The Estimated Volume of Mine-Related Benthic Sediment in Big River at Two Point Bars in St. Francois State Park Using Ground Penetrating Radar and X-Ray Fluorescence

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1.0 Introduction

Abandoned mines have great potential as sources of impairment to aquatic communities. One source of impairment happens when water runs off during rain events and erodes mine wastes directly into nearby waterways. After the wastes enter the waterway, there may be various impacts to aquatic communities depending on its size and contaminant levels. In general, mine waste associated with lead mining in Missouri is referred to as tailings or chat. Tailings are usually defined as fine sediment of sand size or smaller (ca. <2.0 mm) and chat is generally defined as gravel size material. In addition to being the source of contaminants, mine waste clogs the interstitial voids between the larger particles in the substrate and can have destructive effects on invertebrate and fish communities (Chutter 1969; Murphy et al. 1981; Berkman and Rabeni 1987; Smale et al. 1995).

Over a 200 year period lead mining practices in the Big River watershed have contributed large quantities of fine sediment and chat to Big River. One single historic event in 1977 deposited as much as 50,000 cubic yards of mine waste into Big River after the collapse of a tailings pile at Desloge (Flour Daniel Environmental Services 1995). These mining wastes have affected the quality and quantity of habitat used by aquatic life (MDC 1997; MDNR 2004).

In 2002 and 2003 the Missouri Department of Natural Resources (**MDNR**), Environmental Services Program (**ESP**) made visual estimates of fine sediment percent surface area coverage at nine Big River locations (MDNR 2004). The results from that study concluded that fine sediment covered more than 60 percent of the substrate in the St. Francois State Park sample area. This was the second highest percentage identified in the 96-mile study area. Macroinvertebrate populations were impaired or depressed at this station due to the amount of fine benthic sediment or its metal content (MDNR 2004). However, the actual amount of sediment was not determined using these visual estimates.

The mine-related metals content of fine benthic sediment was also established in the MDNR Big River study (2004). Total lead and cadmium content exceeded Probable Effect Levels (**PEL)** (Ingersoll et al. 1996) in the St. Francois State Park station, while zinc was near the PEL. The samples were taken from the surface of the substrate, near visual estimate locations. Like the visual estimates, the metals content analyses did not identify how much mine-related material was present at the site.

In an effort to find an accurate method of measuring the depth of deposited material and ultimately quantifying the volume of mine-related material in the stream, the study group used ground penetrating radar (**GPR**). The GPR technology was used by Webb et al. (2000) to determine water depths and identify in-filled fluvial scour features. They found it to be effective and accurate. The United States Geological Survey (**USGS**) used GPR technology to determine the composition and distribution of streambed sediments (Dudley and Giffen 2001). They also found it convenient and useful in identifying and mapping large areas of shallow streambed quickly.

Accurate measurement of the volume of fine sediment and character of the material is necessary for remediation of the stream. Accurate depth measurements of fine sediments are necessary to determine volume. Characterization of the material at varied depths will determine the vertical extent of contaminants.

Purpose: Estimate the volume of mine-related fine sediment at two locations in Big River at St. Francois State Park.

Objectives: 1) Identify the depth and estimate the volume of fine sediments using GPR technology.

2) Determine the metals content of sediment samples on the point bars using XRF technology.

2.0 Methods

The study group used ground penetrating radar (**GPR**) generated images to estimate the depth or vertical extent of mine-related material to calculate the volume of material on two point bars and in the adjacent wetted stream. X-Ray Fluorescence (**XRF**) was used to characterize mine-related metals contained in three substrate particle sizes from the surface and at depths of three feet in several cases.

2.1 Study Timing

The field portion of the project took place on November 6 and 7, 2007. The study group of eight people started the field study at approximately 1000 on the 6th and finished at 1300 on the 7th. Total field time was approximately 12 hours.

2.2 Planning and Sample Collection

Planning and sampling were conducted by Kenneth B. Lister, David Gullic, and Randy Sarver, MDNR, Environmental Services Program (**ESP**), Water Quality Monitoring Section; Hugh Murrell, MDNR, ESP, Environmental Emergency Response/Field Services Section; Greg Bach, MDNR, Hazardous Waste Program (**HWP**); Joe Blum and Jim Newberry, MDNR, Division of State Parks; and Paul Blanchard, Mike Reed, Mark Haas, and Kevin Meneau, Missouri Department of Conservation (**MDC**). Laboratory analyses were conducted by MDNR, ESP and HWP. Doug Thompson, Brian Allen, Eric Sappington, and Mike Irwin of the ESP and Bob Hinkson (HWP) provided assistance during the project.

2.3 Sample Areas and Locations

Six locations were used for aspects of this project (Figure 1; Table 1). Two areas within St. Francois State Park were the primary focus of this study. These segments included two point bars, named Bar A and Bar B, and their associated stream segments (Figure 2). Bar A was approximately 816 feet long and Bar B was approximately 315 feet long. Table 1 locations for both Bar A and Bar B are shown using upstream and downstream UTM coordinates. The study area was between the upstream and downstream coordinates for each bar.

Three stations were used as controls for background sediment metals characterization (Table 1; Figure 1). Control #3 (C3) was located on a bar at the Route C bridge near Belgrade, Missouri. Control #2 (C2) was located on a bar downstream of the Highway 21 Bridge at the MDC Bootleg Conservation Area (**CA**). Control #1 (C1) was located on a bar at the Route U Bridge near Irondale, Missouri.

Table 1
Location and Description of Big River Bar A, Bar B, and Control Stations

Stream-Station Number	Location-Section, Township, Range/UTM	Description and Method	County
Bar A	S, Survey 2110, T. 38 N., R. 04 E. UTM up 4203674n, 716044e; down 4203892n, 715984e	Upstream bar, St. Francois State Park. 272 yards - GPR/XRF	St. Francois
Bar B	CS, Survey 2110, T. 38 N., R. 04 E. UTM up 4204102n, 716006e; down 4204181n, 716069e	Downstream bar, St. Francois State Park. 105 yards - GPR/XRF	St. Francois
Leadwood CA	NE ¼ sec. 03, T. 36 N., R. 04 E. UTM 4194033n, 712469e	Downstream low water bridge, Leadwood Conservation Area, MO Hwy 8, at Leadwood, MO. - GPR comparison	St. Francois
Control #3 (C3)	SE ¼ sec. 10, T. 36 N., R. 02 E. UTM 4184011n, 690006e	Route C bridge at Belgrade, MO. - XRF Background	St. Francois
Control #2 (C2)	NE, Survey 2180, T. 36 N., R. 02 E. UTM 4187249n, 696005e	MO Hwy 21 bridge at Bootleg Conservation Area - XRF Background	Washington
Control #1 (C1)	SW ¼ sec. 15, T. 36 N., R. 03 E. UTM 4189506n, 703214e	Route U bridge, SW of Irondale, MO. - XRF Background	Washington

CA=Conservation Area; Up=upstream; Down=downstream

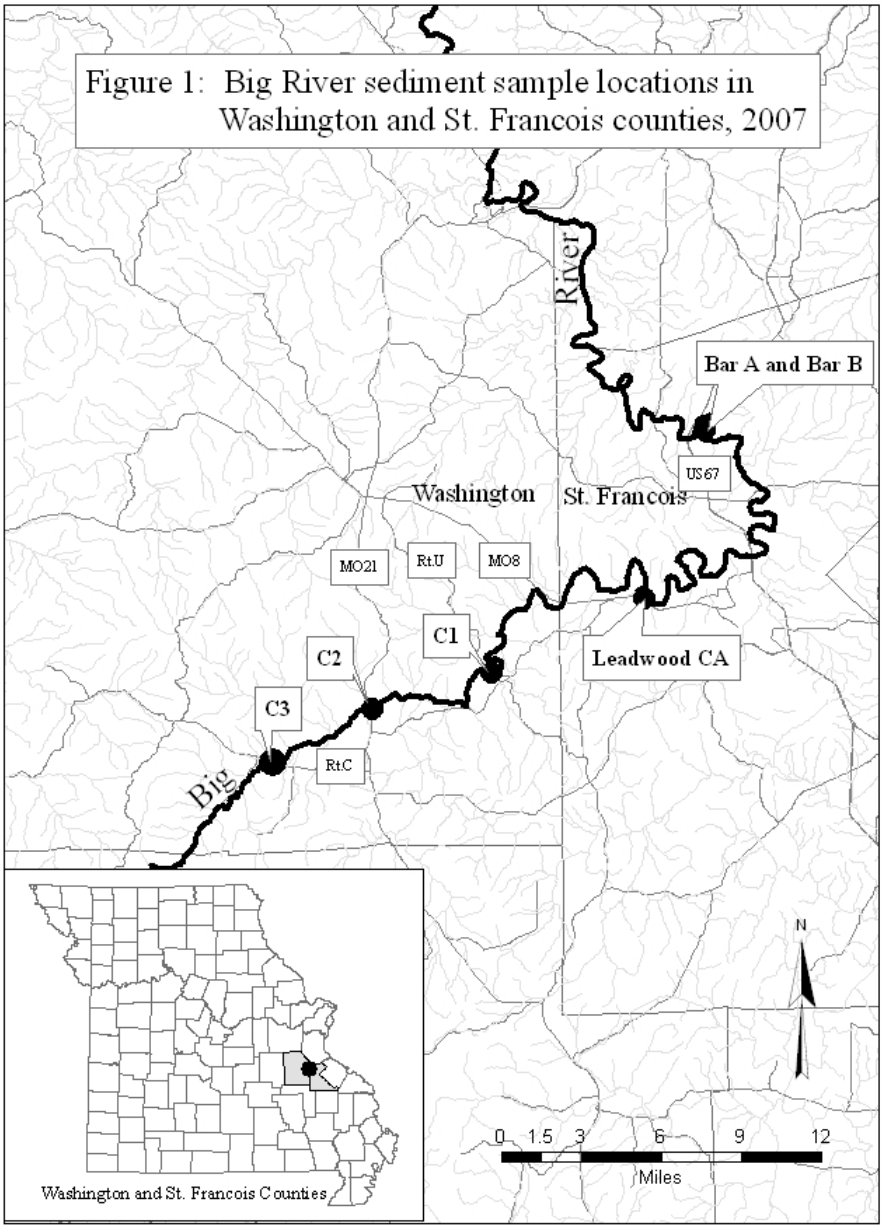


Figure 1: Big River sediment sample locations in Washington and St. Francois counties, 2007
River
Bar A and Bar B
US67
Washington
St. Francois
MO21
RtU
MO8
C1
C2
C3
RtC
Leadwood CA
Big
N
0 1.5 3 6 9 12
Miles
Washington and St. Francois Counties

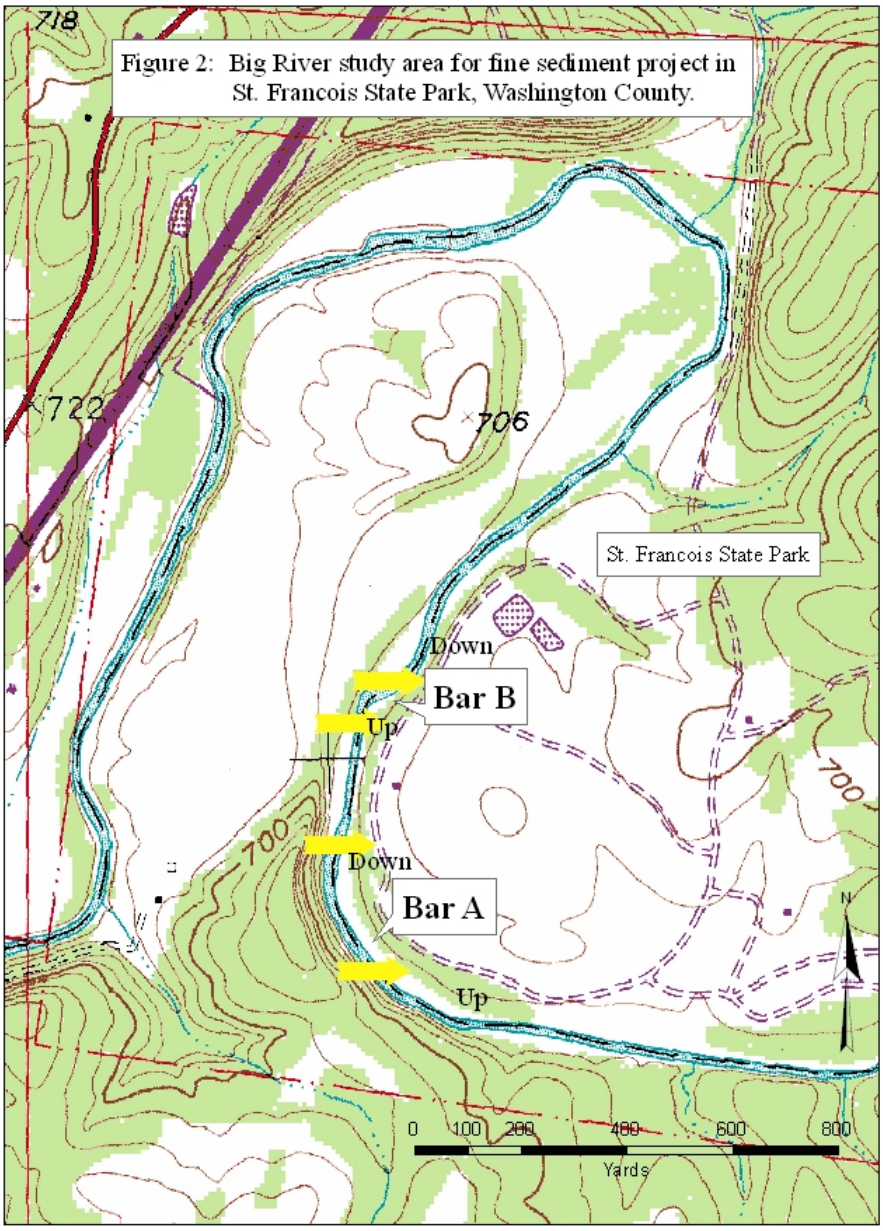


Figure 2: Big River study area for fine sediment project in St. Francois State Park, Washington County.

A bar identified as Leadwood CA served as a GPR comparison location (Table 1; Figure 1; Appendix A). Leadwood CA is located just north of Missouri Highway 8, Leadwood, Missouri. Although this station is upstream of the Desloge Tailings Pile it was also subjected to historic influences of a large mine and mill that was located further upstream.

2.4 Sample Transects

All test data were collected on transects (Figure 3 and Figure 4). Transects were evenly spaced at points equal to 5 percent of the length of each terrestrial bar. This yielded 20 evenly spaced transects per bar (Figures 3 and 4). Each transect was situated perpendicular to channel flow and crossed from inside bend bank to outside bend bank. Transects were numbered from high to low from upstream to downstream.

Each transect consisted of a terrestrial and wetted stream channel for collection of data. Red flags were used to mark the location of each transect at the inside bend edge where the bar met the bank, at the wetted edge, and at the outside bend edge where the stream met the bank. The terrestrial bar transect length was measured and recorded from the inside bend flag to the wetted edge flag. The wetted portion of each transect was measured from the wetted edge flag to the outside edge flag.

Each transect served as sample locations for two purposes: 1) for the GPR estimation of the depth of fine sediment; and 2) for characterization of sediments for metals content.

2.5 Sediment Depth

Sediment depth was measured with a ground penetrating radar (**GPR**) SmartCart, Noggin 250 using Noggin^{plus} software, manufactured by Sensors and Software Inc., Ontario, Canada. Two methods were necessary to measure both the terrestrial portion and wetted portion of each transect.

On the terrestrial bar, the odometer trigger method was used with a gain of 6 or 7; a depth of 20 feet; and a traversing speed of approximately 2 feet per second. The radar velocity value was the default value of 0.328 ft/ns or 0.10 m/ns. The velocity allowed for a good estimate of depth of soil, wet rock, concrete, or pavement. All other settings were preset manufacturer's default settings. The GPR was started at the inside bend transect flag and stopped at the wetted edge flag. We repeated the GPR measurements at all terrestrial transects on both bars. All 40 transects and 2 duplicates were completed with each transect taking less than one minute to measure.

To complete the wetted portion of each transect, the GPR was placed in a small boat and stabilized with shock cord. The boat was a KL Industries 54-inch plastic duck decoy boat. At the wetted edge flag of each transect, the GPR was started and pushed across the stream at approximately 2 feet per second to the outside bend flag, where it was stopped. A stopwatch measured the time from start to stop giving us a speed traveled across the stream. A fiducial marker (virtual marker) was placed on the image for the wetted width

at a given distance (Bar A, 30 feet; Bar B, 15 feet) for relative (x) scale. The water depth was measured at that location as a reference for interpreting the images.

The GPR settings across the wetted transect portion included: continuous trigger mode, data collection speed of 16 stacks, depth of 20 feet, and a radar velocity of 0.328 f/ns (0.10 m/ns). The default velocity allowed for a good estimate of depth in soil, wet rock, concrete, or pavement. All other settings were preset manufacturer's default settings.

2.5.1 Depth Analysis

GPR technology was used to identify the depth or extent of the depositional material of similar size. GPR software filters were used on the data generated, which assigned similar colors to materials of similar opacity or reflectivity. The study group used a filter in generating the images to make it easier to identify the lower extent of the surface material (Appendix A; Red = surface material). Hyperbola indicates an object large enough to scatter the radar wave is present at that location and was used to identify changes in the size of the material in the substrate.

The mean depth for each transect was estimated independently by two observers using GPR images (Appendix A). Each person independently measured the depth of the surface material at four given locations on each image. The locations included the first, center, and last numbers on the x-axis of each image. The fourth location was at the fiducial marker, a random location chosen from a random number list. It is shown as *F* on the x-axis of Bar A in red. It is not shown on Bar B images, but the number was used to find a mean and is available. The two estimates were averaged and a mean depth was created for the four locations on each transect. A 2-D contour map was created using the four measurements per transect. The mean depth was used to calculate a volume of surface materials.

2.5.2 Depth Quality Control

A duplicate was collected immediately adjacent to two transects to illustrate consistency of the images (Appendix A: Bar A, Transect 10 duplicate; Bar A, Transect 20 Duplicate). The transect 10 image should be very similar to the transect 10 duplicate image. The same should be true about transects 20 and 20 duplicate.

The study group was planning to groundtruth all GPR bar images with physical cores of the actual subsurface material by using a Geoprobe coring machine at all sample points on all bar transects. The physical changes were to be compared to the GPR images at each known point. We were not successful in verifying the GPR depths at the random points on all transects as planned. The Geoprobe would not collect and hold samples of wet fine sediment. As a secondary method, the group then used a backhoe to collect samples and groundtruth material at depths up to three feet deep. The surface material to three feet was consistently and predominantly sand, which was similar to the homogenous surface layer that appeared on the GPR images (Appendix A). The study group was in part successful in groundtruthing to that point.

2.6 Sediment Volume

Bar dimensions were derived from measurements taken of each transect. The terrestrial transect portion was measured from the inside bend of the transect to the wetted edge flag. The stream measurement continued from the wetted edge flag to the outside bend flag. Combined, those measurements constituted the total transect length, the distance needed to calculate the quantity of sediment and illustrate the bar and stream in Figures 3 and 4.

2.6.1 Volume Analysis

Calculation of the volume of mine-related material required several variables. The first step was to calculate the area of each transect. This was accomplished by multiplying each transect length by the transect width. The transect width is 42 feet for Bar A and 16 feet for Bar B. The transect area was then multiplied by the mean depth for volume calculation. The quantity per transect was summed to attain a volume per bar. The same was done for both bars and then summed to find a grand total sediment volume.

2.6.2 Volume Quality Control

Quality control for volume was conducted in the wetted stream channel transects by placing a fiducial marker at a location of known depth. Bar A was placed at 30 feet and Bar B was placed at 15 feet. The depth was measured and can be used as a QC check on the depth given on the GPR graph.

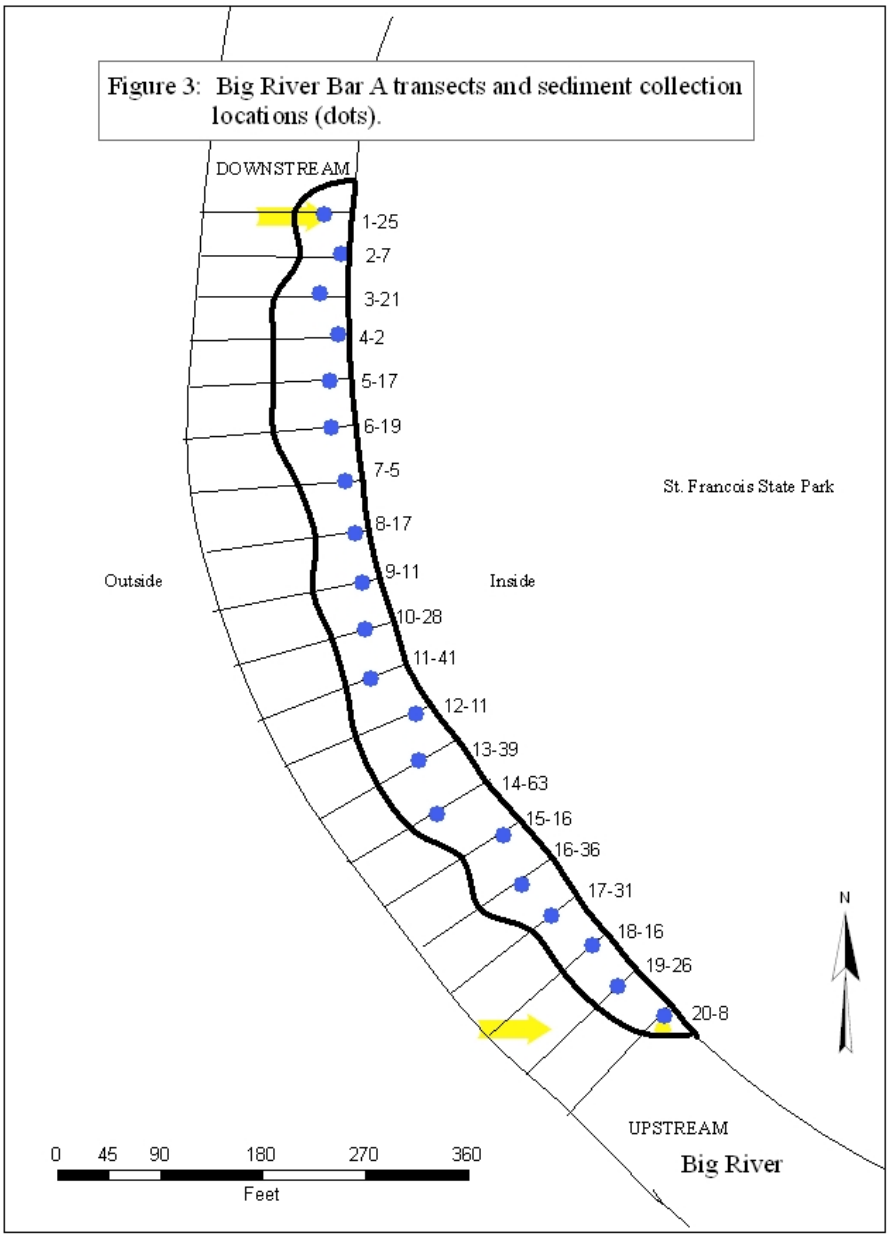


Figure 3: Big River Bar A transects and sediment collection locations (dots).

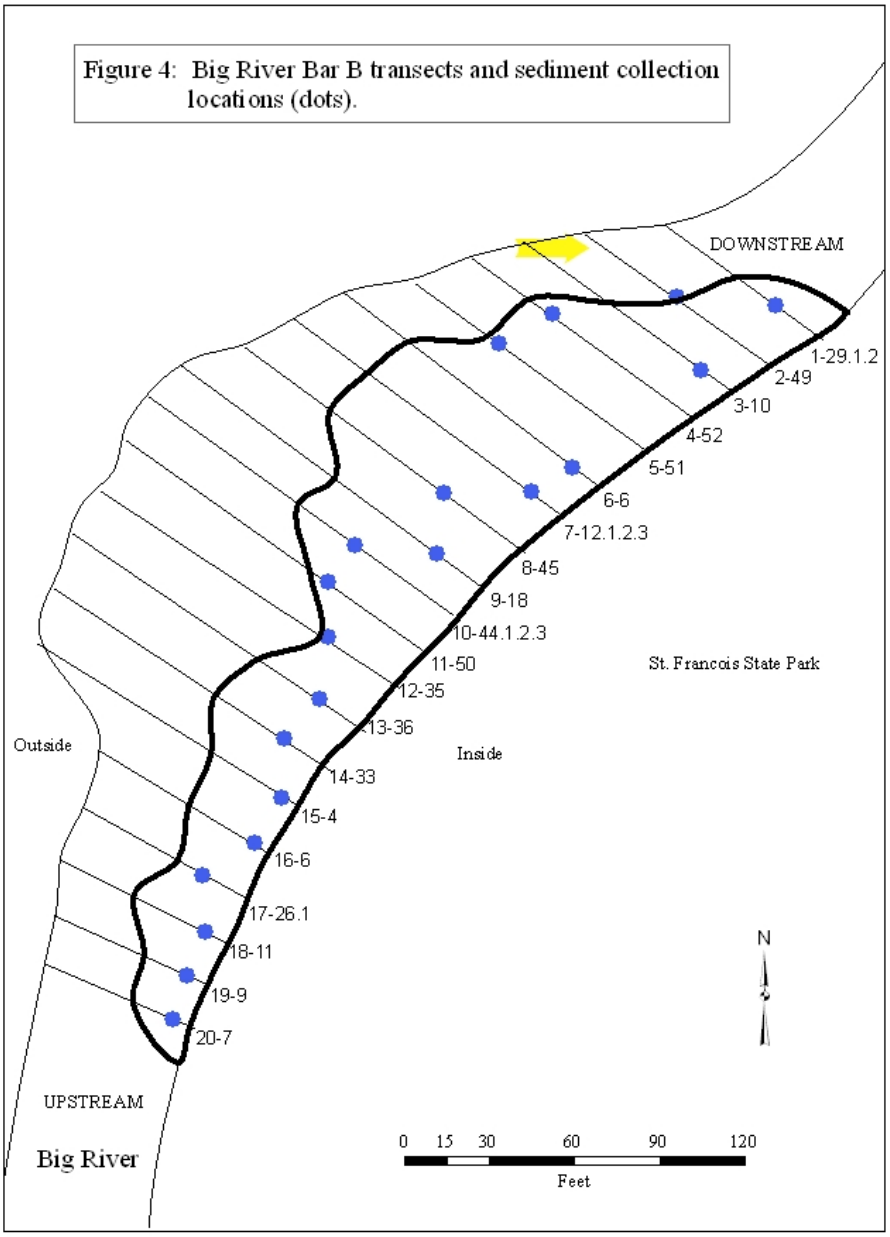


Figure 4: Big River Bar B transects and sediment collection locations (dots).

2.7 Sediment Collection and Analyses

Sediment samples were collected from the surface of Bar A and Bar B at randomly selected locations on all transects (Figures 3 and 4-Blue Dots). Sediment samples were collected and handled according to MDNR-SOPs. Stainless steel spoons were used to collect the sediment from the surface to a depth of 2 inches. A sample consisted of approximately one quart of material, which was placed into an individual zip lock bag. The sample was labeled by transect and random location. Each sample location was determined from the distance along a transect from the inner bank. For example, 1-29 equates to transect 1 at 29 feet from the inner bank. The final qualifier is the depth at which the sample was taken; for example 1-29.1 = a sample from 1 foot deep.

Four locations on Bar B were used to determine the sediment character at various depths. Test pits were dug using a backhoe and, if possible, samples were collected from 0, 1, 2, and 3 foot depths. Water intrusion and subsequent collapse of the pits limited collection to 3 feet.

The samples were returned to ESP and HWP for processing. Each sample was air dried and then sieved at ESP, using MDNR-SOPs. Three sediment-size fractions were sieved from each sample using a 2 mm stainless sieve and a 12.5 mm brass sieve. The sediment-size fractions retrieved were <2.0 mm, 2.0-12.5 mm, and >12.5 mm. For simplicity and ease of identification these fractions will be referred to as *sand*, *gravel*, and *pebble,* respectively. This should be relatively accurate, as each fraction contains at least some of the appropriate particle sizes similar to a modified Wentworth scale by Cummins (1962).

2.8 Sediment Characterization

Sediments were characterized for metals content using X-Ray Fluorescence (XRF). The three metals that served as documentation of mine-related material were total lead, cadmium, and zinc concentrations. Each sample size fraction was exposed a minimum of three times to the XRF. The value was recorded for each size fraction and a mean metals value (n=3) was calculated. The mean metals content for each transect is calculated from a mean of all particle sizes for a transect (n=9).

Sample results were organized by bar and transect to identify mine sediment distribution and compare to freshwater Sediment Quality Guidelines (SQG; MacDonald et al. 2000). The consensus based Probable Effects Concentration (**PEC**) for lead, cadmium, and zinc in sediment was compared to mean level of the mine-related material. The PEC is the level of a contaminant above which harmful effects are likely to be observed. The PEC for lead is 128 mg/kg dry weight. The PEC for cadmium is 4.98 mg/kg. The PEC for zinc is 459 mg/kg (MacDonald et al. 2000).

Statistics were used to compare between particle sizes to analyze if significant differences exist between each size class. The study group used ANOVA if variance and normality assumptions were met or, if not, ANOVA on Ranks (Kruskal-Wallis) (SigmaStat Version 3.5 2006). Significant difference was set at $p < 0.05$. Dunn's Method, or Holm-Sidak,

All Pairwise Multiple Comparison Procedures were used to identify the differences in significance level.

2.8.1 Sediment Character Quality Control

Duplicate analyses were conducted to determine consistency of metals readings. An additional exposure was made of at least 1 sample per analysis session. The additional exposure was compared to the previous exposure for similarity. Both were rejected if >5% difference in total metals concentrations was detected. No significant differences >5% were detected.

The effect sieving may have had on the metals content was then examined in the larger fractions. It is possible that when the samples were sieved that metals laden dust remained on the larger particles. This would cause large particle sizes to have artificially higher metals values and suggest that larger fractions should be washed before using the XRF. Twelve station samples were washed with distilled water, air dried, and additional XRF (n=36) lead analyses were conducted on the gravel and pebble size fractions. T-tests were conducted between washed vs. unwashed samples for gravel (2-12.5 mm) and pebble (>12.5 mm). Data were grouped by washed and unwashed and compared using a paired t-test (Appendix E). No significant difference ($p > 0.05$) was found in either size class, suggesting that residual dust did not contribute to the lead content in either gravel or pebble size classes.

3.0 Results

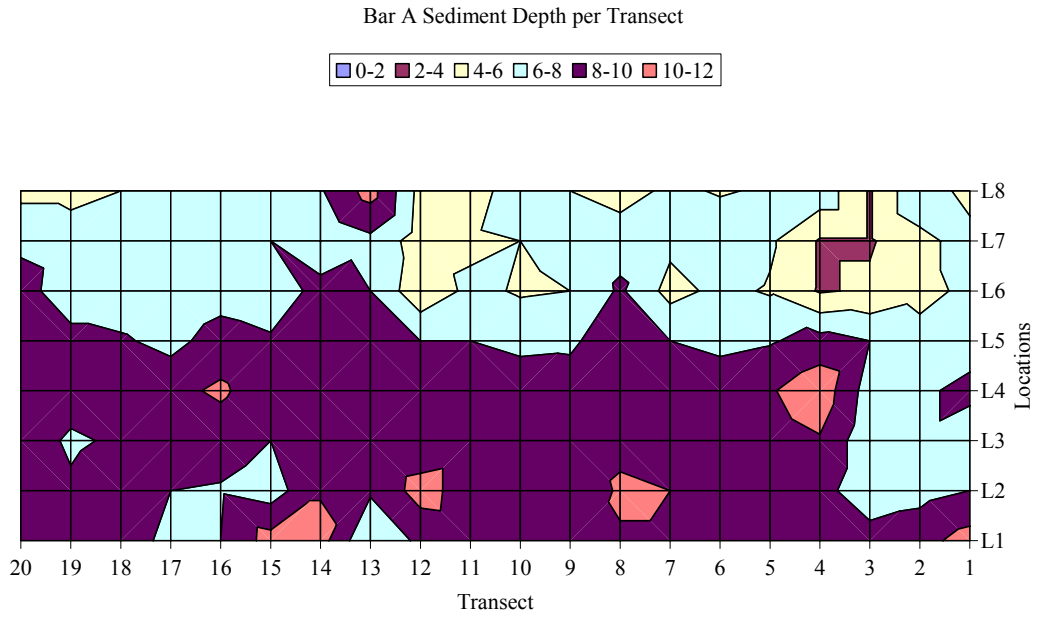
Results identify depth, volume, and character of potential mine-related material. Character is identified by mean, particle size, and depth.

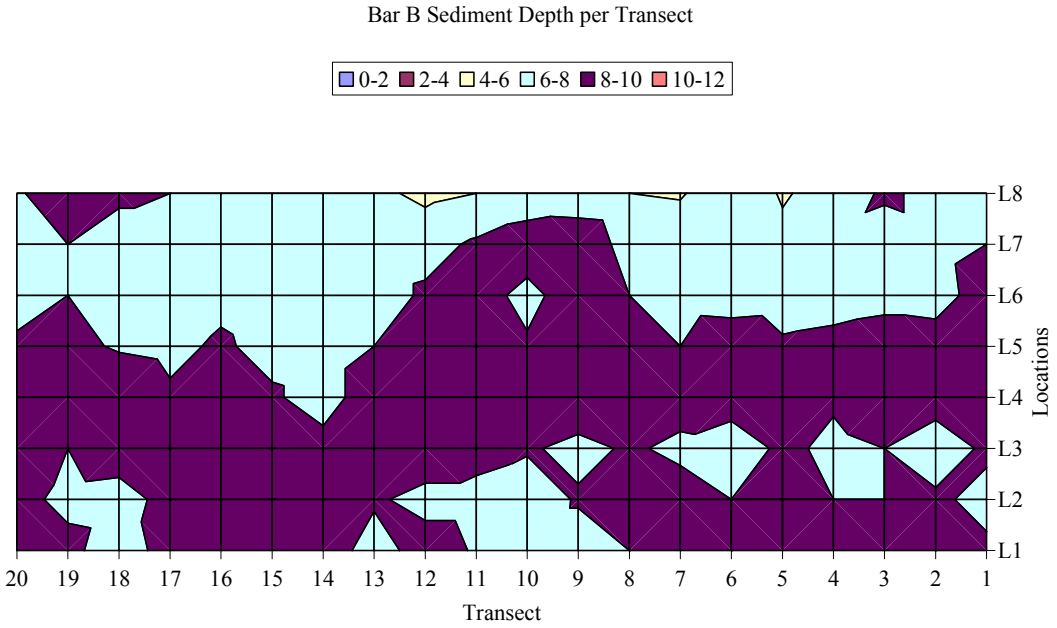
3.1 Sediment Depth

Individual GPR images are shown in Appendix A. Using the filter, bright red colored areas are presumed to be similar-sized materials due to similar opacity or reflectivity. The actual material found on the surface is predominantly sand size material. It appears that the material on the surface may be present at depths from 4 to 12 feet or more in isolated areas. At that depth we found an increase in the number of hyperbolas that are visible, indicating a change in the size of material and a change from what is found on the surface.

Bar and stream GPR depth images are compiled into a 2-D graph to illustrate overall depth measurements of the surface sand material per transect (Figure 5). Figure 5 shows Bar A and Bar B transects (not to longitudinal scale). It appears that sand-sized sediment in Bar A is approximately 8 to 10 feet deep; while in stream sediment depths are from 4 to 8 feet. Bar B is similar in sediment depths.

Figure 5
Depth Contour: Eight Locations (L1-8) of Approximate Sediment Depth (feet) for Bar A and Bar B (distribution is not to scale).





3.2 Sediment Volume

Along with mean depth per transect, bar dimensions were necessary for calculating the volume of mine-related material (Tables 2a & 2b). Bar A was approximately 820 feet long with transects spaced 42 feet apart. Bar B was 315 feet long with transects spaced 16 feet apart. The area of Bar A was approximately 90,000 square feet, while Bar B area was 35,000 square feet. Total transect length was over 2000 feet for Bar A and 2000 feet at Bar B. The average depth of fine sediment was approximately 9 feet on the Bar A and 7 feet in the corresponding stream segment. The average depth of fine sediment on Bar B was approximately 8.5 feet on the bar and 7.5 in the corresponding stream segment.

The area and depth by transect allowed us to calculate an estimated volume of similar-sized material on both bars. The Big River channel at Bar A may contain approximately 671,710 cubic feet and the channel at Bar B contains approximately 275,004 cubic feet of material that is similar to the surface sand. The grand total estimate is 946,715 cubic feet of sand-sized material in the river channel at the location of the two bars in St. Francois State Park.

3.3 Sediment Metals Character

Surface material was collected for Bar A and Bar B for analysis using XRF technology to identify if the material was mine-related. The results allowed for identification of the metals mean (mg/kg) per transect. Sieving allowed for mean metals content for sand, gravel, and pebble-sized particles.

3.3.1 Surface Mean Metals

We examined mean metals concentrations by transect on Bars A and B to identify metals concentrations relative to PEC and to illustrate distribution. Mean lead, cadmium, and zinc concentrations for each transect were examined for Bar A (Table 3) and Bar B (Table 4). Mean concentrations of lead, cadmium, and zinc were compared to their respective PEC and distribution was identified.

Mean metals for controls were compared to Bars A and B (Appendix B). The controls had significantly lower ($p<0.05$) lead, cadmium, and zinc concentrations than Bars A and B. Bars A and B were of similar character in concentrations. This suggests that the metals content of sediment at the test stations are not at background levels.

