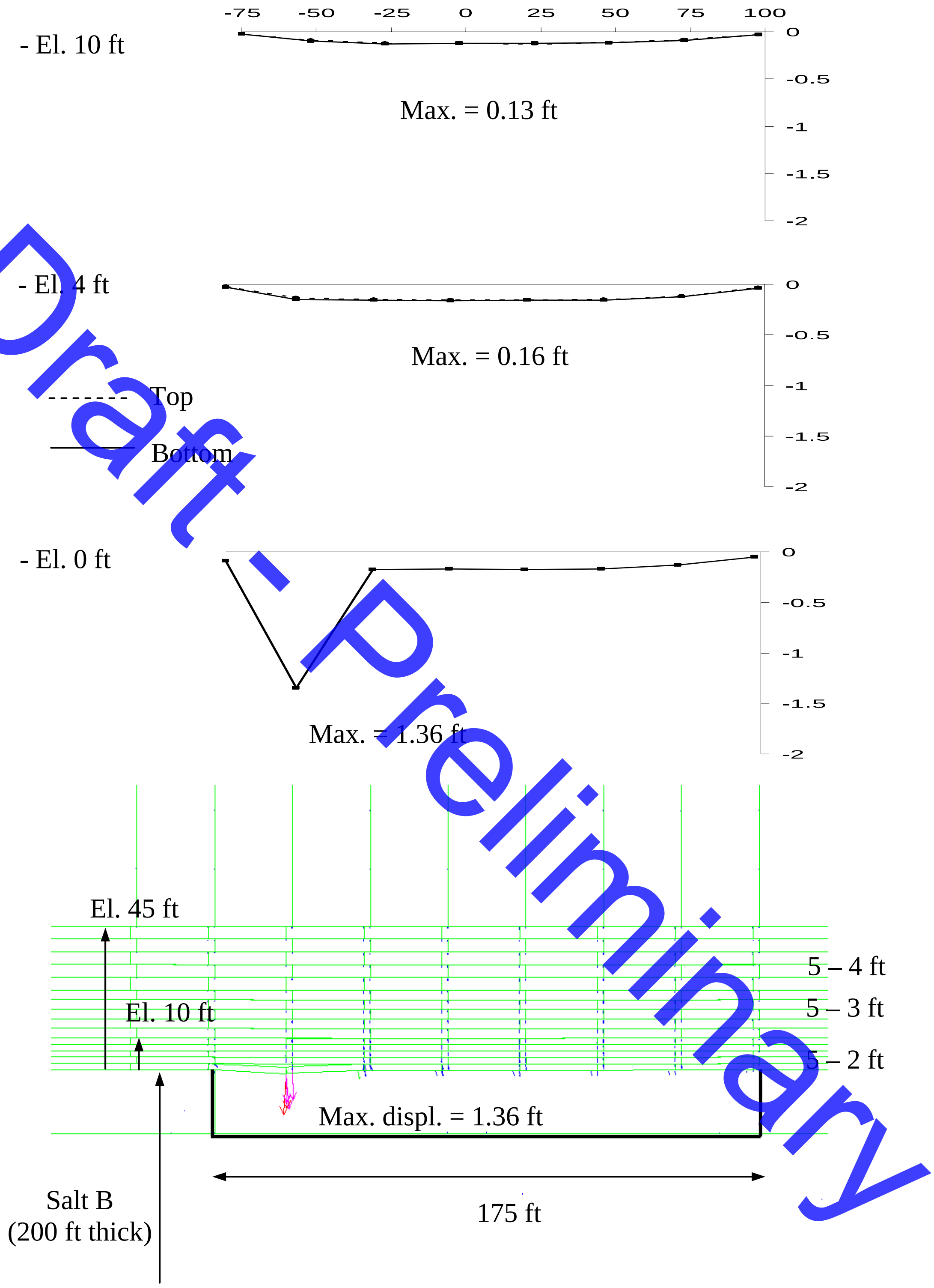


Figure 5 Vertical displacements, Case E, 175 ft wide
Vertical joint offset 2 ft, spaced at 25 ft, 2-ft bedding,1400 ft to the top of the B salt

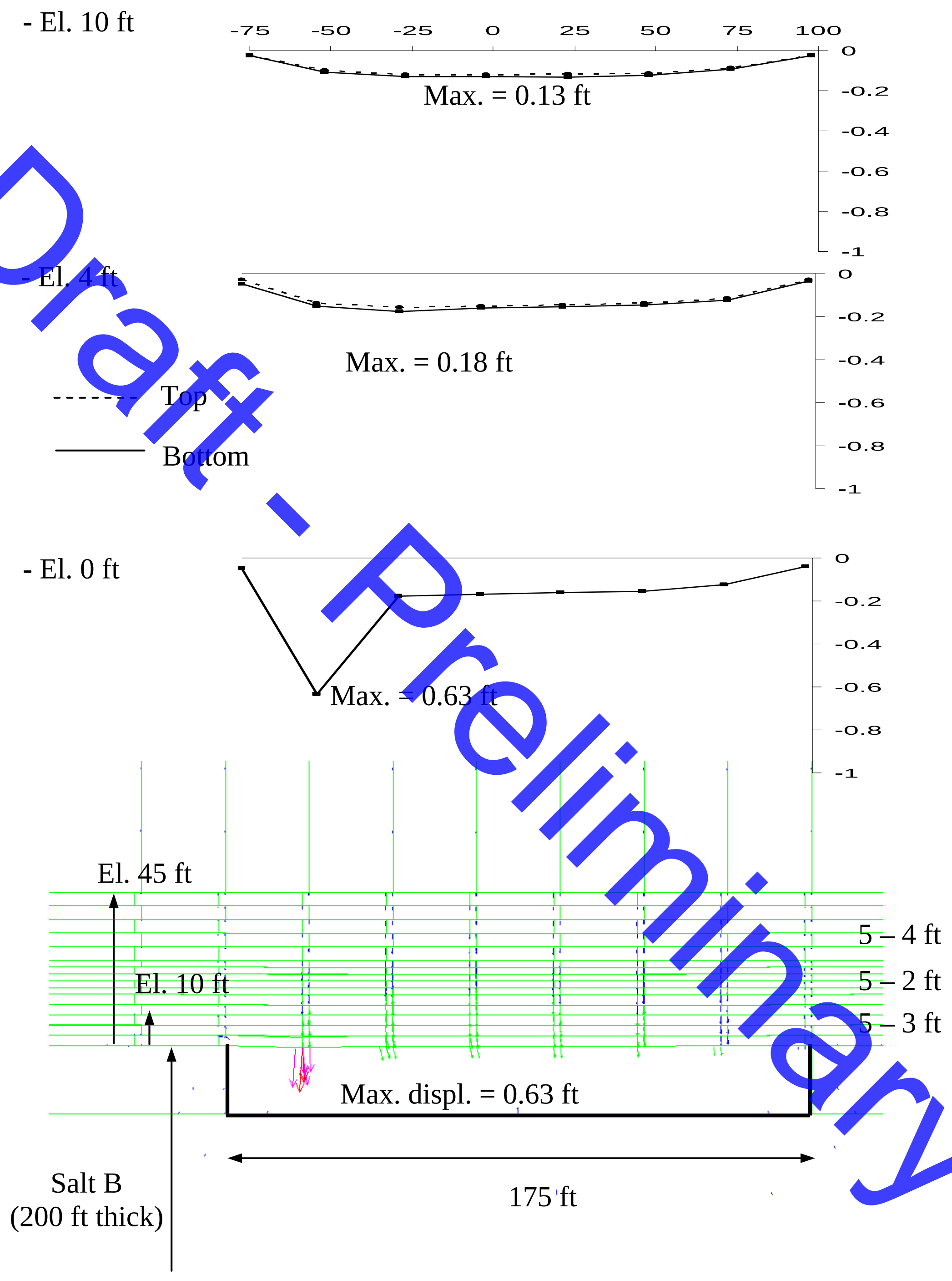
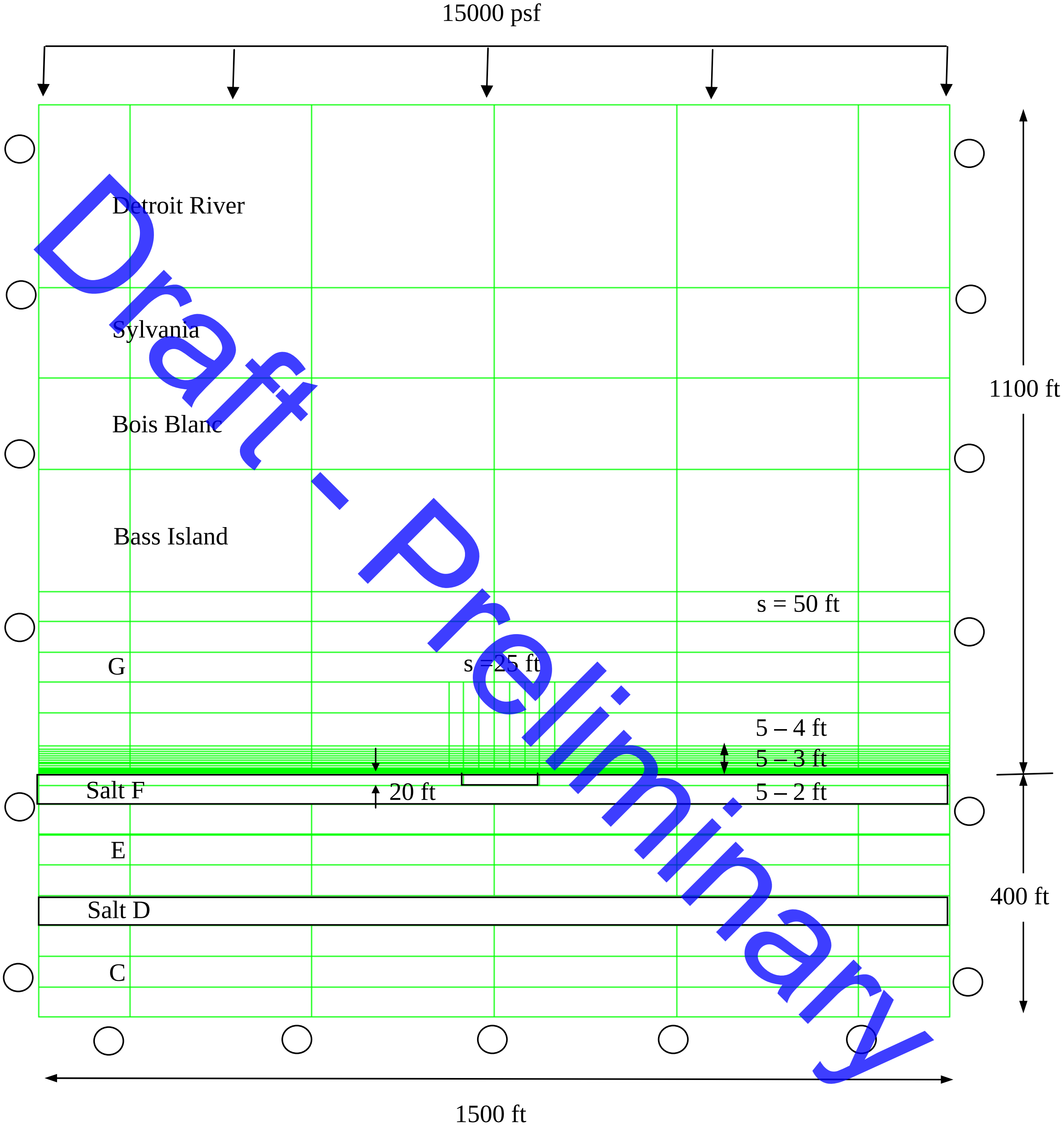


Figure 6 Vertical displacements, Case F, 175 ft wide
Vertical joints offset 2 ft and spaced @ 25 ft, 3 ft beds beneath 2 ft beds,
Cavern at 1400 ft to the top of the B salt

Appendix A.1: CASE 1: Base Case



* Based on Figure A-5B (After Russell, 1993)

Figure 1 Geometry & Boundary condition (perpendicular to Z direction)

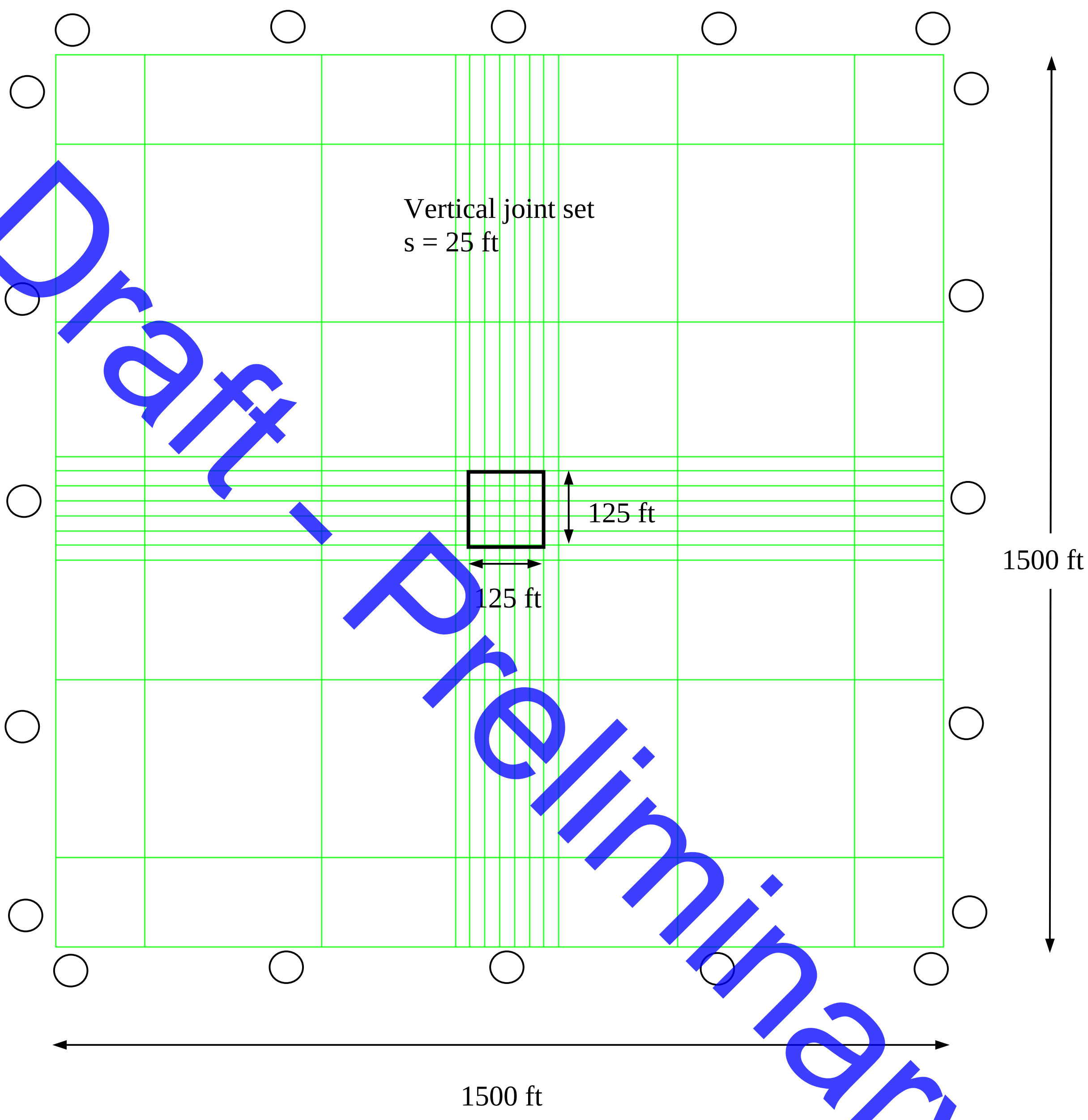


Figure 2 Geometry & Boundary condition (perpendicular to Y direction)

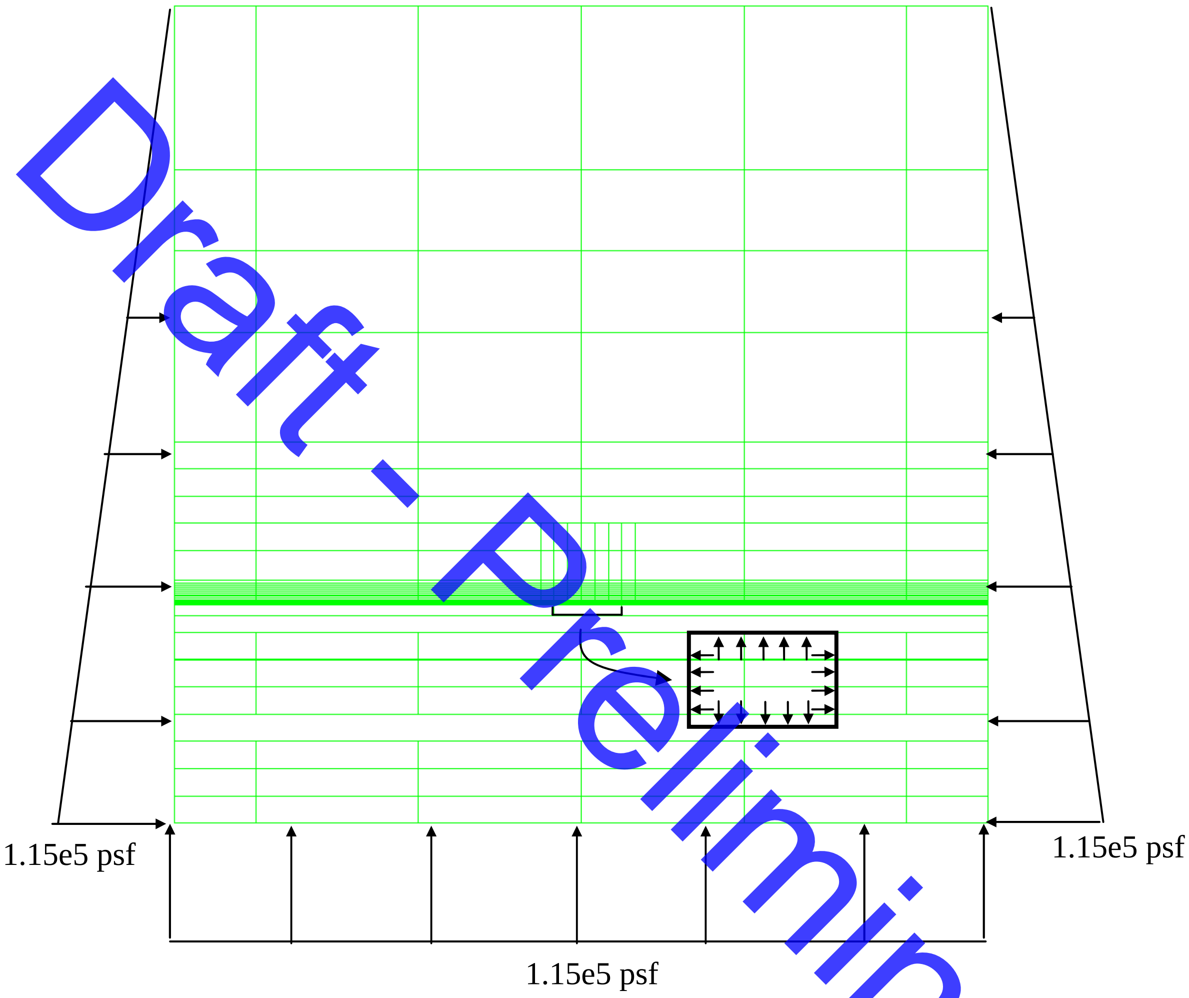


Figure 3 Geometry & Boundary condition (Fluid pressure, γ_{brine} = 76.7 pcf)