Table 2a
Bar and Stream Dimensions and Volume of Fine Sediment for Bar A

Transect	Bar Transect Length (**Lb**)	Bar Area (**Ab**) Bar A=Lbx42' Bar B=Lbx16'	Bar Transect Depth (**Db**)	Bar Volume **Vb**=AbxDb	Stream Transect Length (**Ls**)	Stream Area (**As**) Bar A=Lsx42' Bar B=Lsx16'	Stream Transect Depth (**Ds**)	Stream volume **Vs**=AsxDs	Transect Length Total	Bar and Stream Area	SUM
A20	15	630	9.7	6111.0	85	3570	7.8	27846.0	100	4200	33957.0
19	41	1722	8.9	15325.8	63	2646	6.9	18257.4	104	4368	33583.2
18	42	1764	9	15876.0	57	2394	6.9	16518.6	99	4158	32394.6
17	45	1890	8.2	15498.0	57	2394	7	16758.0	102	4284	32256.0
16	50	2100	8.8	18480.0	56	2352	7.3	17169.6	106	4452	35649.6
15	57	2394	8.7	20827.8	57	2394	7.3	17476.2	114	4788	38304.0
14	71	2982	9.5	28329.0	36	1512	7.7	11642.4	107	4494	39971.4
13	62	2604	7.7	20050.8	44	1848	8.7	16077.6	106	4452	36128.4
12	54	2268	9.3	21092.4	54	2268	5.7	12927.6	108	4536	34020.0
11	44	1848	8.9	16447.2	40	1680	6.1	10248.0	84	3528	26695.2
10	36	1512	9.1	13759.2	69	2898	6.7	19416.6	105	4410	33175.8
9	31	1302	8.9	11587.8	68	2856	6.5	18564.0	99	4158	30151.8
8	27	1134	9.7	10999.8	70	2940	7.6	22344.0	97	4074	33343.8
7	37	1554	9.6	14918.4	70	2940	6.6	19404.0	107	4494	34322.4
6	49	2058	9	18522.0	68	2856	6.8	19420.8	117	4914	37942.8
5	58	2436	9.7	23629.2	61	2562	6.6	16909.2	119	4998	40538.4
4	57	2394	9.6	22982.4	51	2142	5.9	12637.8	108	4536	35620.2
3	45	1890	7.3	13797.0	51	2142	5	10710.0	96	4032	24507.0
2	35	1470	8.1	11907.0	64	2688	6.3	16934.4	99	4158	28841.4
1	31	1302	8.6	11197.2	70	2940	6.5	19110.0	101	4242	30307.2
Totals or mean	887	37254	8.9	331338.0	1191	50022	6.8	340372.2	2078	87276	671710.2

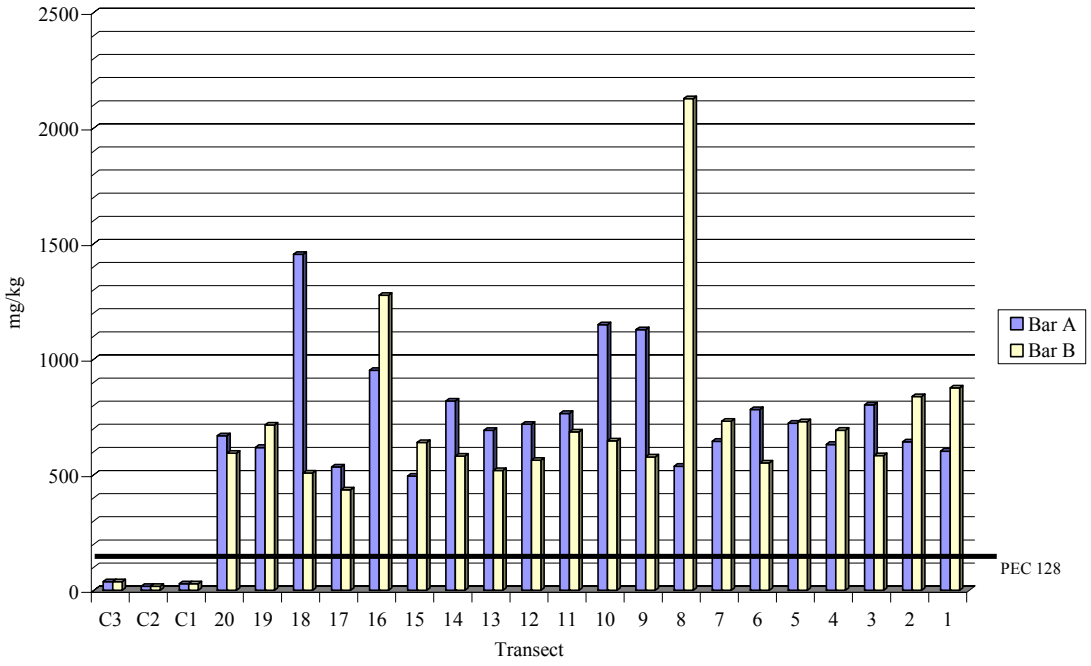
Table 2b
Bar and Stream Dimensions and Volume of Fine Sediment for Bar B

Transect	Bar Transect Length (**Lb**)	Bar Area (**Ab**) Bar A=Lbx42' Bar B=Lbx16'	Bar Transect Depth (**Db**)	Bar Volume **Vb**=AbxDb	Stream Transect Length (**Ls**)	Stream Area (**As**) Bar A=Lsx42' Bar B=Lsx16'	Stream Transect Depth (**Ds**)	Stream volume **Vs**=AsxDs	Transect Length Total	Bar and Stream Area	SUM
B20	20	320	9.2	2944.0	30	480	7.6	3648.0	50	800	6592.0
19	23	368	8.2	3017.6	29	464	8.4	3897.6	52	832	6915.2
18	27	432	8.0	3456.0	26	416	7.5	3120.0	53	848	6576.0
17	35	560	8.7	4872.0	27	432	7.3	3153.6	62	992	8025.6
16	43	688	9.3	6398.4	32	512	7.7	3942.4	75	1200	10340.8
15	52	832	8.7	7238.4	85	1360	7.5	10200.0	137	2192	17438.4
14	59	944	8.5	8024.0	83	1328	7	9296.0	142	2272	17320.0
13	63	1008	8.2	8265.6	88	1408	7.1	9996.8	151	2416	18262.4
12	39	624	8.8	5491.2	88	1408	7.4	10419.2	127	2032	15910.4
11	61	976	8.4	8198.4	80	1280	8	10240.0	141	2256	18438.4
10	85	1360	7.6	10336.0	66	1056	7.9	8342.4	151	2416	18678.4
9	79	1264	8.0	10112.0	62	992	8.5	8432.0	141	2256	18544.0
8	90	1440	8.3	11952.0	53	848	7.3	6190.4	143	2288	18142.4
7	88	1408	8.5	11968.0	48	768	7	5376.0	136	2176	17344.0
6	80	1280	8.0	10240.0	46	736	7.5	5520.0	126	2016	15760.0
5	67	1072	8.5	9112.0	50	800	6.9	5520.0	117	1872	14632.0
4	59	944	8.0	7552.0	36	576	7.5	4320.0	95	1520	11872.0
3	55	880	8.5	7480.0	32	512	7.9	4044.8	87	1392	11524.8
2	48	768	8.0	6144.0	40	640	7.8	4992.0	88	1408	11136.0
1	43	688	8.4	5779.2	44	704	8.2	5772.8	87	1392	11552.0
Totals or mean	1116	17856	8.4	148580.8	1045	16720	7.6	126424.0	2161	34576	275004.8
Bar A & Bar B										GRAND TOTAL	946715.0

3.3.1.1 Lead

Mean lead concentrations of the surface material were examined for the controls (C3, C2, C1) and each transect per bar to identify concentrations and distribution in the substrate (Tables 3 and 4; Figure 6). Mean transect concentrations were over 400 mg/kg (s.d. 14.04) on both bars. The high mean exceeded 2100 mg/kg (s.d. 25.48) on Bar B. Mean concentrations of lead were below PEC at the three controls, while means exceeded the PEC for lead (128 mg/kg) at all transects on Bars A and B. Lead concentrations exceeded PEC and appear to be evenly distributed across both bars.

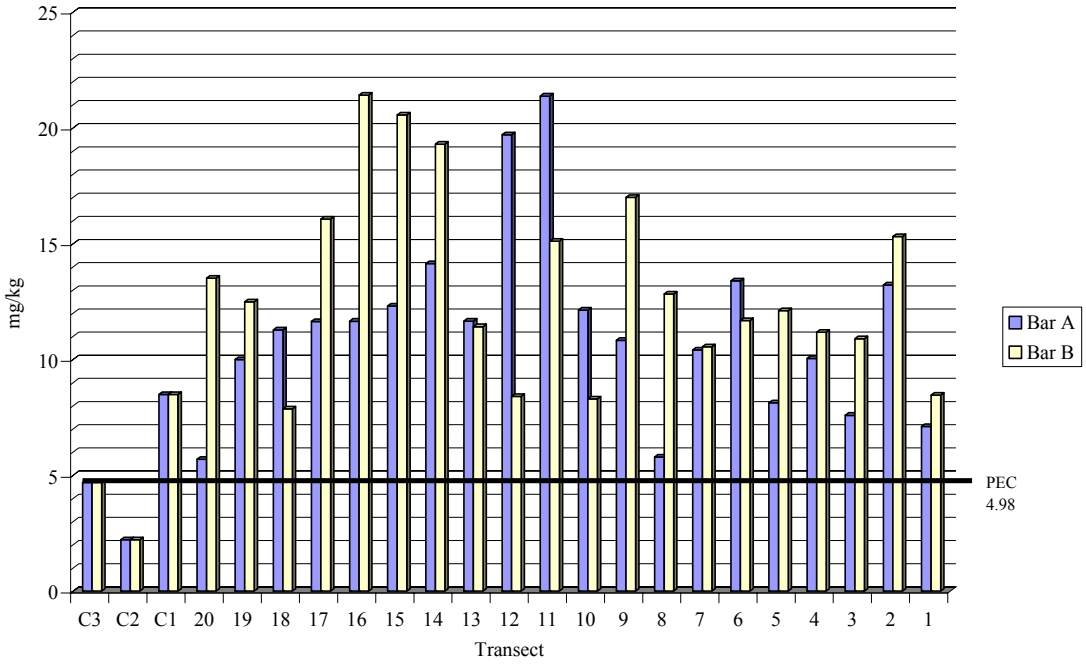
Figure 6: Mean lead concentrations for Bar A and Bar B



3.3.1.2 Cadmium

Mean cadmium concentrations of the surface material were examined for the controls (C3, C2, C1) and each transect per bar to identify concentrations and distribution in the substrate (Tables 3 and 4; Figure 7). Mean transect concentrations were greater than 5.7 mg/kg (s.d. 20.15) on both bars. The highest means exceeded 21 mg/kg on Bars A (s.d. 17.96) and B (s.d. 17.31). Mean concentrations of cadmium exceeded PEC (4.98 mg/kg) at C1 and all transects on Bars A and B. Cadmium concentrations exceeded PEC and appear to be evenly distributed across both bars.

Figure 7: Mean cadmium concentrations for Bar A and Bar B



3.3.1.3 Zinc

Mean zinc concentrations from the surface material were examined for the controls (C3, C2, C1) and each transect per bar to identify concentrations and distribution in the substrate (Tables 3 and 4; Figure 8). Mean transect concentrations were greater than 198 (s.d. 8.86) on both bars. The high mean exceeded 1200 mg/kg (s.d =20.97) on Bar B. Mean concentrations of zinc were below PECs at the three controls, while concentrations exceeded the PEC for zinc (459 mg/kg) at nine transects on Bars A and B combined. Zinc concentrations appear to be evenly distributed across both bars.

Figure 8: Mean zinc concentrations for Bar A and Bar B

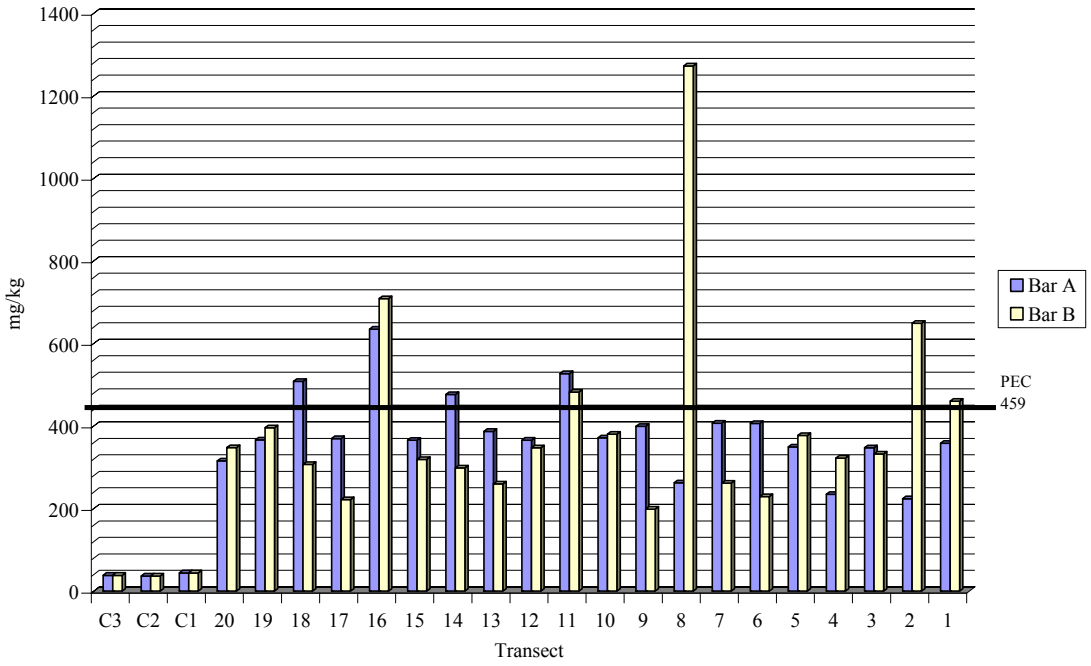


Table 3
Bar A - Mean Metals Concentration and Standard Deviation per Transect

Bar A Transect	Lead mean	S.D. avg.	Cadmium mean	S.D. avg.	Zinc mean	S.D. avg.
C3	37.72	3.83	4.69	17.73	38.62	4.42
C2	18.12	3.04	2.21	16.83	37.05	4.12
C1	28.88	3.45	8.49	17.07	44.54	4.46
20	669.07	13.31	5.70	20.15	315.88	11.43
19	618.70	12.69	10.00	18.22	366.59	11.45
18	1454.29	21.10	11.28	18.63	508.29	13.86
17	534.06	11.69	11.65	18.56	369.88	11.69
16	952.56	16.70	11.66	18.79	635.07	15.77
15	495.04	14.04	12.31	37.25	365.85	13.97
14	819.77	18.14	14.14	37.98	476.66	15.99
13	692.46	13.37	11.66	18.59	387.50	12.10
12	718.71	13.86	19.71	17.99	366.03	11.45
11	765.58	14.16	21.38	17.96	527.23	13.66
10	1149.54	25.24	12.14	60.83	371.62	17.66
9	1128.10	22.37	10.83	47.48	399.54	16.23
8	537.21	11.20	5.79	17.27	262.71	9.19
7	645.11	14.05	10.41	23.04	407.20	12.70
6	783.00	21.08	13.40	50.91	406.26	17.43
5	723.62	17.41	8.13	38.23	349.60	13.92
4	631.64	18.08	10.05	58.16	234.75	13.37
3	803.05	19.62	7.60	47.37	347.53	14.72
2	642.66	16.62	13.22	46.95	224.01	12.27
1	602.84	17.37	7.11	53.05	358.33	15.68
PEC mg/kg (MacDonald et al. 2000)	**128**	**--**	**4.98**	**--**	**459**	**--**

Table 4
Bar B - Mean Metals Concentration and Standard Deviation per Transect

Bar B Transect	Lead mean	S.D.	Cadmium mean	S.D.	Zinc mean	S.D.
C3	37.72	3.83	4.69	17.73	38.62	4.42
C2	18.12	3.04	2.21	16.83	37.05	4.12
C1	28.88	3.45	8.49	17.07	44.54	4.46
20	593.49	12.38	13.52	18.38	348.11	11.23
19	715.07	14.23	12.50	18.86	396.02	12.33
18	507.96	11.62	7.87	18.34	307.27	10.63
17	434.99	10.46	16.07	18.60	222.33	9.12
16	1277.24	18.96	21.42	17.31	708.65	15.90
15	640.16	13.41	20.57	18.55	319.19	11.03
14	581.20	12.91	19.30	19.22	298.59	10.92
13	519.38	11.74	11.42	19.37	259.88	10.09
12	562.73	12.54	8.41	19.41	347.43	11.94
11	685.23	12.98	15.11	17.58	482.55	12.51
10	647.31	13.04	8.30	18.57	380.62	11.85
9	577.50	12.29	17.01	18.72	198.92	8.86
8	2127.94	25.48	12.83	18.48	1272.70	20.97
7	732.10	13.93	10.55	18.85	261.65	10.07
6	551.41	11.72	11.68	18.28	229.63	9.12
5	730.30	14.10	12.12	18.83	377.54	11.69
4	693.00	13.74	11.18	18.47	322.46	10.85
3	582.88	13.08	10.90	19.43	332.36	11.60
2	838.68	16.09	15.32	19.22	649.16	15.90
1	876.00	16.22	8.46	19.16	460.42	13.65
PEC mg/kg (MacDonald et al. 2000)	**128**	**--**	**4.98**	**--**	**459**	**--**

3.4 Sediment Metals by Particle Size

We examined mean metals concentrations grouped by particle size per transect to identify metals character and distribution. The three particle sizes represent sand (<2mm), gravel (2mm-12.5mm); and pebble (>12.5mm). Results are grouped by Bar A or Bar B and sub-grouped by lead, cadmium, or zinc.

Most metal levels were significantly lower at control sites than the test sites for sand, gravel, and pebble (Table 5; Appendix C). Lead and zinc levels in control samples were significantly lower ($p<0.05$) than all sand, gravel, and pebble concentrations at Bars A and B. Cadmium was significantly different in the control for sand, but not in gravel or pebble. Cadmium levels were very low with high variability, which may be why no difference was detected. This suggests that particles of all sizes were not native material at Bars A and B.

Table 5
Difference Between Controls vs. Bars Using Particle Sizes; p-values
(Also see Appendix D)

	Lead	Cadmium	Zinc
Sand	**<0.05**	**<0.05**	**<0.05**
Gravel	**<0.05**	0.381	**<0.05**
Pebble	**<0.05**	0.604	**<0.05**

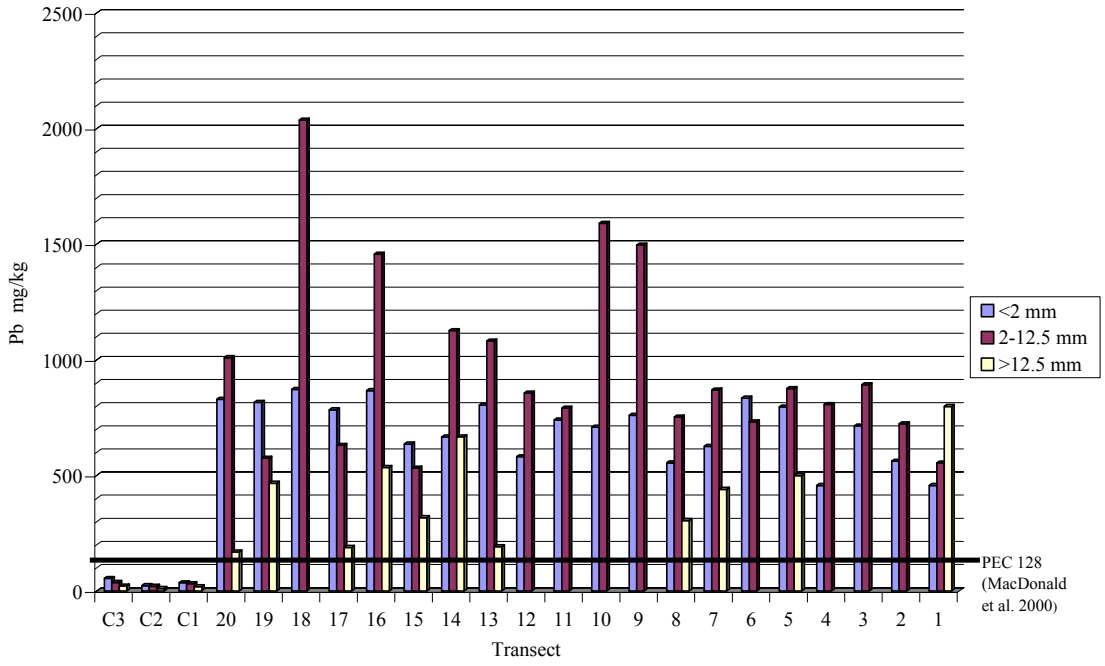
All size classes were represented in most transects on Bar A. Pebble-sized material was collected at 11 of the 20 samples in Bar A (excluding 18, 12, 11, 10, 9, 6, 4, 3, 2).

All three size classes were present in most transects on Bar B. Pebble was collected at 18 of the 20 transects on Bar B (excluding 16, 15). Lead, cadmium, and zinc were examined for all three size classes.

3.4.1 Bar A: Lead by Particle Size

Bar A transects were examined for lead concentration by particle size (Table 6; Figure 9). Sand-sized material exceeded the lead PEC at all transects, with little variation from near 500 mg/kg to approximately 900 mg/kg. Interestingly, gravel-sized material was higher than sand and also exceeded the lead PEC at all transects. Gravel ranged from approximately 500 mg/kg to over 2000 mg/kg with high variability. Pebble-sized material exceeded the lead PEC at all of the 11 transects where it was collected and ranged from nearly 200 to nearly 800 mg/kg with high variability. All size class controls were well below PEC. It appears that lead can be found in high concentrations, in all size classes, across all of Bar A.

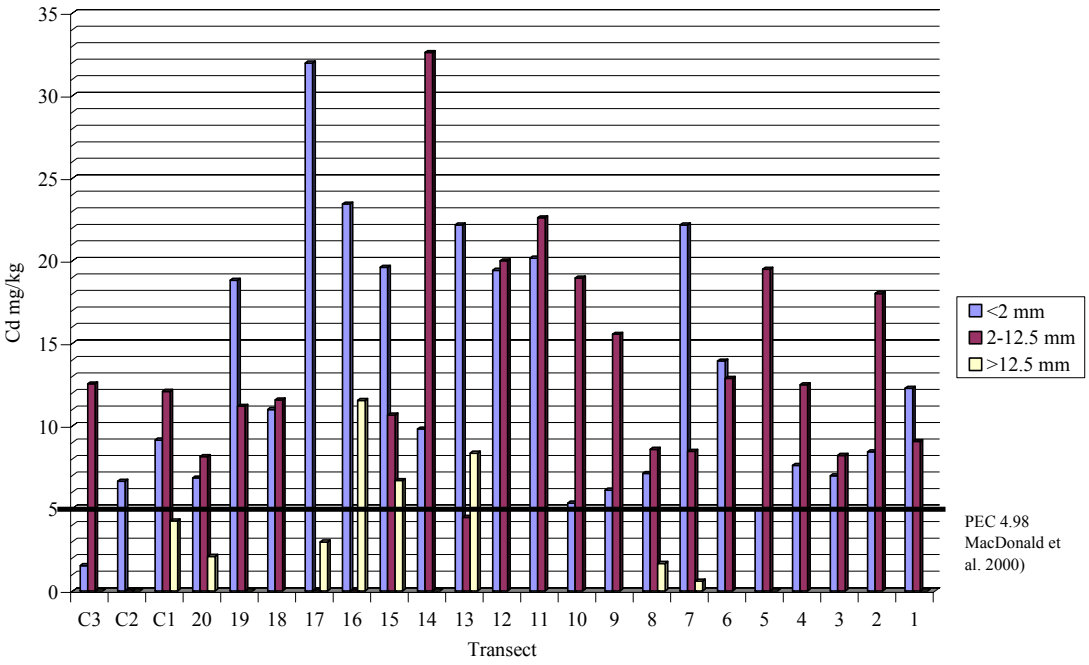
Figure 9: Bar A - Mean lead concentration by particle size per transect (C=control)



3.4.2 Bar A: Cadmium by Particle Size

Bar A transects were examined for cadmium concentrations by particle size (Table 6; Figure 10). Cadmium is present above PEC mostly in the sand- and gravel-sized material and is evenly distributed on Bar A. Sand-sized material exceeded the cadmium PEC at all but one transect and varied from approximately 5 mg/kg to over 30m/kg. Two of the three sand controls also exceeded the cadmium PEC. Gravel-sized material had higher concentrations than sand and exceeded the cadmium PEC at all transects. Gravel ranged from approximately 8 mg/kg to over 32 mg/kg with high variability. Two of the three gravel controls exceeded PEC. Pebble-sized material was found in 11 transects and exceeded the cadmium PEC at three of the seven transects where it was detected. Cadmium in the pebble size ranged from <1 mg/kg to nearly 12 mg/kg with high variability. All pebble controls were lower than the cadmium PEC. Cadmium was not detected in pebble at four transects (1, 4, 5, 18) where that size was collected, suggesting that it is not common in that size class.

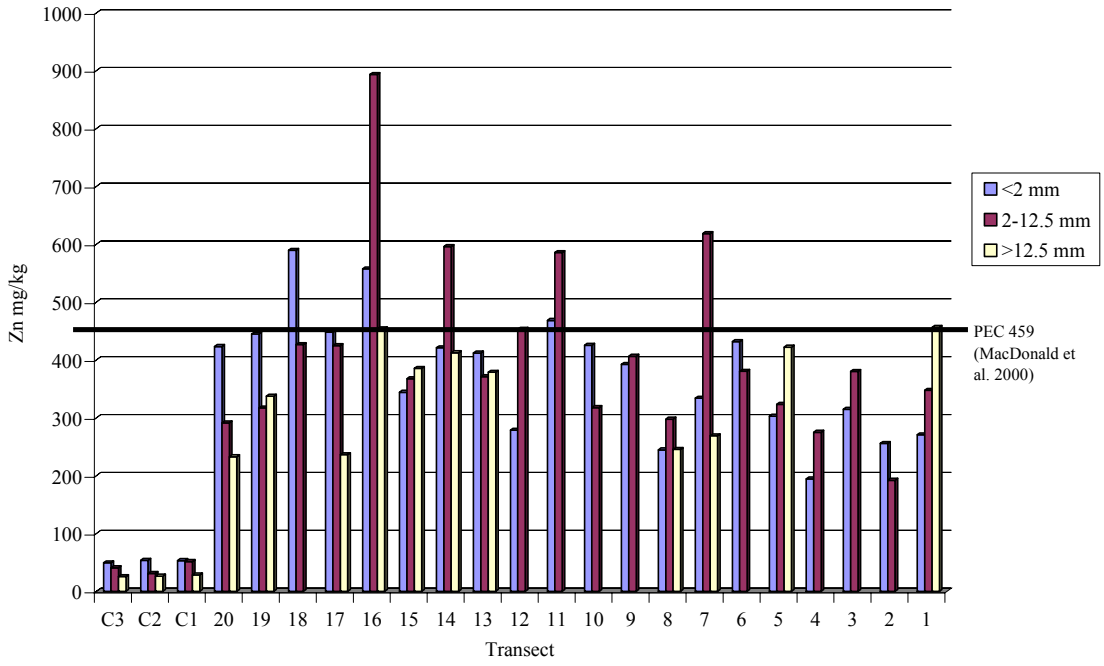
Figure 10: Bar A - Mean cadmium concentration by particle size per transect (C=control)



3.4.3 Bar A: Zinc by Particle Size

Bar A transects were examined for zinc concentrations by particle size (Table 6; Figure 11). Sand-sized material exceeded the zinc PEC at three transects and varied from approximately 190 to 590 mg/kg. Gravel material exceeded the PEC at four transects and ranged from approximately 190 to over 890 mg/kg. Pebble-sized-material did not exceed the zinc PEC and varied from approximately 230 to 450 mg/kg. Control samples contained zinc that was below PEC in all size classes. Zinc was found to be above PEC in sand and gravel fractions and distributed fairly evenly across the bar.

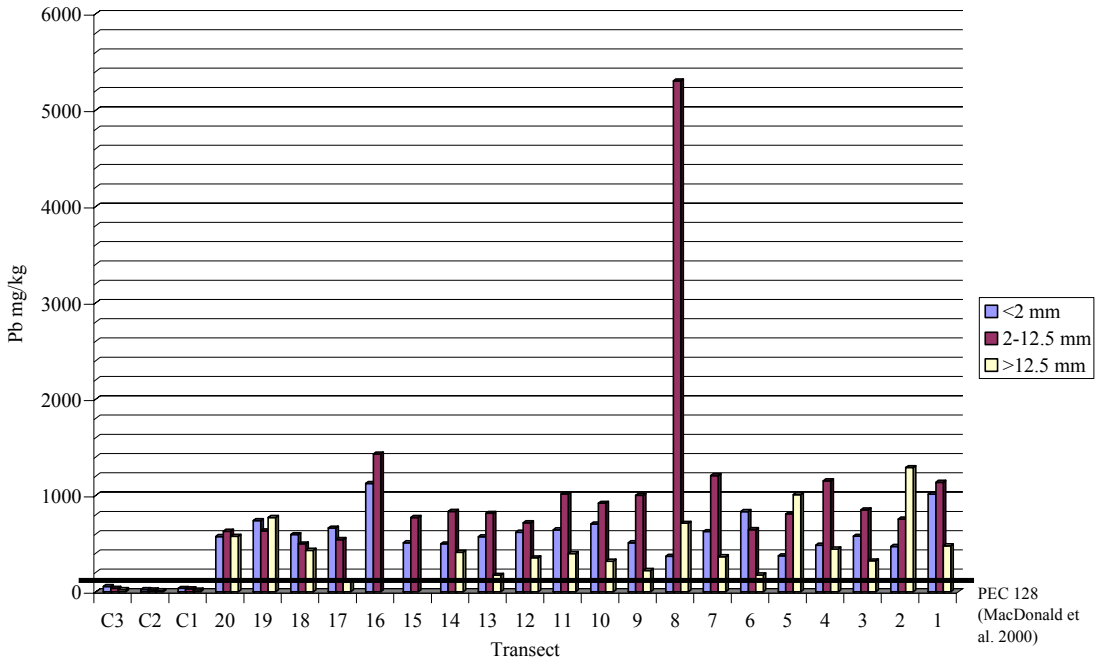
Figure 11: Bar A - Mean zinc concentration by particle size per transect (C=control)



3.4.4 Bar B: Lead by Particle Size

Bar B transects were examined for lead concentration by particle size (Table 7; Figure 12). Sand-sized material exceeded the lead PEC at all transects with little variation from approximately 500 mg/kg to 1000 mg/kg. Again, gravel-sized material had higher concentrations than sand and also exceeded the lead PEC at all transects. Gravel ranged from approximately 500 to over 5200 mg/kg with high variability. Pebble-sized material exceeded the lead PEC at 17 of the 18 transects in which it was collected and ranged from approximately 100 to 1200 mg/kg with high variability. All size classes for controls were well below PEC. It appears that lead can be found in higher concentrations in all size classes across all of Bar A.

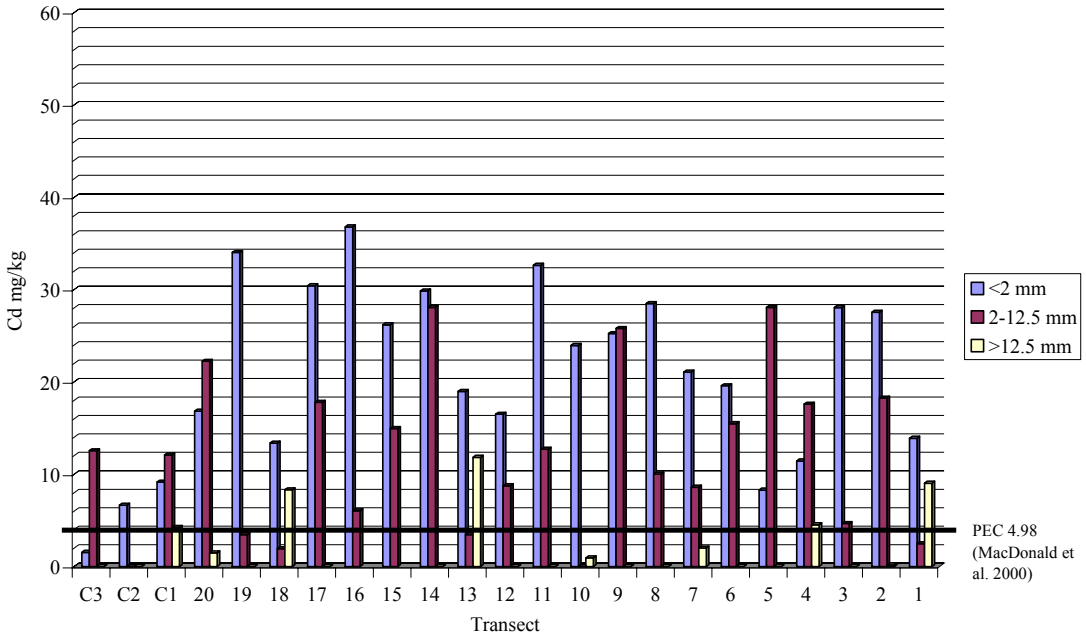
Figure 12: Bar B - Mean lead concentration by particle size per transect (C=control)



3.4.5 Bar B: Cadmium by Particle Size

Bar B transects were examined for cadmium concentrations by particle size (Table 7; Figure 13). Sand-sized material exceeded the cadmium PEC at all transects and varied from approximately 8 mg/kg to 37mg/kg. Two of the three sand controls exceeded the cadmium PEC. Gravel-sized material was usually lower than sand but exceeded the cadmium PEC at 15 of the 20 transects. Gravel ranged from approximately 2 mg/kg to 28 mg/kg with high variability. Pebble-sized material was collected from 18 of the 20 transects. Cadmium was detected at seven transects and exceeded the cadmium PEC at three transects. It ranged from <1.0 to approximately 12 mg/kg with high variability. The pebble controls were lower than cadmium PEC. Cadmium is present above PEC predominately in the sand- and gravel-sized material and is evenly distributed on Bar B.

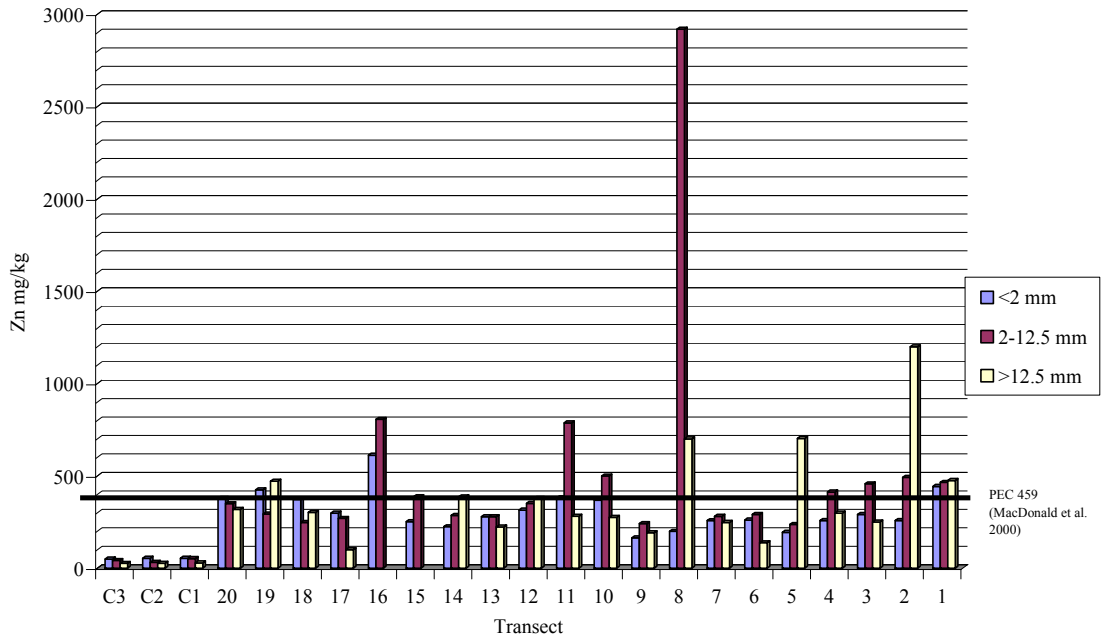
Figure 13: Bar B - Mean cadmium concentration by particle size per transect (C=control)



3.4.6 Bar B: Zinc by Particle Size

Bar B transects were examined for zinc concentrations by particle size (Table 7; Figure 14). Sand-sized material exceeded the zinc PEC at one transect and varied from approximately 160 to over 600 mg/kg. Gravel material exceeded the PEC at six transects and ranged from approximately 190 to over 2900 mg/kg. Pebbles exceed the PEC at five stations and varied from 99 to nearly 1200 mg/kg. Control samples contained zinc that was below PEC in all size classes. Zinc was found to be above PEC in sand and gravel fractions and distributed fairly evenly across the bar.

Figure 14: Bar B - Mean zinc concentration by particle size per transect (C=control)



3.4.7 Overall Analysis of Metals by Particle Size

Gravel was significantly higher ($p<0.05$) in lead than either sand or pebble (Appendix D). Gravel and sand were significantly higher in cadmium than pebble. All size fractions were not significantly different in zinc concentrations.