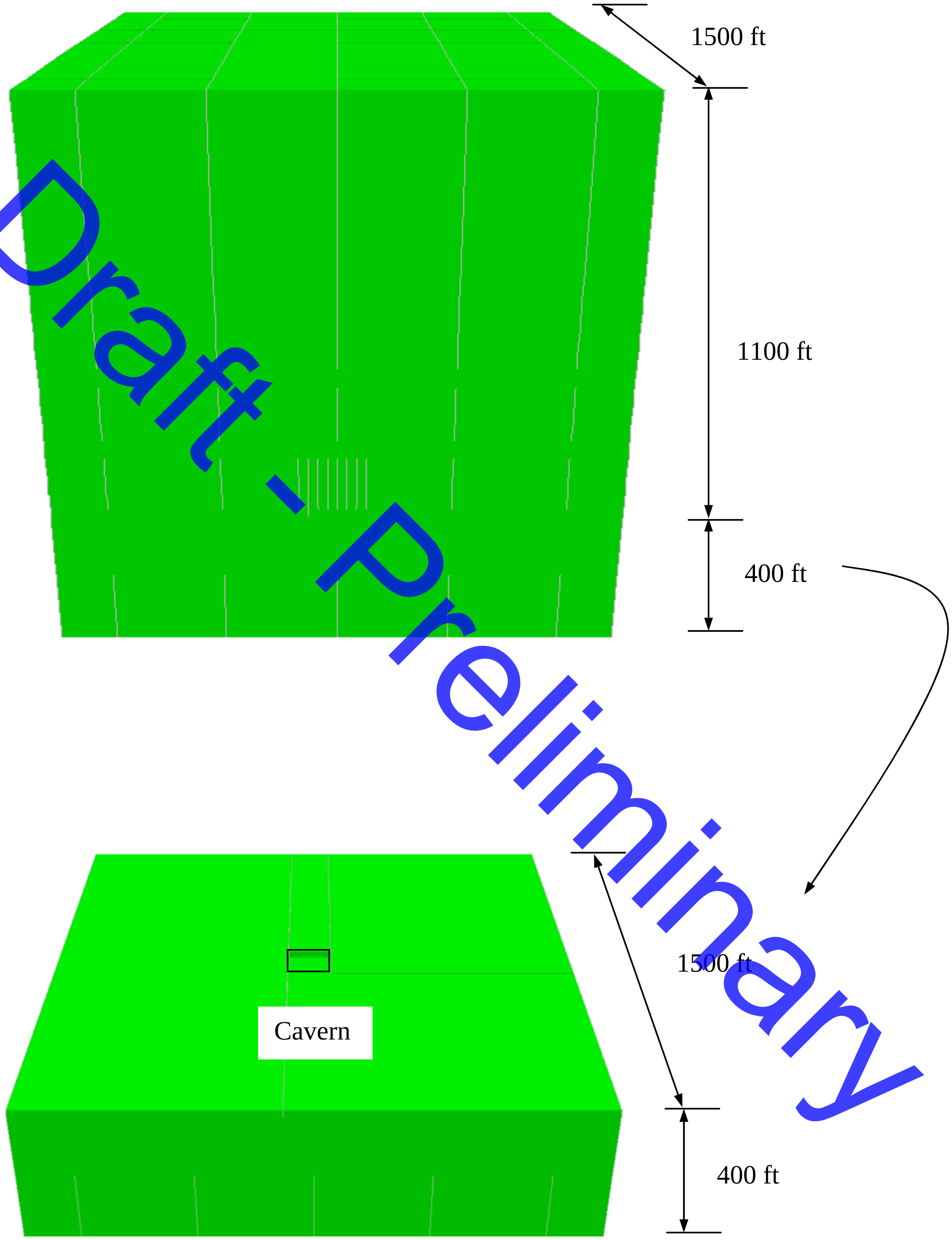


Figure 4 3-D model

- Rock: Elastic

	E (psi)	K (psf)	G (psf)
Dolomite	4.0×10^{6}	3.84×10^{8}	2.30×10^{8}
Salt	1.0×10^{6}	9.60×10^{7}	5.76×10^{7}

- Joint: C-Y model

	K_n (psf/ft)	K_s (psf/ft)	ϕ_i (degree)	ϕ_r (degree)	R (ft)
Vertical joint	1.7×10^{8}	1.7×10^{7}	45	35	1.8×10^{-1}
Bedding	1.7×10^{7}	1.7×10^{6}	35	30	1.0×10^{-1}

- Simulation of direct shear test (τ vs. δ_h) under the normal stress of 9.56×10^{4} psf

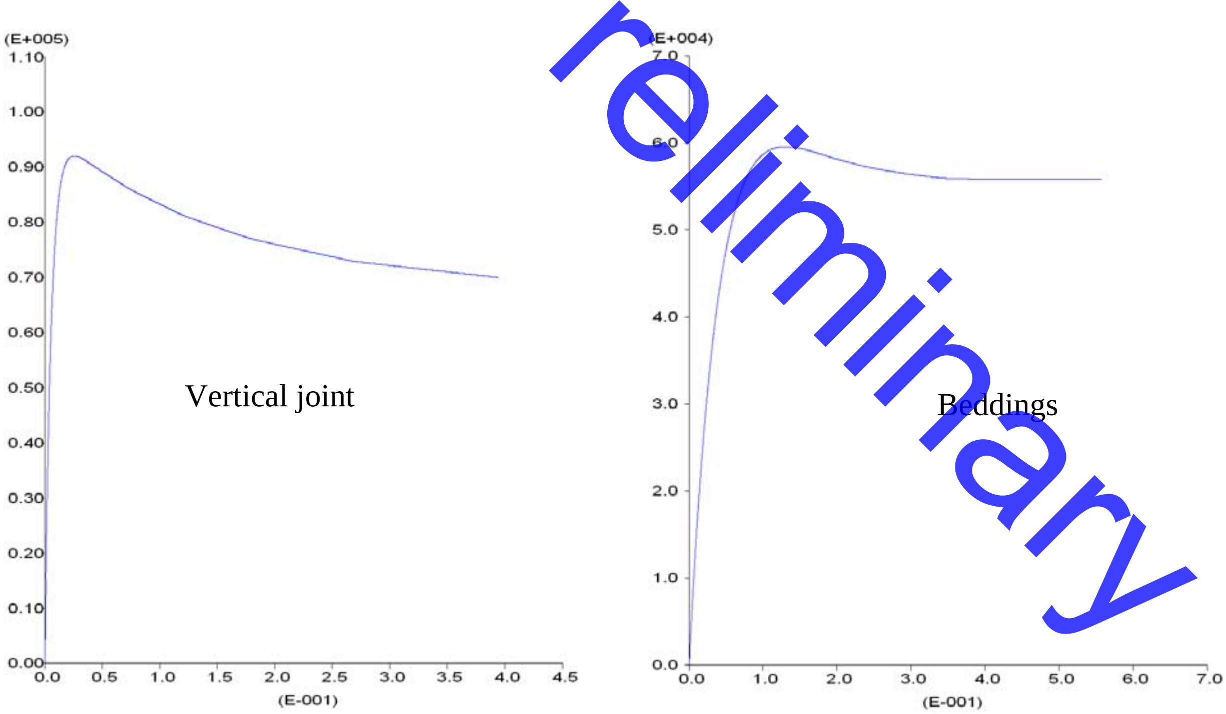
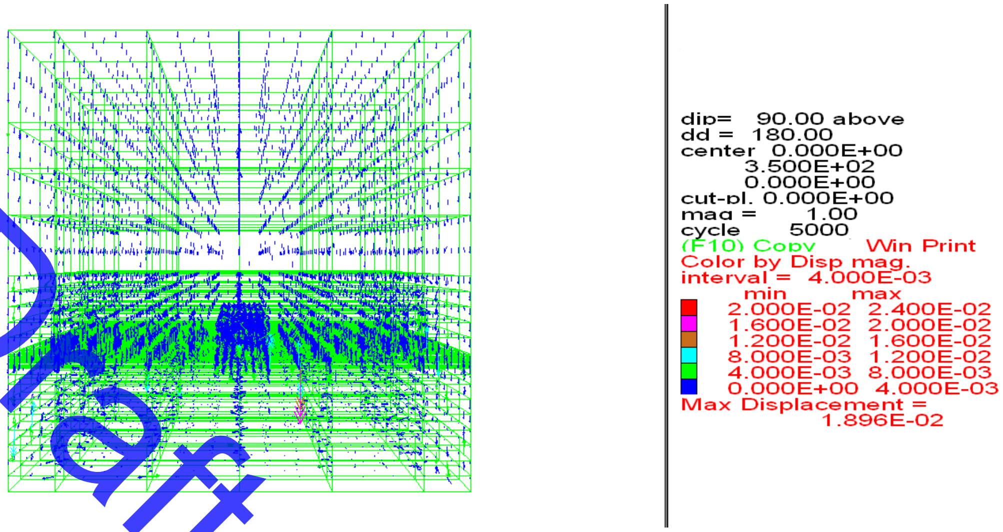


Figure 5 Material properties and simulation of direct shear test for joints used in model

- Displacement vector:



- Fluid pressure contours on joints:

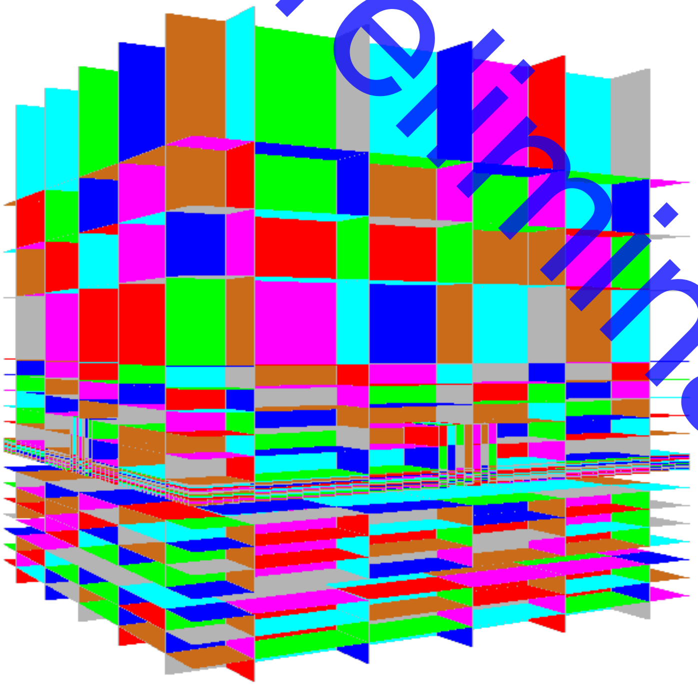
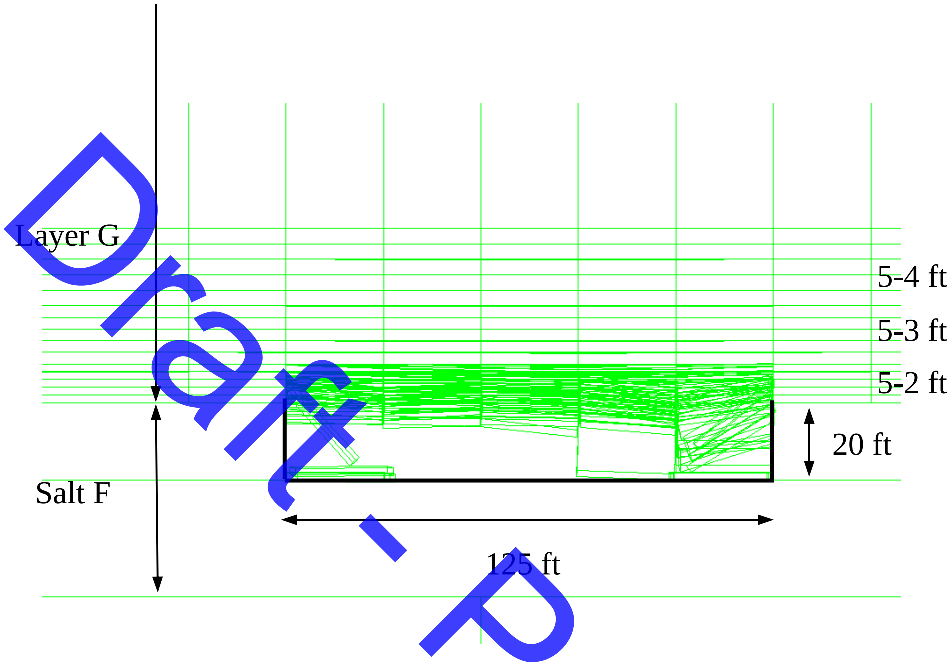


Figure 6 Initial condition (before cavern made)

➔ Analysis results (stabilized)

- View perpendicular to Z direction



- View from the elevation of the cavern top (refer to Figure 4)

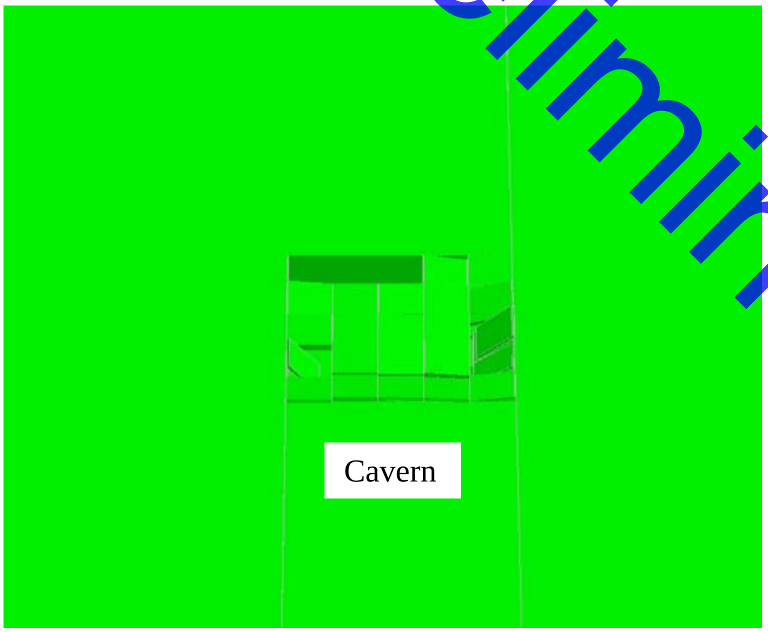


Figure 7 3-D views of displaced blocks and cavern

➔ Analysis results (stabilized)

- X-section view at AA line (-40 ft to the z-direction from center)

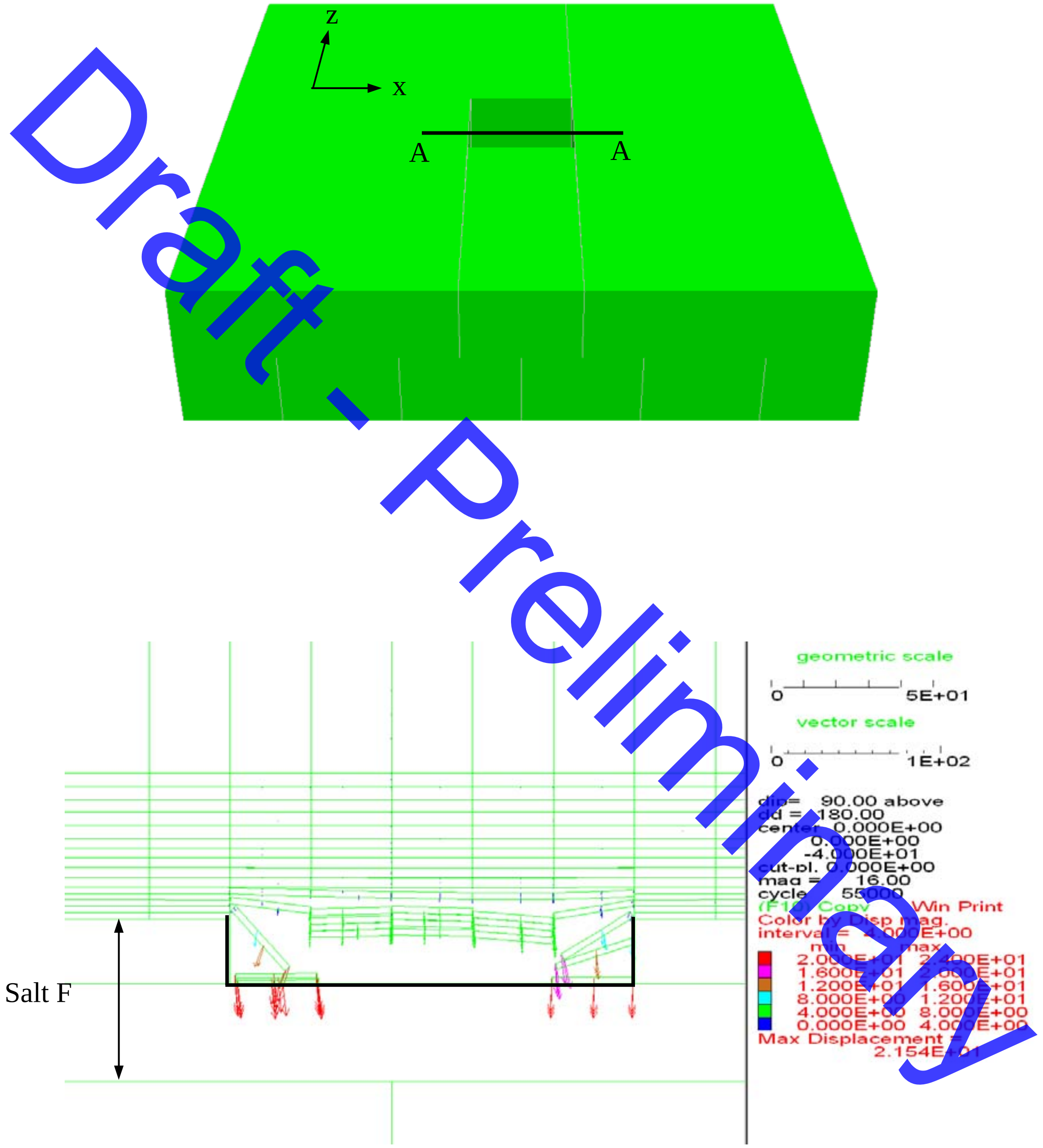


Figure 8 Displacement vectors on the x-section, AA line

- X-section view at AA line

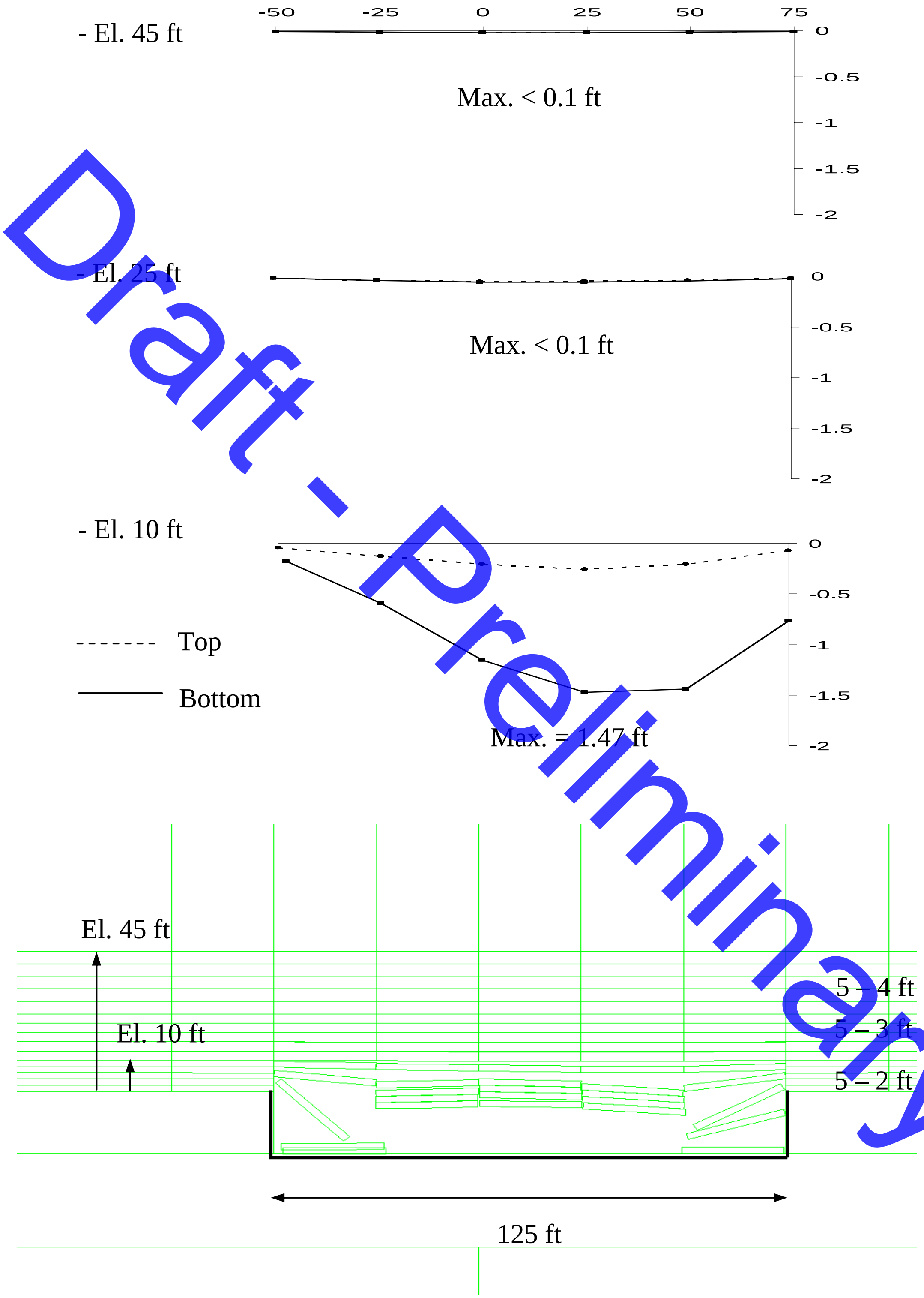
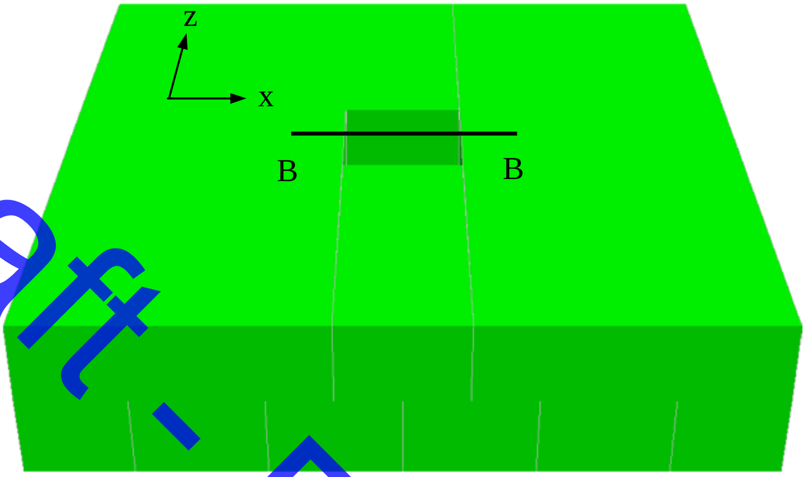


Figure 9 Vertical displacements at different elevations on the x-section, AA

➔ Analysis results (stabilized)

- X-section view at BB line (center)



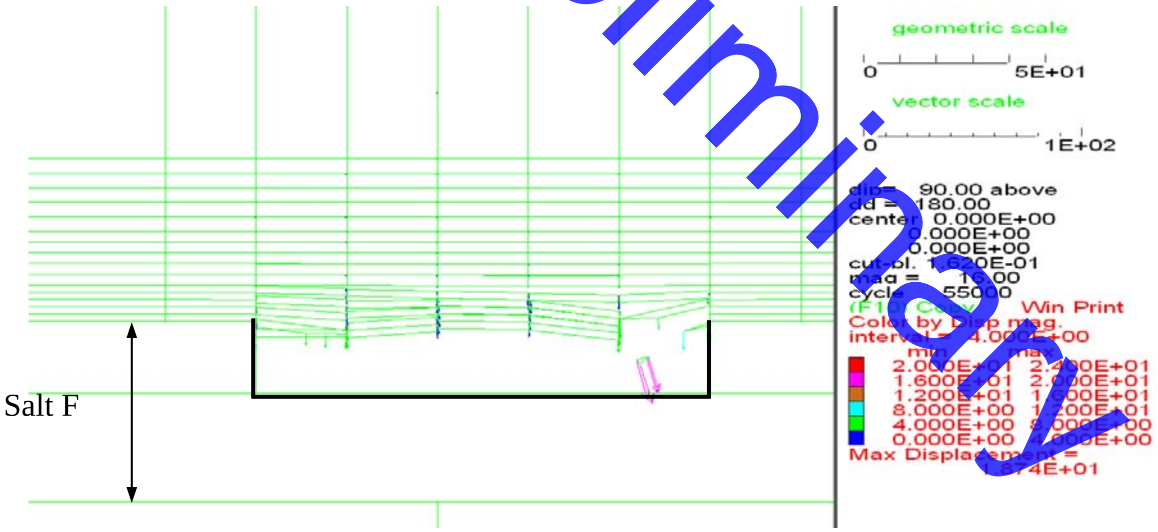


Figure 10 Displacement vectors on the x-section, BB line

- X-section view at BB line

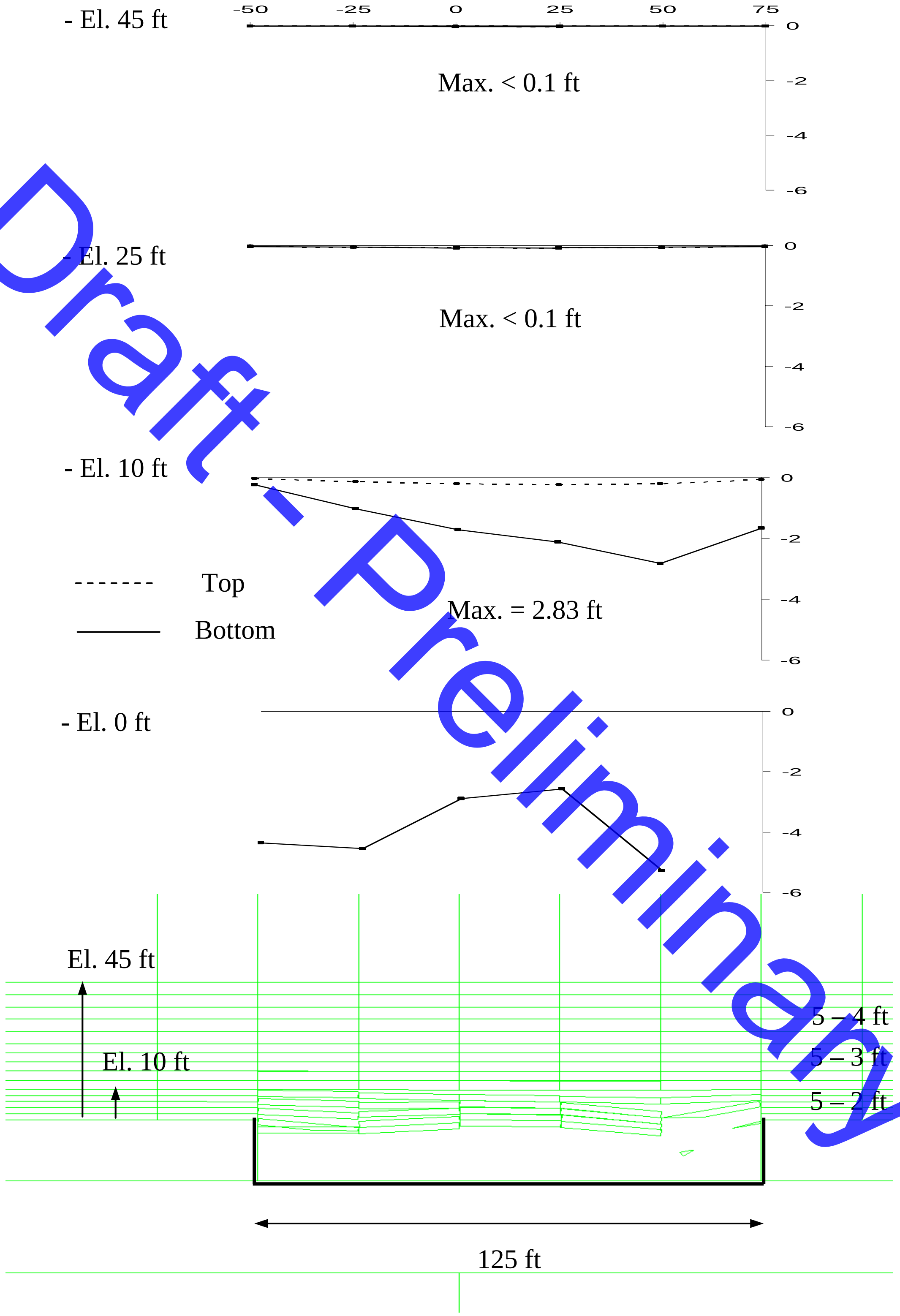


Figure 11 Vertical displacements at different elevations on the x-section, BB

➔ Analysis results (stabilized)

- X-section view at CC line (+40 ft to the z-direction from center)