Table 6
Bar A and Controls: Mean Lead, Cadmium, and Zinc Concentrations (mg/kg) and Standard Deviations by Particle Size per Transect

Flag Number	Transect	Size Fraction	Sample Number	Lead mean	S.D.	Cadmium mean	S.D.	Zinc mean	S.D.
BG-03	C3	<2	H0602895-2	54.16	4.17	1.54	17.21	49.34	4.68
BG3	C3	2-12.5	H0602895+2	37.19	3.97	12.54	18.33	40.85	4.66
BG3	C3	>12.5	H0602895+12.5	21.81	3.34	0.00	17.66	25.66	3.92
BG-02	C2	<2	H0602896-2	23.07	3.09	6.64	16.22	53.70	4.52
BG2	C2	2-12.5	H0602896+2	20.33	3.06	0.00	16.67	30.99	3.90
BG2	C2	>12.5	H0602896+12.5	10.94	2.97	0.00	17.61	26.46	3.95
BG-01	C1	<2	H0602897-2	36.02	3.58	9.15	16.49	53.38	4.65
BG1	C1	2-12.5	H0602897+2	31.73	3.49	12.09	16.81	51.64	4.63
BG1	C1	>12.5	H0602897+12.5	18.89	3.28	4.24	17.90	28.61	4.09
A.20.8.0	20	<2	H0602933-2	828.98	14.78	6.85	17.96	423.48	12.24
A.20.8.0	20	2-12.5	H0602933+2	1009.42	16.86	8.14	18.87	291.42	10.70
A.20.8.0	20	>12.5	H0602933+12.5	168.80	8.28	2.10	23.61	232.73	11.36
A.19.26.0	19	<2	H0602934-2	815.95	14.87	18.82	18.11	445.01	12.73
A.19.26.0	19	2-12.5	H0602934+2	574.34	12.57	11.19	18.54	317.24	10.89
A.19.26.0	19	>12.5	H0602934+12.5	465.81	10.63	0.00	18.02	337.51	10.74
A.18.16.0	18	<2	H0602935-2	871.76	15.67	10.99	18.42	589.74	14.78
A.18.16.0	18	2-12.5	H0602935+2	2036.83	26.54	11.57	18.84	426.85	12.94
A.18.16.0	18	>12.5	N/A	--	--	--	--	--	--
A.17.31.0	17	<2	H0602936-2	783.43	14.51	31.97	17.89	448.09	12.69
A.17.31.0	17	2-12.5	H0602936+2	629.89	12.48	0.00	17.58	425.05	11.89
A.17.31.0	17	>12.5	H0602936+12.5	188.85	8.07	2.97	20.20	236.49	10.47

Table 6 Continued

A.16.36.0	16	<2	H0602937-2	866.61	15.21	23.43	17.92	557.52	14.08
A.16.36.0	16	2-12.5	H0602937+2	1456.92	22.74	0.00	19.82	893.64	20.08
A.16.36.0	16	>12.5	H0602937+12.5	534.15	12.15	11.54	18.63	454.04	13.16
A.15.16.0	15	<2	H0602938.-2	635.88	21.48	19.60	75.79	344.36	18.95
A.15.16.0	15	2-12.5	H0602938+2	532.16	11.86	10.65	18.19	367.70	11.54
A.15.16.0	15	>12.5	H0602938+12.5	317.08	8.78	6.69	17.78	385.50	11.42
A.14.63.0	14	<2	H0602939.-2	666.25	21.92	9.82	75.81	421.25	19.59
A.14.63.0	14	2-12.5	H0602939+2	1126.16	18.36	32.61	18.83	596.23	15.27
A.14.63.0	14	>12.5	H0602939+12.5	666.91	14.13	0.00	19.29	412.51	13.12
A.13.39.0	13	<2	H0602940-2	804.14	14.53	22.17	17.68	412.25	12.05
A.13.39.0	13	2-12.5	H0602940+2	1081.52	18.30	4.46	19.39	371.37	12.32
A.13.39.0	13	>12.5	H0602940+12.5	191.72	7.28	8.35	18.71	378.87	11.94
A.12.11.0	12	<2	H0602941-2	581.16	12.09	19.42	17.61	278.76	9.86
A.12.11.0	12	2-12.5	H0602941+2	856.26	15.63	19.99	18.37	453.29	13.05
A.12.11.0	12	>12.5	N/A	--	--	--	--	--	--
A.11.41.0	11	<2	H0602942-2	739.99	13.96	20.16	17.93	468.54	12.92
A.11.41.0	11	2-12.5	H0602942+2	791.18	14.36	22.60	17.99	585.92	14.41
A.11.41.0	11	>12.5	N/A	--	--	--	--	--	--
A.10.28.0	10	<2	H0602943-2	708.76	27.34	5.33	102.13	425.51	23.72
A.10.28.0	10	2-12.5	H0602943+2	1590.32	23.14	18.95	19.53	317.73	11.61
A.10.28.0	10	>12.5	N/A	--	--	--	--	--	--
A.9.11.0	9	<2	H0602944-2	760.06	23.31	6.11	76.45	392.49	19.94
A.9.11.0	9	2-12.5	H0602944+2	1496.14	21.43	15.55	18.51	406.58	12.53
A.9.11.0	9	>12.5	N/A	--	--	--	--	--	--
A.8.17.0	8	<2	H0602945-2	554.18	11.44	7.12	17.06	244.69	9.04
A.8.17.0	8	2-12.5	H0602945+2	752.49	14.23	8.58	18.63	297.91	10.11

Table 6 Continued

A.8.17.0	8	>12.5	H0602945+12.5	304.97	7.94	1.67	16.12	245.53	8.42
A.7.5.0	7	<2	H0602946-2	625.56	12.46	22.17	17.32	334.07	10.61
A.7.5.0	7	2-12.5	H0602946+2	869.90	15.93	8.46	18.89	618.61	15.41
A.7.5.0	7	>12.5	H0602946+12.5	439.87	13.76	0.60	32.92	268.93	12.09
A.6.19.0	6	<2	H0602947-2	834.55	27.05	13.93	82.29	431.85	22.28
A.6.19.0	6	2-12.5	H0602947+2	731.45	15.11	12.88	19.53	380.67	12.58
A.6.19.0	6	>12.5	N/A	--	--	--	--	--	--
A.5.17.0	5	<2	H0602948.-2	796.35	24.81	4.91	77.19	302.98	18.27
A.5.17.0	5	2-12.5	H0602948+2	875.26	15.95	19.48	19.04	323.41	11.15
A.5.17.0	5	>12.5	H0602948+12.5	499.26	11.46	0.00	18.45	422.43	12.33
A.4.2.0	4	<2	H0602949.-2	456.37	20.94	7.61	98.00	194.43	16.33
A.4.2.0	4	2-12.5	H0602949+2	806.90	15.22	12.49	18.32	275.07	10.40
A.4.2.0	4	>12.5	N/A	--	--	--	--	--	--
A.3.21.0	3	<2	H0602950-2	714.04	23.81	6.98	77.16	314.88	17.89
A.3.21.0	3	2-12.5	H0602950+2	892.06	15.43	8.21	17.58	380.17	11.56
A.3.21.0	3	>12.5	N/A	--	--	--	--	--	--
A.2.7.0	2	<2	H0602951.-2	561.92	20.13	8.43	76.36	255.82	16.22
A.2.7.0	2	2-12.5	H0602951+2	723.40	13.12	18.01	17.55	192.20	8.33
A.2.7.0	2	>12.5	N/A	--	--	--	--	--	--
A.1.25.0	1	<2	H0602952.-2	456.32	16.22	12.27	64.75	270.77	14.77
A.1.25.0	1	2-12.5	H0602952+2	553.72	20.74	9.05	76.20	347.74	19.04
A.1.25.0	1	>12.5	H0602952+12.5	798.48	15.15	0.00	18.19	456.47	13.23

BG = Control (C3, C2, C1); N/A=size class not found in the sample.

Table 7
Bar B and Controls: Mean Lead, Cadmium, and Zinc Concentrations (mg/kg) and Standard Deviations by Particle Size per Transect

Flag Number	Transect	Size Fraction	Sample Number	Lead mean	S.D.	Cadmium mean	S.D.	Zinc mean	S.D.
BG-03	C3	<2	H0602895-2	54.16	4.17	1.54	17.21	49.34	4.68
	C3	2-12.5	H0602895+2	37.19	3.97	12.54	18.33	40.85	4.66
	C3	>12.5	H0602895+12.5	21.81	3.34	0.00	17.66	25.66	3.92
BG-02	C2	<2	H0602896-2	23.07	3.09	6.64	16.22	53.70	4.52
	C2	2-12.5	H0602896+2	20.33	3.06	0.00	16.67	30.99	3.90
	C2	>12.5	H0602896+12.5	10.94	2.97	0.00	17.61	26.46	3.95
BG-01	C1	<2	H0602897-2	36.02	3.58	9.15	16.49	53.38	4.65
	C1	2-12.5	H0602897+2	31.73	3.49	12.09	16.81	51.64	4.63
	C1	>12.5	H0602897+12.5	18.89	3.28	4.24	17.90	28.61	4.09
B.20.7.0	20	<2	H0602913-2	574.87	12.04	16.83	17.72	377.29	11.32
	20	2-12.5	H0602913+2	628.99	13.43	22.24	19.40	348.95	11.83
	20	>12.5	H0602913+12.5	576.61	11.68	1.48	18.03	318.08	10.53
B.19.9.0	19	<2	H0602914-2	739.46	14.17	34.02	18.34	424.30	12.49
	19	2-12.5	H0602914+2	633.78	13.45	3.47	18.88	293.13	10.74
	19	>12.5	H0602914+12.5	771.96	15.08	0.00	19.35	470.62	13.76
B.18.11.0	18	<2	H0602915-2	594.57	12.34	13.37	17.93	372.77	11.42
	18	2-12.5	H0602915+2	497.95	11.45	1.93	18.39	247.12	9.57
	18	>12.5	H0602915+12.5	431.36	11.06	8.31	18.70	301.92	10.91
B.17.26.0	17	<2	H0602916-2	661.44	13.15	30.42	18.10	298.10	10.35
	17	2-12.5	H0602916+2	543.22	12.62	17.78	19.19	269.02	10.46
	17	>12.5	H0602916+12.5	100.30	5.60	0.00	18.52	99.87	6.56

Table 7 Continued

B.16.6.0	16	<2	H0602917-2	1124.40	17.24	36.80	17.38	611.59	14.43
	16	2-12.5	H0602917+2	1430.07	20.68	6.04	17.24	805.71	17.37
	16	>12.5	N/A	--	--	--	--	--	--
B.15.4.0	15	<2	H0602918-2	509.01	11.06	26.18	17.31	251.42	9.23
	15	2-12.5	H0602918+2	771.32	15.75	14.95	19.79	386.97	12.83
	15	>12.5	N/A	--	--	--	--	--	--
B.14.33.0	14	<2	H0602919-2	498.14	11.12	29.84	17.68	224.00	8.87
	14	2-12.5	H0602919+2	835.22	16.05	28.07	19.66	285.44	10.91
	14	>12.5	H0602919+12.5	410.25	11.56	0.00	20.32	386.33	12.99
B.13.36.0	13	<2	H0602920-2	570.98	12.10	18.97	17.90	277.95	9.95
	13	2-12.5	H0602920+2	815.14	15.46	3.46	19.17	278.65	10.53
	13	>12.5	H0602920+12.5	172.03	7.65	11.84	21.05	223.04	9.80
B.12.35.0	12	<2	H0602921-2	618.31	12.63	16.49	17.89	314.79	10.56
	12	2-12.5	H0602921+2	716.82	15.13	8.74	20.65	350.82	12.78
	12	>12.5	H0602921+12.5	353.06	9.86	0.00	19.70	376.69	12.47
B.11.50.0	11	<2	H0602922-2	643.17	12.84	32.63	17.86	380.00	11.55
	11	2-12.5	H0602922+2	1014.31	16.57	12.71	17.67	786.73	16.46
	11	>12.5	H0602922+12.5	398.20	9.53	0.00	17.21	280.91	9.52
B.10.44.0	10	<2	H0602923-2	704.18	13.59	23.95	17.96	367.90	11.48
	10	2-12.5	H0602923+2	920.13	16.01	0.00	18.18	499.16	13.47
	10	>12.5	H0602923+12.5	317.61	9.51	0.94	19.56	274.80	10.62
B.9.18.0	9	<2	H0602924-2	509.12	11.17	25.24	17.57	163.80	7.64
	9	2-12.5	H0602924+2	1002.04	17.82	25.78	19.53	240.99	10.08
	9	>12.5	H0602924+12.5	221.33	7.89	0.00	19.08	191.96	8.84

Table 7 Continued

B.8.45.0	8	<2	H0602925-2	368.77	9.18	28.48	16.95	198.96	8.07
	8	2-12.5	H0602925+2	5303.37	52.26	10.01	17.91	2919.11	37.57
	8	>12.5	H0602925+12.5	711.67	15.00	0.00	20.58	700.05	17.28
B.7.12.0	7	<2	H0602926-2	625.65	12.74	21.06	17.84	257.02	9.60
	7	2-12.5	H0602926+2	1206.54	18.89	8.58	19.07	280.45	10.47
	7	>12.5	H0602926+12.5	364.12	10.17	2.01	19.63	247.50	10.13
B.6.6.0	6	<2	H0602927-2	832.44	14.84	19.58	18.04	260.96	9.70
	6	2-12.5	H0602927+2	645.93	13.75	15.47	19.16	290.52	10.63
	6	>12.5	H0602927+12.5	175.85	6.56	0.00	17.63	137.42	7.04
B.5.51.0	5	<2	H0602928-2	373.60	9.29	8.29	16.91	194.15	8.02
	5	2-12.5	H0602928+2	808.21	15.41	28.06	19.07	236.08	9.84
	5	>12.5	H0602928+12.5	1009.09	17.60	0.00	20.52	702.38	17.22
B.4.52.0	4	<2	H0602929-2	483.70	10.80	11.43	17.38	257.29	9.29
	4	2-12.5	H0602929+2	1151.59	20.15	17.59	20.43	412.24	13.41
	4	>12.5	H0602929+12.5	443.70	10.28	4.52	17.61	297.87	9.83
B.3.10.0	3	<2	H0602930-2	577.56	12.22	28.05	17.98	290.50	9.97
	3	2-12.5	H0602930+2	850.14	17.19	4.66	20.45	456.50	14.43
	3	>12.5	H0602930+12.5	320.93	9.83	0.00	19.85	250.09	10.38
B.2.49.0	2	<2	H0602931-2	471.60	10.61	27.54	17.40	257.68	9.31
	2	2-12.5	H0602931+2	754.59	15.07	18.24	19.14	491.28	14.05
	2	>12.5	H0602931+12.5	1289.85	22.60	0.17	21.12	1198.52	24.35
B.1.29.0	1	<2	H0602932-2	1013.26	17.26	13.89	18.60	442.59	12.99
	1	2-12.5	H0602932+2	1137.51	19.18	2.46	19.29	464.10	13.73
	1	>12.5	H0602932+12.5	477.22	12.22	9.03	19.60	474.58	14.23

N/A=none available in the sample.

3.4.8 QC Washed vs. Unwashed

The study group looked at possible effects that the sieving process may have had on the lead concentrations in larger size fractions (Appendix E). It is possible that when the samples were sieved metal laden dust remained on the larger fractions and contributed to higher values for gravel and pebble. Additional XRF (n=36) testing was conducted on samples that were not washed (n=12). Those samples were washed using distilled water, dried, and exposed and then paired t-tests were run on the data. There was no significant difference ($p>0.05$) between washed and unwashed gravel or pebble samples. Sieving without washing the samples did not have an effect on the outcome. It also appears that the brass 12.5 mm sieve had no effect on the 12.5 mm fraction.

3.5 Sediment Metals by Depth

At four transects on Bar B samples were collected from vertical depths ranging from the surface (0) to 1, 2, or 3 feet to verify the vertical extent of mine-related material (Table 8). In general, surface samples had the same concentrations of lead, cadmium, and zinc as the samples taken at depths. Most samples were above PECs for lead, cadmium, and zinc.

In general, metals concentrations were not significantly different between the surface and depths of three feet (Appendix F). Lead and cadmium were not different from surface to 3 feet. Zinc was significantly higher ($p<0.05$) at 1 foot than was found on the surface, yet both the surface and 1 foot were similar to all other depths.

3.5.1 Depth and Particle Size

The sediment metals concentrations by particle size and depth are shown in Table 9. Lead, cadmium, and zinc exceeded PECs for most particle sizes. However, we did not conduct ANOVA by particle size at all depths. The earlier comparison of means between the surface and depths found no significant difference, except the surface and one foot for zinc. This suggested that particle sizes at depths would not be that different from the surface. Most particle sizes exceeded PECs for lead, while pebble was lower in cadmium and zinc. The surface showed that the gravel contained more lead, at least as much cadmium for sand, and was similar between all sizes for zinc.

Table 8
Mean Metals Concentration (mg/kg) and Standard Deviation for Vertical Extent by Transect and Depth (ft.)

Bar B Transect, depth	Lead mean	S.D.	Cadmium mean	S.D.	Zinc mean	S.D.
C3	37.72	3.83	4.69	17.73	38.62	4.42
C2	18.12	3.04	2.21	16.83	37.05	4.12
C1	28.88	3.45	8.49	17.07	44.54	4.46
17.26.0	434.99	10.46	16.07	18.60	222.33	9.12
17.26.1	751.03	22.37	4.15	70.71	451.21	20.51
10.44.0	647.31	13.04	8.30	18.57	380.62	11.85
10.44.1	670.20	13.31	12.07	18.31	391.69	11.94
10.44.2	556.90	12.54	13.70	19.07	380.03	11.99
10.44.3	755.32	13.22	14.99	17.96	352.12	10.83
7.12.0	732.10	13.93	10.55	18.85	261.65	10.07
7.12.1	992.38	16.87	14.44	18.65	628.54	15.23
7.12.2	750.88	14.50	18.38	19.16	407.32	12.75
7.12.3	738.18	14.39	8.56	18.88	389.94	12.31
1.29.0	875.10	16.22	8.46	19.16	460.42	13.65
1.29.1	862.71	15.46	10.26	18.04	631.16	15.26
1.29.2	867.43	15.52	10.49	18.82	421.28	12.28
PEC mg/kg (MacDonald et al. 2000)	**128**	**--**	**4.98**	**--**	**459**	**--**

Table 9
Particle Size per Transect and Depth
Bar B and Controls: Mean Lead, Cadmium, and Zinc Concentrations (mg/kg) and Standard Deviations

Flag Number	Transect	Size Fraction	Sample Number	Lead mean	S.D.	Cadmium mean	S.D.	Zinc mean	S.D.
BG-03	C3	<2	H0602895-2	54.16	4.17	1.54	17.21	49.34	4.68
	C3	2-12.5	H0602895+2	37.19	3.97	12.54	18.33	40.85	4.66
	C3	>12.5	H0602895+12.5	21.81	3.34	0.00	17.66	25.66	3.92
BG-02	C2	<2	H0602896-2	23.07	3.09	6.64	16.22	53.70	4.52
	C2	2-12.5	H0602896+2	20.33	3.06	0.00	16.67	30.99	3.90
	C2	>12.5	H0602896+12.5	10.94	2.97	0.00	17.61	26.46	3.95
BG-01	C1	<2	H0602897-2	36.02	3.58	9.15	16.49	53.38	4.65
	C1	2-12.5	H0602897+2	31.73	3.49	12.09	16.81	51.64	4.63
	C1	>12.5	H0602897+12.5	18.89	3.28	4.24	17.90	28.61	4.09
B.17.26.0	20	<2	H0602916-2	661.44	13.15	30.42	18.10	298.10	10.35
	20	2-12.5	H0602916+2	543.22	12.62	17.78	19.19	269.02	10.46
	20	>12.5	H0602916+12.5	100.30	5.60	0.00	18.52	99.87	6.56
B.17.26.1	19	<2	H0602903.-2	624.21	25.94	0.66	102.01	407.31	24.43
	19	2-12.5	H0602903+2	956.64	16.13	19.96	18.30	485.98	13.37
	19	>12.5	H0602903+12.5	968.16	16.70	0.00	18.75	562.80	14.57
B.10.44.0	18	<2	H0602923-2	704.18	13.59	23.95	17.96	367.90	11.48
	18	2-12.5	H0602923+2	920.13	16.01	0.00	18.18	499.16	13.47
	18	>12.5	H0602923+12.5	317.61	9.51	0.94	19.56	274.80	10.62
B.10.44.1	17	<2	H0602909-2	626.81	12.70	9.68	17.95	342.14	10.98
	17	2-12.5	H0602909+2	955.04	16.93	12.02	19.04	461.78	13.45
	17	>12.5	H0602909+12.5	443.21	10.51	15.30	18.08	387.67	11.71

Table 9 Continued

B.10.44.2	16	<2	H0602908-2	740.80	14.17	34.01	18.28	292.84	10.41
	16	2-12.5	H0602908+2	274.33	8.63	0.44	18.55	149.22	7.68
	16	>12.5	H0602908+12.5	655.56	14.82	6.66	20.37	698.04	17.89
B.10.44.3	15	<2	H0602907-2	967.41	16.84	9.25	18.64	561.97	14.62
	15	2-12.5	H0602907+2	1478.50	21.95	31.42	19.08	489.72	13.93
	15	>12.5	H0602907+12.5	53.86	3.96	6.96	16.61	91.54	5.66
B.7.12.0	14	<2	H0602926-2	625.65	12.74	21.06	17.84	257.02	9.60
	14	2-12.5	H0602926+2	1206.54	18.89	8.58	19.07	280.45	10.47
	14	>12.5	H0602926+12.5	364.12	10.17	2.01	19.63	247.50	10.13
B.7.12.1	13	<2	H0602902-2	622.77	12.46	17.90	17.79	387.84	11.47
	13	2-12.5	H0602902+2	526.66	11.82	20.73	18.22	500.99	13.17
	13	>12.5	H0602902+12.5	1827.71	26.34	4.69	19.95	996.79	21.05
B.7.12.2	12	<2	H0602901-2	640.92	12.82	22.46	17.86	356.71	11.18
	12	2-12.5	H0602901+2	1237.71	19.86	28.55	19.67	452.12	13.66
	12	>12.5	H0602901+12.5	374.00	10.81	4.14	19.93	413.14	13.41
B.7.12.3	11	<2	H0602900-2	649.37	13.06	21.40	18.15	327.87	10.87
	11	2-12.5	H0602900+2	899.48	16.45	4.27	19.16	468.48	13.57
	11	>12.5	H0602900+12.5	665.71	13.65	0.00	19.32	373.48	12.50
B.1.29.0	10	<2	H0602932-2	1013.26	17.26	13.89	18.60	442.59	12.99
	10	2-12.5	H0602932+2	1137.51	19.18	2.46	19.29	464.10	13.73
	10	>12.5	H0602932+12.5	477.22	12.22	9.03	19.60	474.58	14.23
B.1.29.1	9	<2	H0602906-2	620.24	12.56	21.23	17.71	400.93	11.81
	9	2-12.5	H0602906+2	947.22	16.22	8.50	17.65	773.54	16.96
	9	>12.5	H0602906+12.5	1020.66	17.60	1.06	18.75	719.01	17.02
B.1.29.2	8	<2	H0602905-2	569.72	11.90	14.80	17.67	252.70	9.41
	8	2-12.5	H0602905+2	990.22	18.12	12.68	19.74	480.16	13.65
	8	>12.5	H0602905+12.5	1001.41	15.68	3.25	18.75	511.37	13.34

4.0 Discussion

The volume and character of sediments are discussed. The character of the material by particles sizes and by depth is also discussed.

4.1 Sediment Volume

The volume of mine-related sediment was identified for the stream channel associated with Bar A and Bar B. The stream channel at Bar A contained approximately 671,710 cubic feet of material. The stream channel at Bar B was smaller yet contained approximately 275,000 cubic feet of material. When combined there appears to be as much as 946,715 cubic feet, or 35,063 cubic yards, of material in the stream channel at this location.

GPR identified a mean depth of nearly 9 feet on the bars and 7 feet in the stream. GPR also identified an almost homogenous layer (without hyperbola) of fine material that ranged from the surface to 3 feet or more on both bars and 2 or more feet in the stream. The presence of this homogenous layer of material suggests that the source may have been a pulse such as the Desloge tailings pile collapse in 1977.

4.2 Characterization of Sediment

Characterization involved identifying the metals content of the sediment by particle size and depth.

4.2.1 Mine-related Material

The surface material is consistent with mine-related material. The material found on the surface of both bars contained high levels of lead, cadmium, and zinc. The mean metals contents exceeded PECs at all transects for lead and cadmium, and at several transects for zinc. This is consistent with previous MDNR (2004) findings.

The controls were significantly lower ($p<0.05$) in metals content than Bar A and Bar B. Bar A and Bar B were similar in metals content. This suggests that Bar A and Bar B are not composed of native material.

4.2.2 Characterization by Particle Size

As suspected, metals content was significantly higher in some size fractions (Appendix D). What wasn't expected was that gravel-sized material contained significantly higher ($p<0.05$) amounts of lead than sand or pebble. All size fractions were above the lead PEC. Gravel and sand were similar in cadmium content and above PEC and both were higher than pebble, which was below PEC most of the time. Particle sizes for zinc were all similar in content with only sand and gravel exceeding PEC a few times. Overall, gravel-sized particles had higher concentrations of lead, cadmium, and zinc than the sand size materials. This at first seems to contradict findings by Schmitt and Finger (1982) where higher concentrations of lead, cadmium, and zinc were found in smaller size fractions. However, they did not analyze gravel-sized material and we did not sieve and analyze the silt fraction (4-64 um) from the sand fraction (0.064-2.0 mm). It is possible that silt may have had higher metals concentrations than sand.

One possible explanation of the difference of size fraction metal content may be due to how the material was processed in mining history. Gravel-sized material is called *chat* based on its size and how it was processed. Chat was generated by a dry gravity separation process resulting in fine gravel size material, usually from ¼ to ⅝ inch in diameter. Mine *tailings* are sand or smaller material from a chemical or wet processing, which produced smaller size material (EPA 2007a; EPA 2007b). We found that gravel-sized chat contained higher concentrations of metals. This supports four conclusions: 1) sand and gravel size mine-related materials are present in the Big River channel; 2) sand and gravel size materials found in the channel are consistent with both tailings and chat; 3) the more recent wet processing method is more effective at metals extraction than the older gravity separation process; and 4) repeatable findings in other portions of Big River would require remediation of mine-related material that must include gravel-sized material.

Pebble-sized material usually had lower concentrations of lead, cadmium, and zinc, although some large pieces that appeared to be processed (broken or melted) were found in the samples. Pebble was almost always lower and variable in metals concentrations, which suggests that some material of this size was processed and probably not native material. But lower and more variable metals content also suggests that some of the larger material is native stream rock.

4.2.3 Characterization by Depth

No difference was found between the surface material and materials up to 3 feet for mean lead and cadmium concentrations. Zinc on the surface was significantly lower than at 1 foot, but both the surface and 1 foot depths were roughly similar to the other depth samples; so the difference had little consequence. This showed that mine-related material reached at least 3 feet deep. Physical observations of the surface to 3 feet level showed similar material with no clear strata distinction. This observation is consistent with the homogenous layer observed in GPR images.

Although we could not collect samples from all depths for verification of GPR imagery, the images showed material with similar reflectivity (opacity) from the surface to depths exceeding nine feet or more. This suggests that lead, cadmium, and zinc containing material can be found at nine or more feet. Based on this information, we could conclude that the GPR may identify the vertical extent of the surface material identified by XRF on the surface. We recommend that XRF be used to characterize the surface material and GPR be used to identify its vertical extent.

4.3 Native Material

Control data and particle size characterization suggests that the stream substrate is not representative of background levels. Upstream controls were significantly lower in most metals content than either bar, suggesting that the bars did not contain much native stream material. The pebble particle size was significantly lower and more variable in metals concentrations than either gravel or sand. If high metals concentrations were related to the native material in the stream, the unprocessed pebble material would

probably have higher levels than the chat or tailings-sized material already gleaned of metals. This suggests that the pebble fraction is more closely related to native material.

4.4 Verification Problems

We were not able to verify the GPR readings for metals concentrations at all depths. We unsuccessfully attempted to use a Geoprobe coring machine to capture actual depth samples of sediment from all strata shown on the GPR to correlate actual depths with the GPR image depths. Those cores were to be collected for comparison at sample locations with a fiducial mark on the GPR images. However, the Geoprobe could not collect the fine sandy material or larger rocks in the 2" plastic tubes.

Test pits excavated on the bar using a backhoe served as a limited verification of the GPR readings. No visual or metals content difference was observed in the strata up to three feet and material appeared to be uniform to that depth. This is similar to the layer that we observed on the GPR images that appeared to be homogenous with no or few hyperbolas to a depth of three feet. This served as a limited verification of the GPR.

Material that appeared to be bedrock was observed on the GPR image at a relatively consistent depth. This also suggests that GPR depth readings were accurate (see Arrows and "flat-lines" on Leadwood CA GPR image, Appendix A).

4.5 Interference

The wetted portion of transect images in Appendix A show considerable noise and incorrect water depth readings. This was a result of GPR radar velocity set to penetrate the substrate, not the water. This setting created noise and incorrect water depth readings, but appeared to give consistent sediment depth measures similar or slightly less than the bar measurements. Sediment depth slightly less than bars would be expected given the potential for more active bedload transport in the wetted channel.

Water intrusion has interfered with GPR readings in the field, according to the ESP Field Services Section personnel. Very deep scanning with water intrusion and heavy clay can cause the image to disappear or lose distinction. Contaminated water can reflect or absorb the radar waves, as well. In fact, GPR has been used to identify plumes of contaminated groundwater. Regardless, we were able to scan through fine loose material throughout the study area and had great distinction in the images to a depth of 12-14 feet. Fading at that level is expected given that the GPR depth was set at 20 feet and will not extend beyond the set level under normal circumstances. Water levels were approximately one to three feet below the surface of the bars, which suggests that water had no effect on the quality of the images.

4.6 Feasibility

The GPR platform worked well on smooth (sandy) and uninterrupted material. If the surface material was large pebble, cobble, or boulder the GPR would be harder to maneuver. Trees or other vegetation on the bar would also interfere with deployment of

the GPR. As shown by Webb et al. (2000) and Dudley et al. (1999), these devices can be adapted to a variety of platforms.

The speed of collecting data with the GPR was impressive. A smooth sand substrate or stream transect took less than one minute at approximately two feet per second. Twenty terrestrial transects could be done in less than an hour, including setup. The GPR traveled over 4,000 feet in less than an hour run time.

Most of the time spent on this project was in processing samples, analyzing data, generating figures, and writing the report. Ground penetrating radar image processing alone required approximately four hours. New software creates depth contour maps and estimates the quantity of a selected material for the user. The volumes of similar materials can be illustrated along with a contour map in seconds using a new product, Voxler 3-D imaging for GPR technology (Sensors and Software Inc.). This saves enormous amounts of time in processing and reporting. ESP has recently acquired this technology in addition to GPS Trimble units.

4.7 Future GPR/XRF Sampling

Future projects should be done to identify the volume of material in other Big River locations. The study area in this report appeared to have similar distribution of material from upstream to downstream. A large number of transects may not be necessary in future sampling to identify volume of material. The metals content of surface material may provide the necessary information for remediation.

5.0 Summary

Using GPR and XRF technology, we found as much as 940,000 cubic feet, or 35,000 cubic yards, of mine-related material at two point bars in St. Francois State Park. The material extends to 9 feet deep or more on the bars and 8 feet or more in the adjacent stream. Lead, cadmium, and some areas of zinc were above PECs (MacDonald et al. 2000). Gravel-sized material contained higher concentrations of lead, cadmium, and zinc than sand-sized material. The metals content of surface material was similar down to a depth of three feet.

6.0 Recommendations:

1) Evaluate the number of GPR transects necessary to identify sediment volume.

2) Use XRF to characterize the surface material and GPR to identify its vertical extent.

3) Estimate the volume of mine-related material in Big River.

4) Stop uncontrolled downstream movement of mine-related material.

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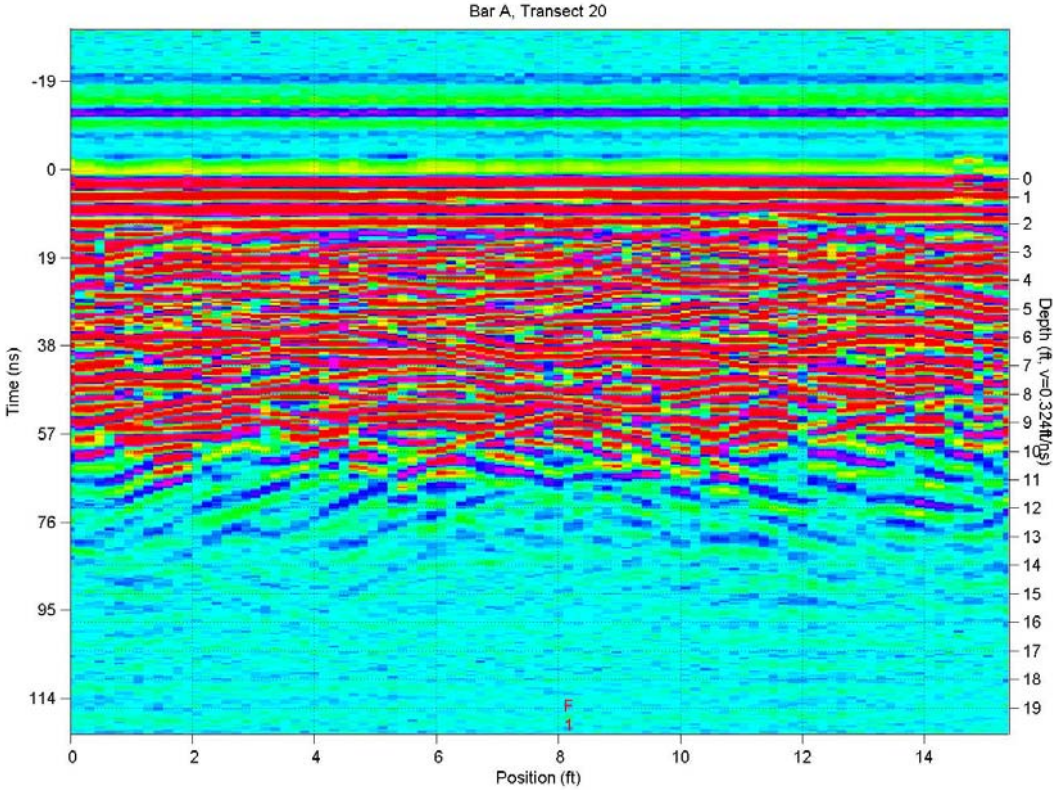
Appendix A