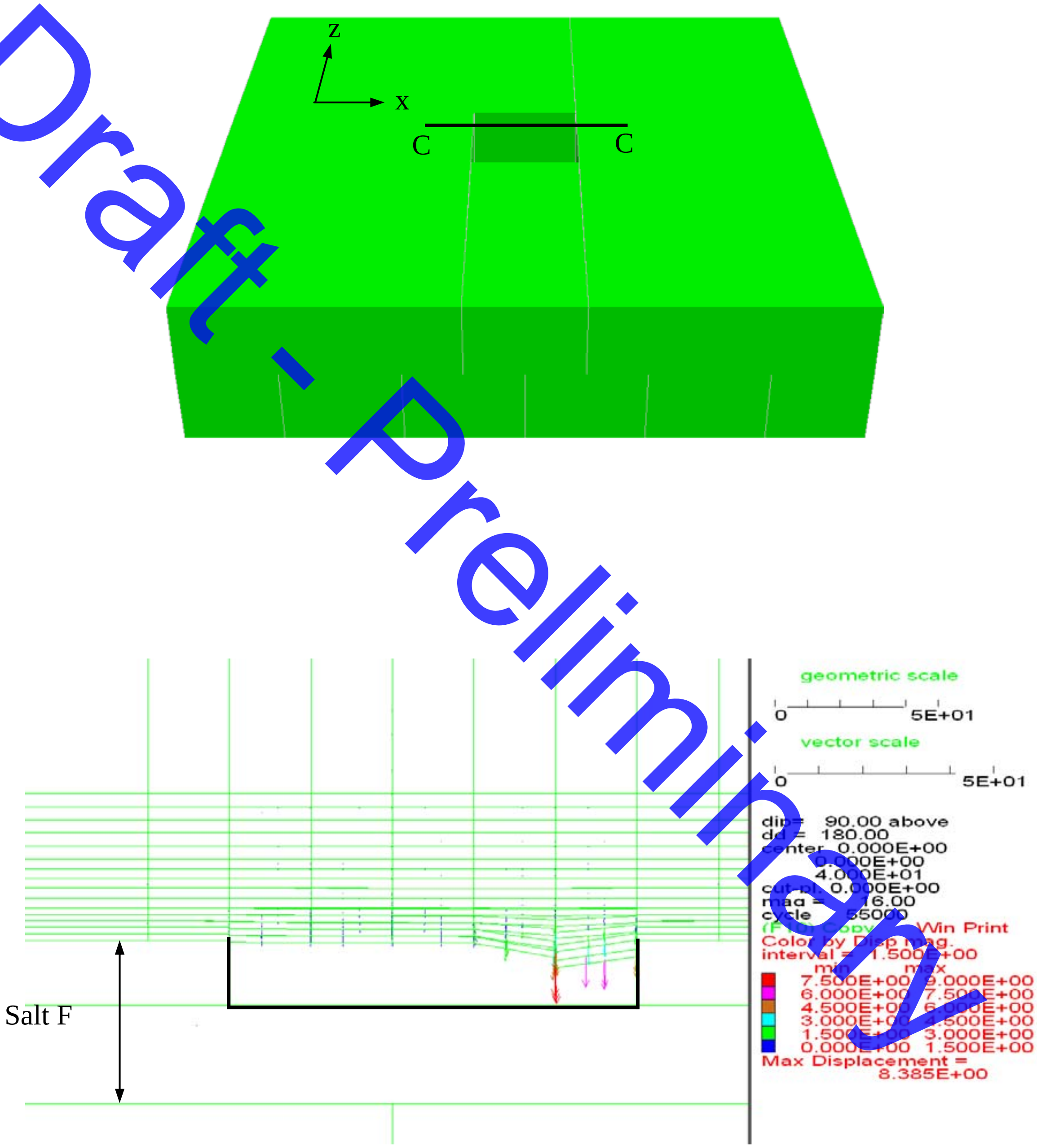


Figure 12 Displacement vectors on the x-section, CC line

- X-section view at CC line

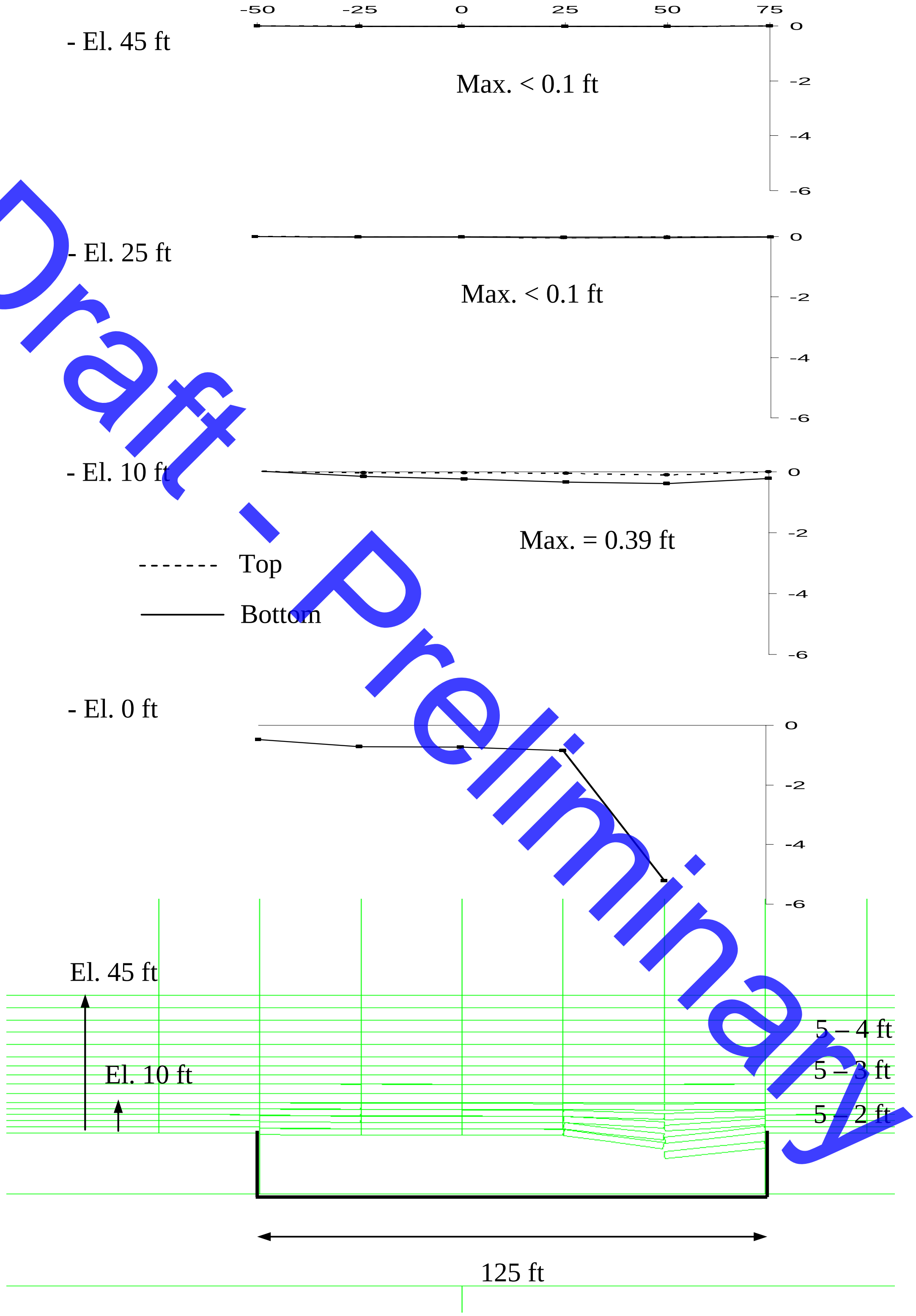
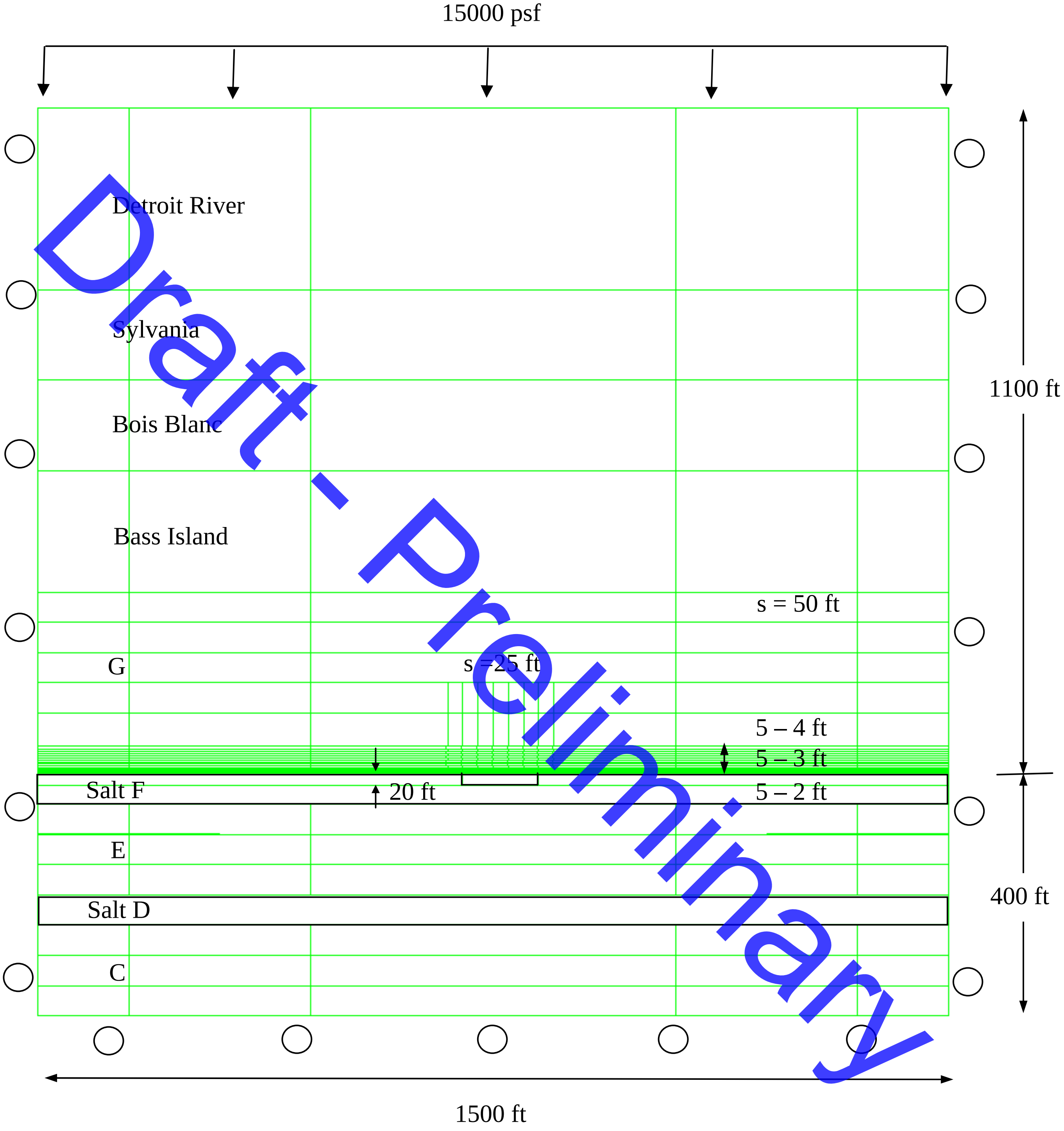


Figure 13 Vertical displacements at different elevations on the x-section, CC

Appendix A.2: Base Case with offset vertical joints



* Based on Figure A-5B (After Russell, 1993)

Figure 1 Geometry & Boundary condition (perpendicular to Z direction)

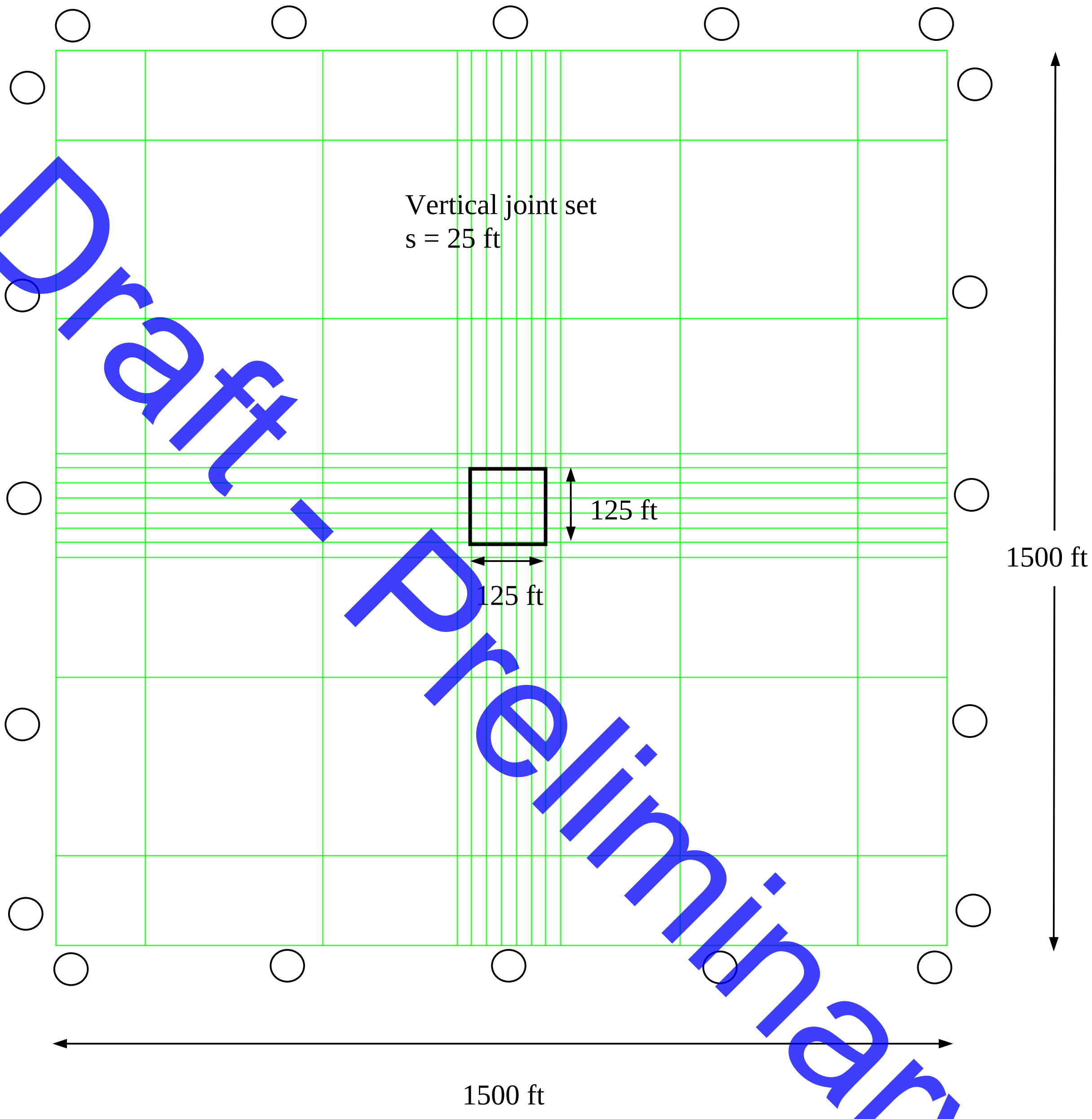


Figure 2 Geometry & Boundary condition (perpendicular to Y direction)

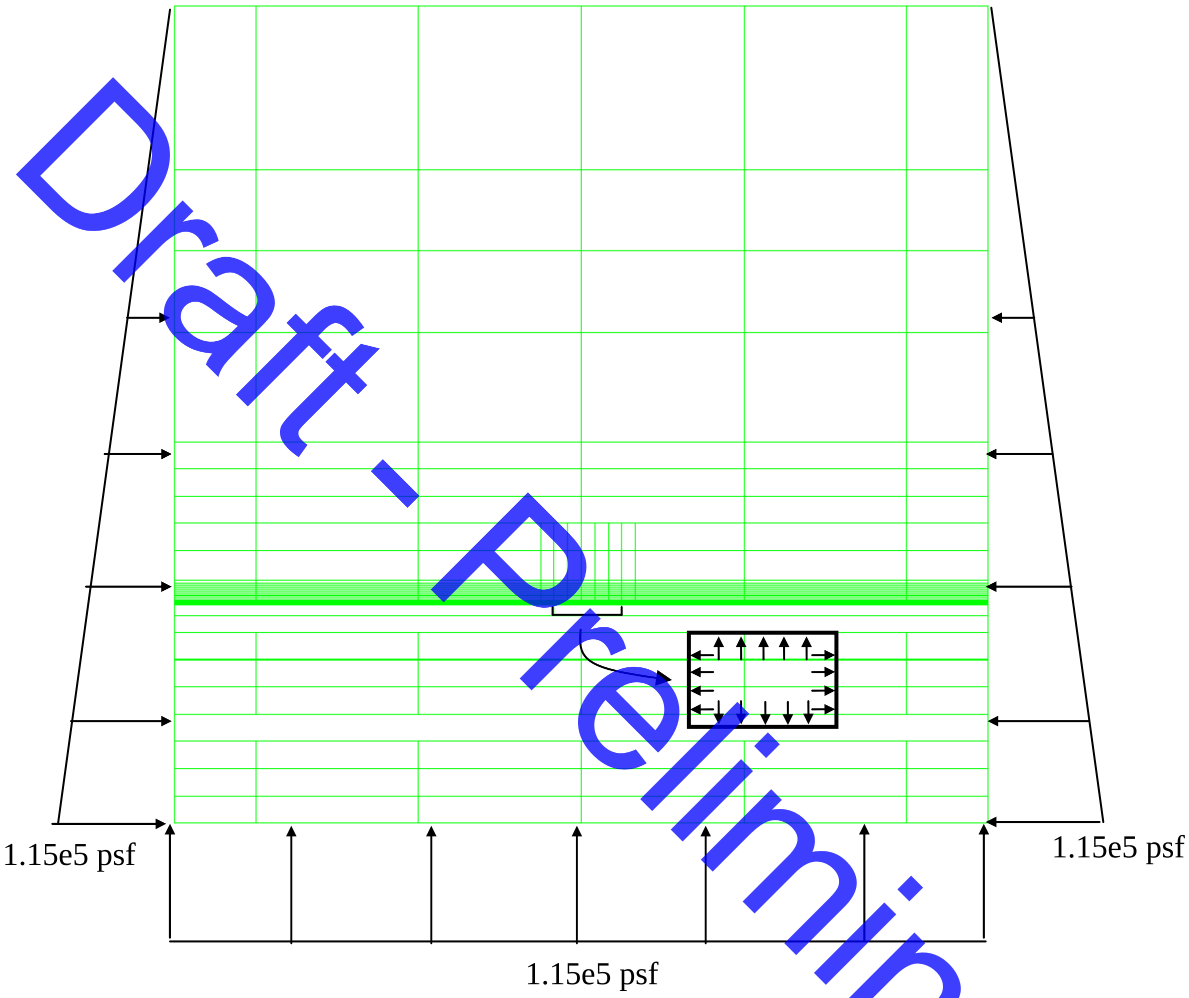


Figure 3 Geometry & Boundary condition (Fluid pressure, γ_{brine} = 76.7 pcf)

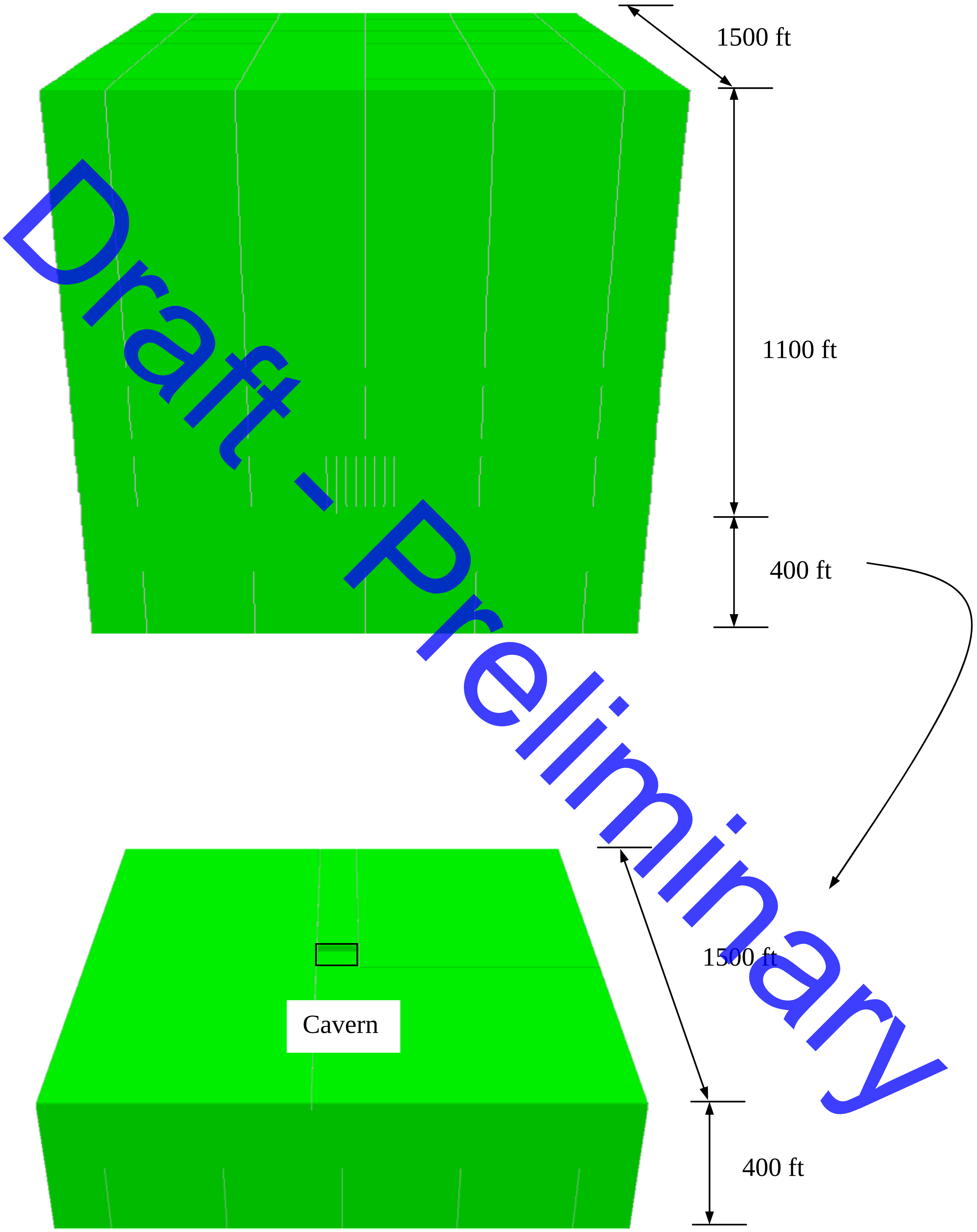


Figure 4 3 – D model

- Rock: Elastic

	E (psi)	K (psf)	G (psf)
Dolomite	4.0×10^6	3.84×10^8	2.30×10^8
Salt	1.0×10^6	9.60×10^7	5.76×10^7