GPR Images: Bar A and Stream A, Transects 20-1 and Duplicates;
Bar B and Stream B, Transects 20-1; Leadwood CA Images.
Red color=surface material; Depth on Y Axis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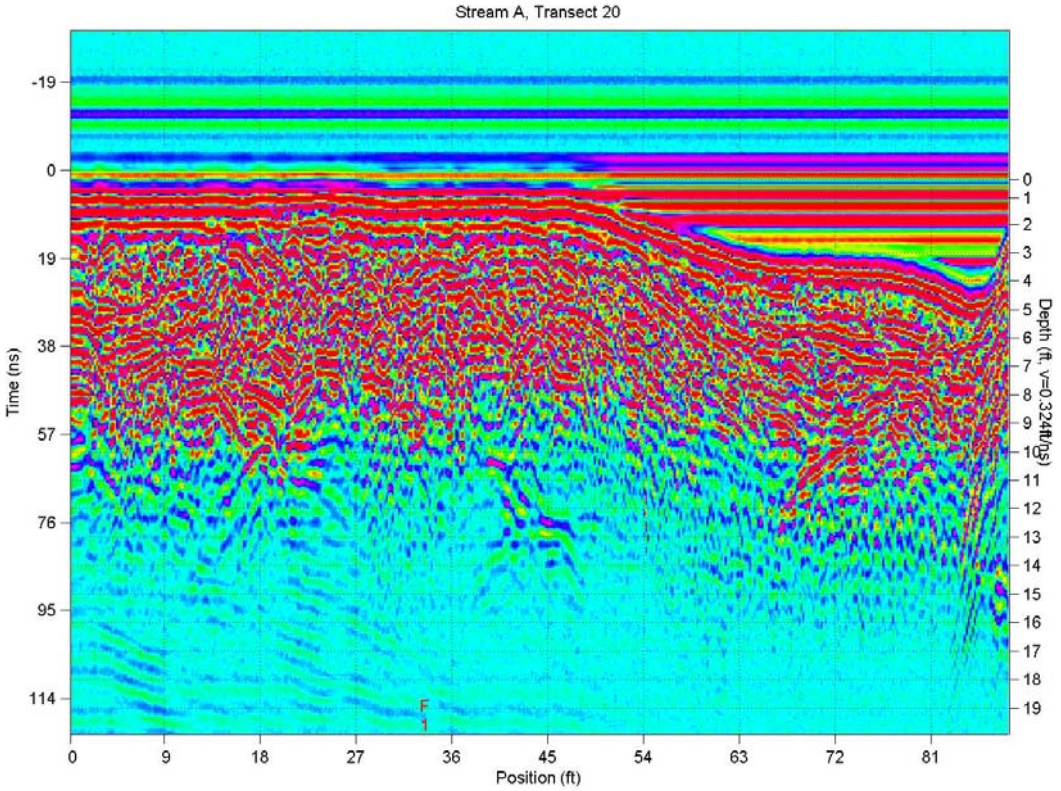
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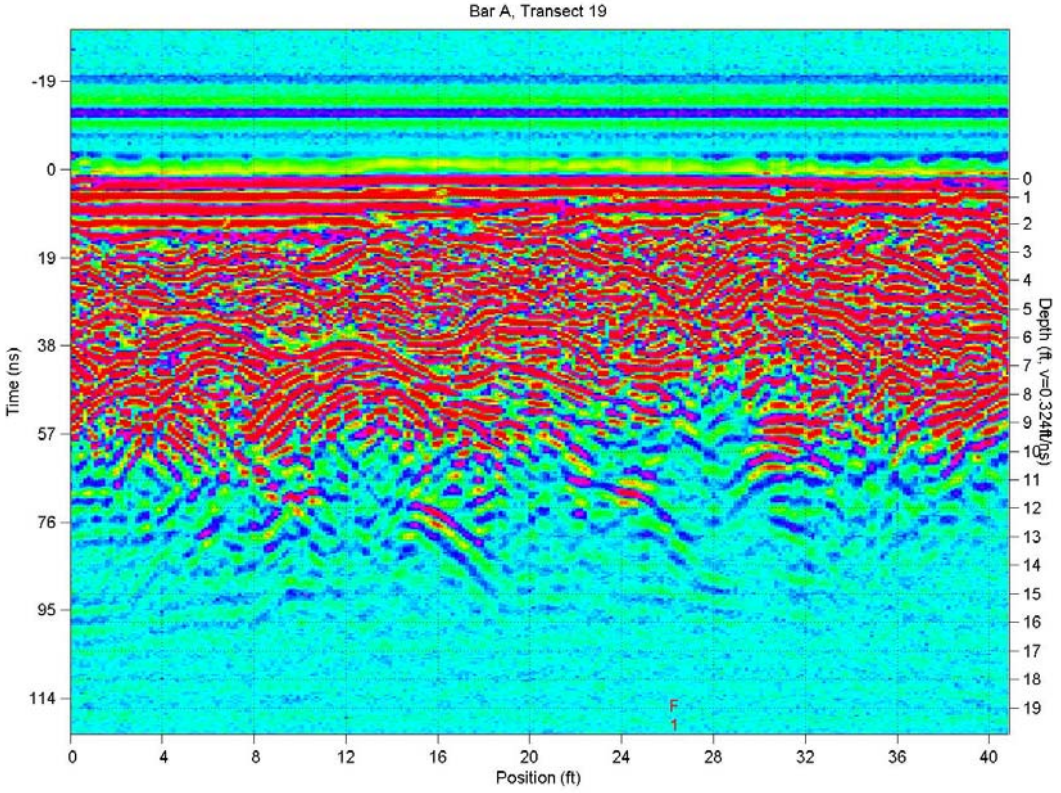
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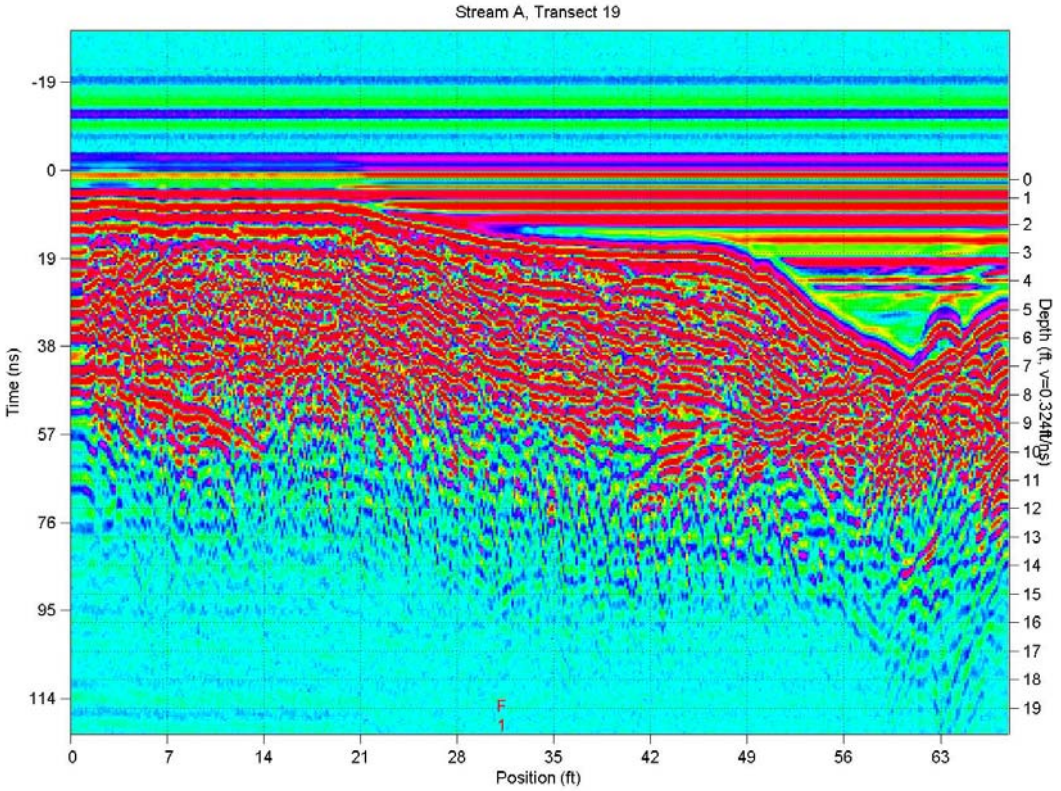
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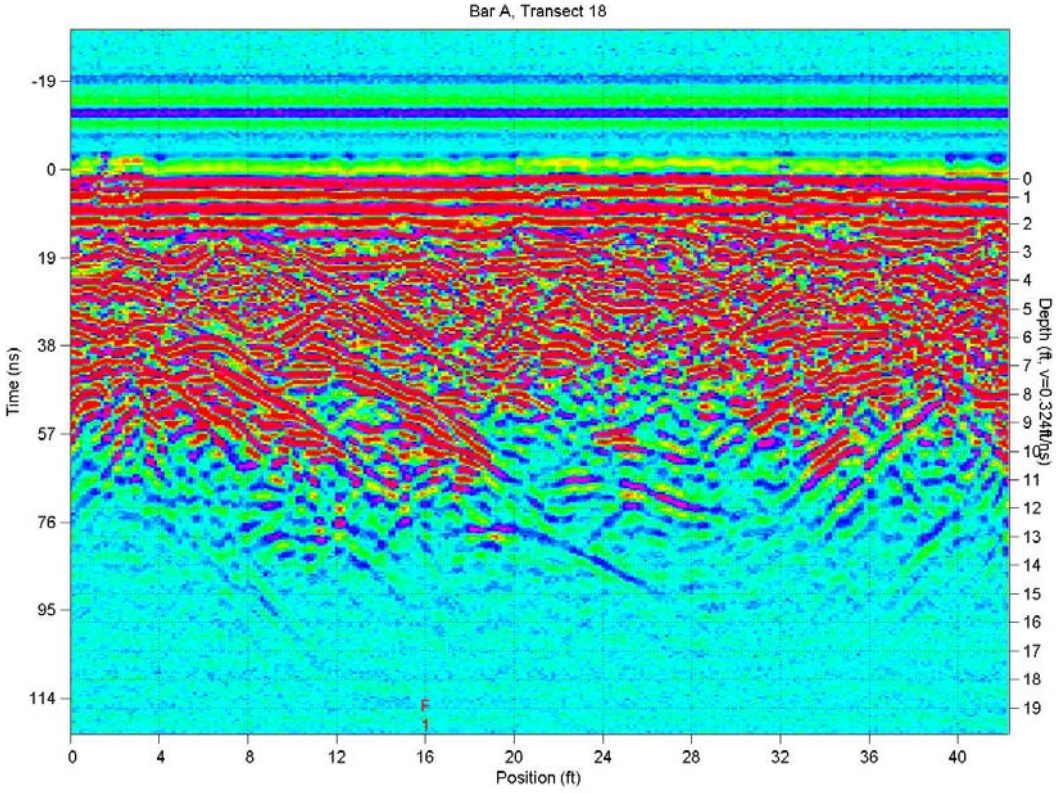
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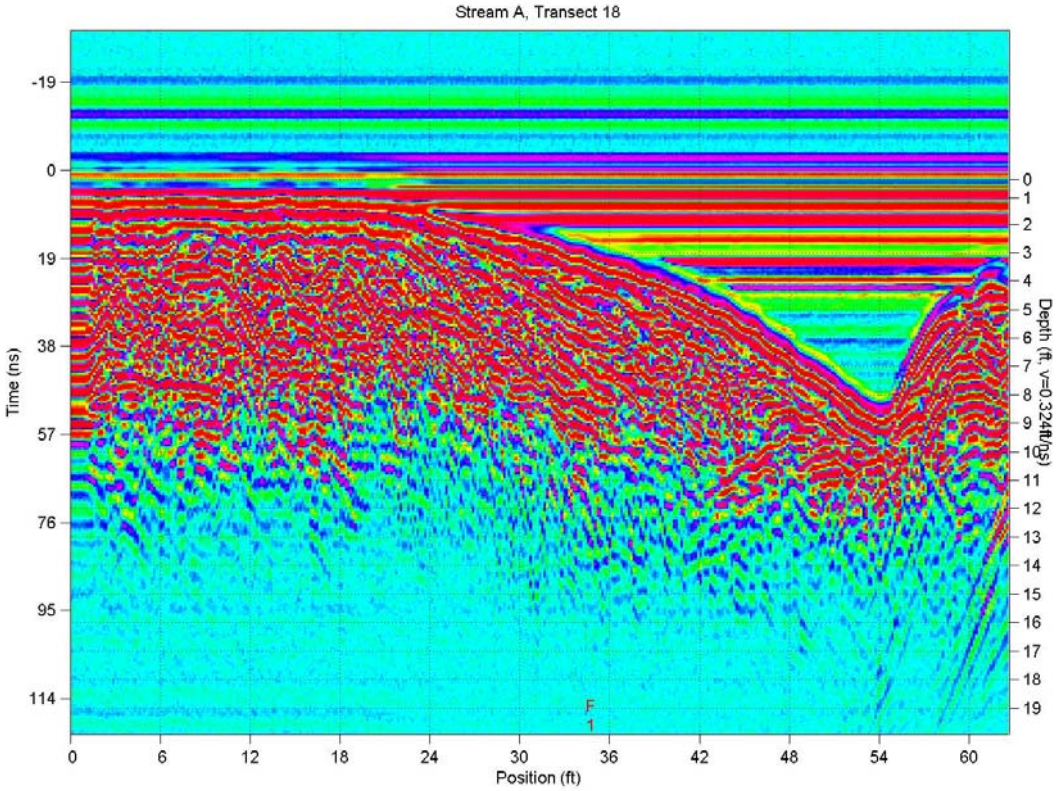
Position (ft)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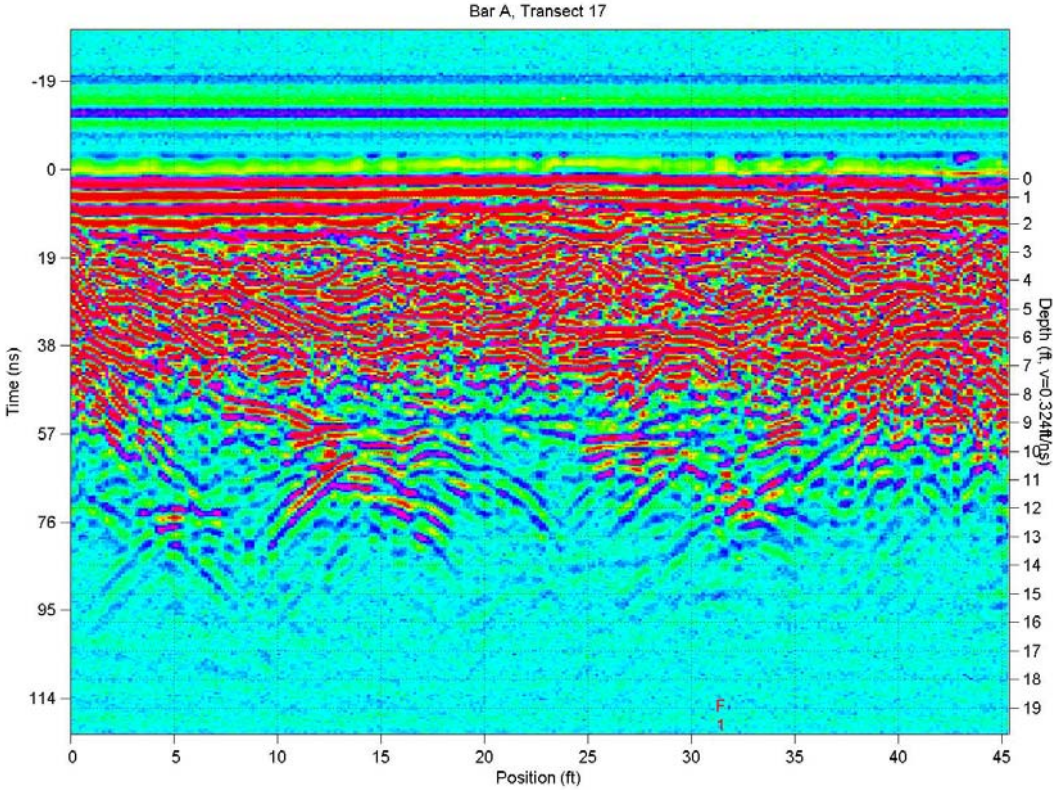
Position (ft)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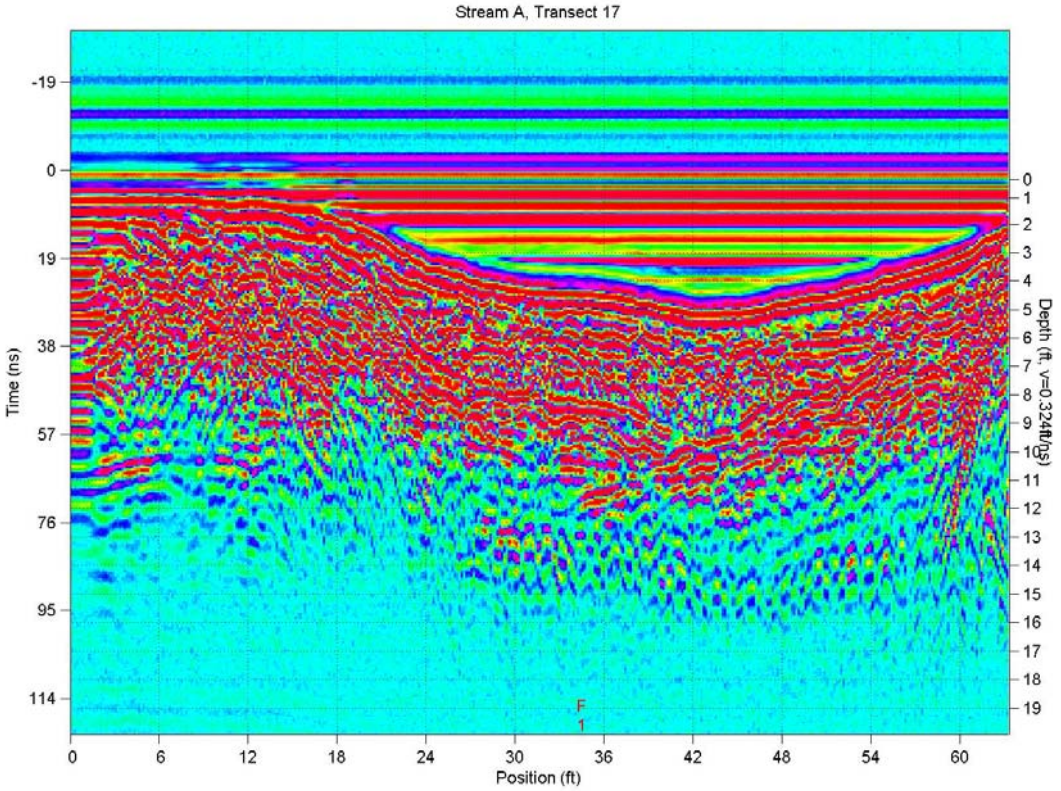
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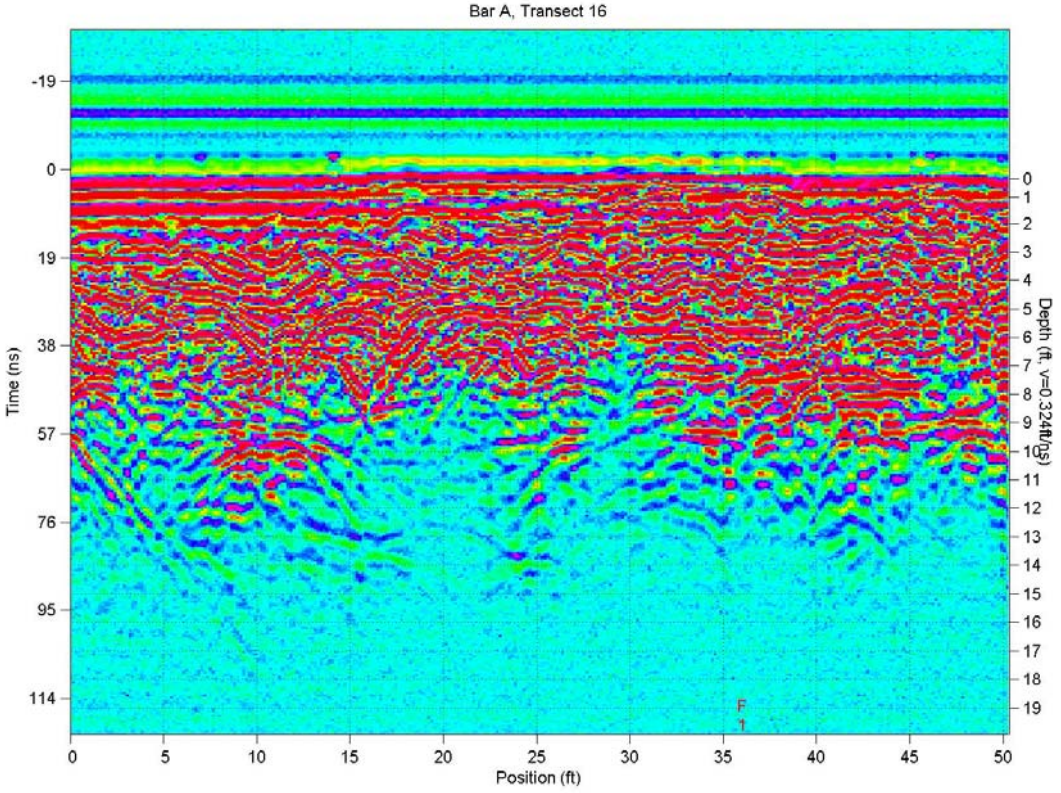
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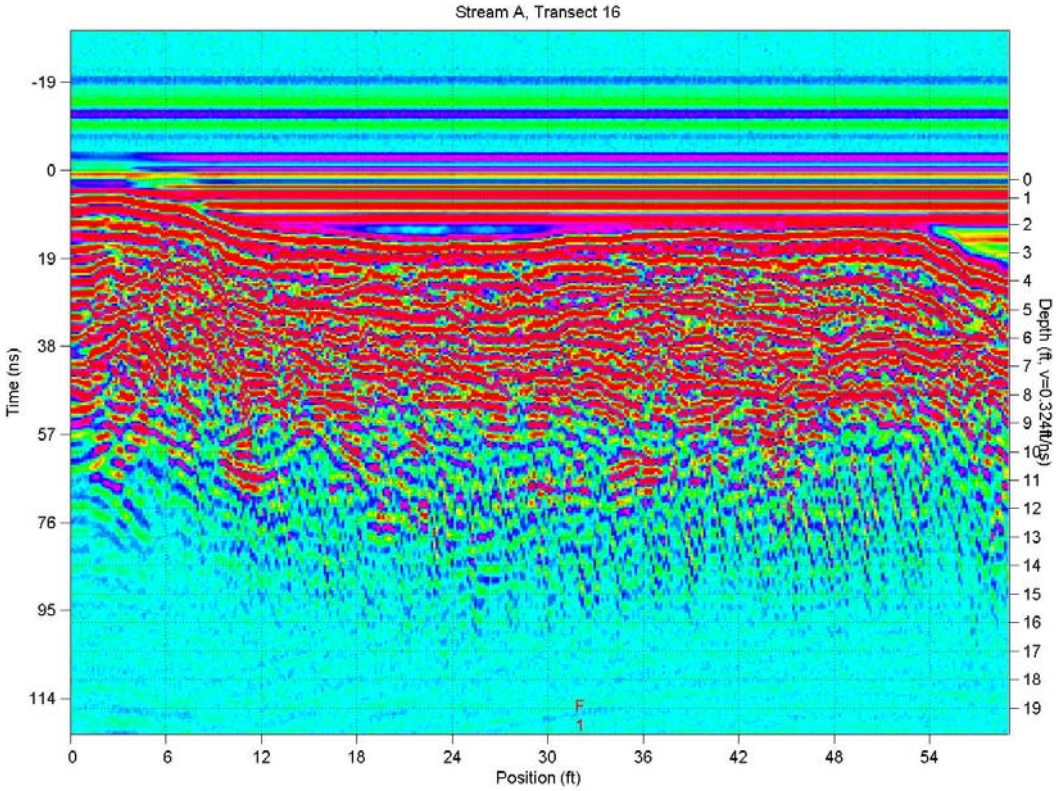
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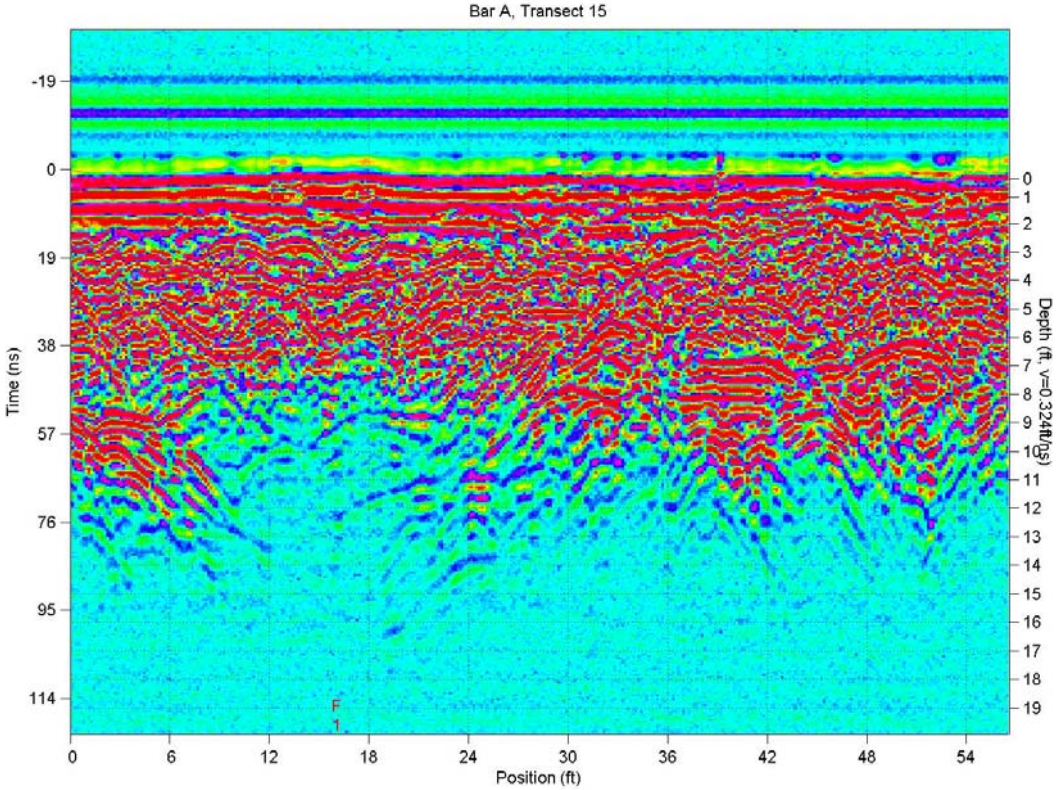
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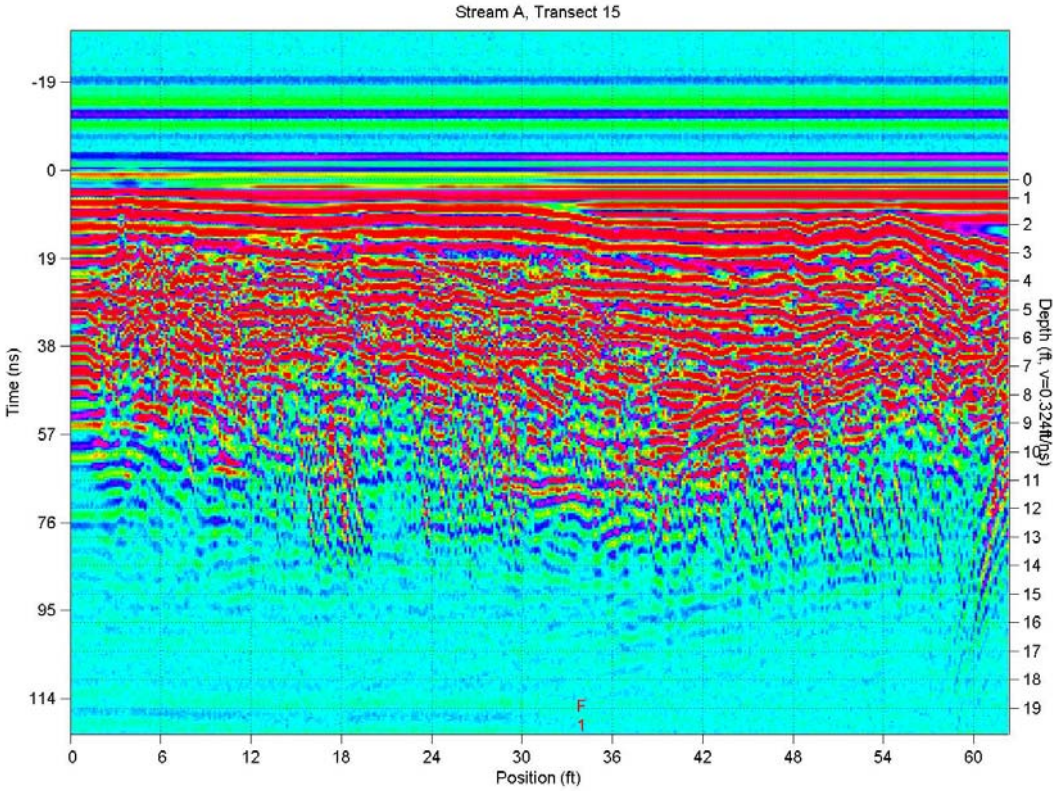
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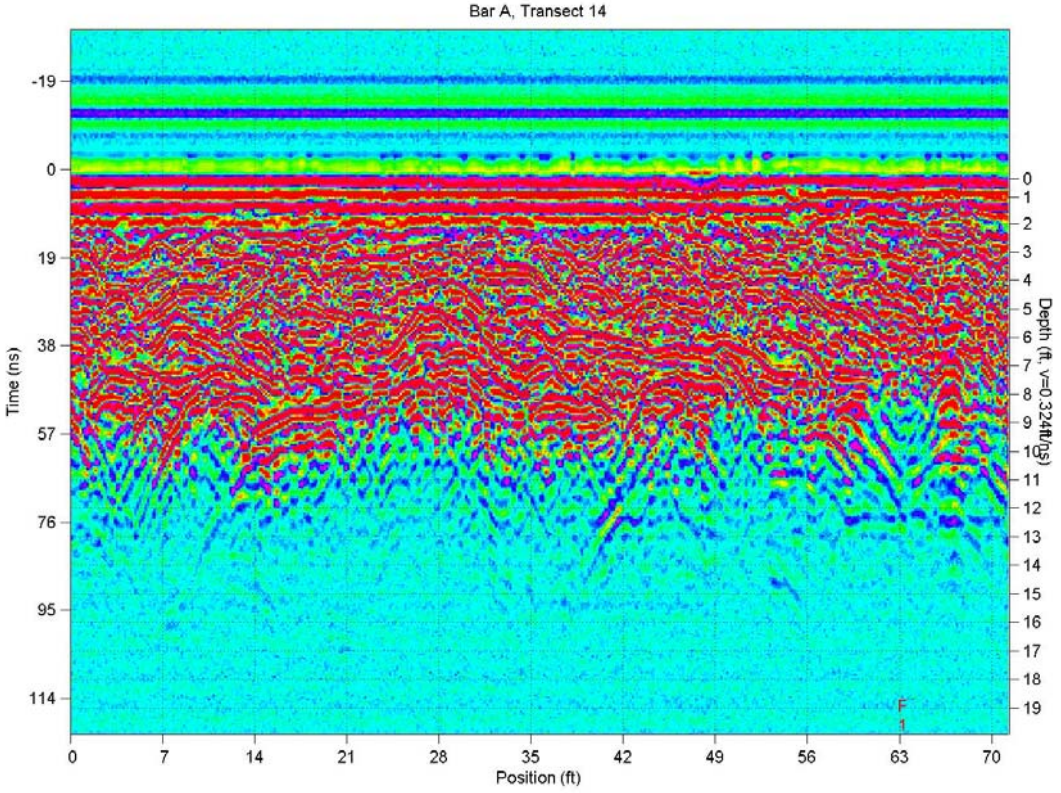
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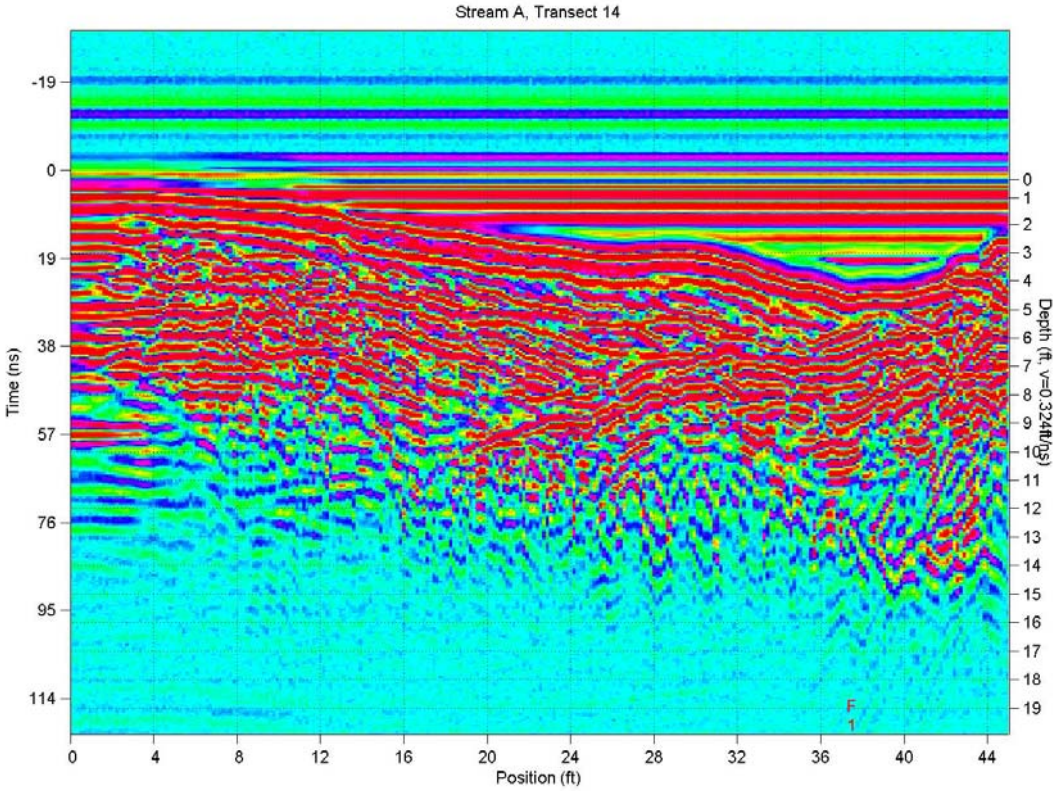
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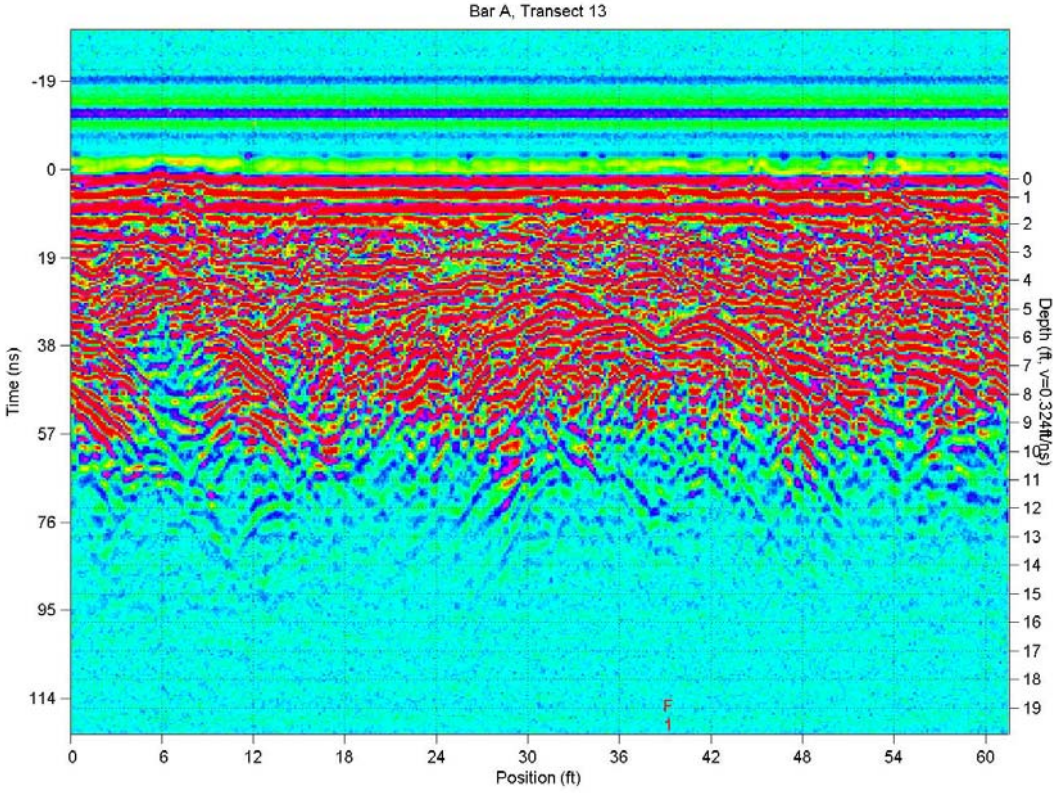
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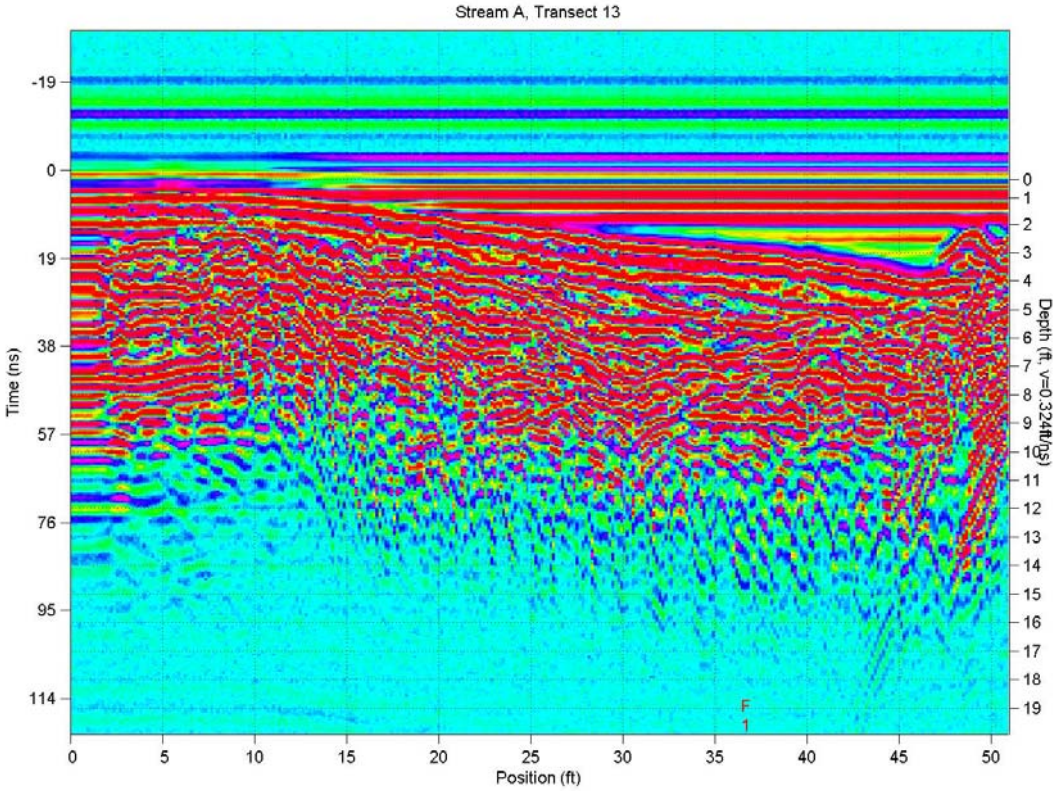
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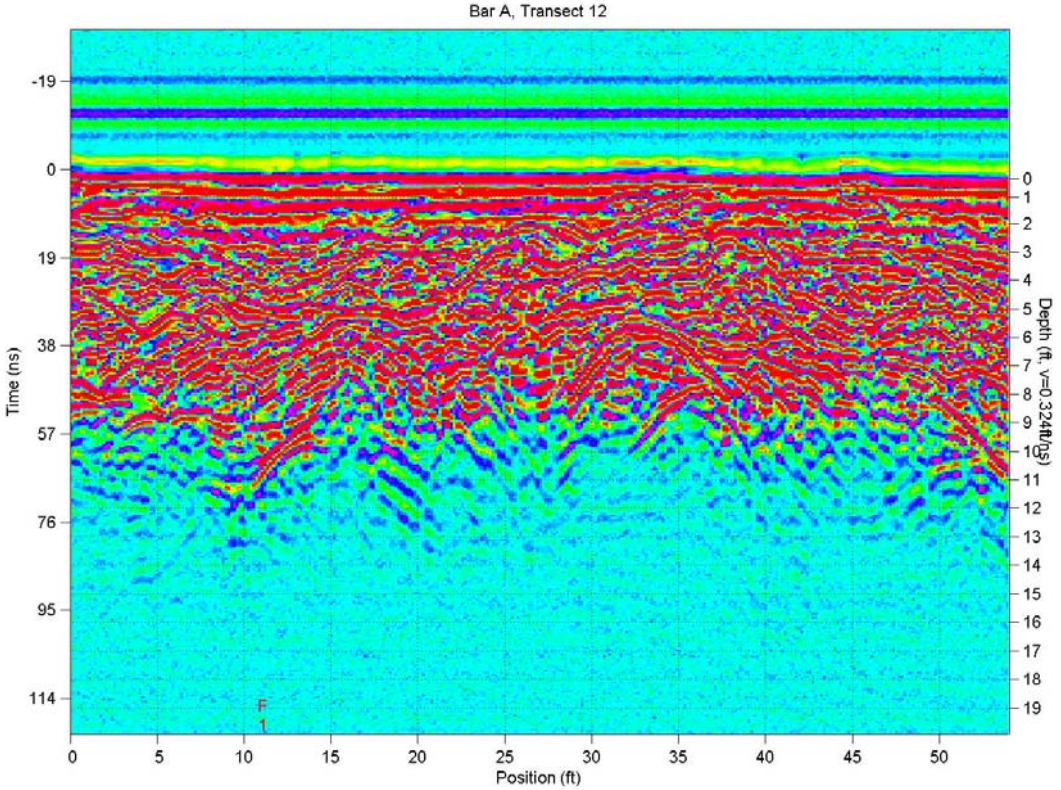
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50
Position (ft)
Depth (ft, v=0.324ft/ns)
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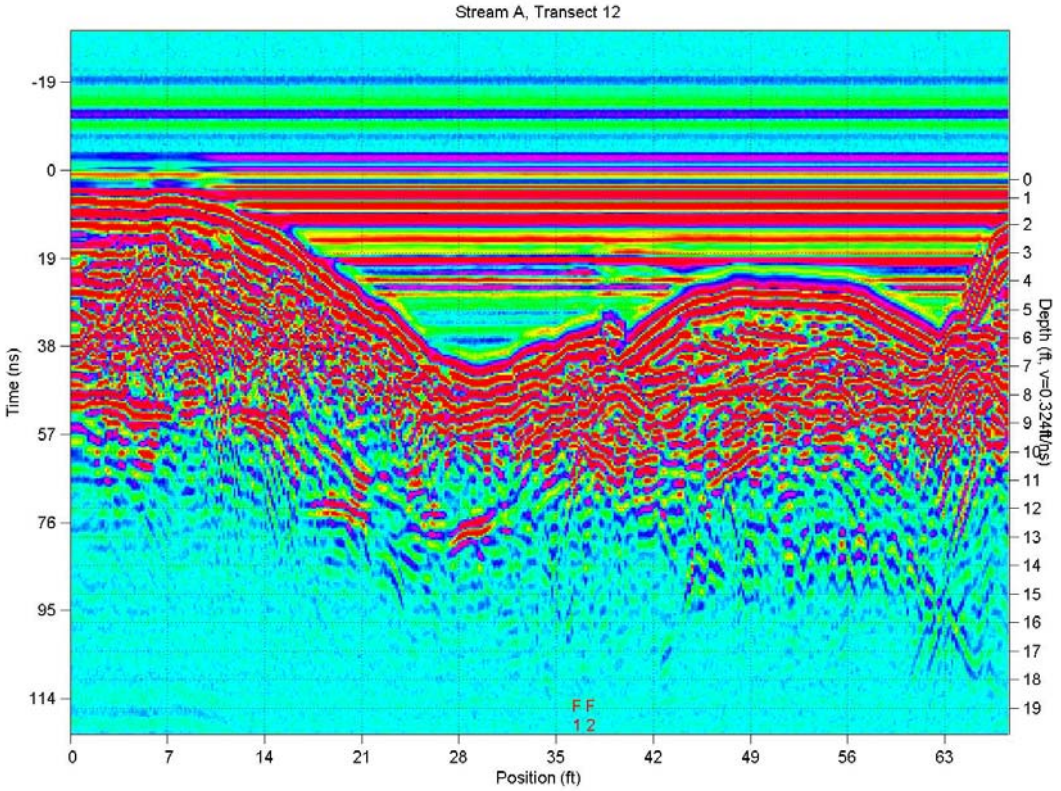
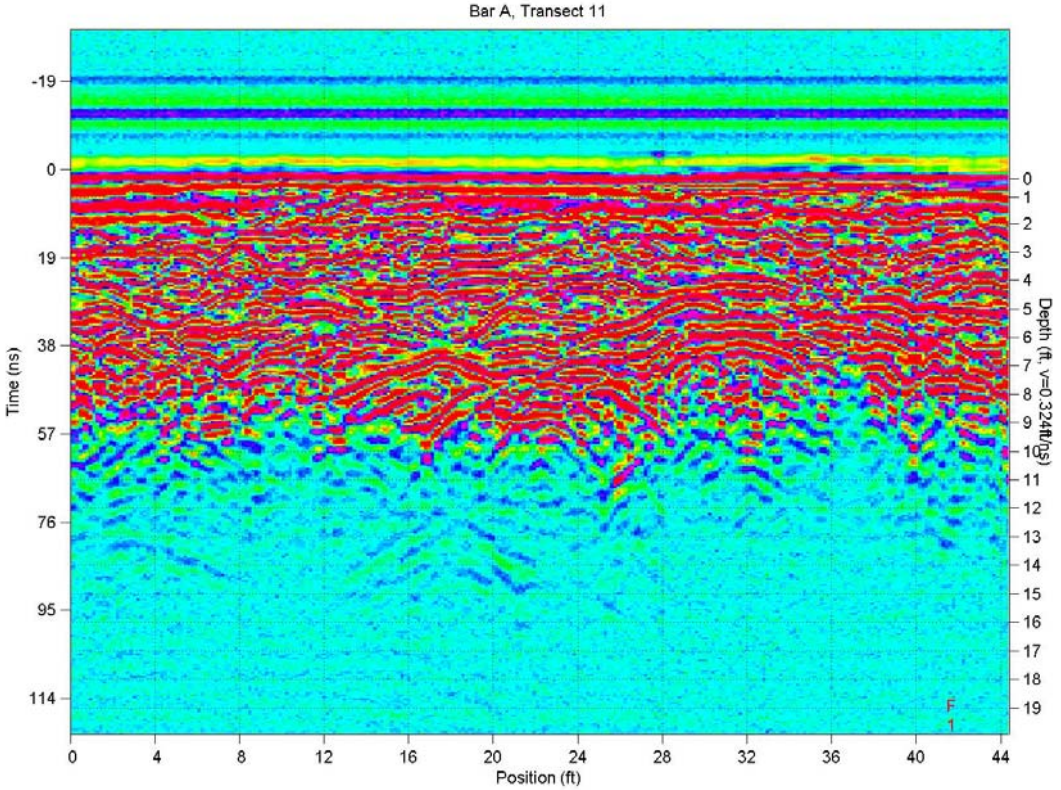
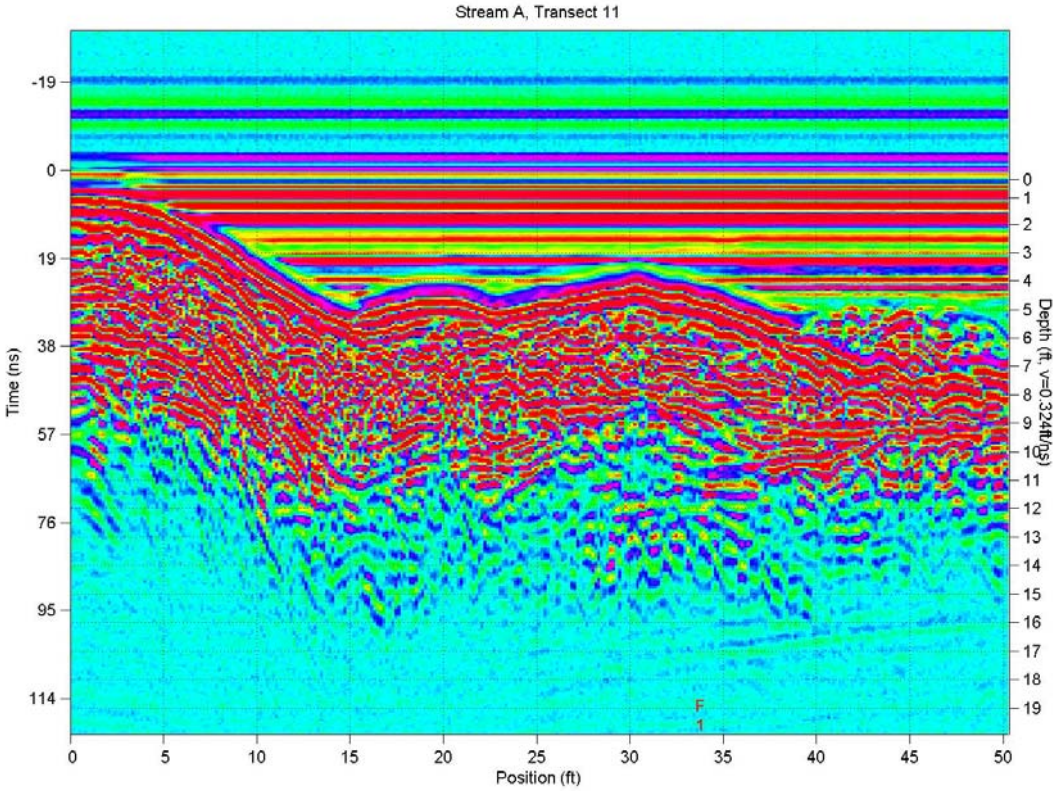
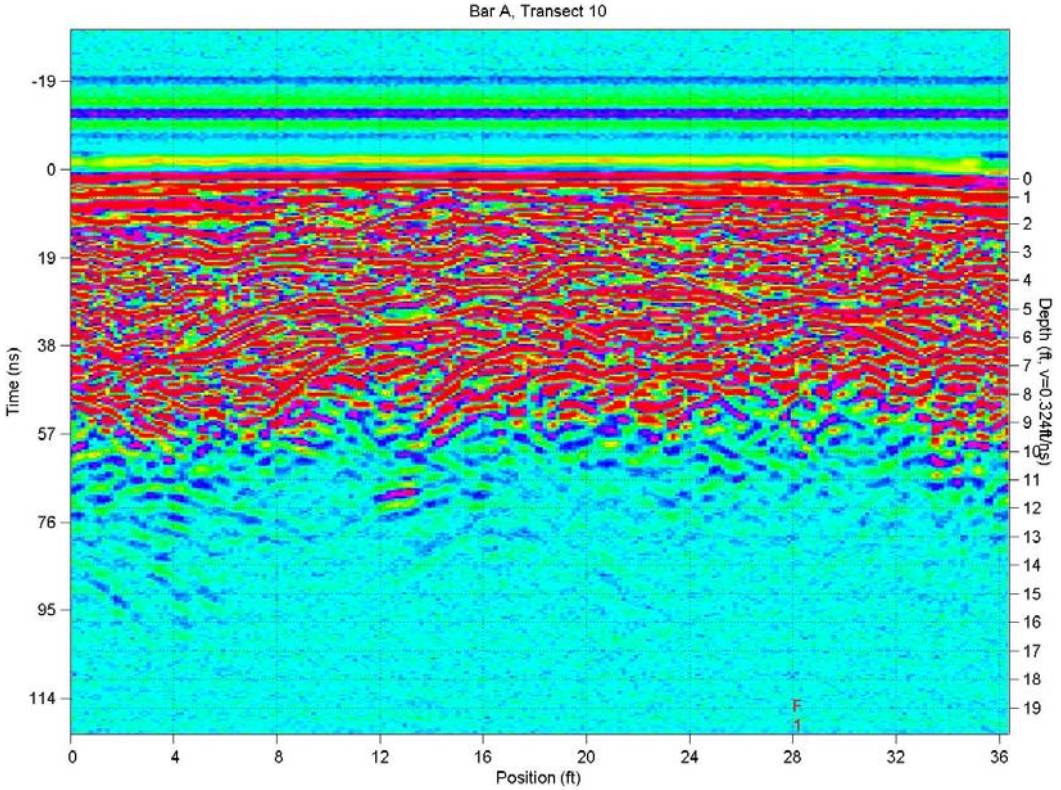
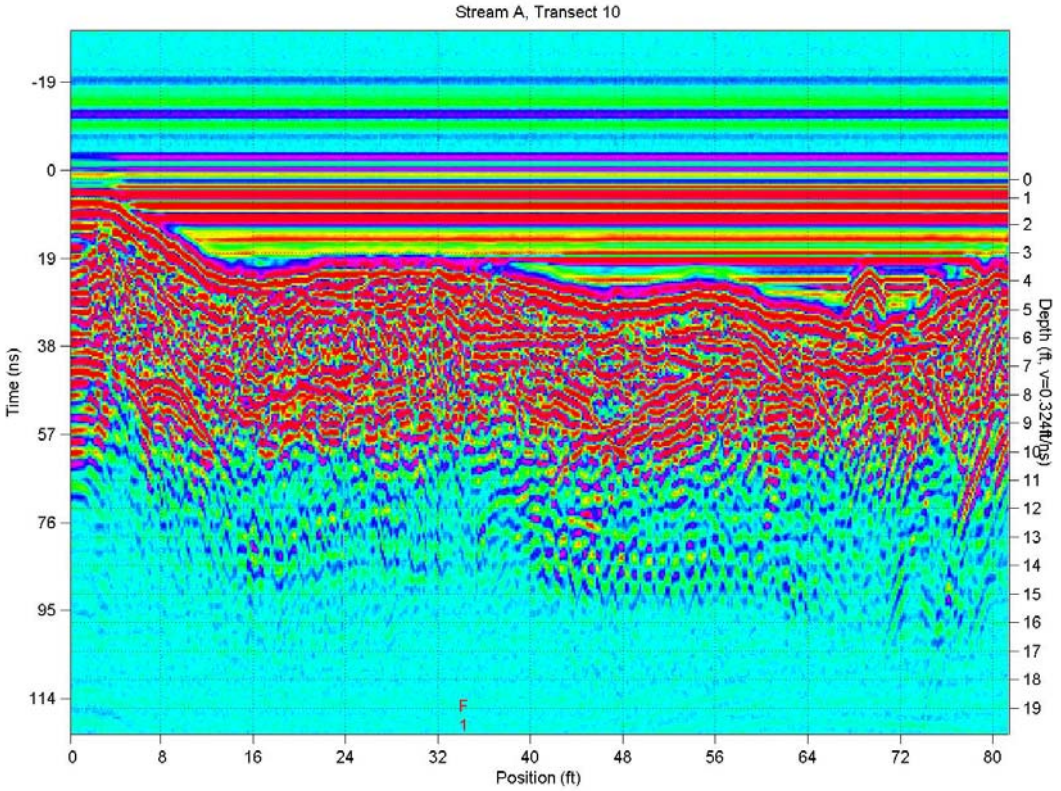
19


Stream A, Transect 12
Time (ns)
-19
0
19
38
57
76
95
114
F F
1 2
0
7
14
21
28
35
42
49
56
63
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar A, Transect 11
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
40
44
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Stream A, Transect 11
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
5
10
15
20
25
30
35
40
45
50
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Bar A, Transect 10
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Stream A, Transect 10
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
8
16
24
32
40
48
56
64
72
80
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
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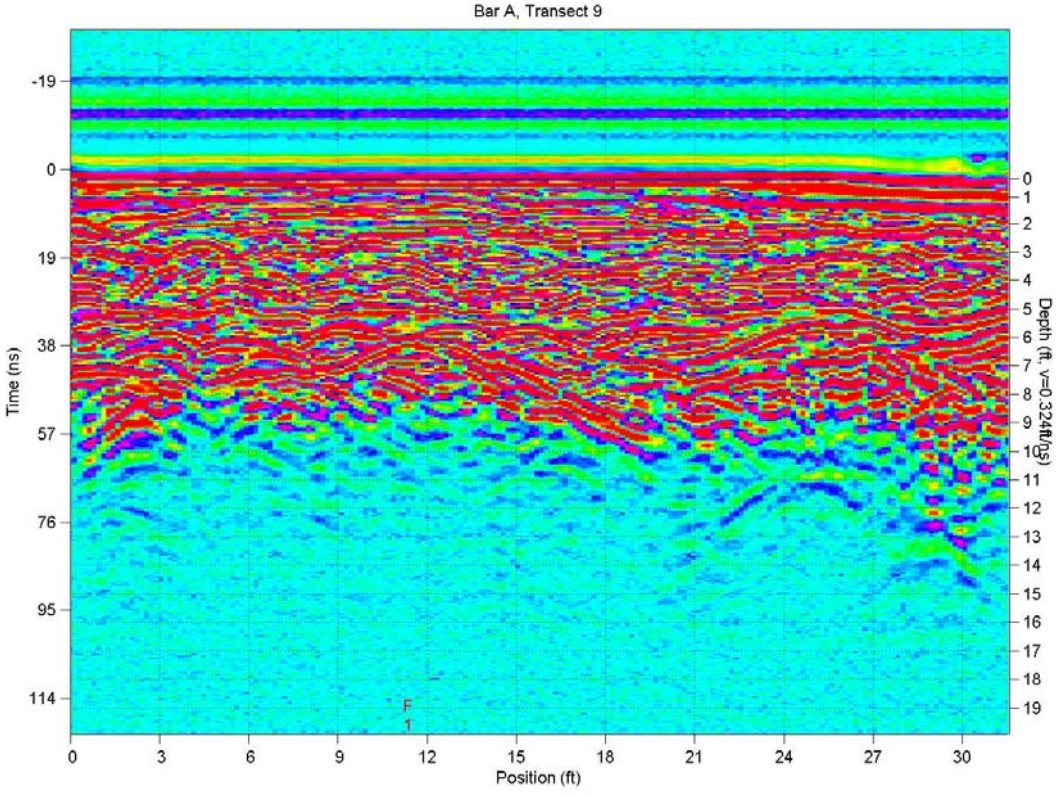
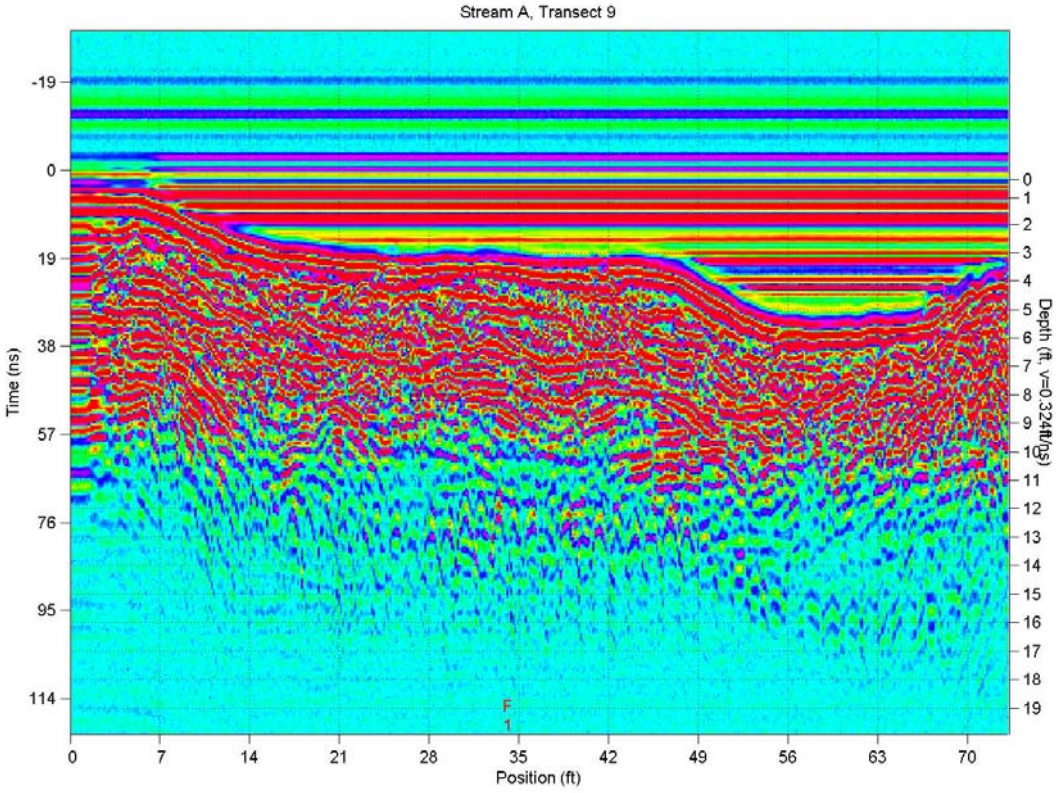
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Bar A, Transect 9
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
3
6
9
12
15
18
21
24
27
30
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Stream A, Transect 9
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
7
14
21
28
35
42
49
56
63
70
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
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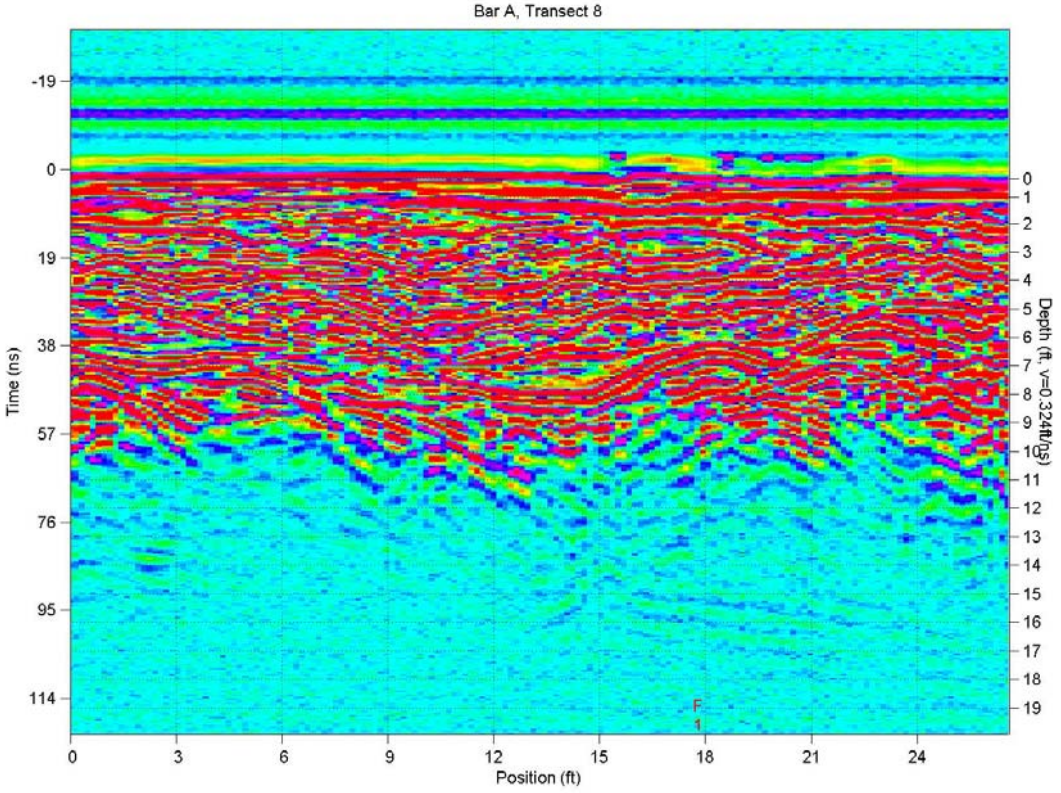
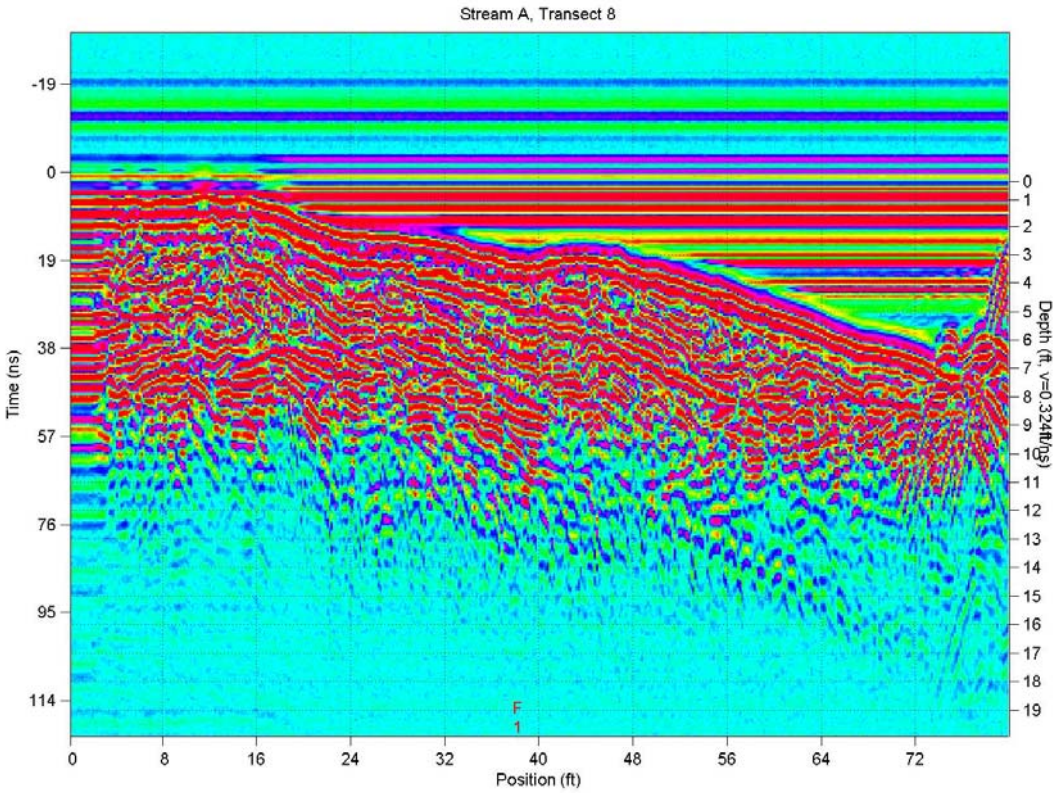
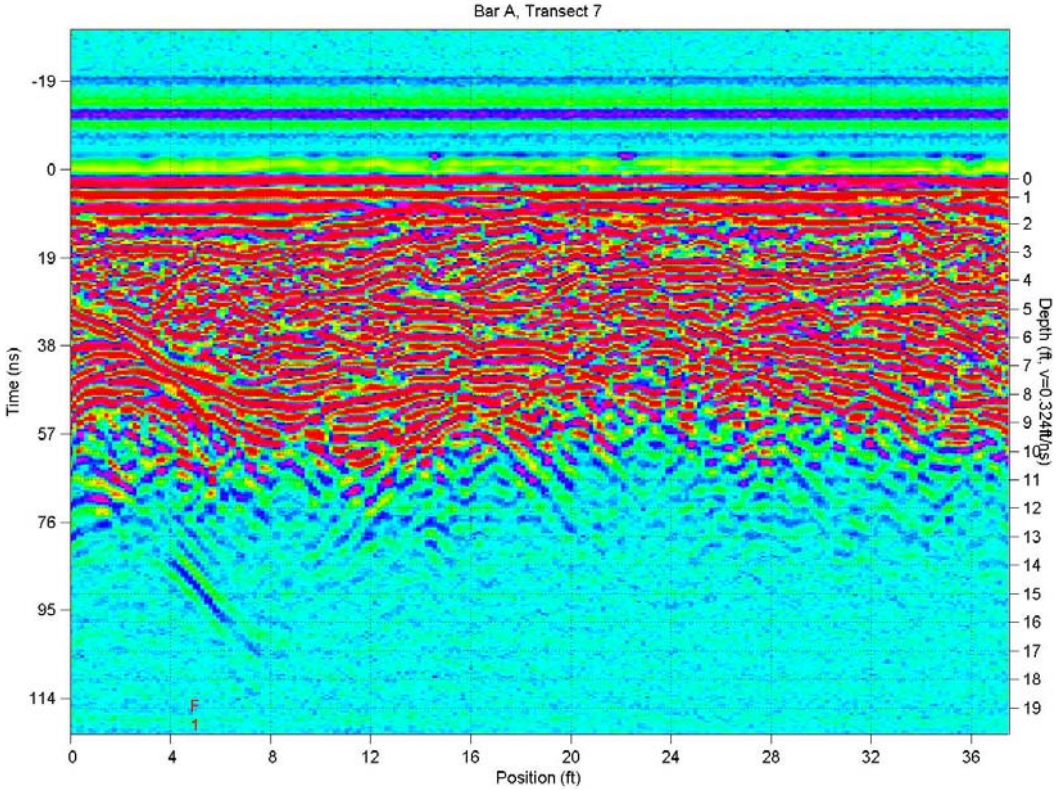
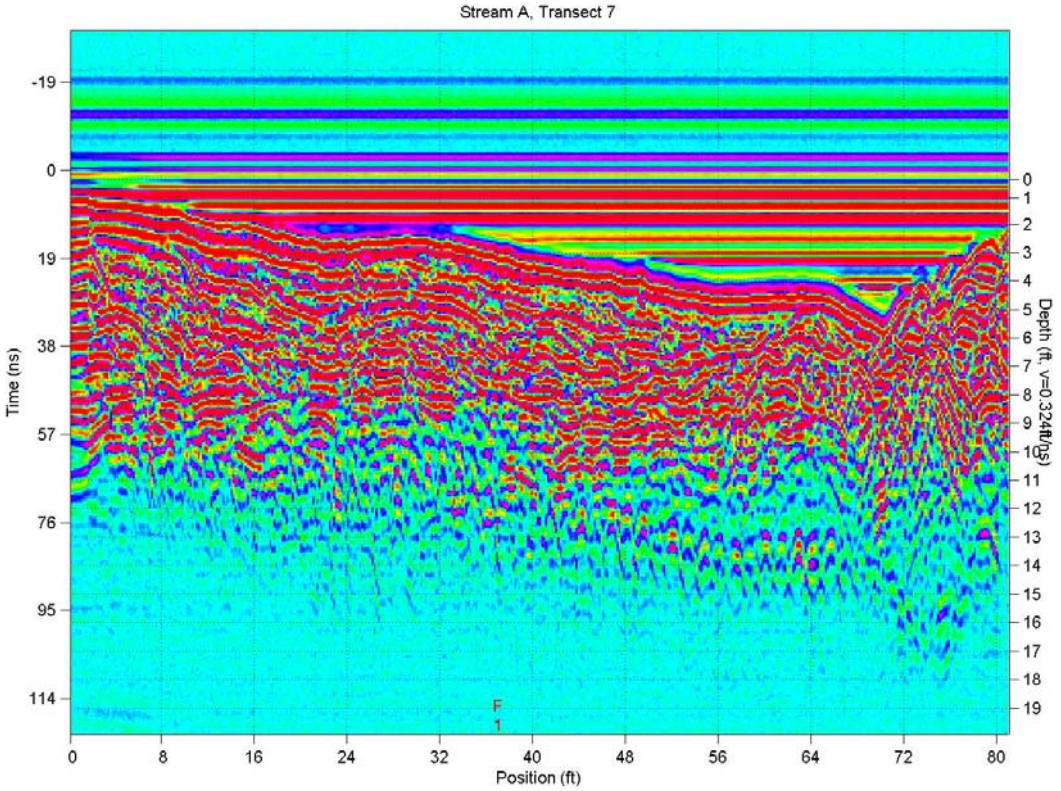
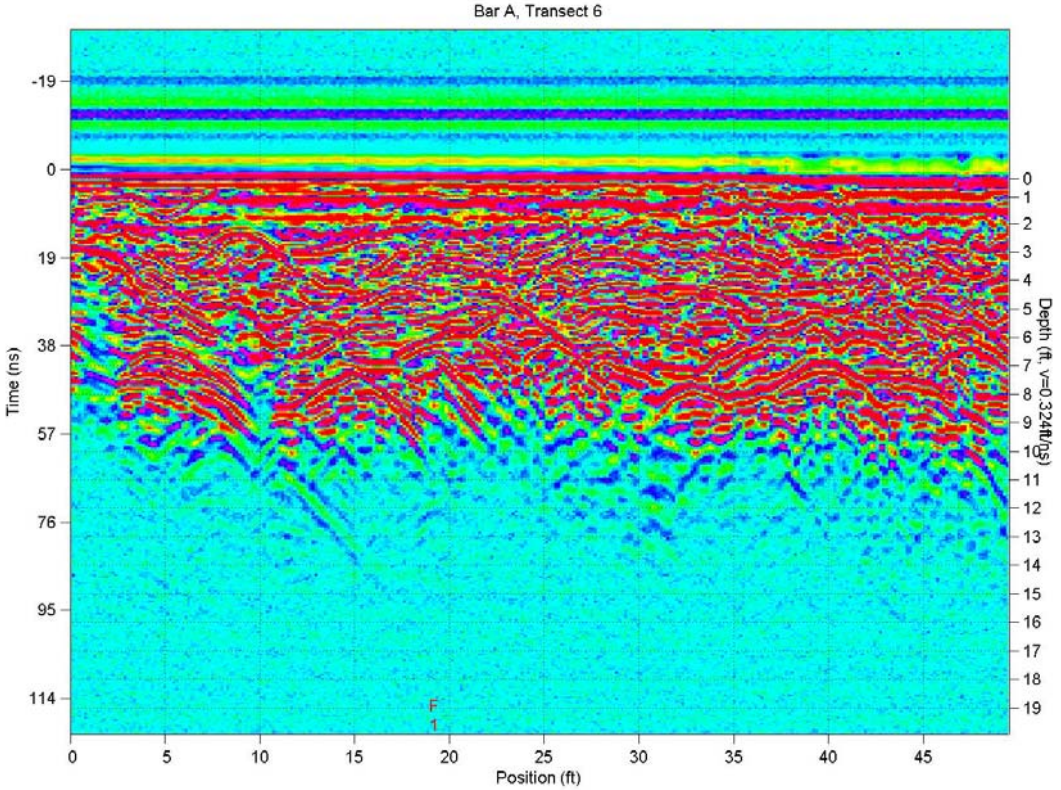
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1

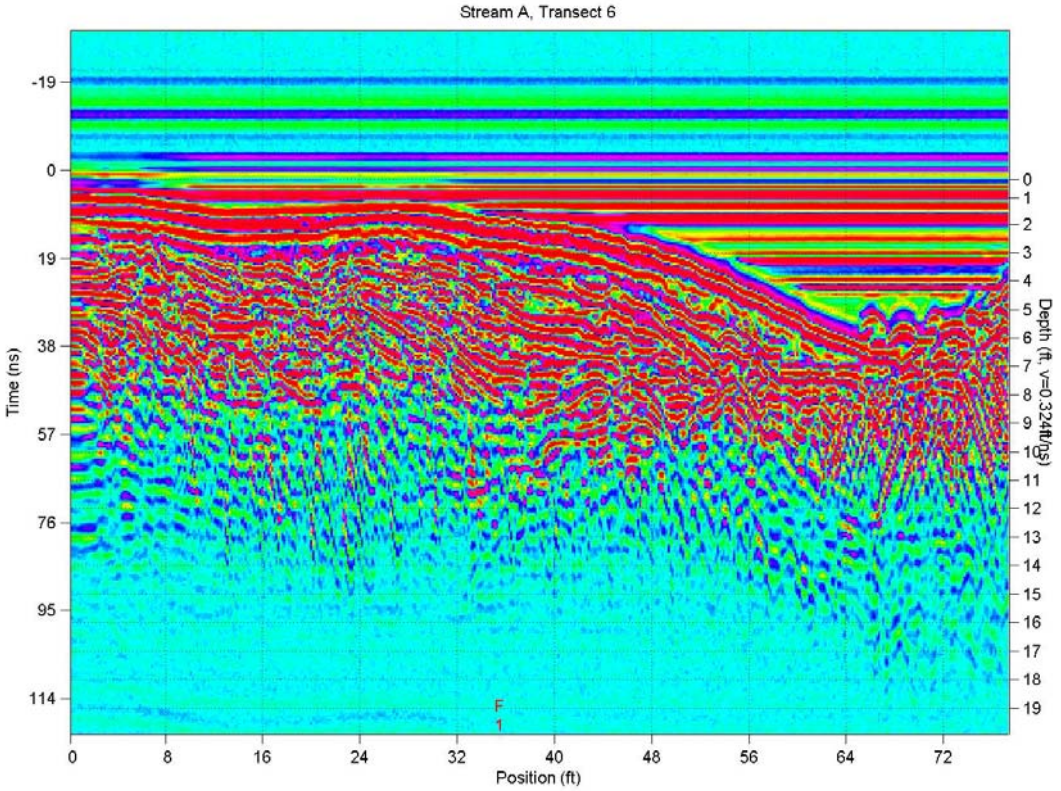

Bar A, Transect 8
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1
0
3
6
9
12
15
18
21
24
Position (ft)

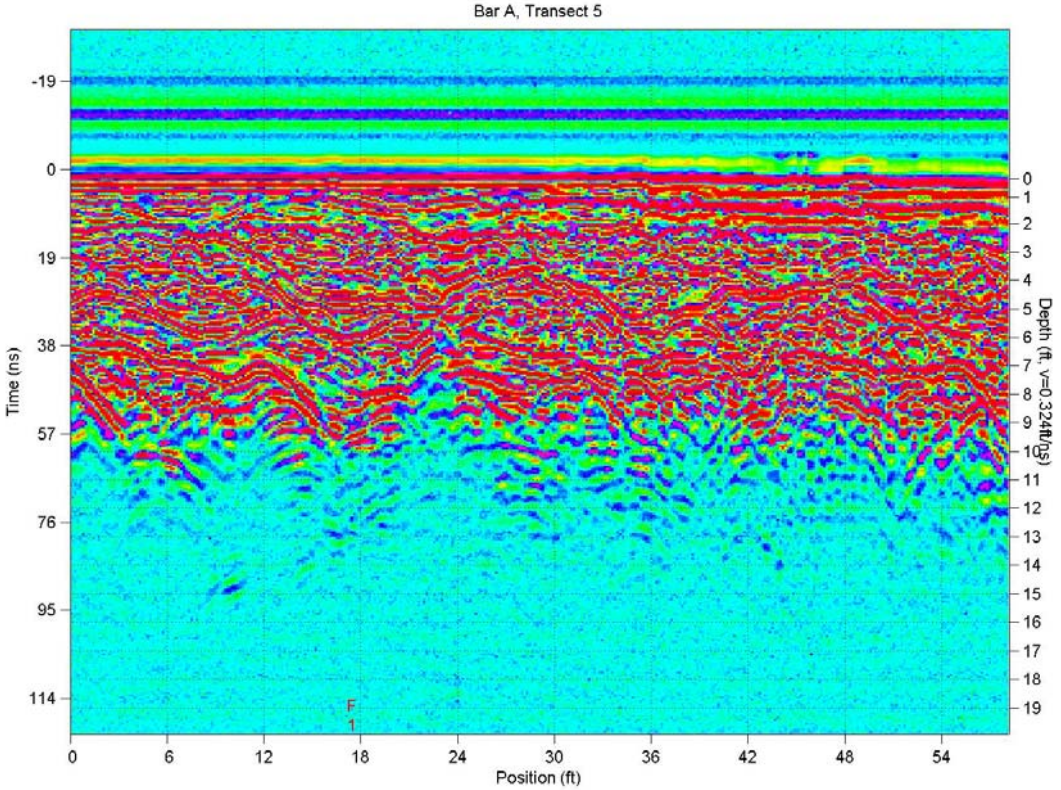

Stream A, Transect 8
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1
0
8
16
24
32
40
48
56
64
72
Position (ft)