- Joint: C-Y model

	K_n (psf/ft)	K_s (psf/ft)	ϕ_i (degree)	ϕ_r (degree)	R (ft)
Vertical joint	1.7×10^8	1.7×10^7	45	35	1.8×10^{-1}
Bedding	1.7×10^7	1.7×10^6	35	30	1.0×10^{-1}

- Simulation of direct shear test (τ vs. δ_h) under the normal stress of 9.56×10^4 psf

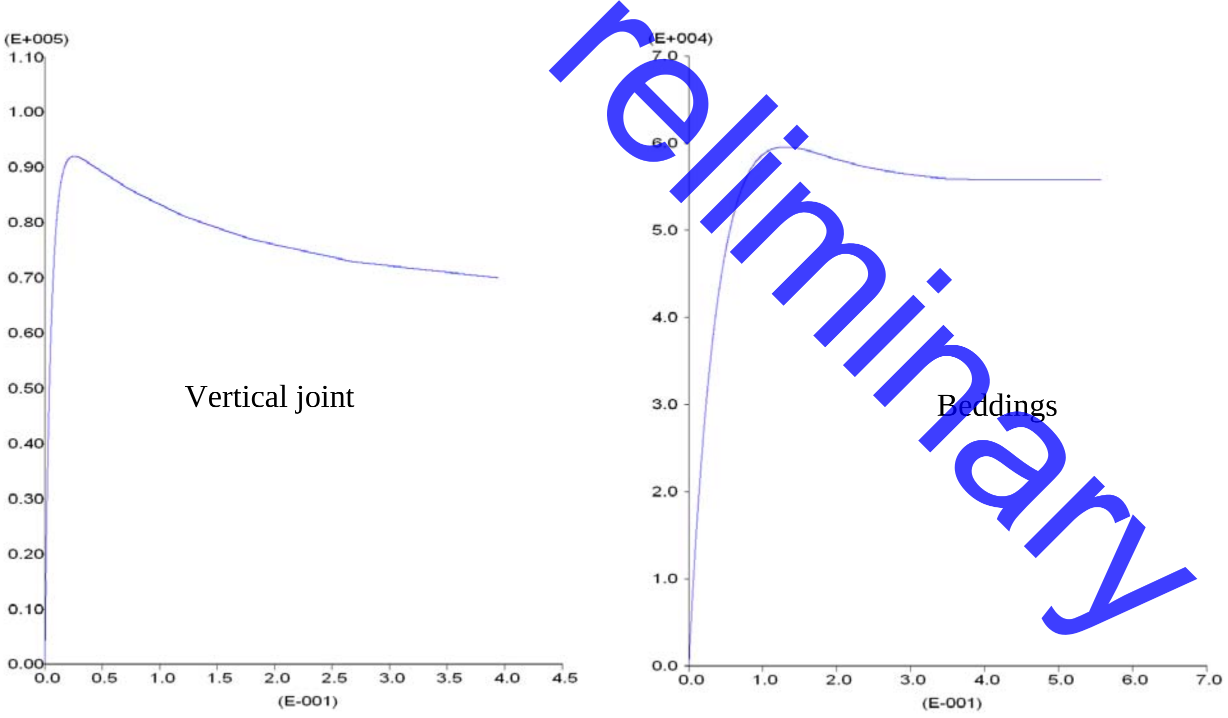
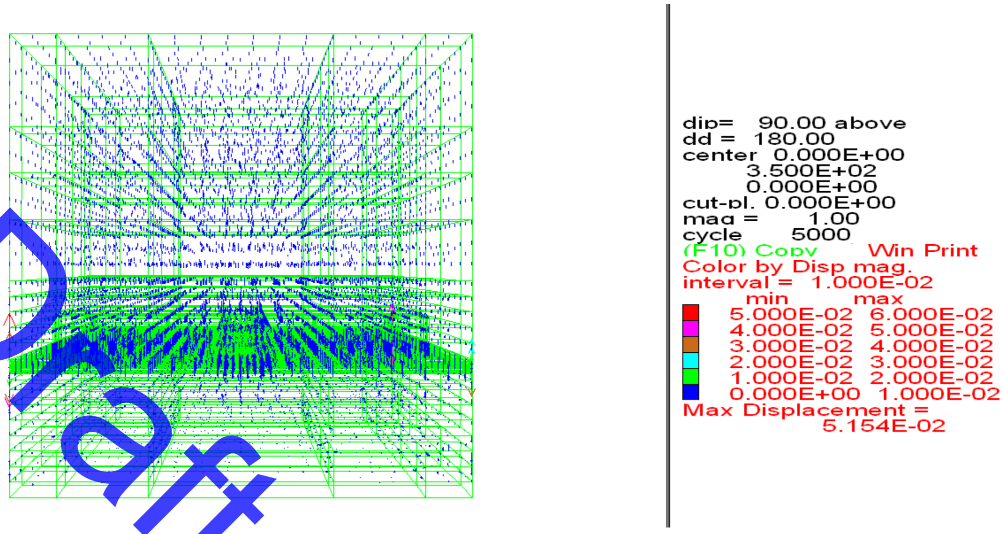


Figure 5 Material properties and simulation of direct shear test for joints used in model

- Displacement vector:



- Fluid pressure contours on joints:

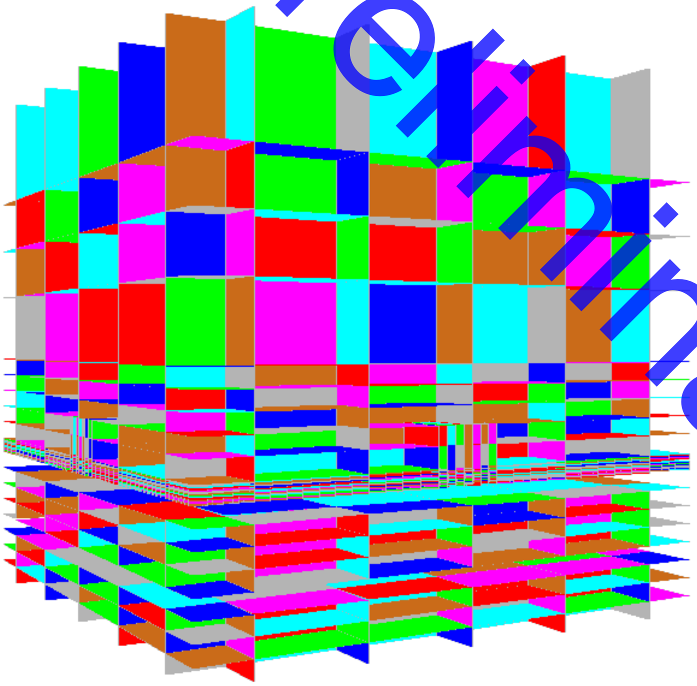
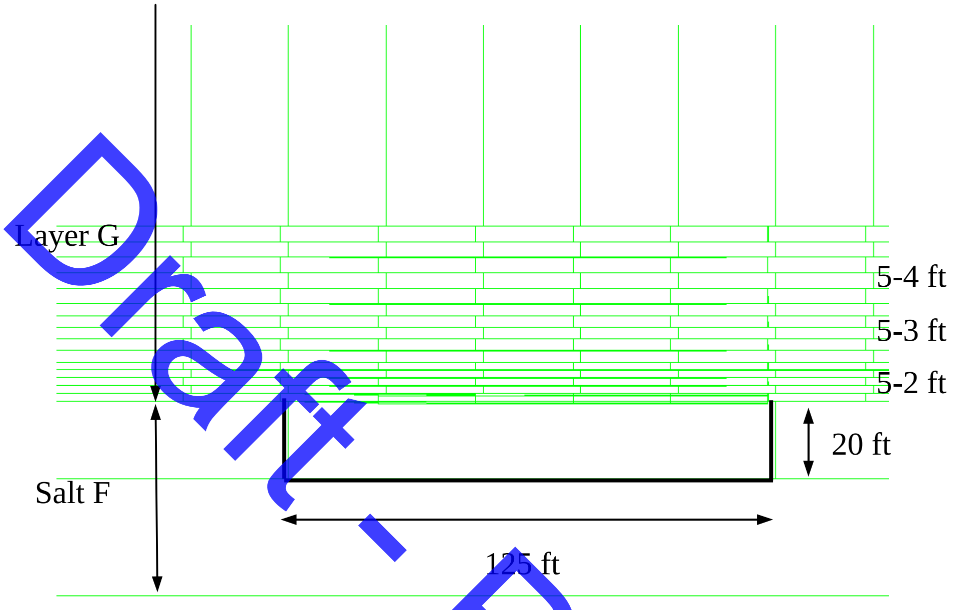


Figure 6 Initial condition (before cavern made)

➔ Analysis results (stabilized)

- View perpendicular to Z direction



- View perpendicular to Z direction (displacement vectors)

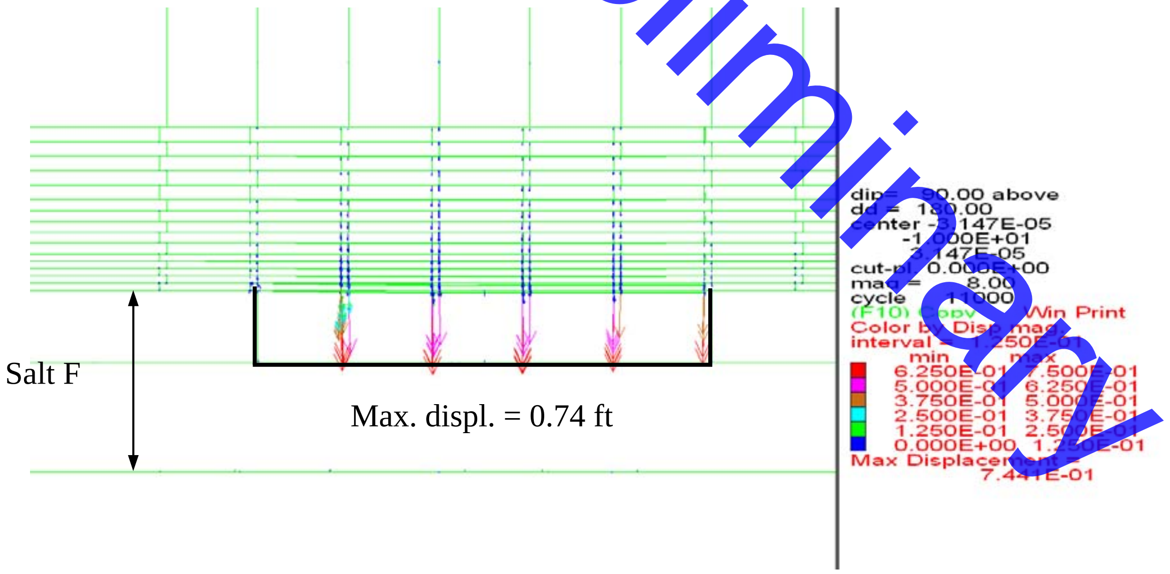


Figure 7 3-D views of displaced blocks and cavern

➔ Analysis results (stabilized)

- X-section view at AA line (-40 ft to the z-direction from center)

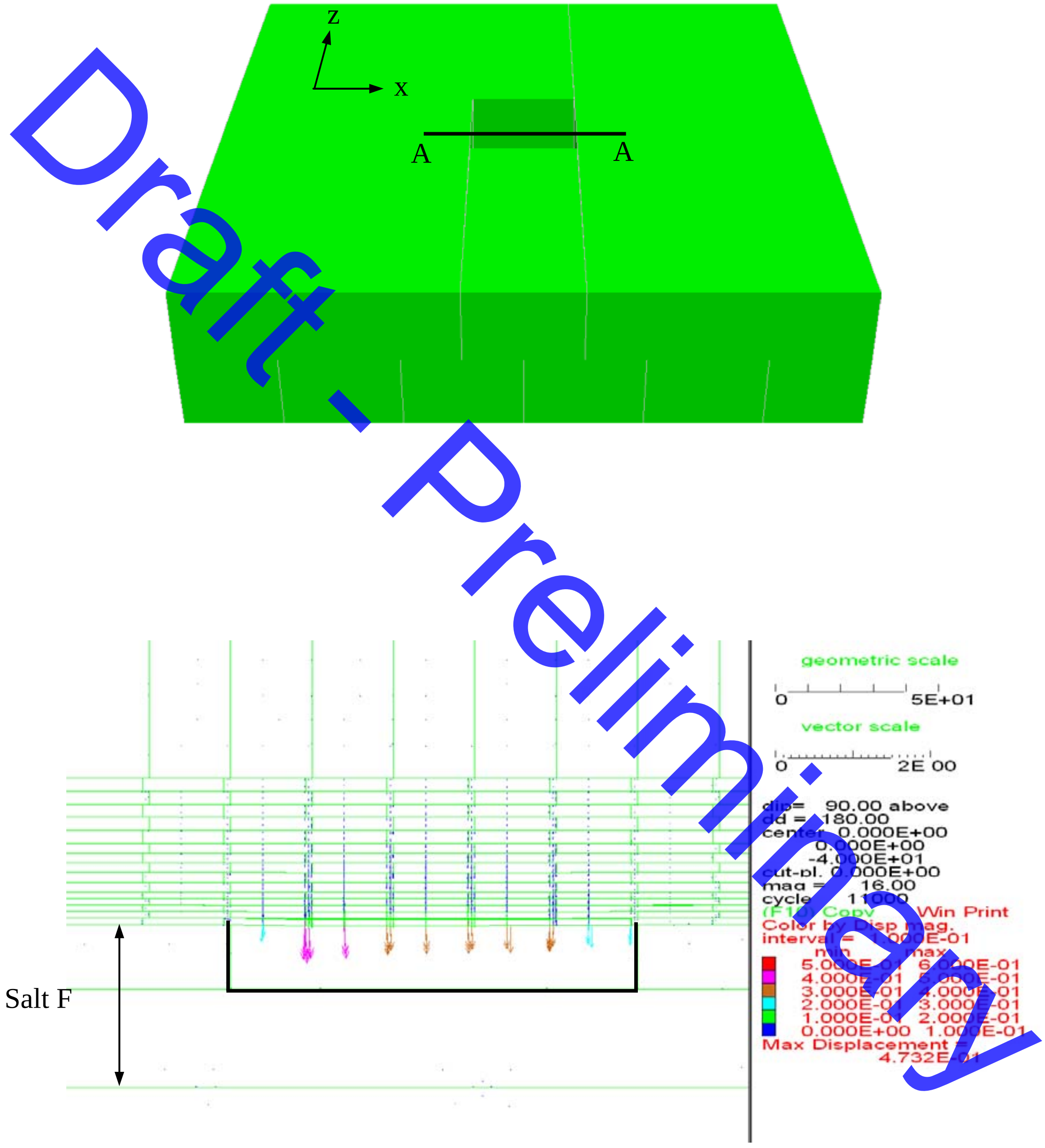


Figure 8 Displacement vectors on the x-section, AA line

- X-section view at AA line

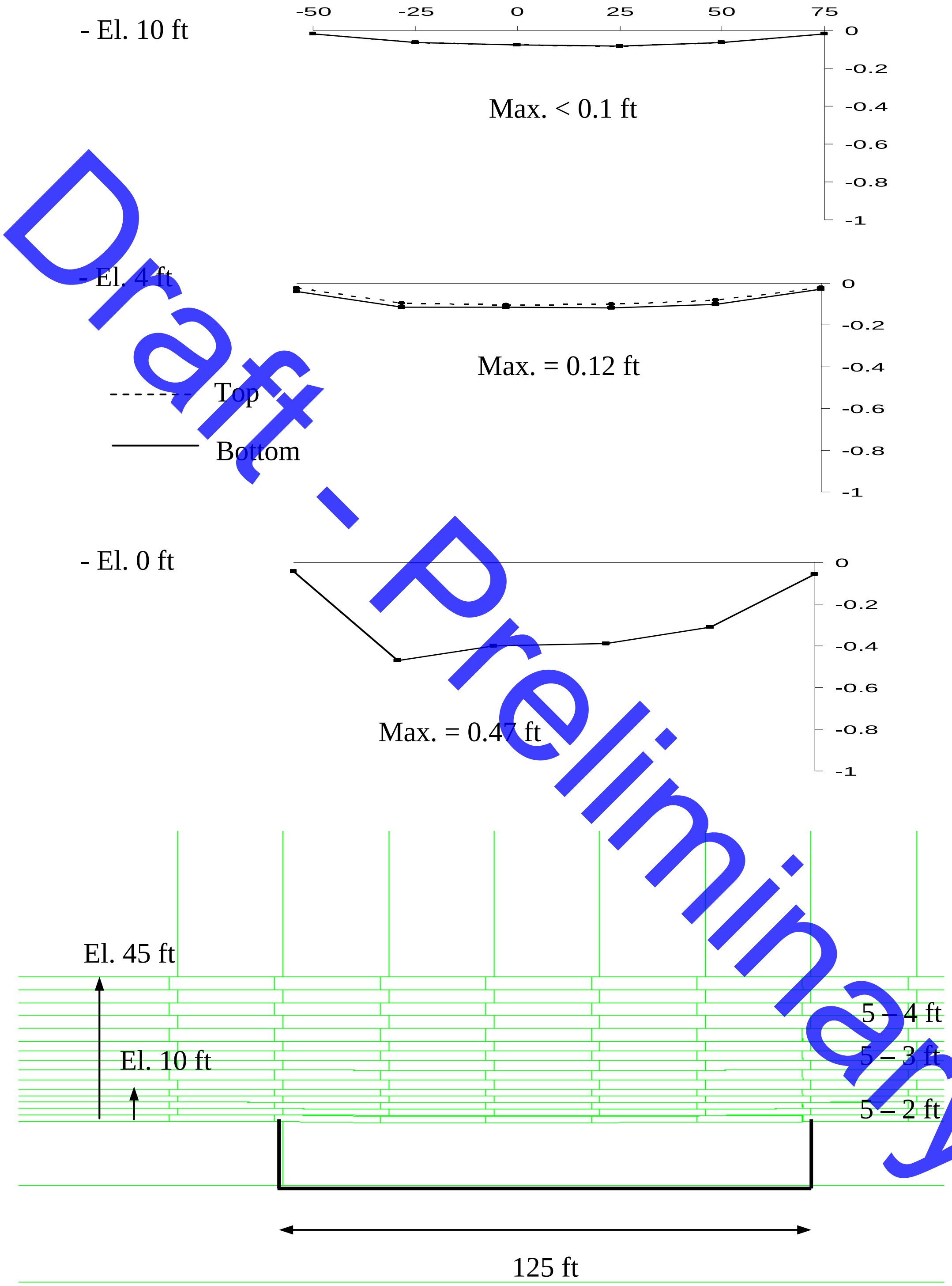
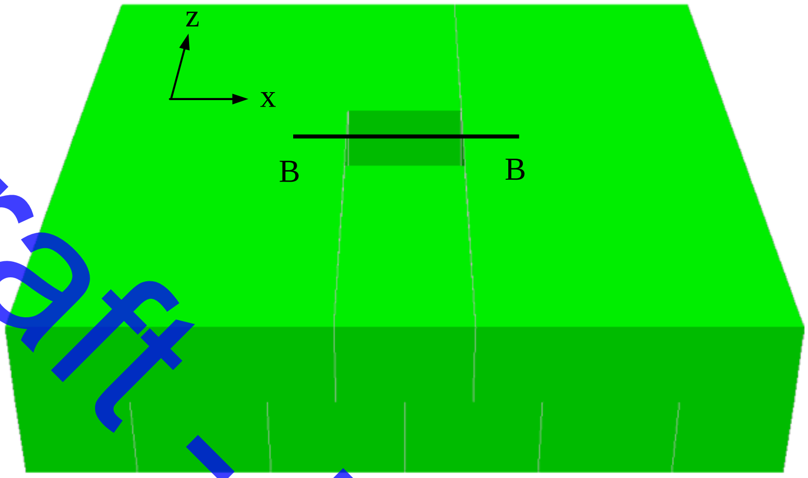


Figure 9 Vertical displacements at different elevations on the x-section, AA

➔ Analysis results (stabilized)

- X-section view at BB line (center)



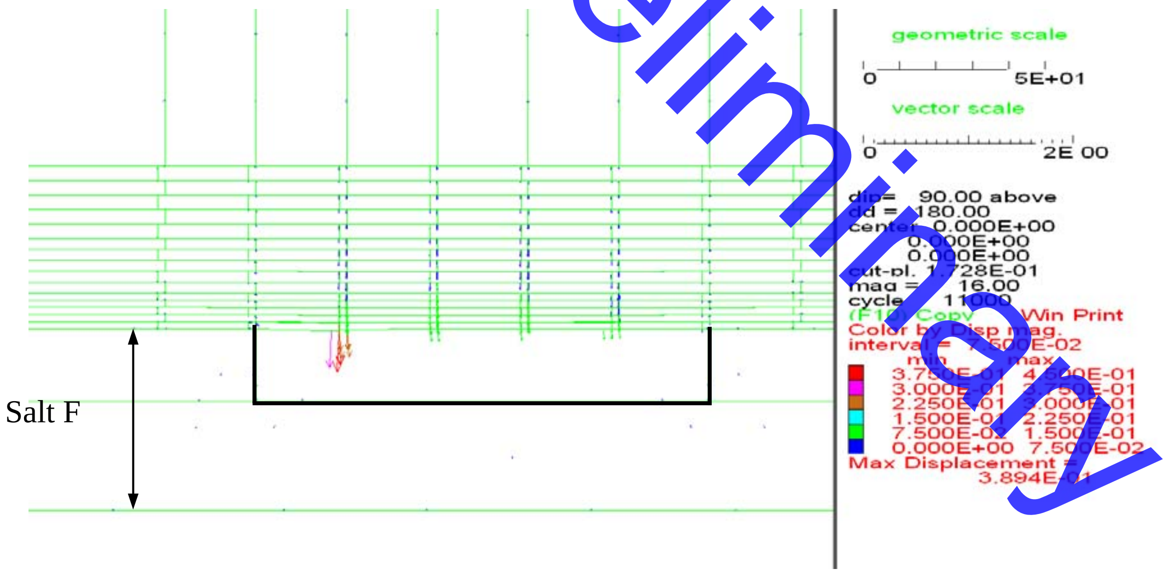


Figure 10 Displacement vectors on the x-section, BB line

- X-section view at BB line

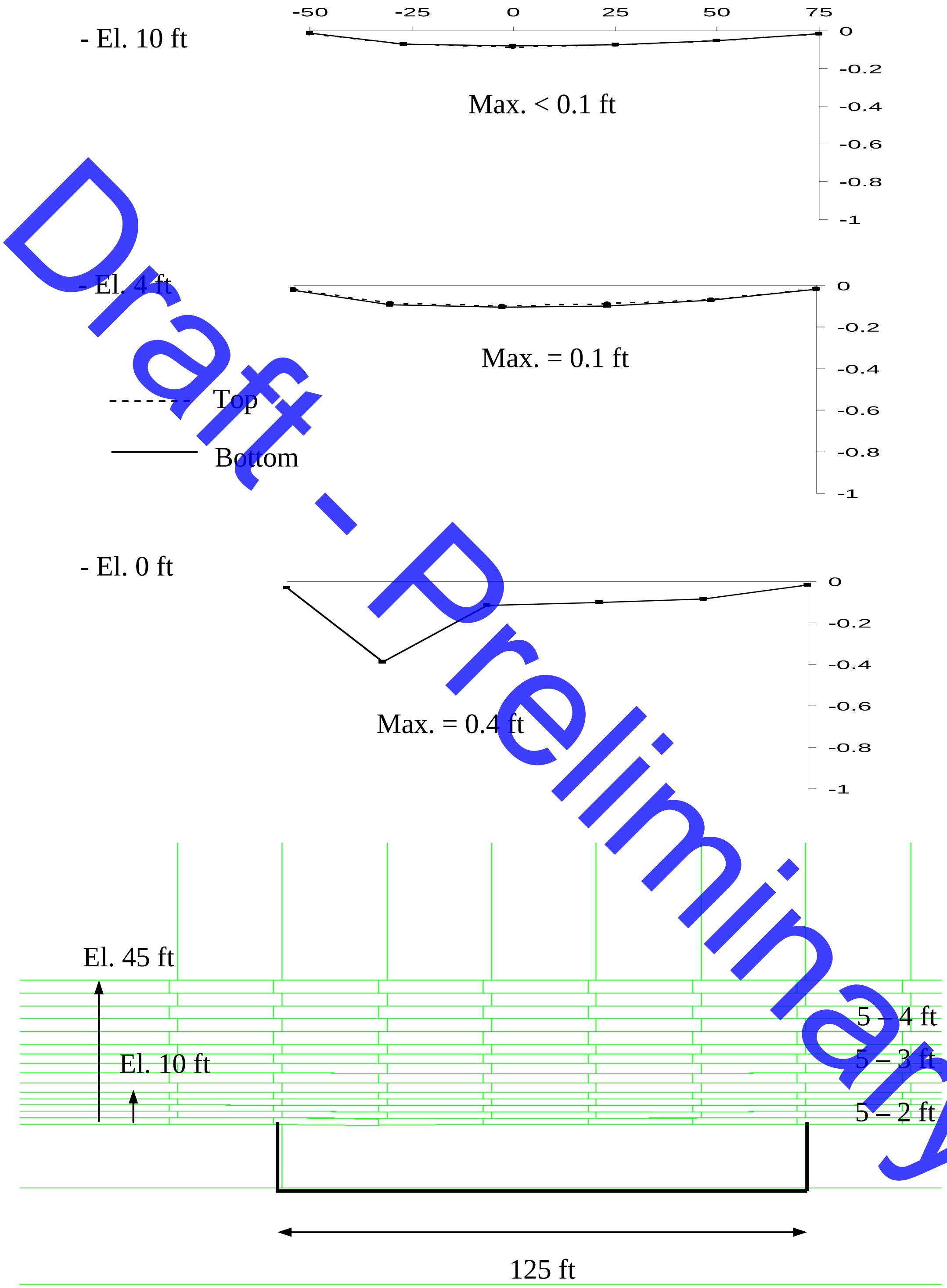
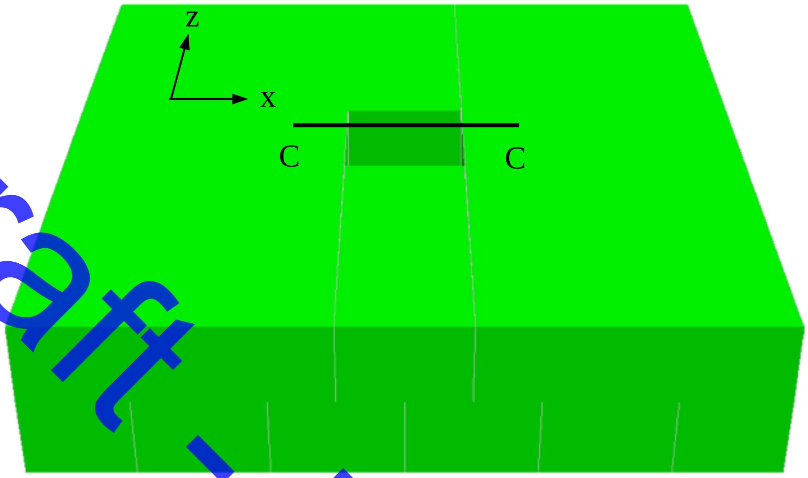


Figure 11 Vertical displacements at different elevations on the x-section, BB

➔ Analysis results (stabilized)

- X-section view at AA line (+40 ft to the z-direction from center)



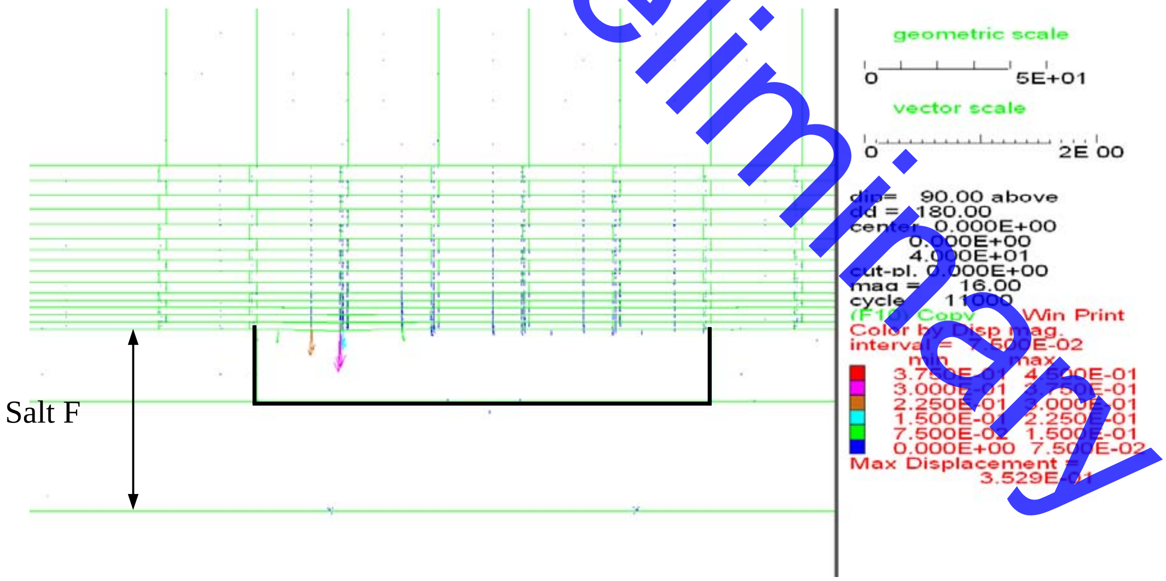


Figure 12 Displacement vectors on the x-section, CC line

- X-section view at CC line

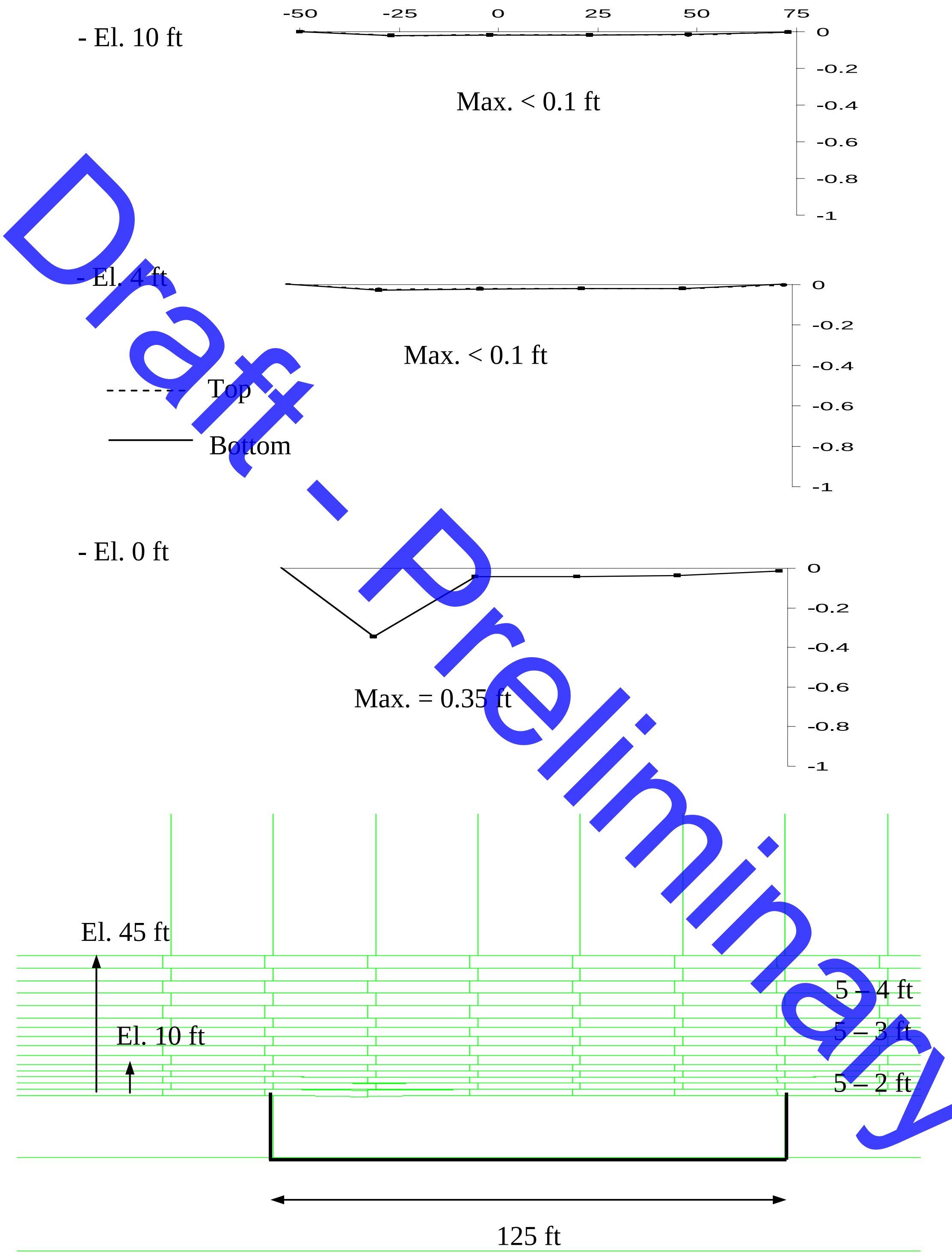


Figure 13 Vertical displacements at different elevations on the x-section, CC

Appendix J

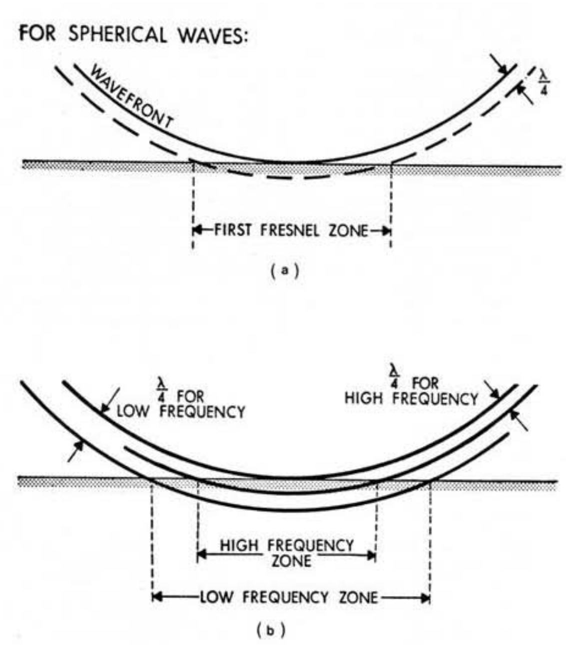
Detroit River International Crossing Study
Explanation of Fresnel Zone

APPENDIX J
EXPLANATION OF FRESNEL ZONE

The “Fresnel zone” describes the width or depth of the two-dimensional image that is presented on a seismic crosswell panel (profile). The concept of the Fresnel zone conveys the fact that all seismic methods, including crosswell reflection methods, illuminate and image a volume of earth. Because seismic techniques rely heavily on ray-tracing methods, is it easy for the user to believe that the method, especially a 2-D method, images only an infinitely thin (the “thickness of a ray”) volume of earth. Moving from the abstract concept of a plane wave front to the more realistic concept of a spherical wave front immediately brings along the concept of a Fresnel zone, especially in reflection work.