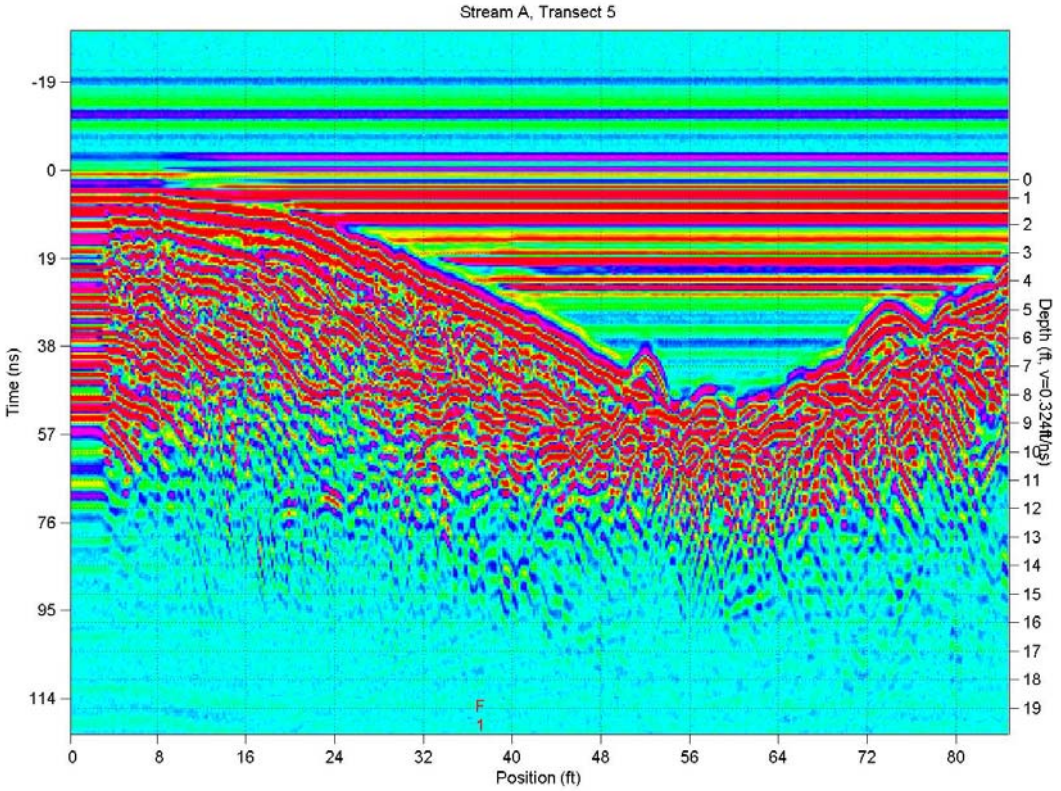

Bar A, Transect 7
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
4
8
12
16
20
24
28
32
36
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

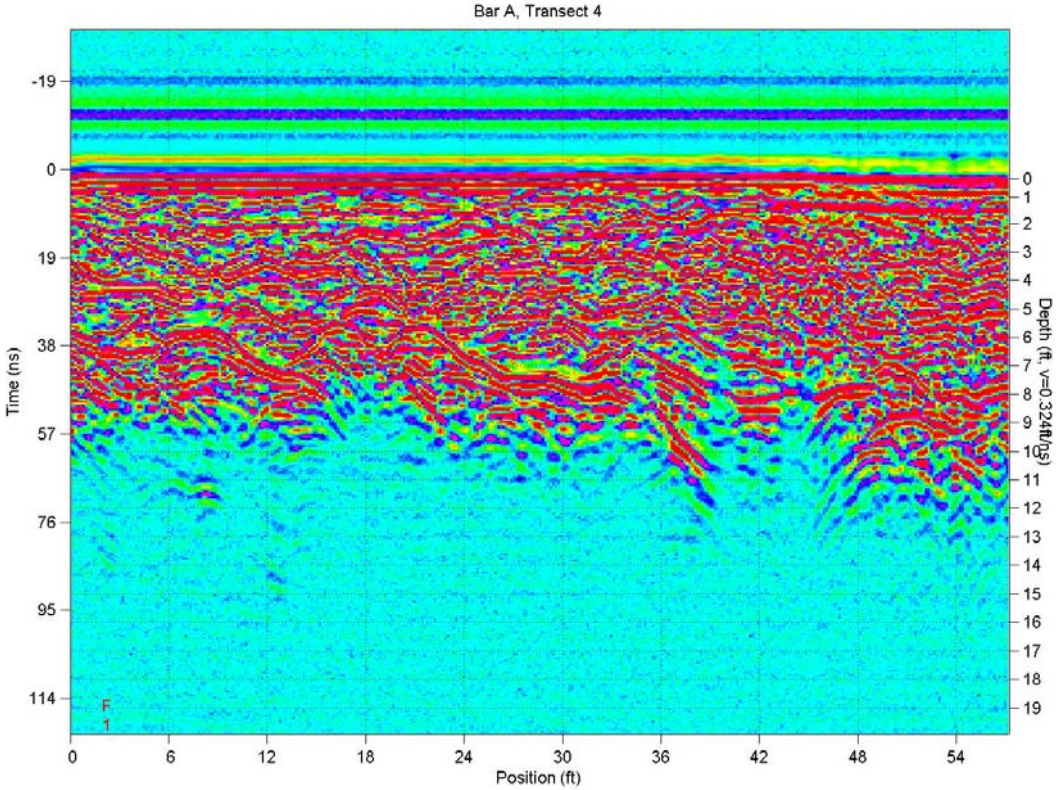

Stream A, Transect 7
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
8
16
24
32
40
48
56
64
72
80
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

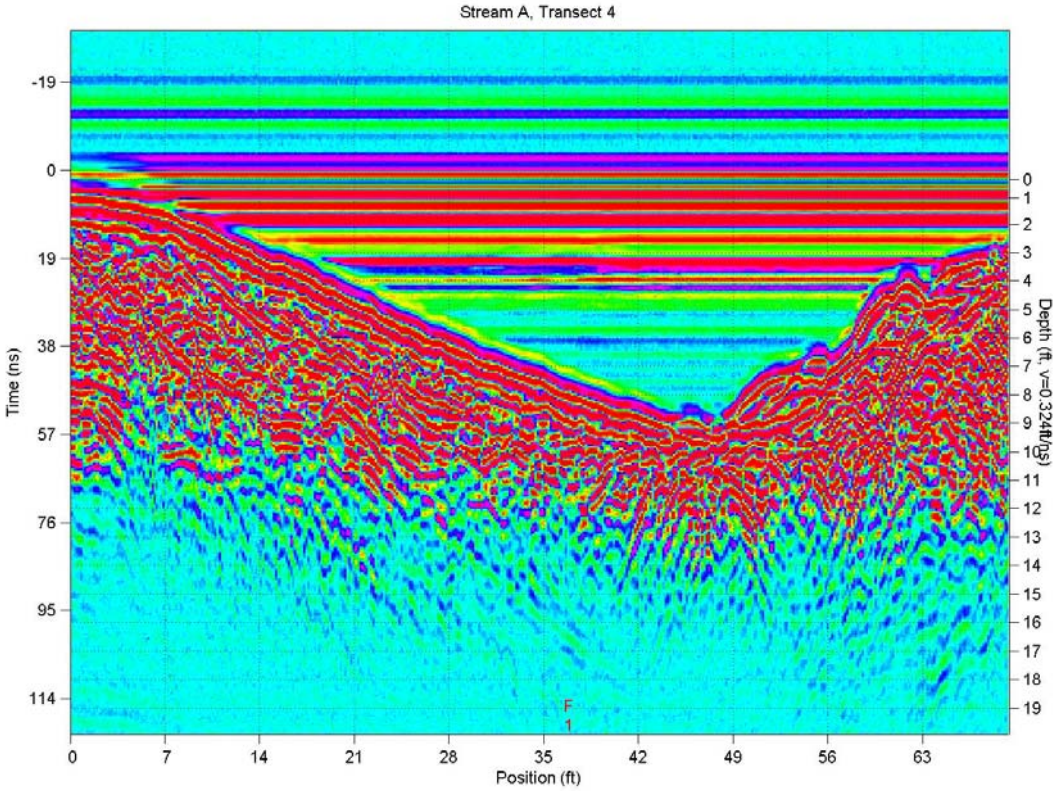

Bar A, Transect 6
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
5
10
15
20
25
30
35
40
45
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

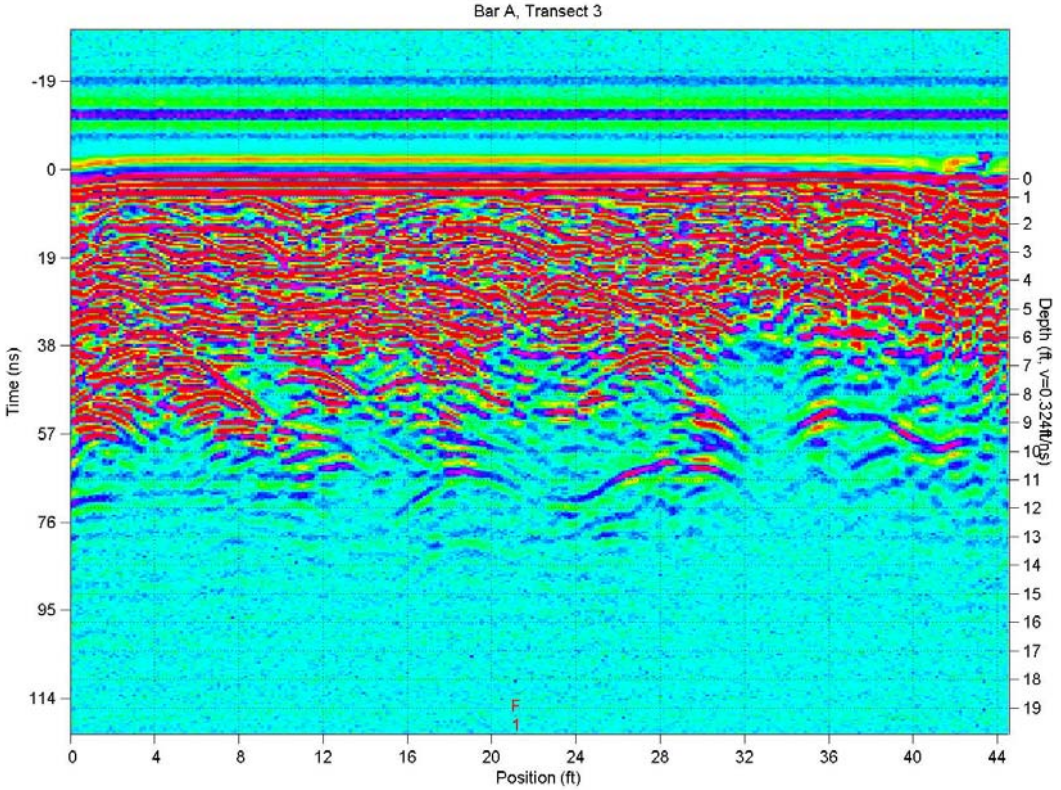

Stream A, Transect 6
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
8
16
24
32
40
48
56
64
72
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

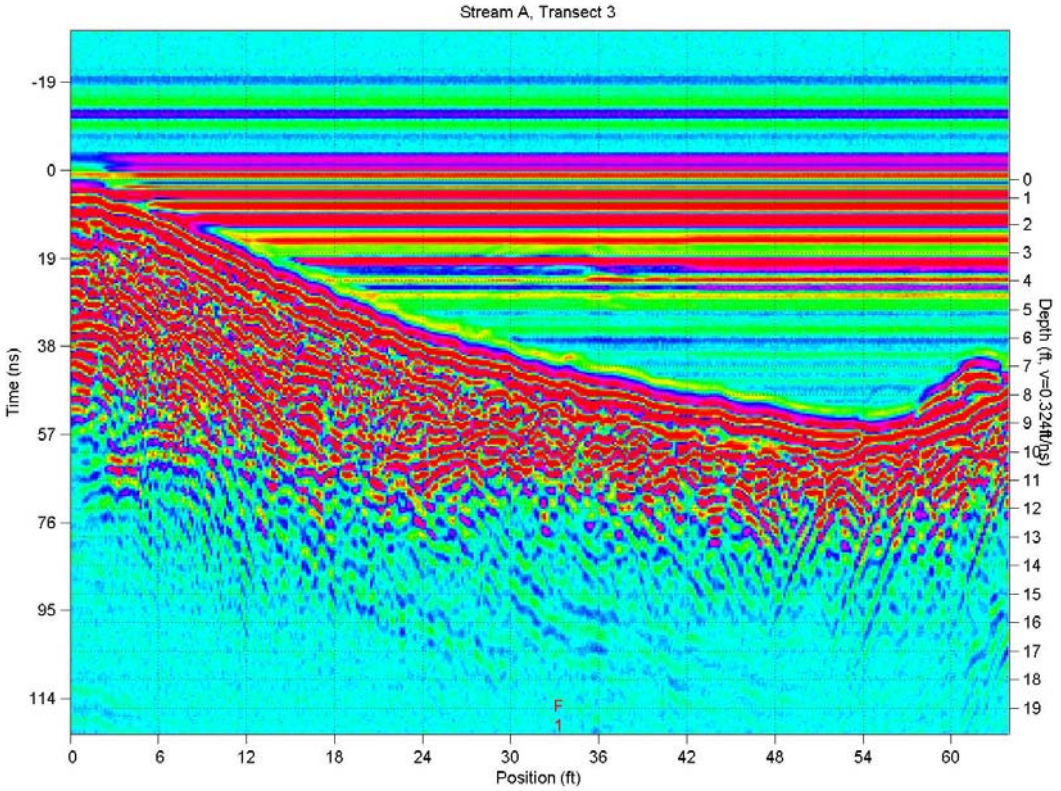

Bar A, Transect 5
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
6
12
18
24
30
36
42
48
54
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

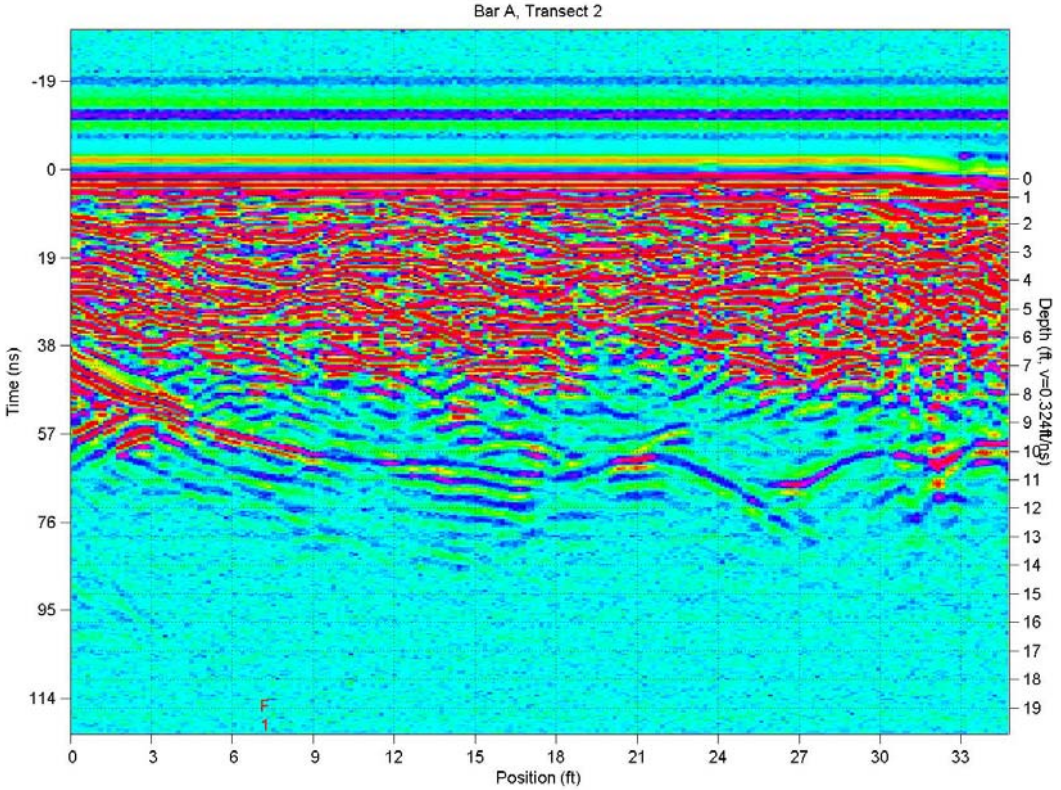

Stream A, Transect 5
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
8
16
24
32
40
48
56
64
72
80
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

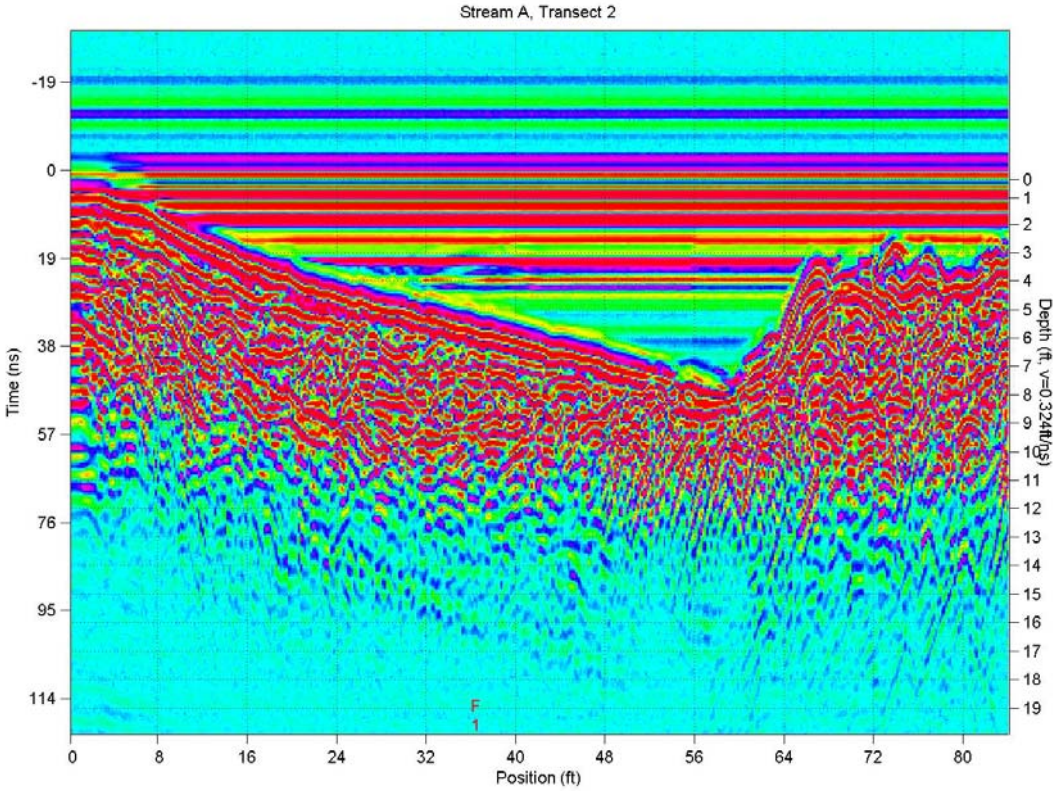

Bar A, Transect 4
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
6
12
18
24
30
36
42
48
54
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

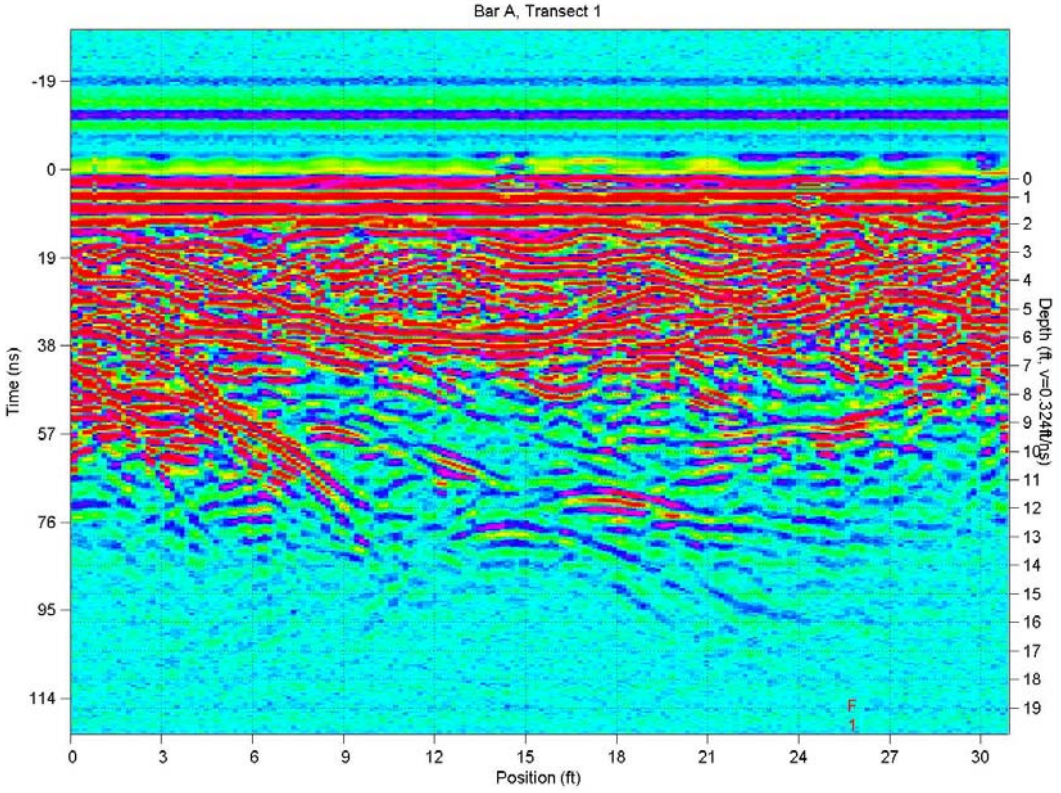

Stream A, Transect 4
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
7
14
21
28
35
42
49
56
63
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

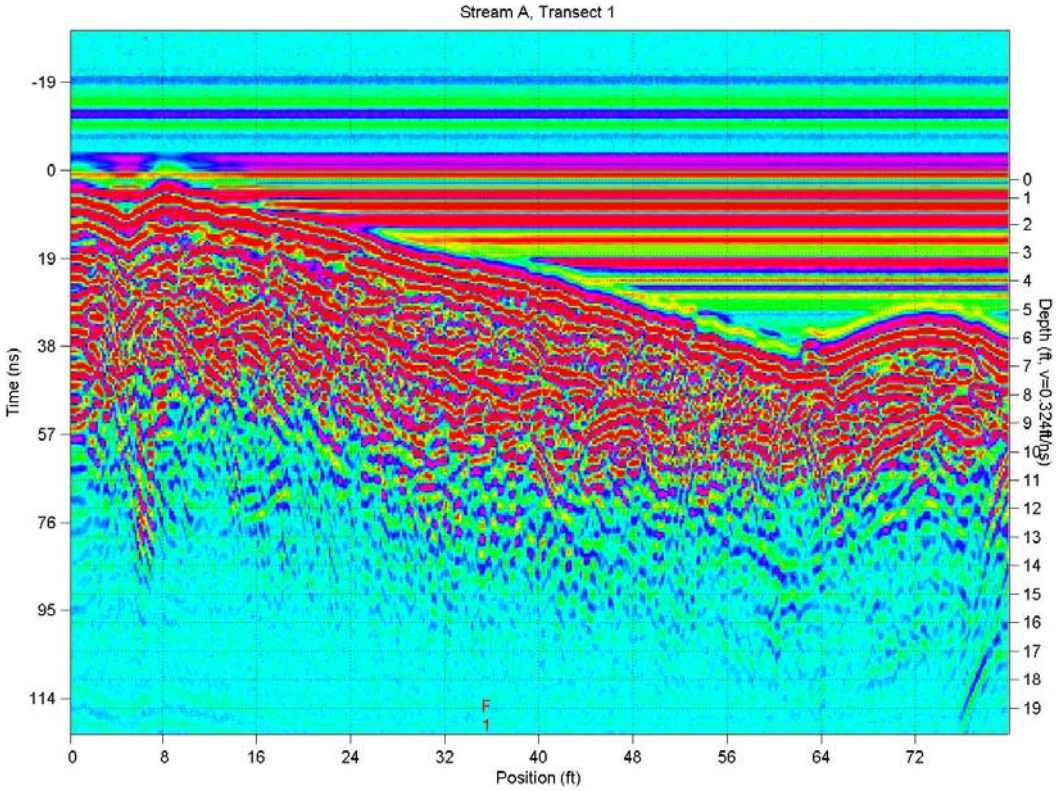

Bar A, Transect 3
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
40
44
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1

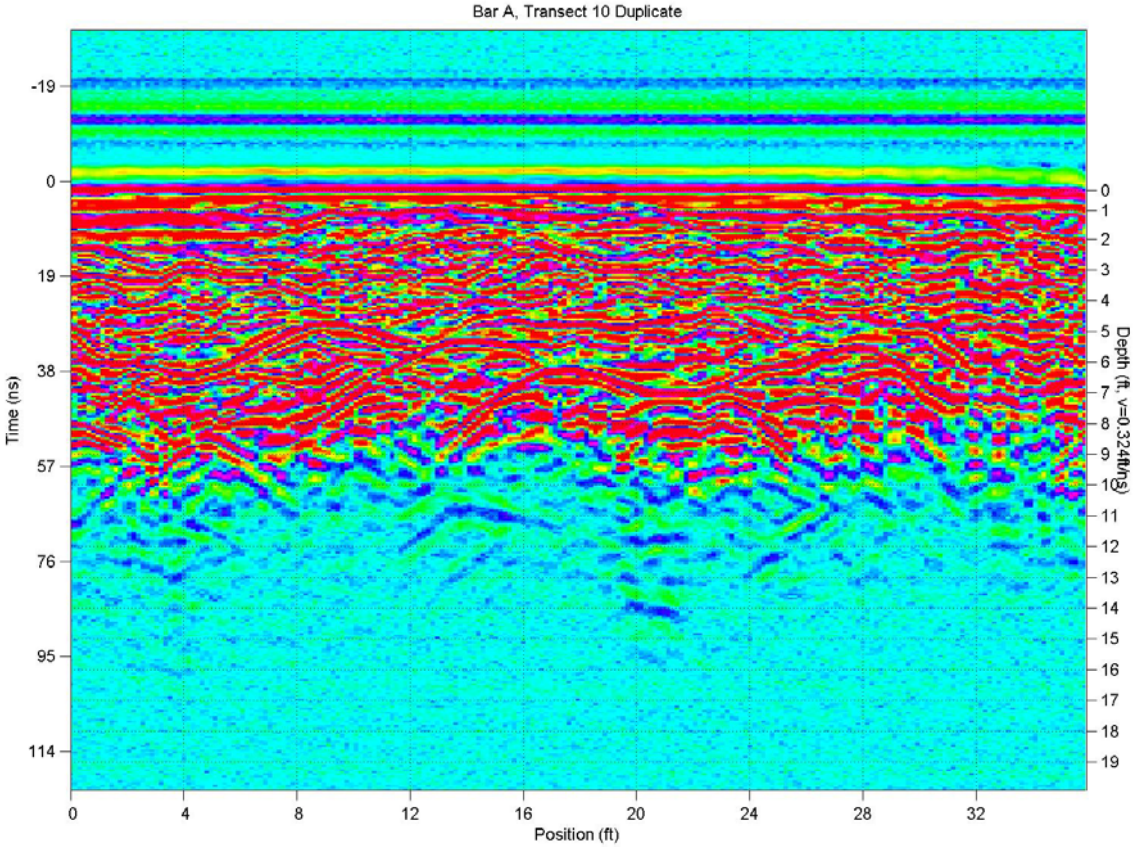

Stream A, Transect 3
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
6
12
18
24
30
36
42
48
54
60
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1

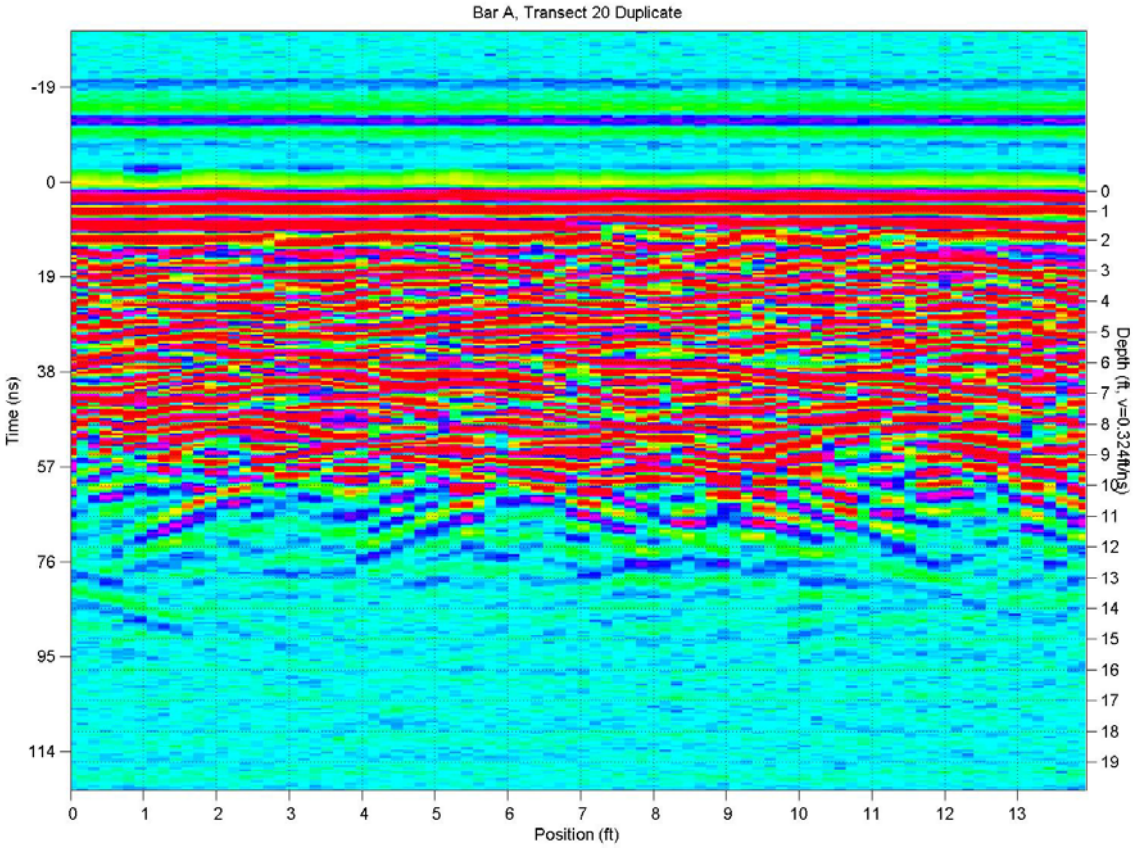

Bar A, Transect 2
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
3
6
9
12
15
18
21
24
27
30
33
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

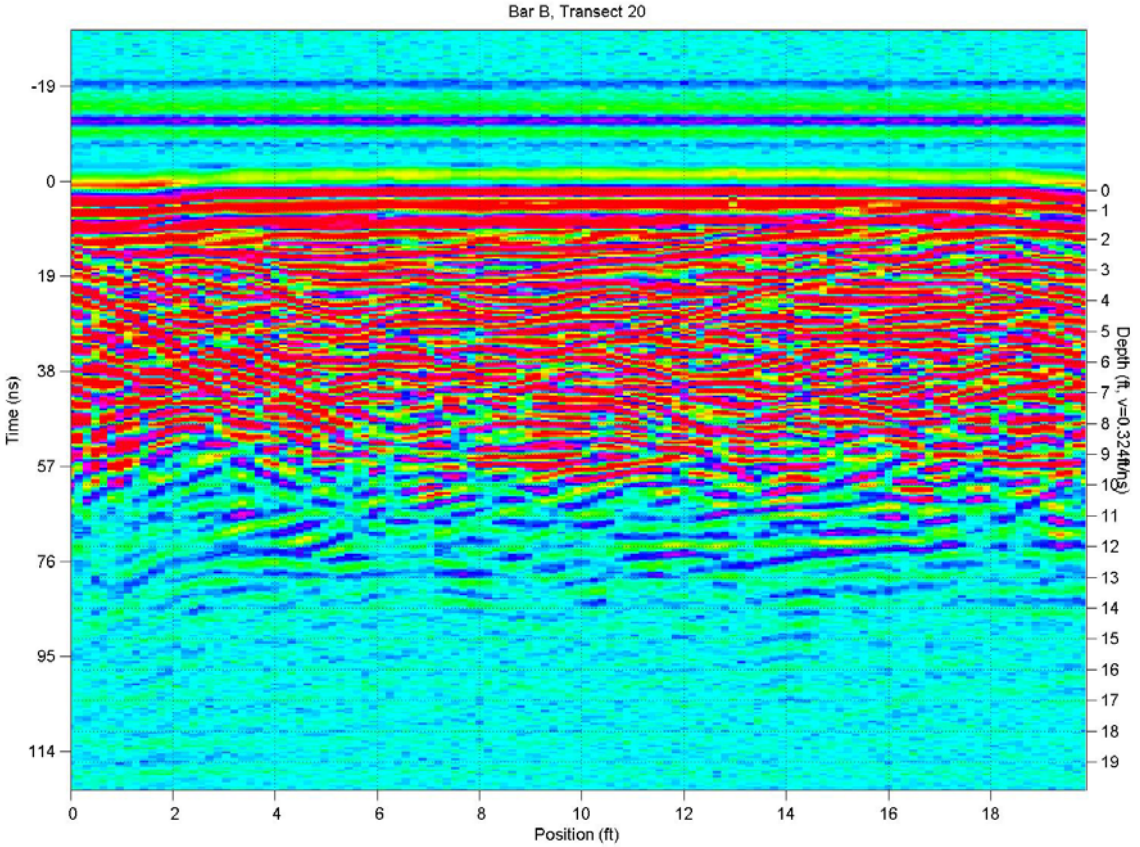

Stream A, Transect 2
Time (ns)
-19
0
19
38
57
76
95
114
F
1
0
8
16
24
32
40
48
56
64
72
80
Position (ft)
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19

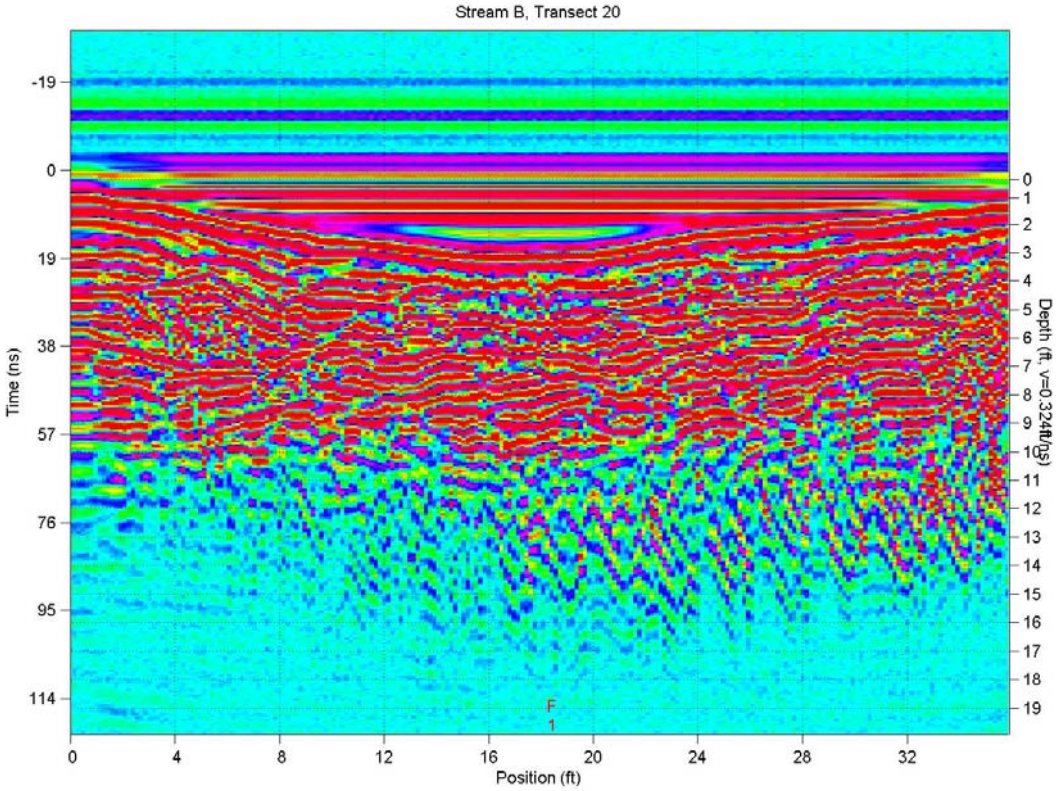

Bar A, Transect 1
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
3
6
9
12
15
18
21
24
27
30
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Stream A, Transect 1
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
8
16
24
32
40
48
56
64
72
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1


Bar A, Transect 10 Duplicate
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar A, Transect 20 Duplicate
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 20
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
2
4
6
8
10
12
14
16
18
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 20
Time (ns)
-19
0
19
38
57
76
95
114
F
1
Position (ft)
0
4
8
12
16
20
24
28
32
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
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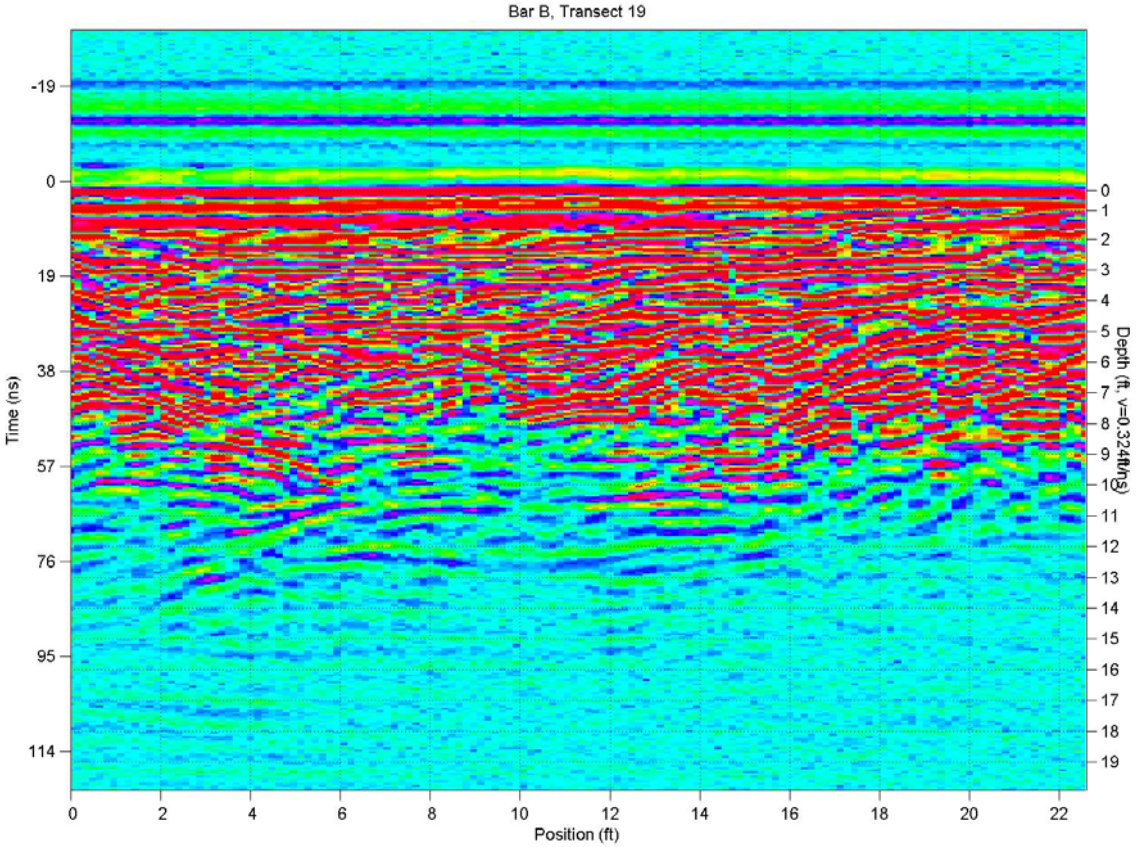
12
13
14
15
16
17
18
19