The size of the Fresnel zone is of interest in both oil exploration and engineering applications with the longest history being with the surface reflection method in the oil industry. As observed in Figure J-1, the concept of a spherical wave front is the core idea. Then one considers how much of that curved wave front contributes energy, coherently, to the wavelet that is finally received and recorded as a reflection from that interface.

Figure J-1
Detroit River International Crossing Study
Sketch of a 2-D Slice through a 3-D Spherical Wave Front Impinging at Normal Incidence on a Horizontal Reflector[a]



[a] In order that the reflected energy contributes coherently to the first one-half cycle, it must in the first one-quarter wavelength. (b) Long wavelengths (low frequency) wavelets yield larger, first-order Fresnel zones (after Sheriff, 1977).

Source: NTH Consultants, Ltd.

Figure J-1 shows that it is the first one quarter wavelengths (the downgoing quarter wavelength plus the upgoing quarter wavelength) that contribute to the reflected wavelet. So, to estimate the size of the Fresnel zone (b), the wavelength (λ) of the impinging energy and the curvature of the wave front just above the reflector must be known. But, neither of these parameters is known precisely prior to a seismic acquisition program. Even after the data have been acquired, they remain estimates. An estimate of the curvature can be obtained given the depth of the reflector beneath the earth's surface (surface seismic reflection method) or the distance from the sources and receivers down (or up) to the reflector (crosswell reflection techniques).

Because of seismic attenuation and scattering, the wavelength of the impinging energy is more difficult to estimate before data acquisition. It remains difficult for the surface seismic method after acquisition. Crosswell reflection methods are better in the sense that some receivers are very close to any given interface, therefore a measure of the impinging energy can be made.

Hardage gives a formulation for Fresnel zone radius that does not assume that the sources and receivers are on the earth's surface. That form is used here with a modification that allows the source to move into the earth in the same manner as the receivers. It is required that the wavelength λ be smaller than the distances of the sources and receivers above (or below) the interface in question. This is easily satisfied for crosswell measurements in the kilohertz range.

Given the geometry in Figure J-2, and the requirement that the wavelengths (λ) be small, the radius of the Fresnel zone is:

$$r = c \sqrt{}x(d - x) \qquad \text{(Exp ression1)}$$

Where:

$c = (1/d)\sqrt{}h\lambda$
d = distance between boreholes
h = the maximum distance between sources and receivers and the interface
λ = wavelength
x = point along the line between the two boreholes.

Wavelength

The wavelength is the important parameter in the determination of the Fresnel zone radius. It, in turn, is a function of the spectral content of the data. It is difficult to estimate the frequency content of the data prior to an acquisition program. The experience of the team with crosswell reflection using these sources/receivers in Michigan Basin formations was helpful in estimating a 100 foot radius for the Fresnel zone as part of the initial forward modeling efforts. The spectra obtained after data acquisition (Figures J-3 through J-6) show, as expected, that the entire source sweep (100Hz to 2,000Hz.) of more than four octaves is detected.

However, we also see that a spectral peak, with a variety of shapes, occurs in the lower portion of the signal band (200Hz to 600Hz).

Using this frequency band and the range of velocities at the project site, (13,000 feet/sec for the Sylvania Sandstone to 20,000 feet/sec for the E-Dolomite) wavelengths are obtained that range from approximately 20 feet to 100 feet. For the planning portion of the investigation, together with the forward modeling, a wavelength of 75 feet was conservatively selected, to yields a maximum Fresnel zone radius of approximately 168 feet. This was based on using sources and receivers that are 750 feet above (or below) the reflector.

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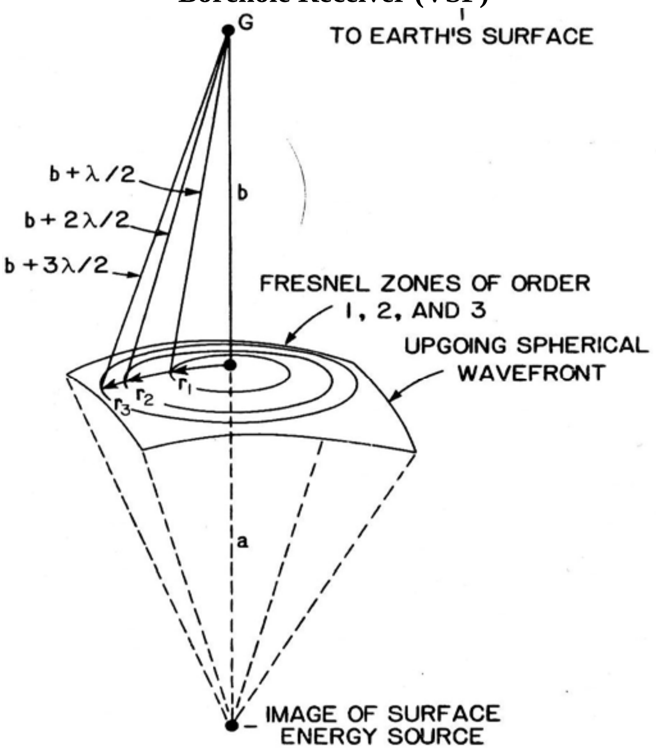
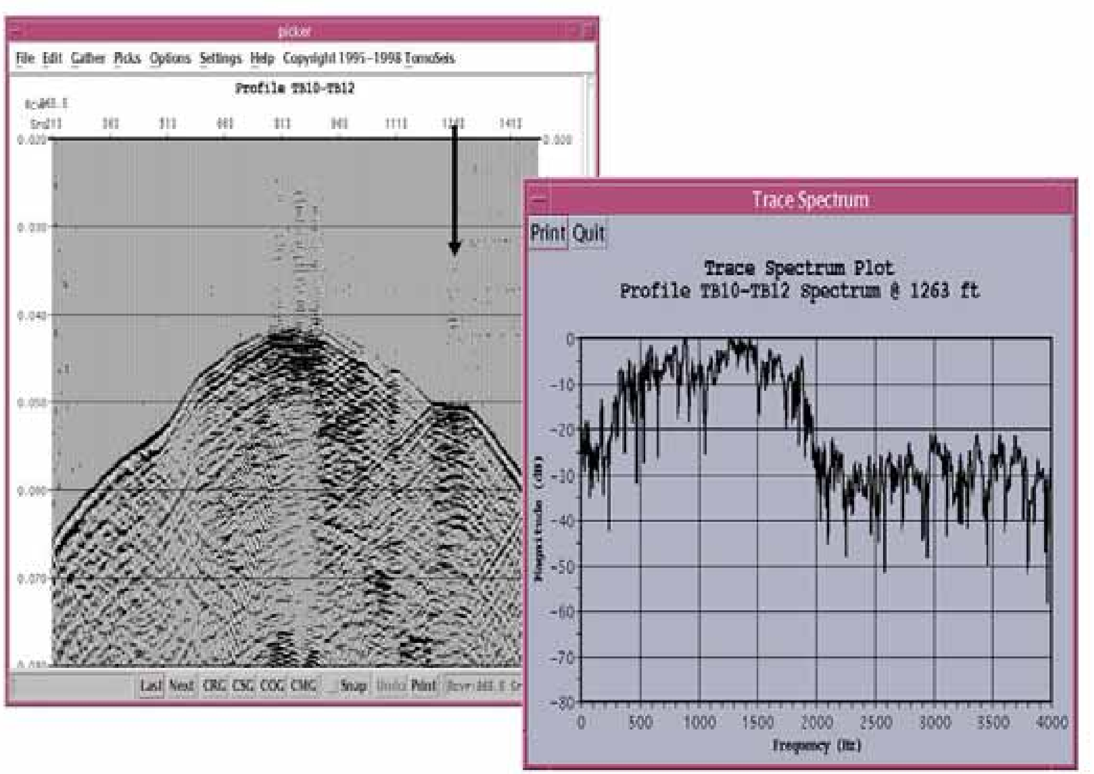
Figure J-2
Detroit River International Crossing Study
Geometry for a Fresnel Zone Computation for the Case of Surface Source and Borehole Receiver (VSP)[a]



[a] The cross well formulation is derived from this geometry by allowing the source to move into the earth (after Hardage, 1983).

Source: NTH Consultants, Ltd.

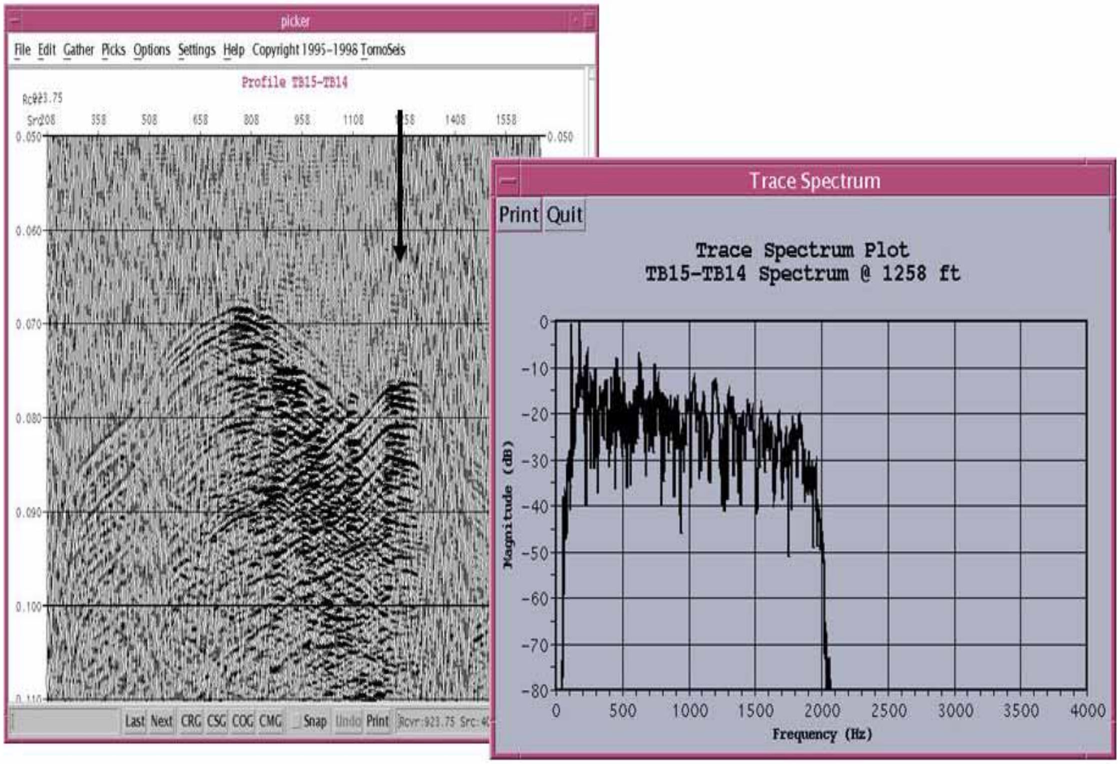
Figure J-3
Detroit River International Crossing Study
A Fan of Data from the TB-10 to TB-12 Survey in the X-11 Crossing[a]



[a] The receiver is at 865.5 feet (in the G-Shale) and the source is at 1,263 feet (in the E-Dolomite). Nearly the entire sweep is observed with a peak at approximately 1,300Hz.

Source: NTH Consultants, Ltd.

Figure J-4
Detroit River International Crossing Study
A Fan of Data and Associated Spectrum from the TB-15 and TB-14 Survey in the X-11 Crossing[a]



[a] The receiver is at a depth of 924 feet and the source is at a depth of 1,258 feet. Ignoring the electrical noise spikes at 120 and 180Hz. we see that the spectrum peaks at approximately 200Hz.

Source: NTH Consultants, Ltd.

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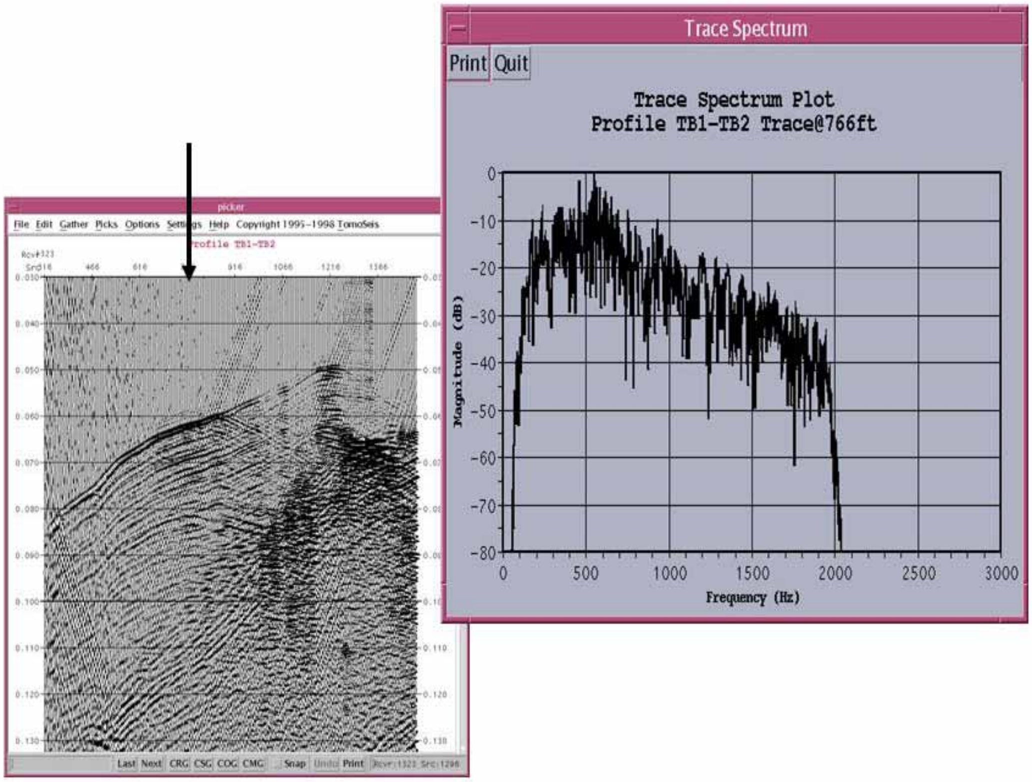
Figure J-5
Detroit River International Crossing Study
A Fan of Data and Associated Spectrum from the TB-1 to TB-2 Survey[a]



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[a] The receiver is at a depth of 1,223 feet (in the E-Dolomite) and the source is at a depth of 766 feet (in the Bass Island Dolomite). The spectrum peaks at 600Hz.

Source: NTH Consultants, Ltd.