Bar B, Transect 19
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
2
4
6
8
10
12
14
16
18
20
22
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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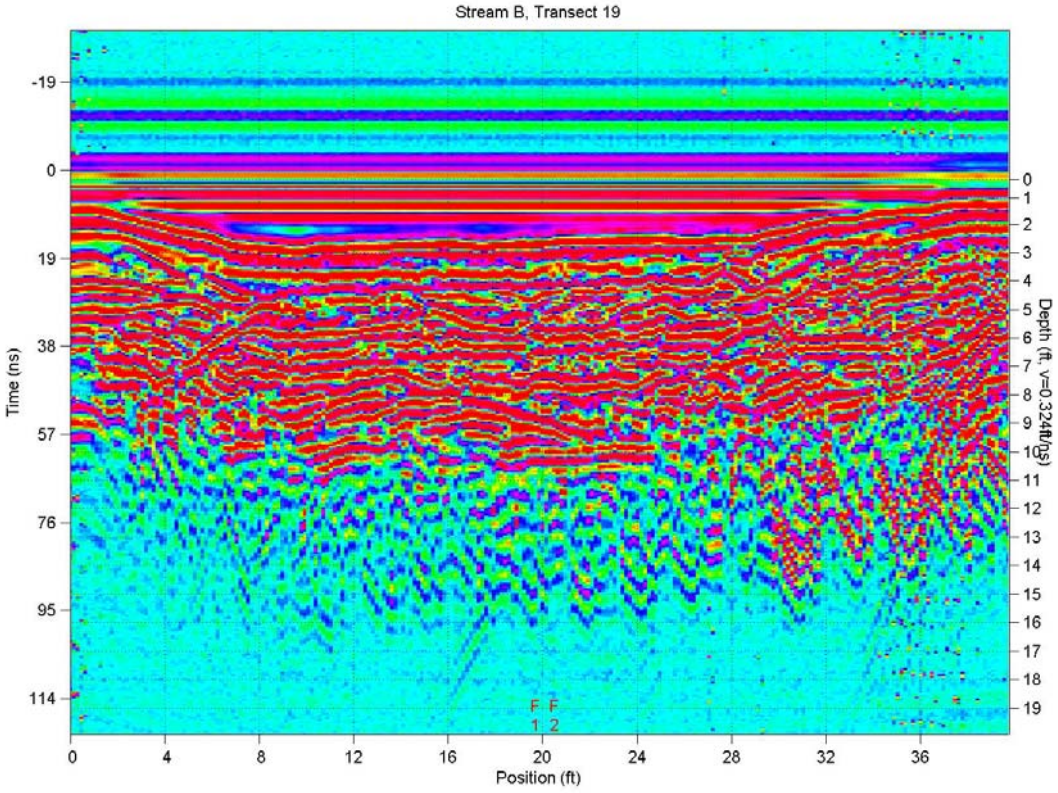
16
17
18
19


Stream B, Transect 19
Time (ns)
-19
0
19
38
57
76
95
114
F F
1 2
Position (ft)
0
4
8
12
16
20
24
28
32
36
Depth (ft, v=0.324ft/ns)
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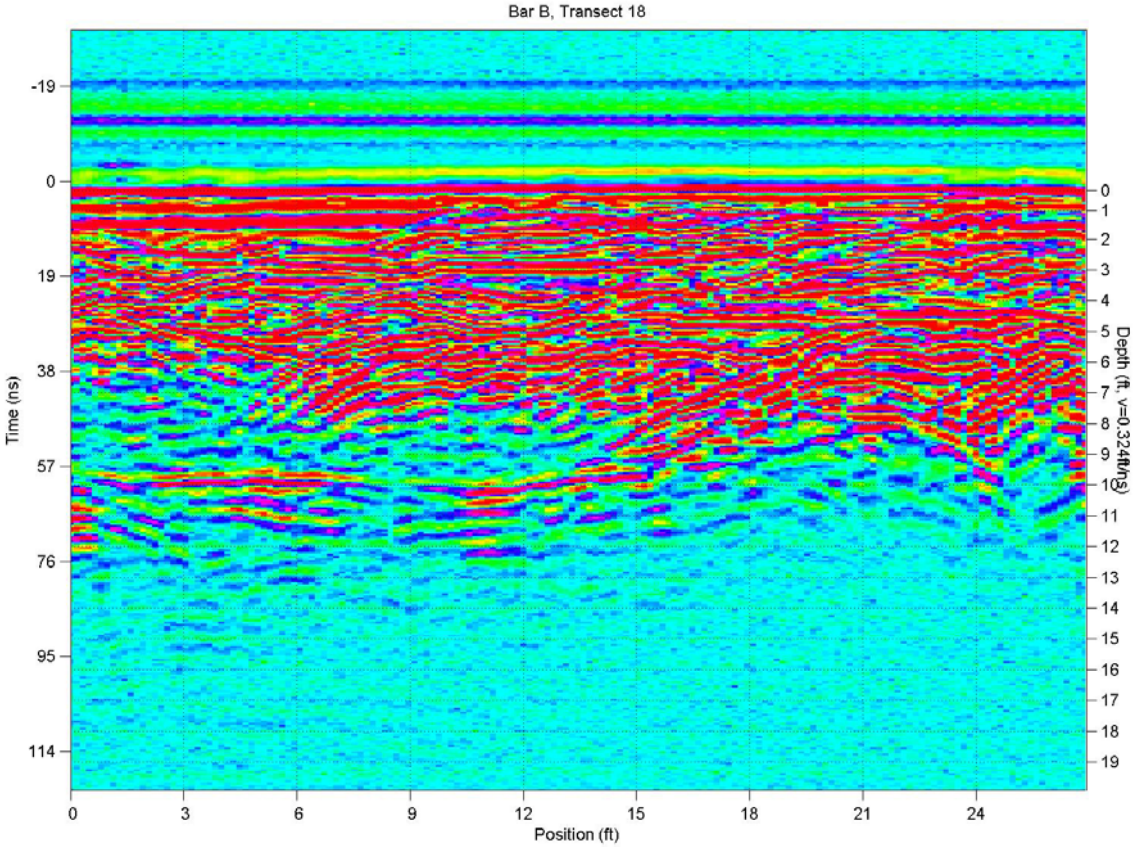
Bar B, Transect 18
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
3
6
9
12
15
18
21
24
Depth (ft, v=0.324ft/ns)
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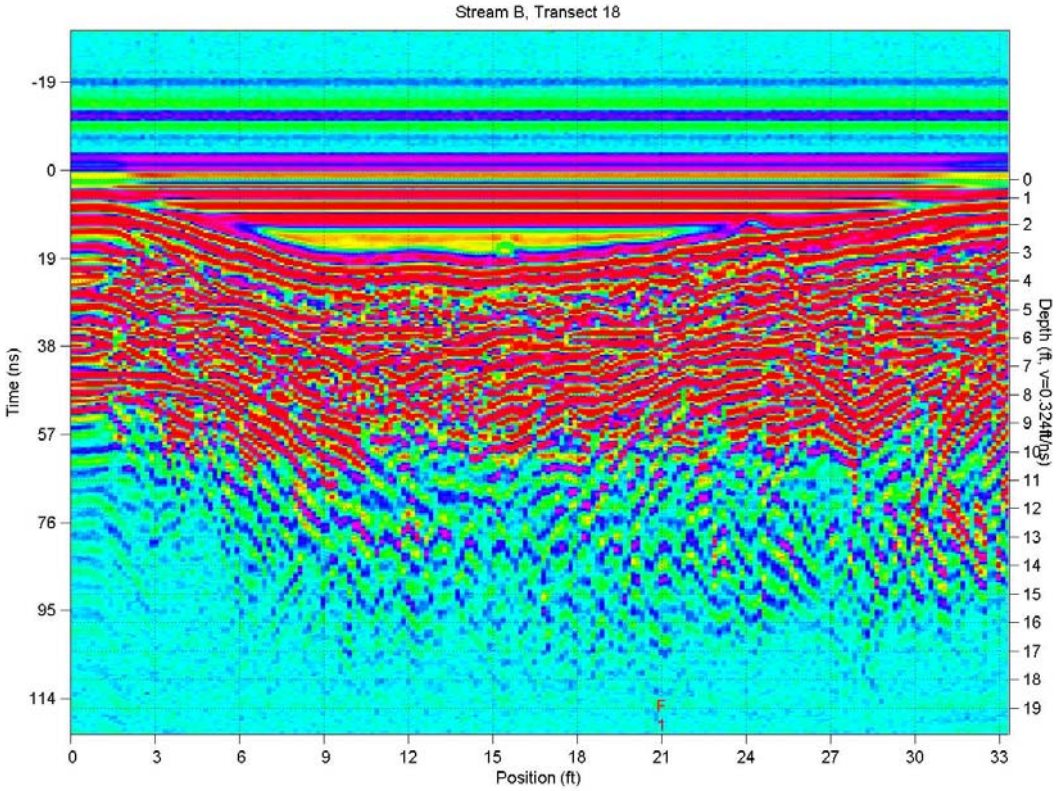
Stream B, Transect 18
Time (ns)
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114
Position (ft)
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6
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12
15
18
21
24
27
30
33
Depth (ft, v=0.324ft/ns)
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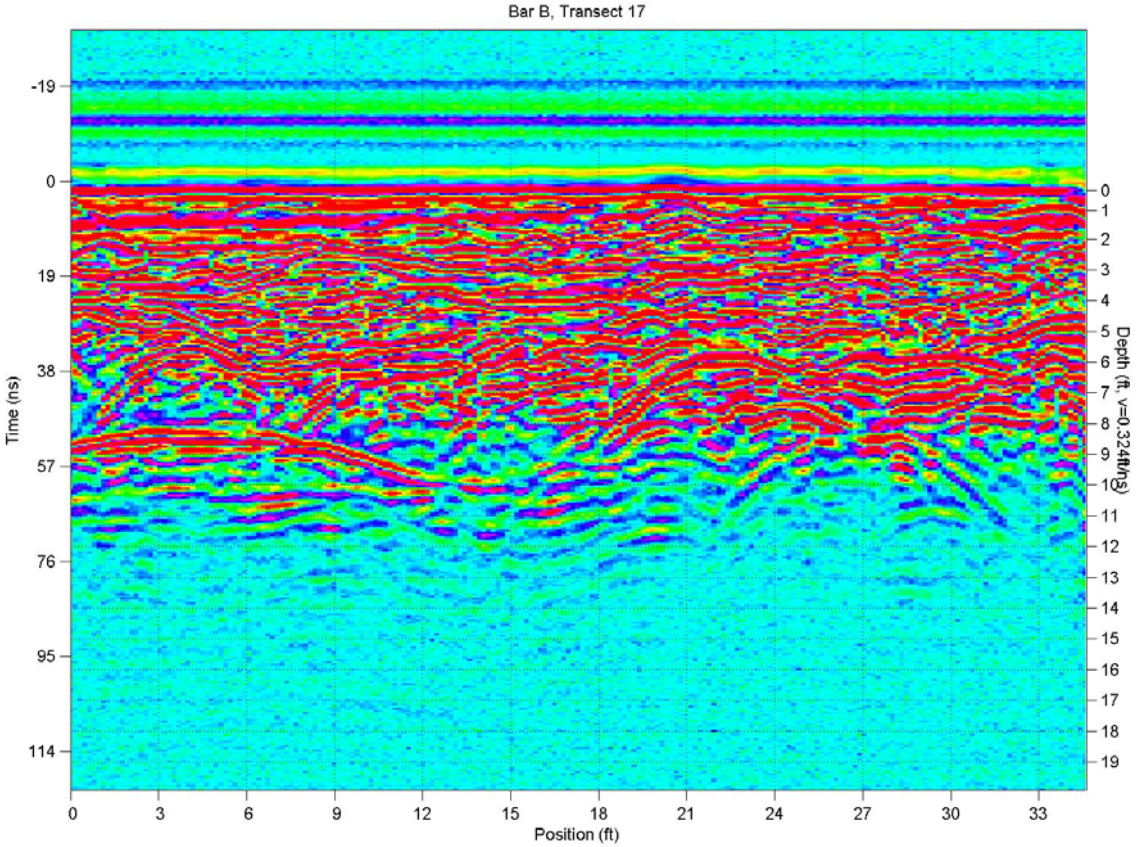
Bar B, Transect 17
Time (ns)
-19
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57
76
95
114
Position (ft)
0
3
6
9
12
15
18
21
24
27
30
33
Depth (ft, v=0.324ft/ns)
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4
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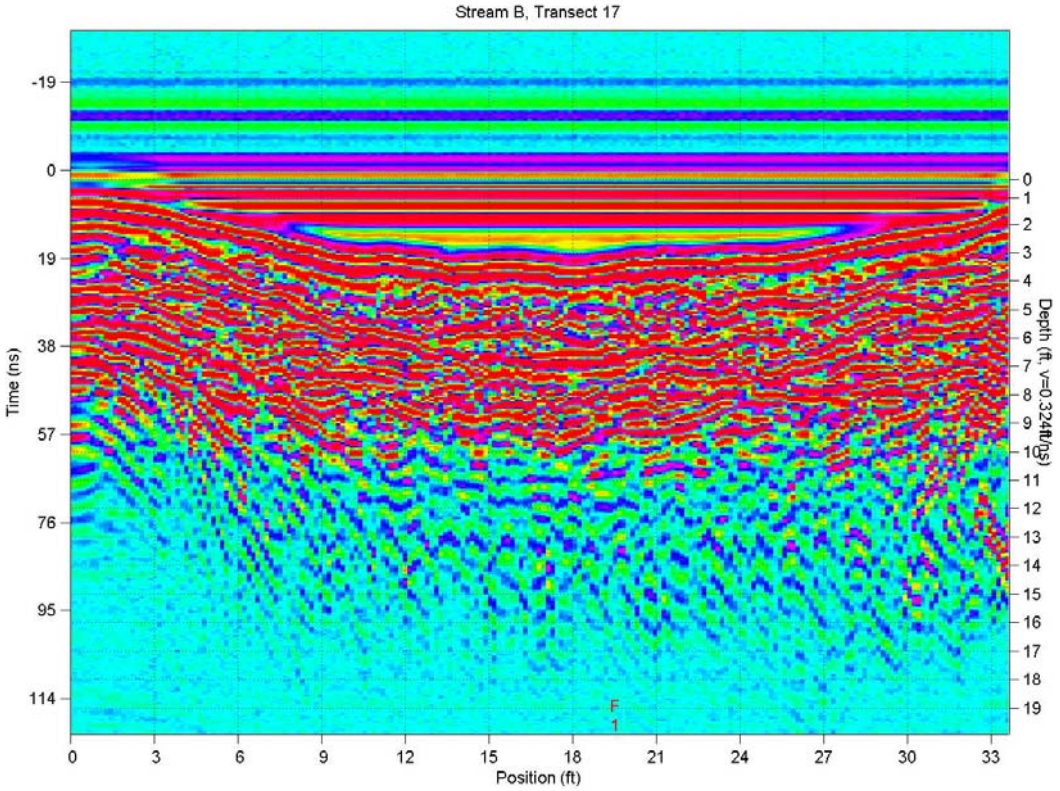
Stream B, Transect 17
Time (ns)
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38
57
76
95
114
Position (ft)
0
3
6
9
12
15
18
21
24
27
30
33
Depth (ft, v=0.324ft/ns)
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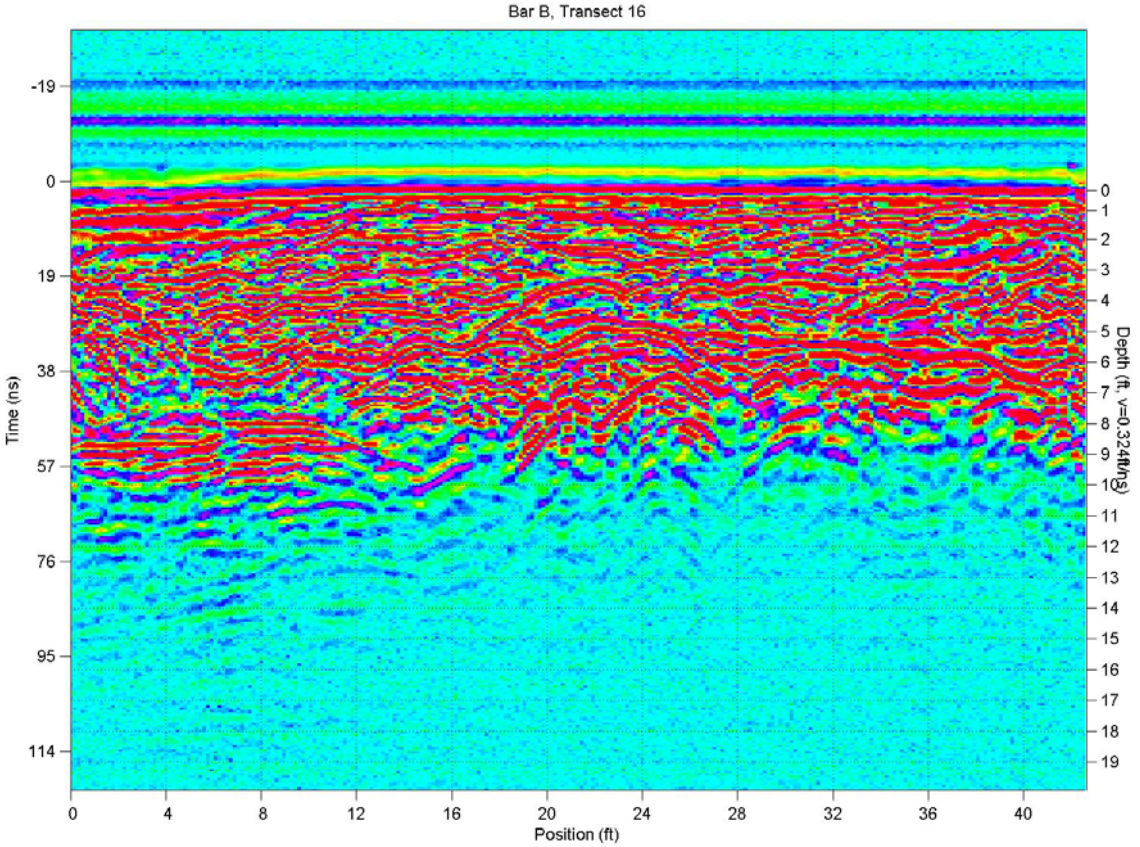
Bar B, Transect 16
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
40
Depth (ft, v=0.324ft/ns)
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4
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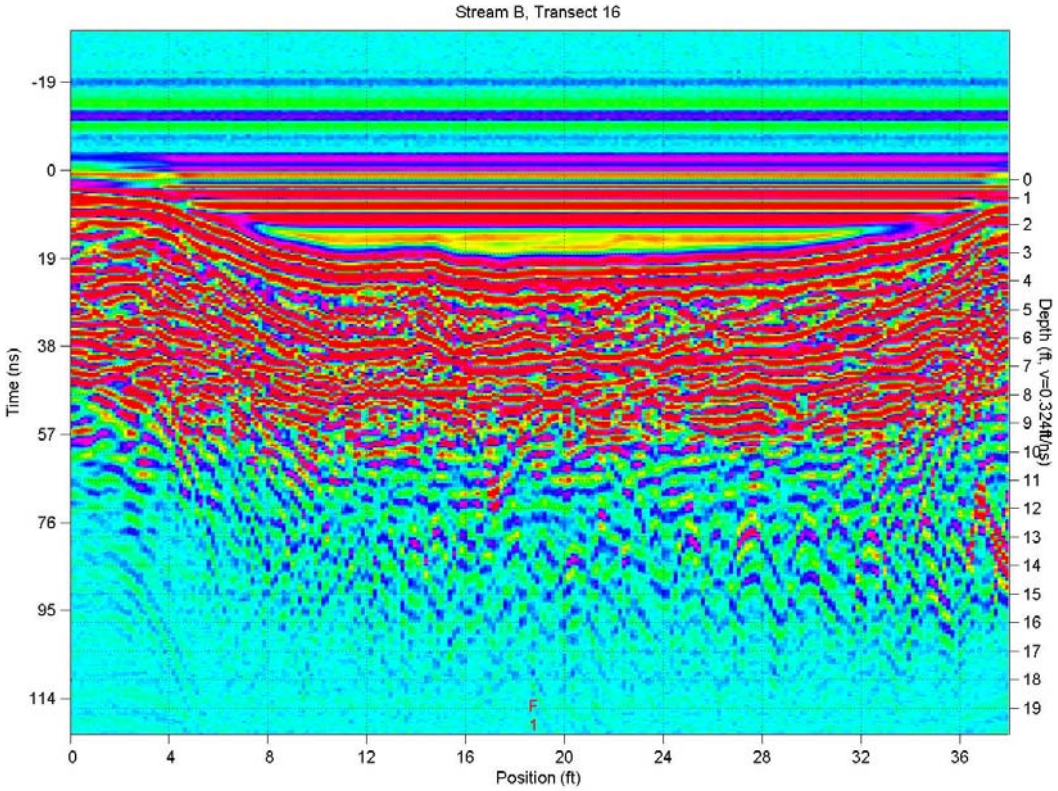
Stream B, Transect 16
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
Depth (ft, v=0.324ft/ns)
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4
5
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12
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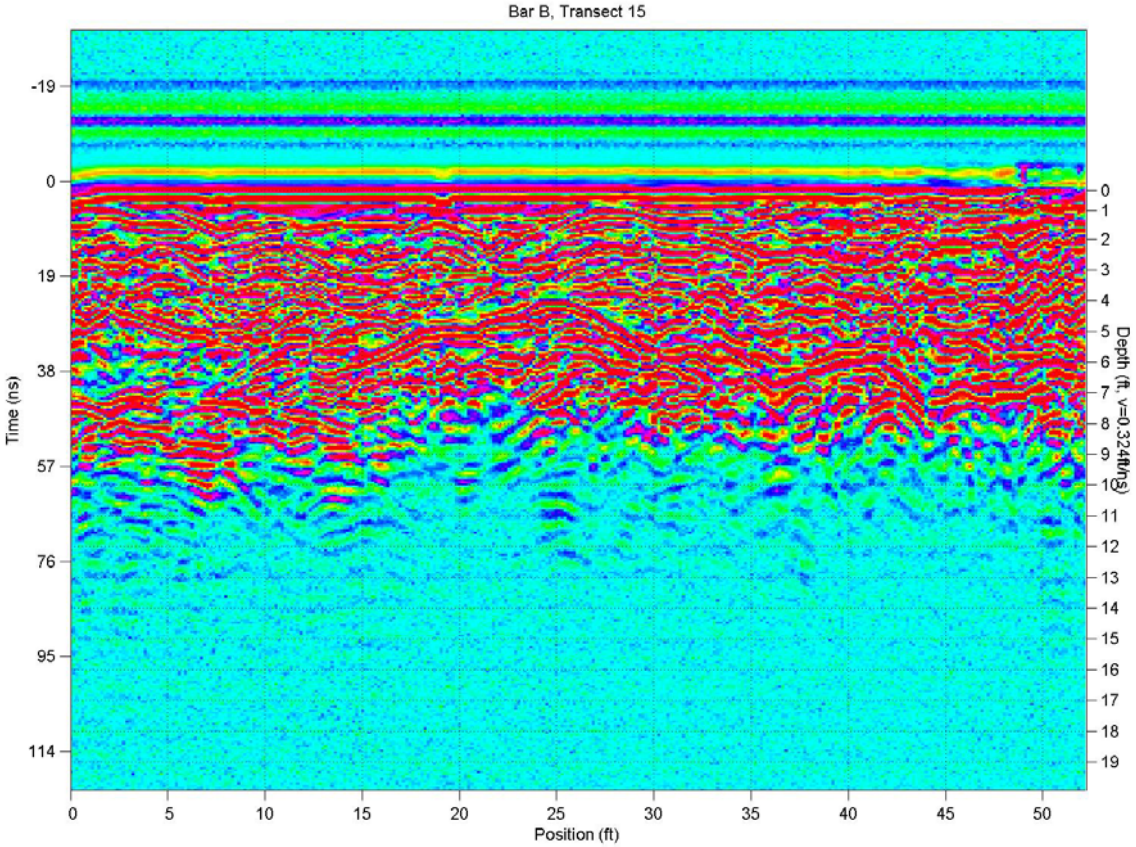
Bar B, Transect 15
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
5
10
15
20
25
30
35
40
45
50
Depth (ft, v=0.324ft/ns)
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4
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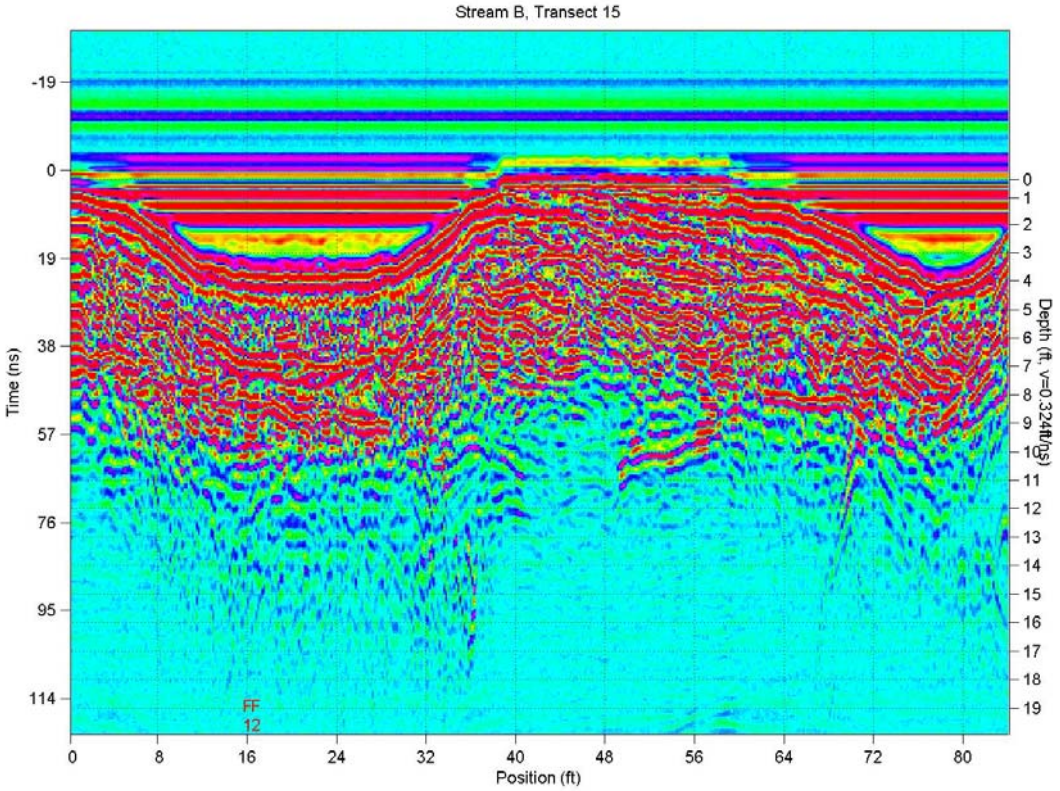
Stream B, Transect 15
Time (ns)
-19
0
19
38
57
76
95
114
FF
12
Position (ft)
0
8
16
24
32
40
48
56
64
72
80
Depth (ft, v=0.324ft/ns)
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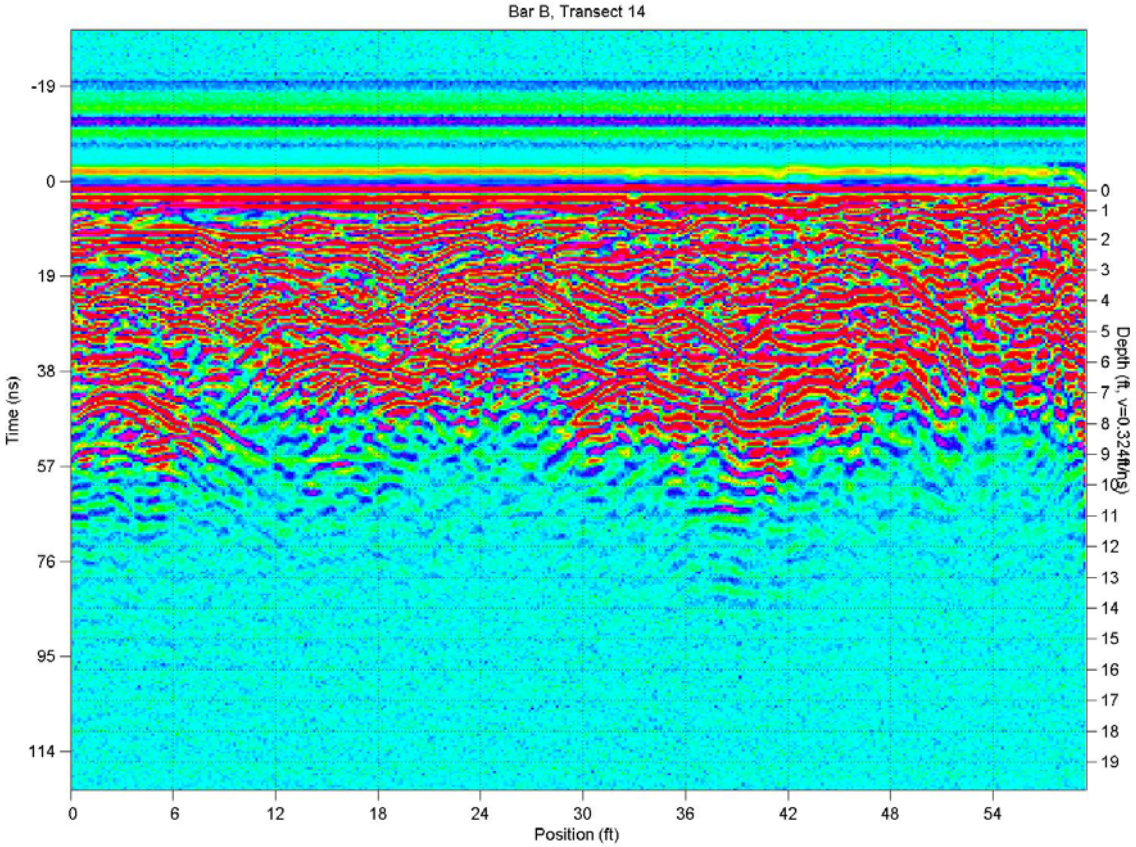
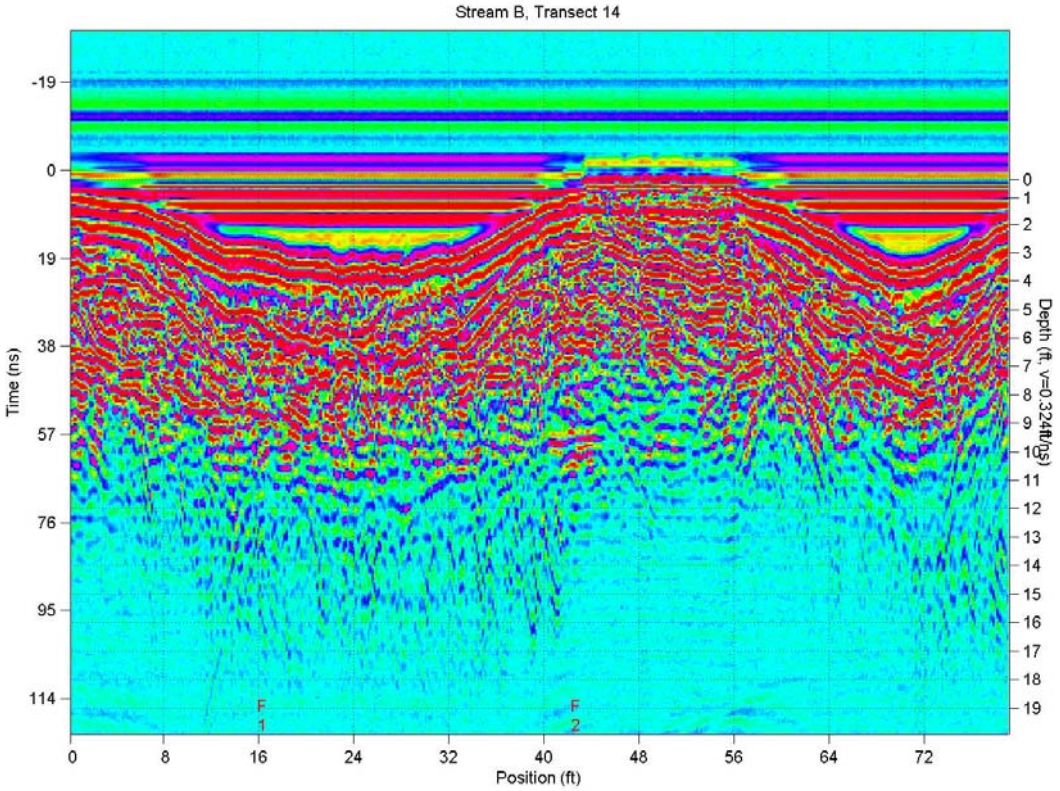
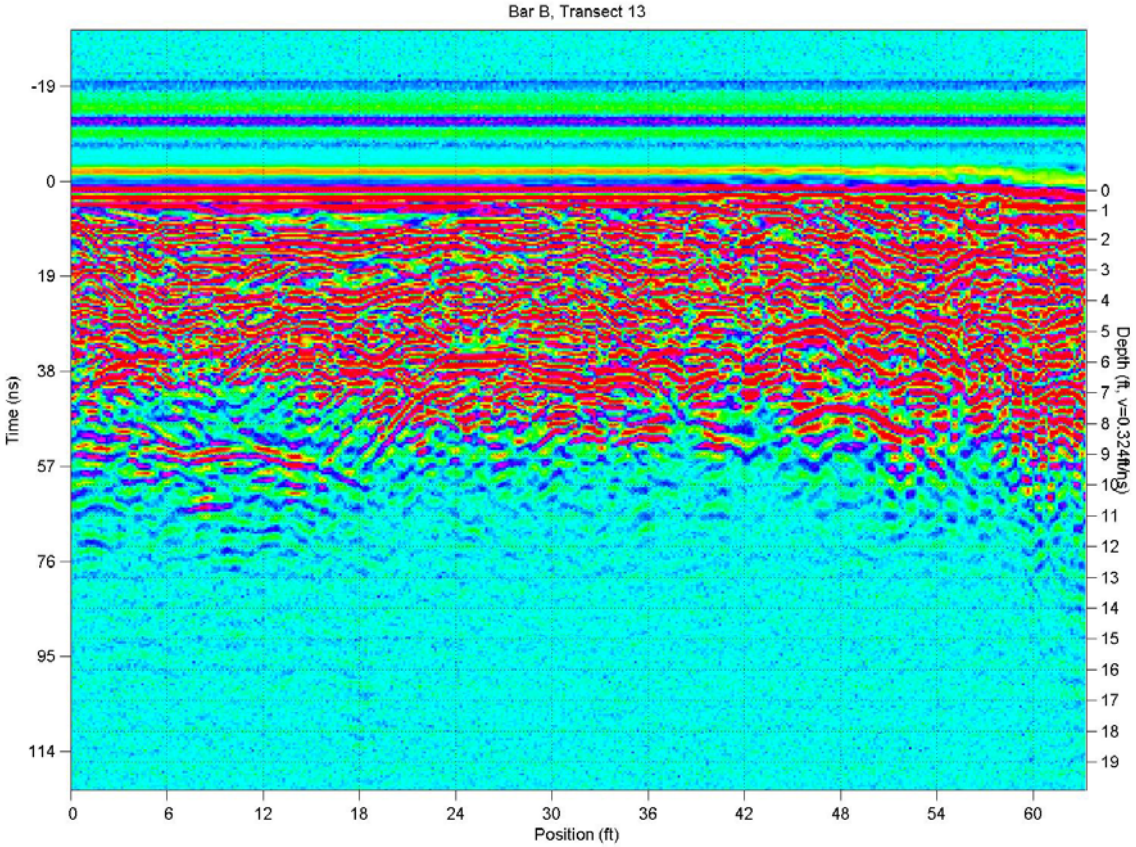
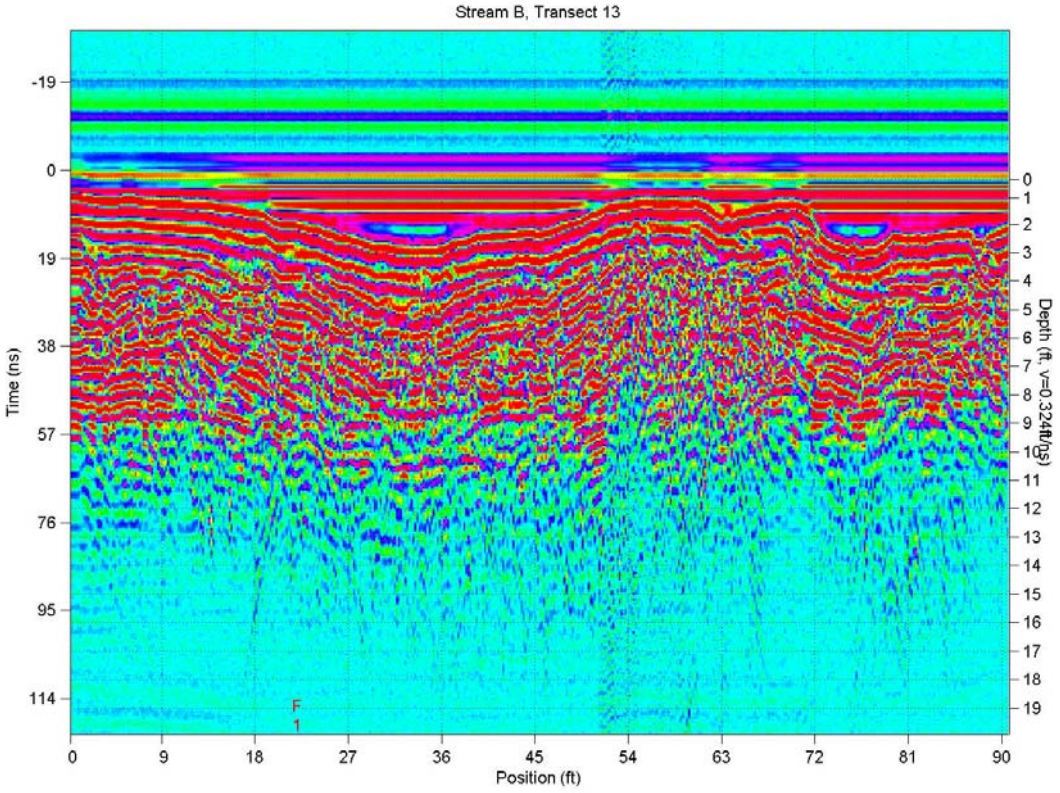
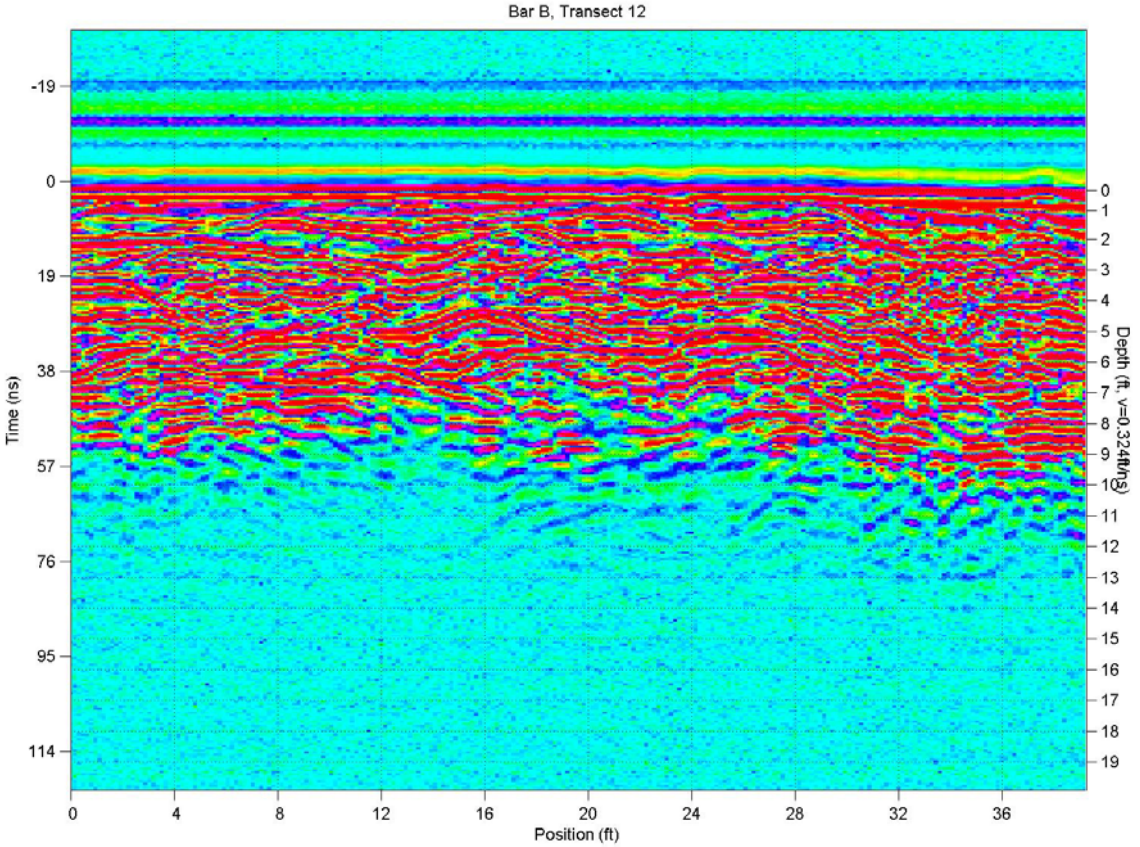
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 14
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
6
12
18
24
30
36
42
48
54
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 14
Time (ns)
-19
0
19
38
57
76
95
114
F 1
F 2
Position (ft)
0
8
16
24
32
40
48
56
64
72
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 13
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
6
12
18
24
30
36
42
48
54
60
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 13
Time (ns)
-19
0
19
38
57
76
95
114
F
1
Position (ft)
0
9
18
27
36
45
54
63
72
81
90
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 12
Time (ns)
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0
19
38
57
76
95
114
Position (ft)
0
4
8
12
16
20
24
28
32
36
Depth (ft, v=0.324ft/ns)
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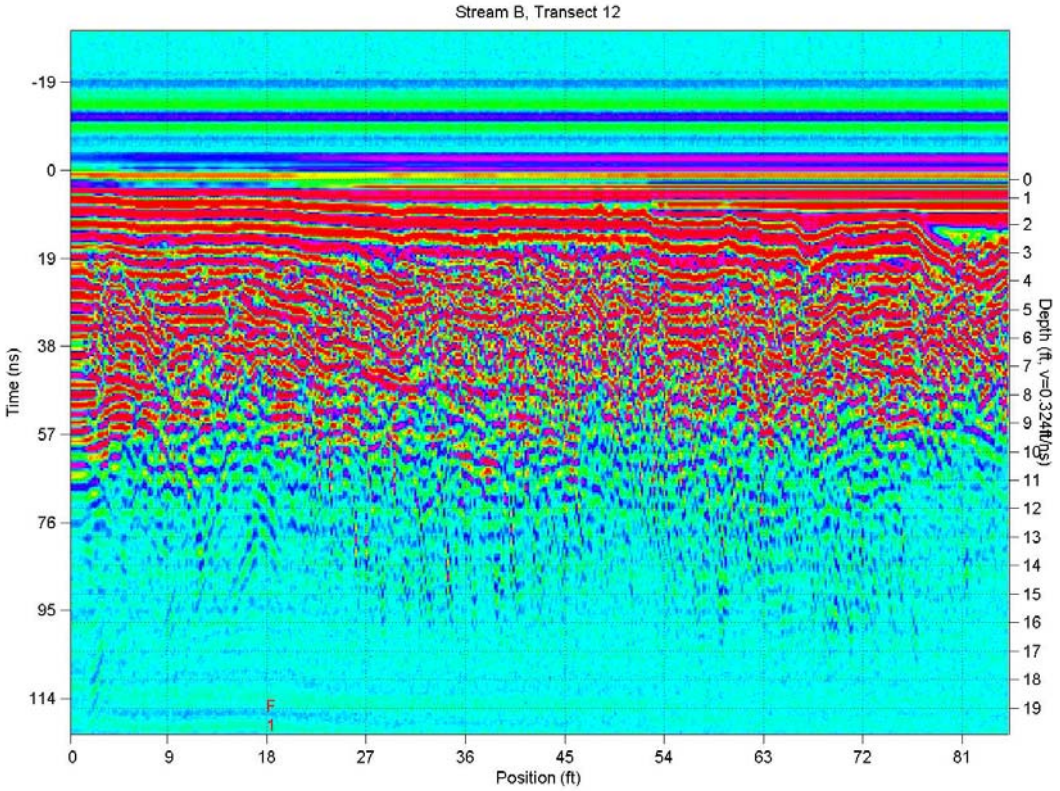
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 12
Time (ns)
-19
0
19
38
57
76
95
114
F
1
Position (ft)
0
9
18
27
36
45
54
63
72
81
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
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9
10
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12
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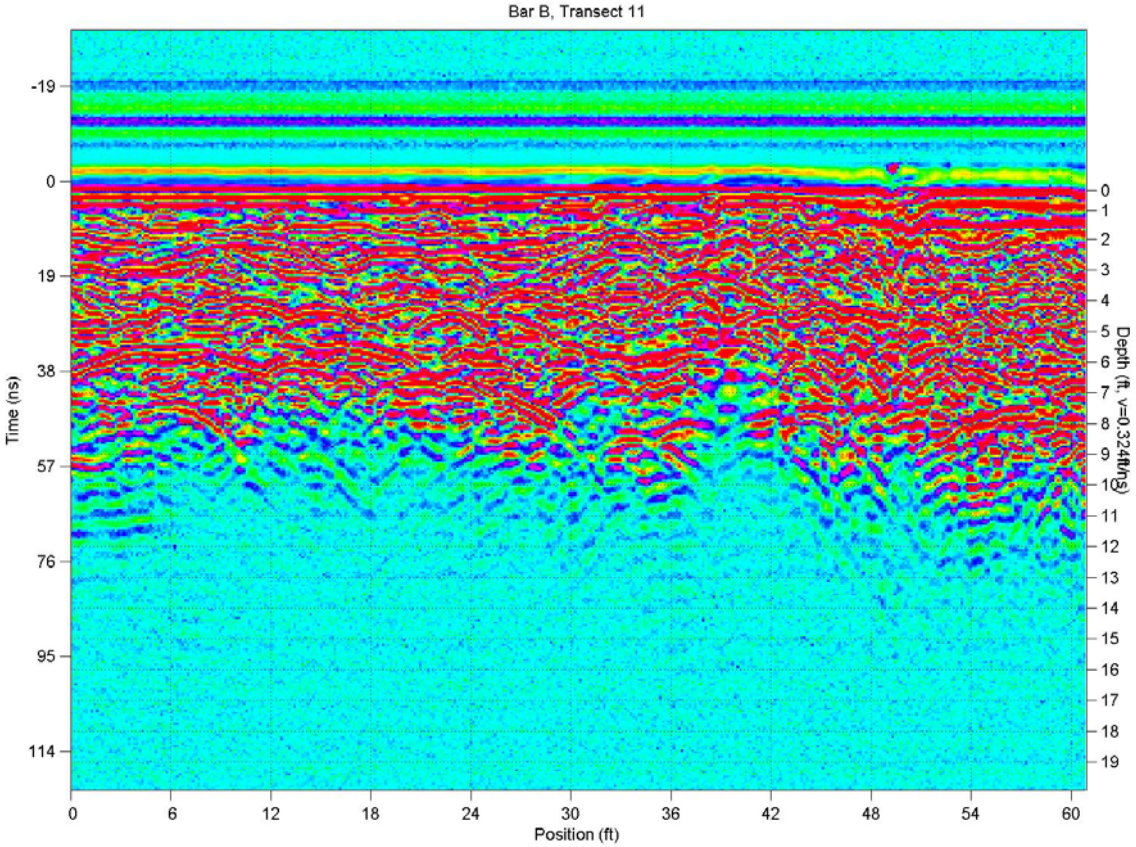
16
17
18
19