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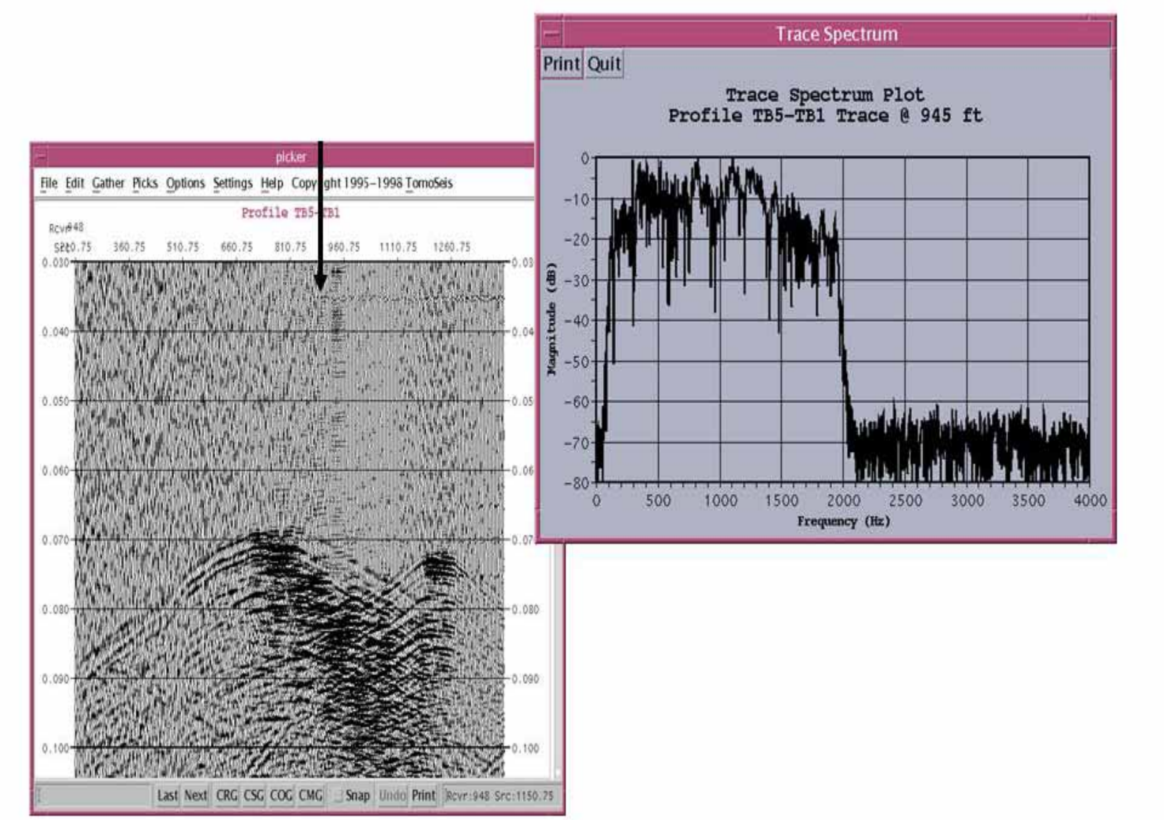
Figure J-6
Detroit River International Crossing Study
A Fan of Data and Associated Spectrum from the TB-1 to TB-5 Survey[a]



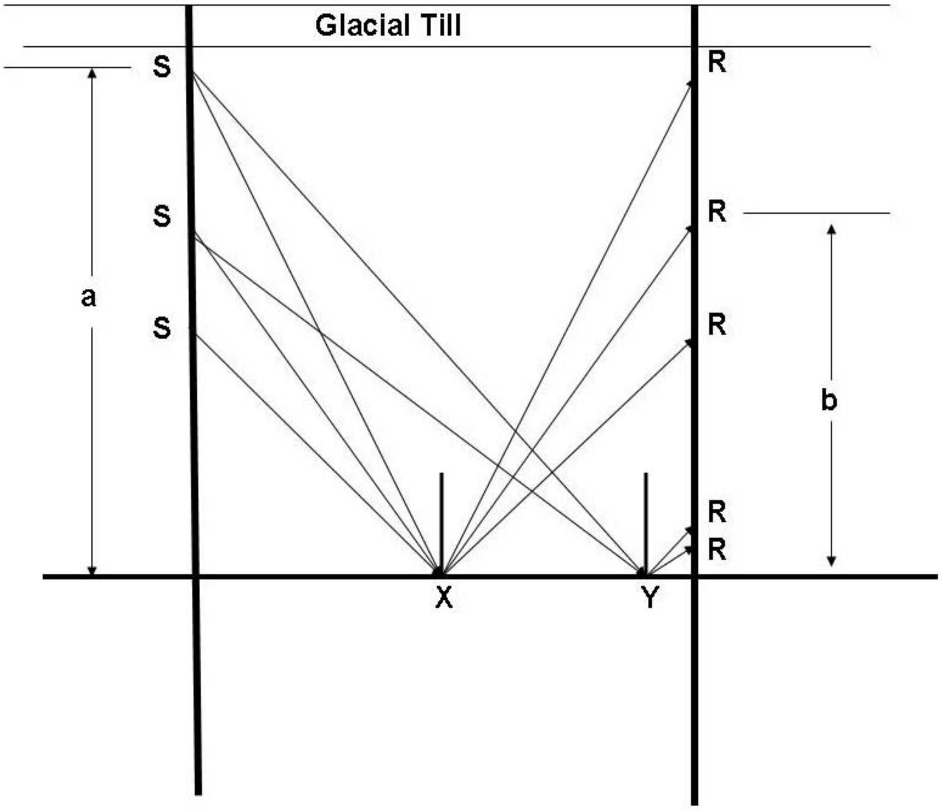
[a] The receiver is at a depth of 948 feet (in the G-Shale) and the source is at a depth of 945 feet (in the G-Shale). The spectrum has a broad peak from 600Hz to approximately 1,200 Hz.

Source: NTH Consultants, Ltd.

Fresnel Zone Size Given Broadband Signals - When a signal with a broad frequency spectrum, as noted in the work here, illuminates a reflector one can visualize the smaller, high frequency Fresnel zones being encompassed and embedded in the larger, low frequency zones. Thus, the total reflected signal that reaches the receiver is composed of energy from the largest Fresnel zone in addition to the smaller, higher frequency, zones.

Fresnel Zone Size of Stacked Data - To increase the signal-to-noise ratio, the data are stacked. Figure J-7 shows that any given reflection point is illuminated by different source/receiver pairs which are located at various distances above, or below, a given interface. The radius of a Fresnel zone can be given by an expression that explicitly uses these distances (Hardage, 1983). It is clear that after stacking, that the reflected signal is composed of energy from different sizes of Fresnel zones. The largest of these comes from the source/receiver pair at the greatest distance above or below the given reflector.

Figure J-7
Detroit River international Crossing Study
A Fan of Reflections from an Interface[a]



[a] To increase signal to noise ratio, fans of data over a limited range of angles are stacked. Here, at point X, a fan of rays with incidence angles from approximately 30° to 50° are depicted. Parameter “a” is the distance of the source above the interface and “b” is the distance of the receiver above the interface.

Source: NTH Consultants, Ltd.

Expression (1) is only valid if the wavelength is small compared to the distance of the source and receiver above (or below) the interface. Therefore, the greatest error in these diagrams occurs near each borehole; however, this is the region where the greatest overlap of Fresnel zones exists, and so complete coverage is assured.

Figure J-7 also illustrates the fact that as the reflection point moves towards the receiver borehole (and in like manner towards the source borehole) the number of ray paths (source/receiver combinations) available for the stack decreases, thereby reducing the signal-to-noise ratio. It is also clear that as the reflection point nears either borehole, that “a” or “b” approach zero. This is where the assumption that the wavelength be small compared to distance to the interface breaks down.

Fresnel Zone Size is a Function of Several Variables

However, the main point of Figures J-3 through J-7 and equation (1) is the Fresnel zone size is a function of:

1. Spectral content of the seismic signal
2. Velocity of the medium

(used together as wavelength)

3. Location of source and receiver (i.e. wavefront curvature)

During the data processing (e.g. stacking of fans of rays) and imaging steps, various Fresnel zones are summed. Although this obscures the contribution of particular Fresnel zones one can associate the largest Fresnel zone with a given reflection point, which is valuable for this project where lateral coverage is important. (Migration of the crosswell reflection data collapses the Fresnel zone in the in-line direction but does not alter the cross-line dimension).

Table J-1
Detroit River International Crossing Study
Maximum Fresnel Zone Diameter at Specific Salt Layer Interfaces (200 Hz)

Formation	**Maximum wavelength in overlying formation Lowest predominate frequency = 200Hz**	**Maximum distance up to sources and receivers**	**Maximum Fresnel Zone Diameter**
F-Salt	90 ft. (G-Shale)	900 ft.	280 ft.
D-Salt	100 ft. (E-Dolomite)	1,100 ft	330 ft.
B-Salt	66 ft. (C-Shale)	1,200 ft.	280 ft.

Source: NTH Consultants, Ltd.

Given that we are especially interested in the tops of the B-Salt, D-Salt and the F-Salt we can make a table of the maximum size of the Fresnel zone (halfway between two boreholes) as a function of the largest wavelength impinging on those interfaces and the maximum distance the sources and receivers are above the interface. The predominate wavelength impinging on the target interface depends on the spectral content of the wavelet and the velocity of the medium above the interface.

The tops of these salts are in the bottom half of the boreholes therefore imaging these tops from the bottom-up is not recommended. Small distances to the interfaces and (relatively) large distances between boreholes conspire to make large angles of incidence at those interfaces. This causes large changes in the phase spectrum upon reflection and that, in turn, creates a broad, distorted wavelet, unsuitable for imaging.

Signal Power at the Low End of the Spectrum

In the spectra shown in Figures J-3 through J-6, we observe that the amplitude does not always decay monotonically as the frequency increases. Stated in another way, the highest amplitudes are not always at the lowest frequencies (200Hz-250Hz). A strong peak can be seen at 500Hz-600Hz. Therefore, in the computation of various representative wavelengths for the maximum Fresnel zone radius, we will not solely use 200Hz (Table J-2)

Table J-2
Detroit River International Crossing Study
Maximum Fresnel Zone Diameter at Specific Salt Layer Interfaces (500 Hz)

Formation	Maximum wavelength in overlying formation Lowest predominate frequency = 500Hz	Maximum distance up to sources and receivers	Maximum Fresnel Zone Diameter
F-Salt	36 ft. (G-Shale)	900 ft.	180 ft.
D-Salt	40 ft. (E-Dolomite)	1,100 ft.	210 ft.
B-Salt	27 ft. (C-Shale)	1,200 ft.	180 ft.

Source: NTH Consultants, Ltd.

Fresnel Zone Coverage Provided by Multiple Surveys

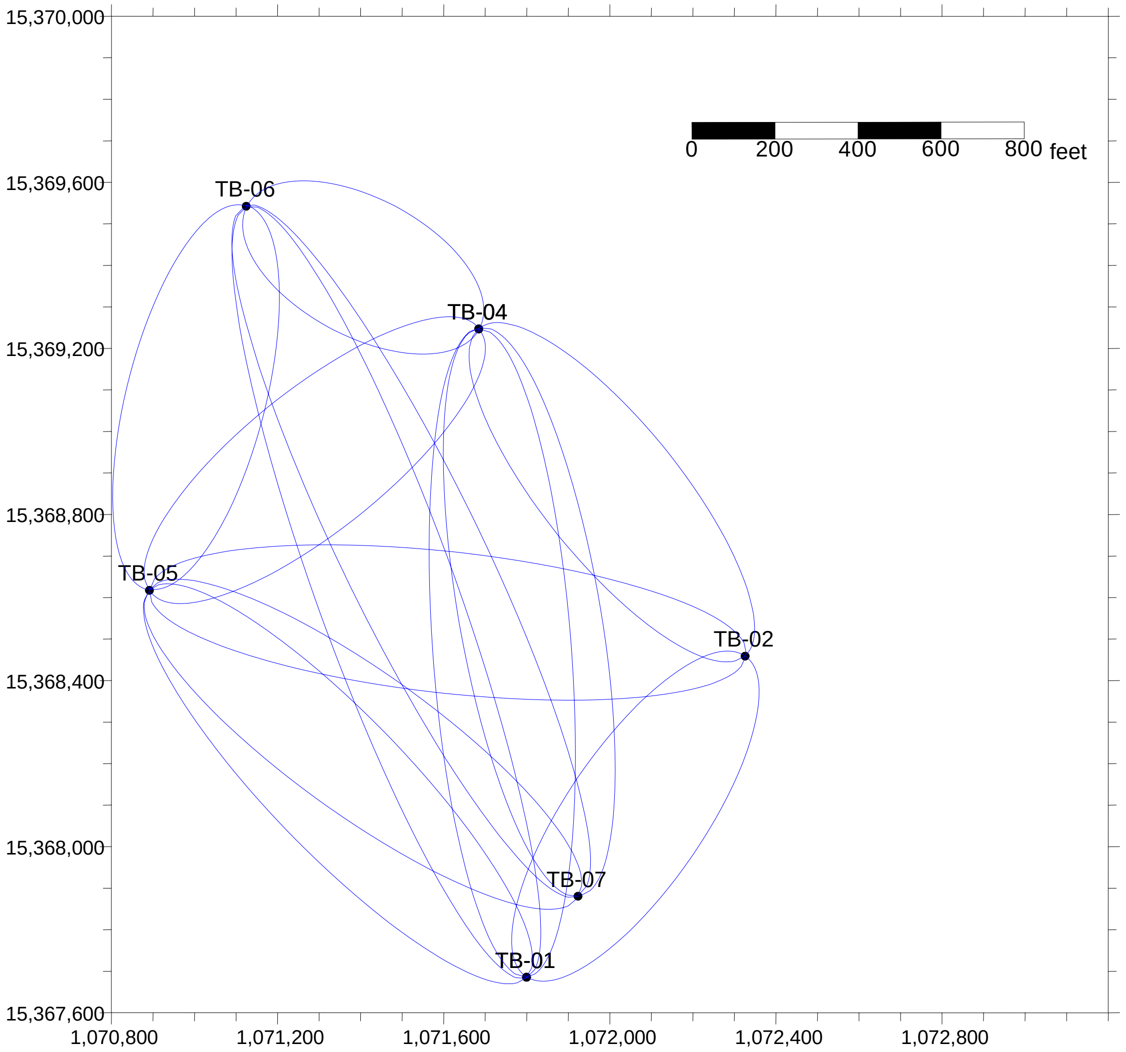
Taking some of the parameters (signal spectrum and formation velocity yielding wavelength) given above along with typical source and receiver locations we can plot, in plan view, the Fresnel zone (“banana shapes”) as a function of location between boreholes in all of the U.S. survey areas. Figures J-8 and J-9 display those results.

Summary

The Fresnel zone identifies the area of a reflector that is imaged upon reflection. Although the migration step in the imaging process collapses the in-line dimension (to one half of the predominate wavelength) of the Fresnel zone the cross-line dimension is unaffected.

The radius of the Fresnel zone is a function of the wavelength of the impinging signal and the spherical size (radius) of the wavefront (distance of source and receiver from the interface being imaged). Although the spectrum of the signal and the velocity of the medium varies over the surveys we can estimate the maximum Fresnel zone radius. Using a formulation that is valid for small wavelengths and (relatively) long distances (a good approximation for high frequency crosswell reflection surveying) we have computed an example of the Fresnel zone coverage on the top of the D-Salt in the X-10 and X-11 corridors.

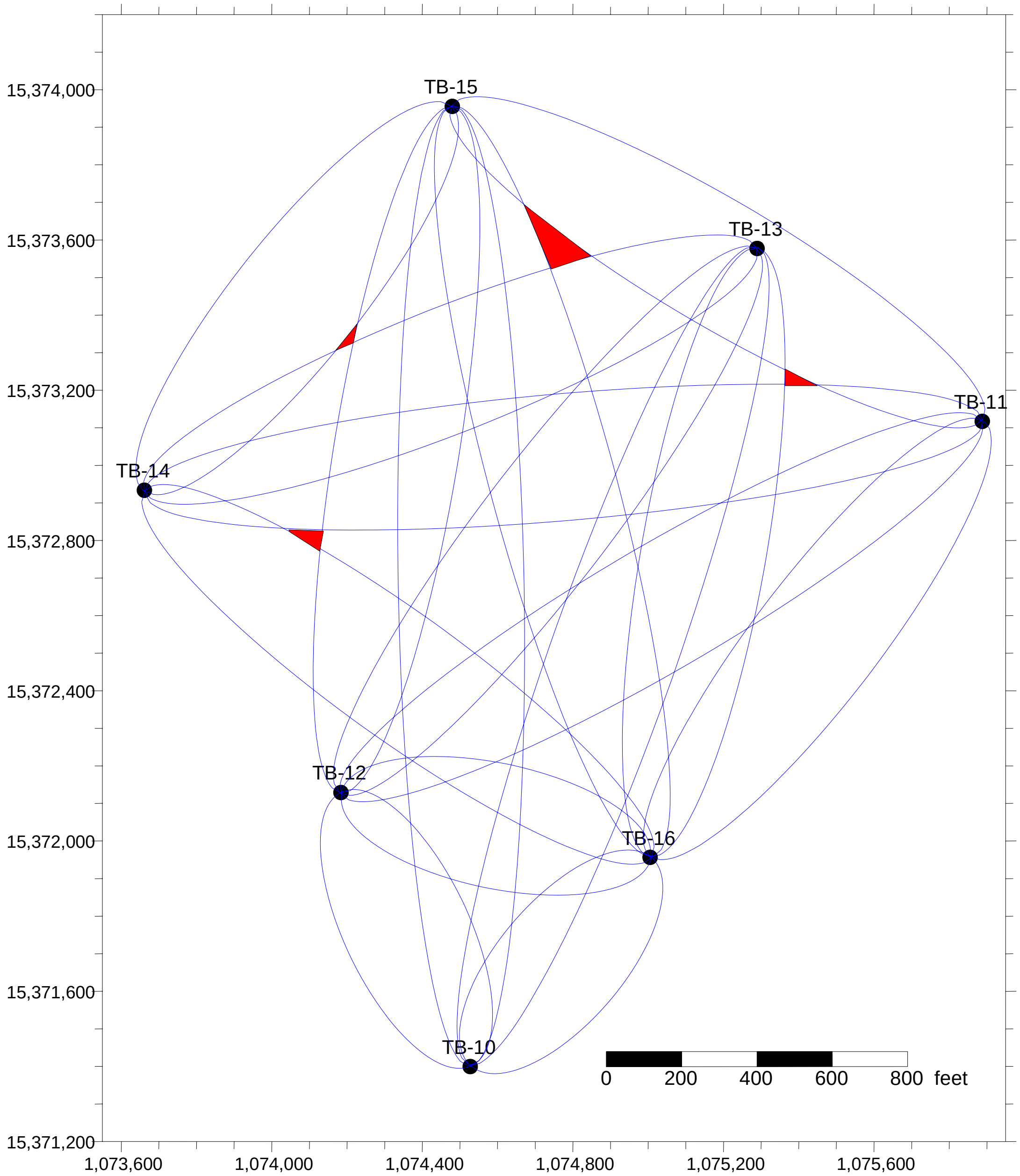
Figure J-8
Detroit River International Crossing Study
Fresnel Zone Diagram for the X-10 Crossing[a]



[a] This diagram represents the coverage that would be observed on top of the D-Salt. The low end of the signal spectrum (200Hz) has propagated through the high velocity E-Dolomite (20,000 ft/sec) yielding a wavelength (λ) of 100 ft. It is also assumed that the maximum distance for the sources and receivers above the D-Salt is 1,100 ft, (i.e. they did not go up into the glacial till).

Source: NTH Consultants, Ltd.

Figure J-9
Detroit River International Crossing Study
Fresnel Zone Diagram for the X-11 Crossing[a]



[a] This diagram represent the coverage that would be observed on top of the D-Salt. The low end of the signal spectrum (200Hz) has propagated through the high velocity E-Dolomite (20,000 ft/sec) yielding a wavelength (λ) of 100 ft. It is also assumed the maximum distance for the sources and receivers above the D-Salt Is 1,100 ft, (i.e. they did not go up into the glacial till).

Source: NTH Consultants, Ltd.