Bar B, Transect 11
Time (ns)
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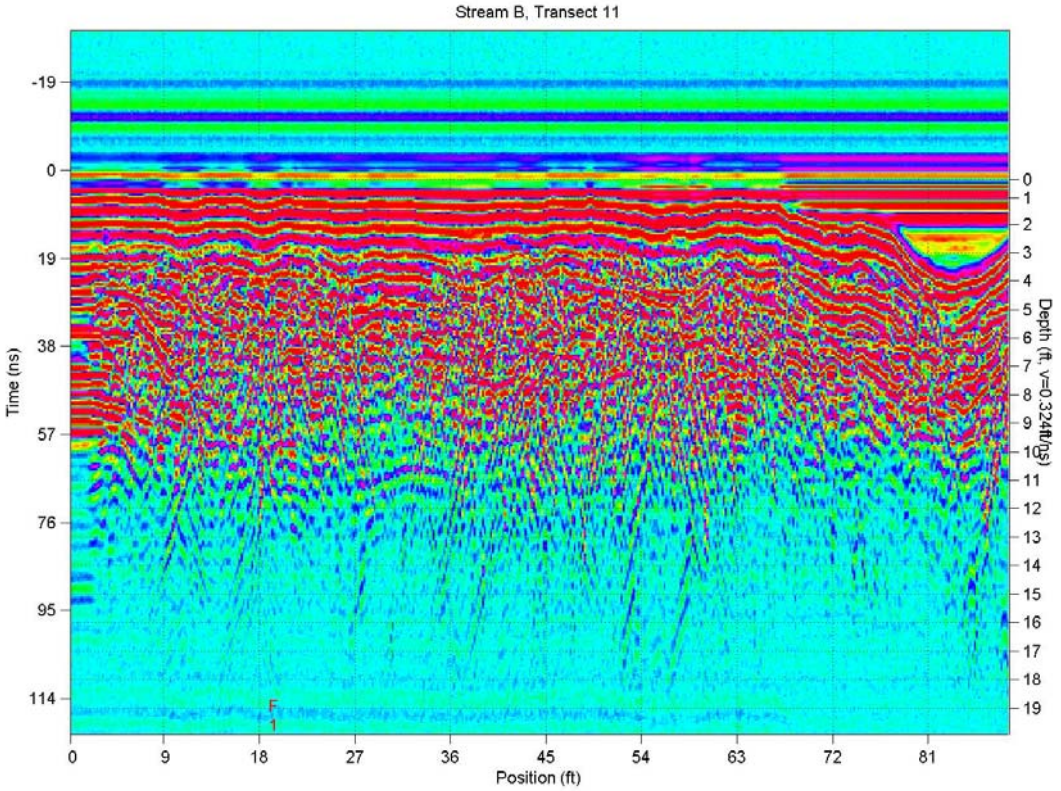
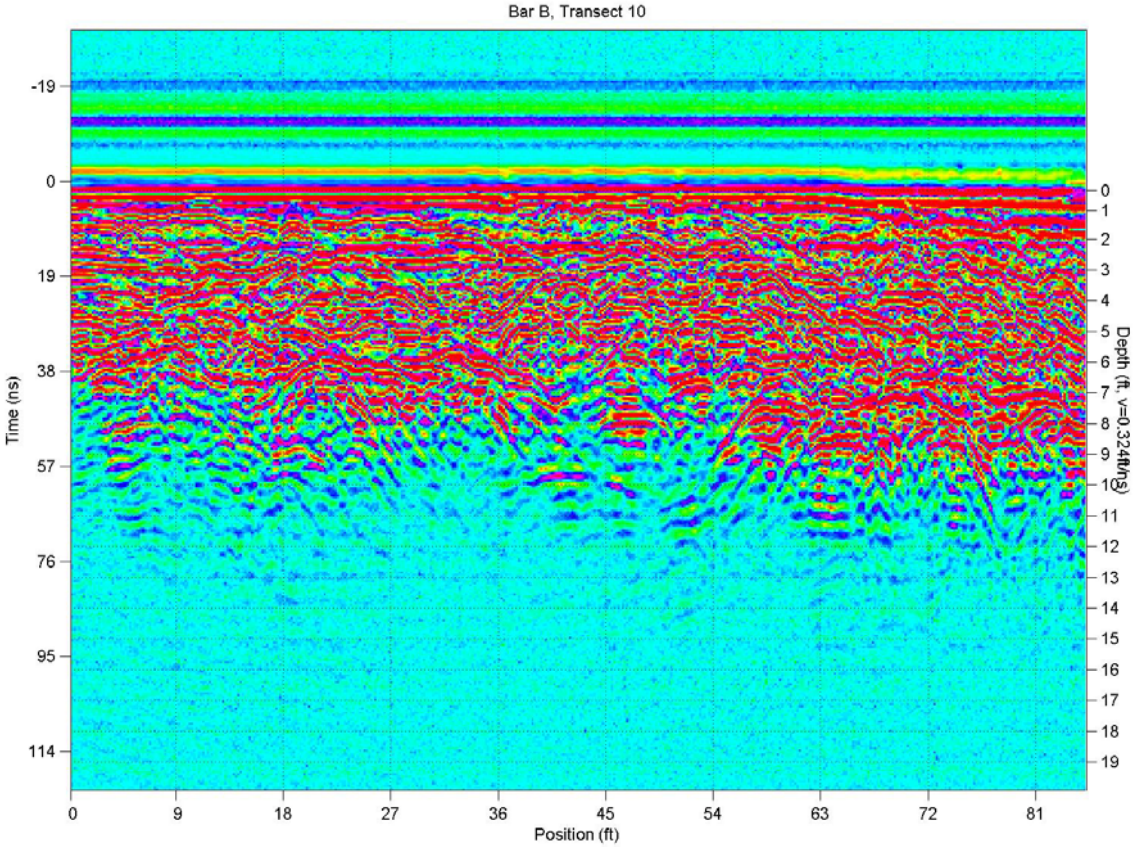
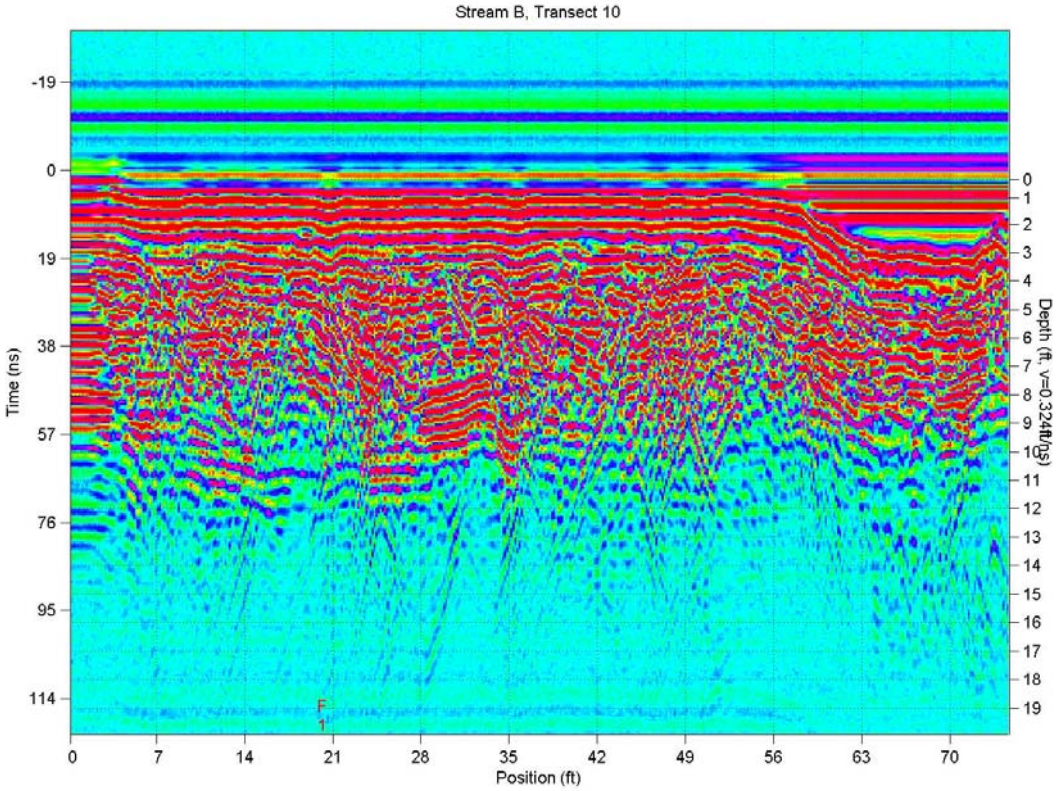
0
19
38
57
76
95
114
Position (ft)
0
6
12
18
24
30
36
42
48
54
60
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 11
Time (ns)
-19
0
19
38
57
76
95
114
F
1
Position (ft)
0
9
18
27
36
45
54
63
72
81
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 10
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
9
18
27
36
45
54
63
72
81
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 10
Time (ns)
-19
0
19
38
57
76
95
114
F
1'
Position (ft)
0
7
14
21
28
35
42
49
56
63
70
Depth (ft, v=0.324ft/ns)
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4
5
6
7
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10
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12
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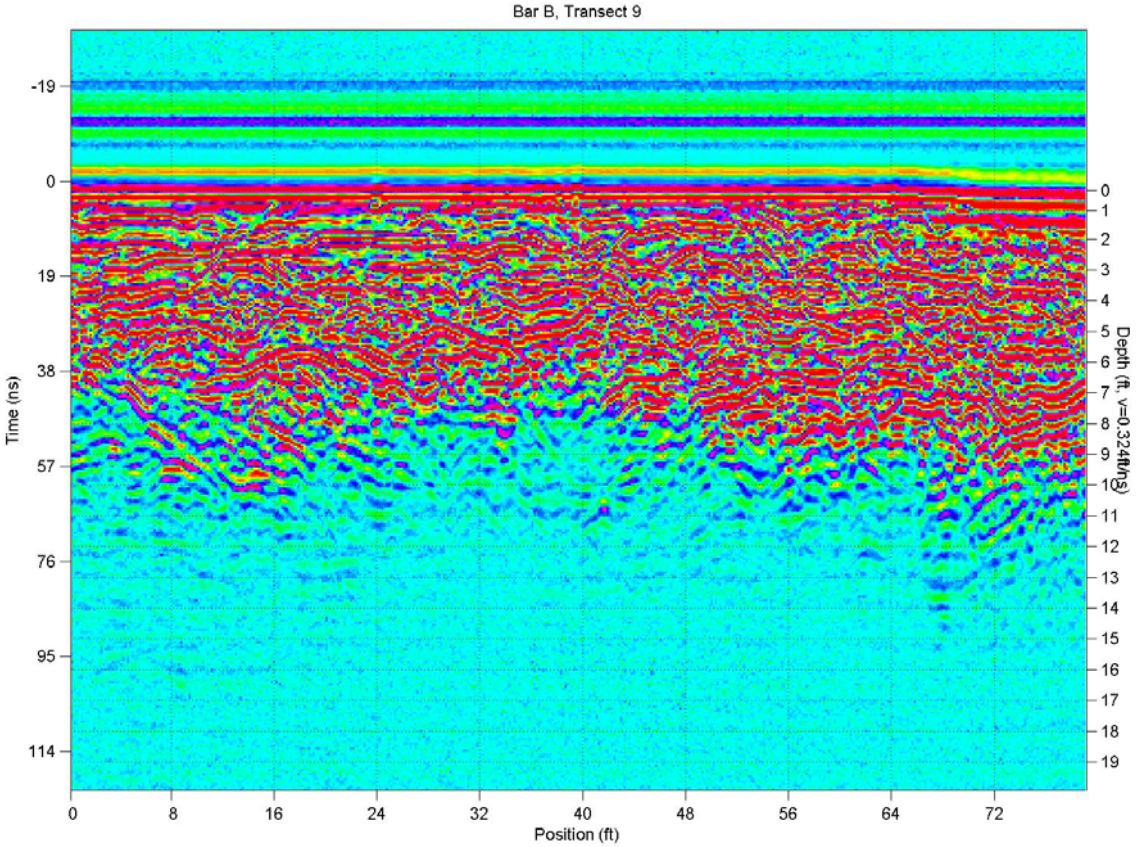
16
17
18
19


Bar B, Transect 9
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
8
16
24
32
40
48
56
64
72
Depth (ft, v=0.324ft/ns)
0
1
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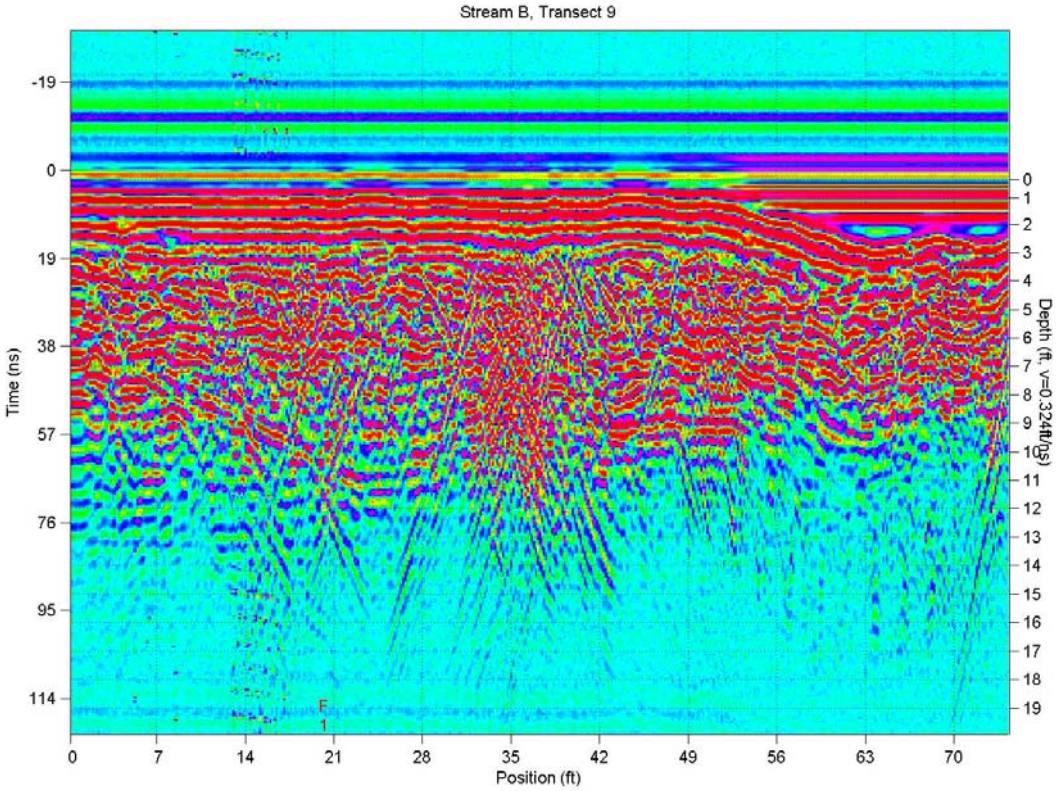
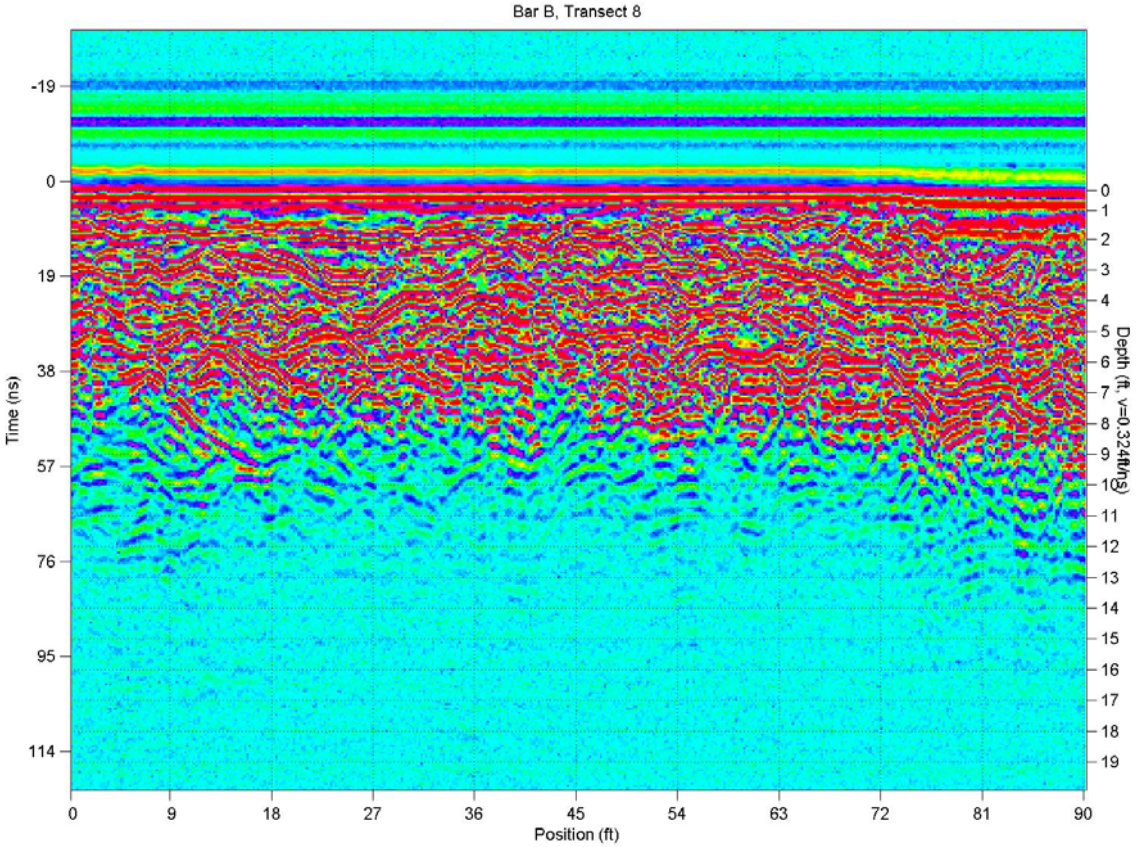
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Stream B, Transect 9
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
7
14
21
28
35
42
49
56
63
70
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 8
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
9
18
27
36
45
54
63
72
81
90
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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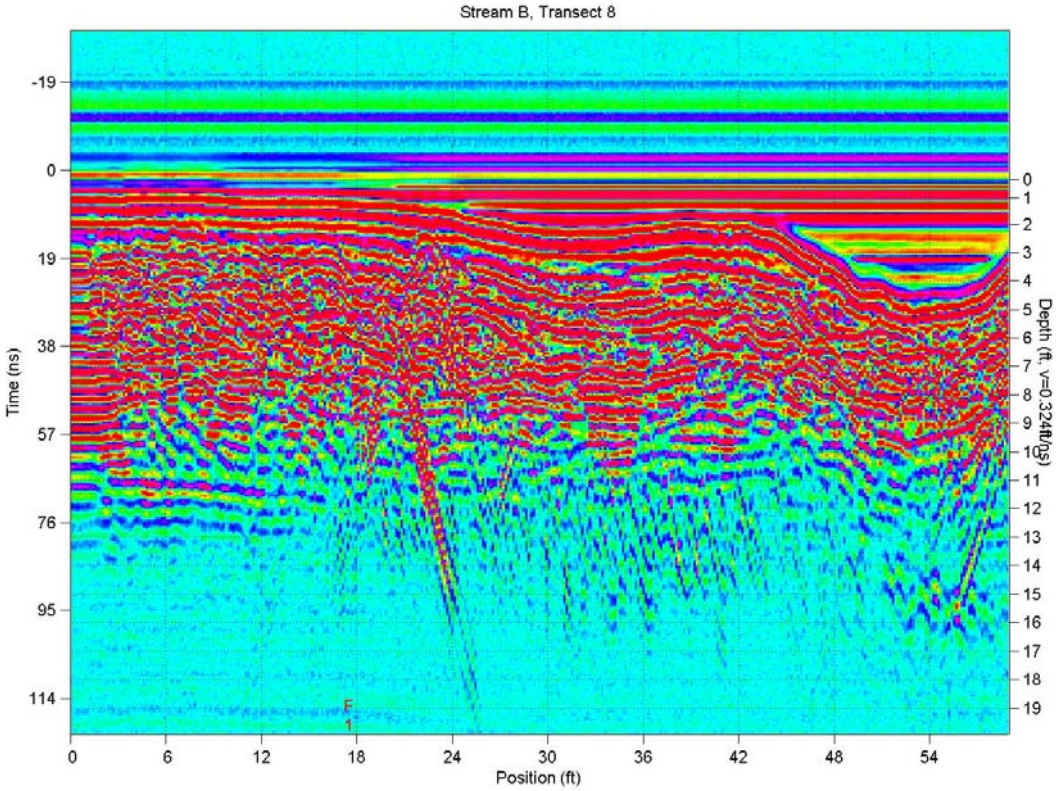
16
17
18
19


Stream B, Transect 8
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
6
12
18
24
30
36
42
48
54
Depth (ft, v=0.324ft/ns)
0
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2
3
4
5
6
7
8
9
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12
13
14
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16
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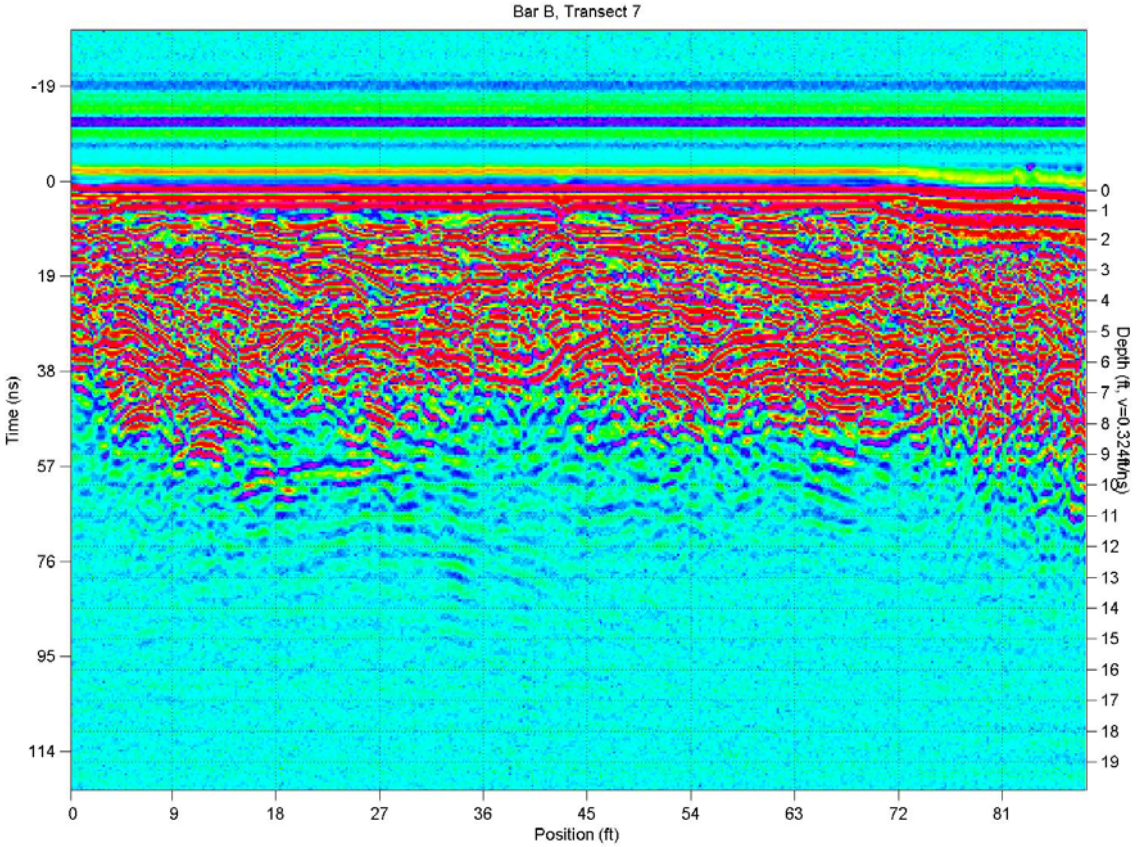
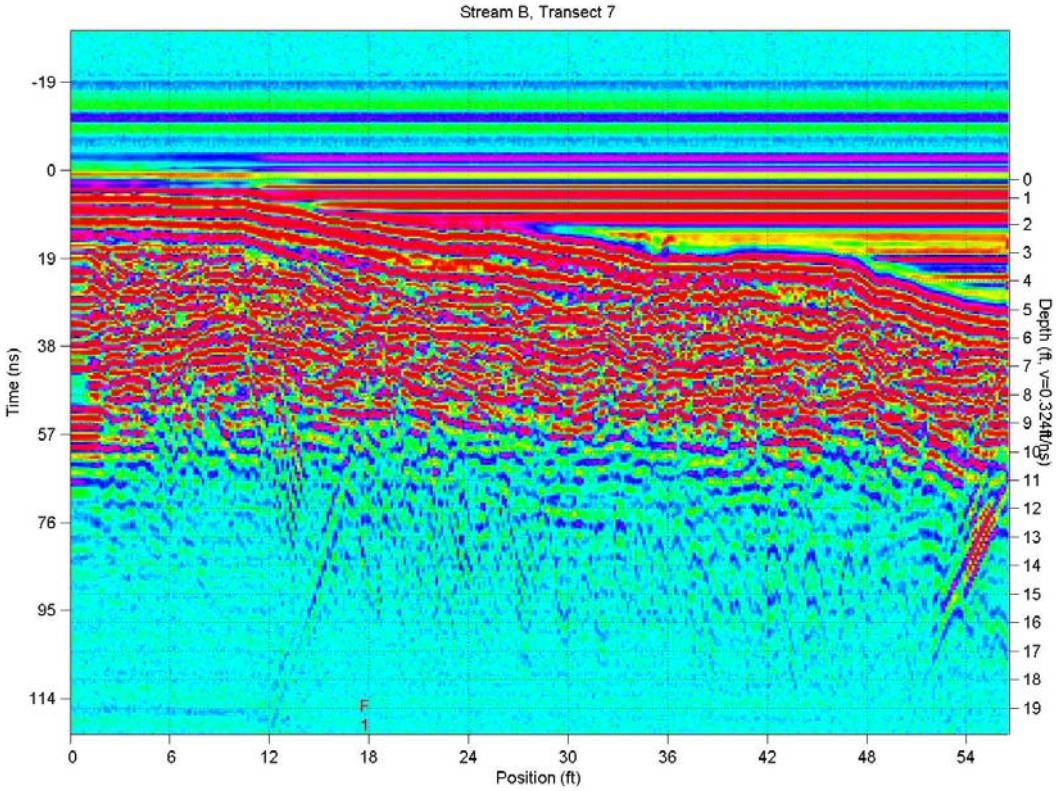
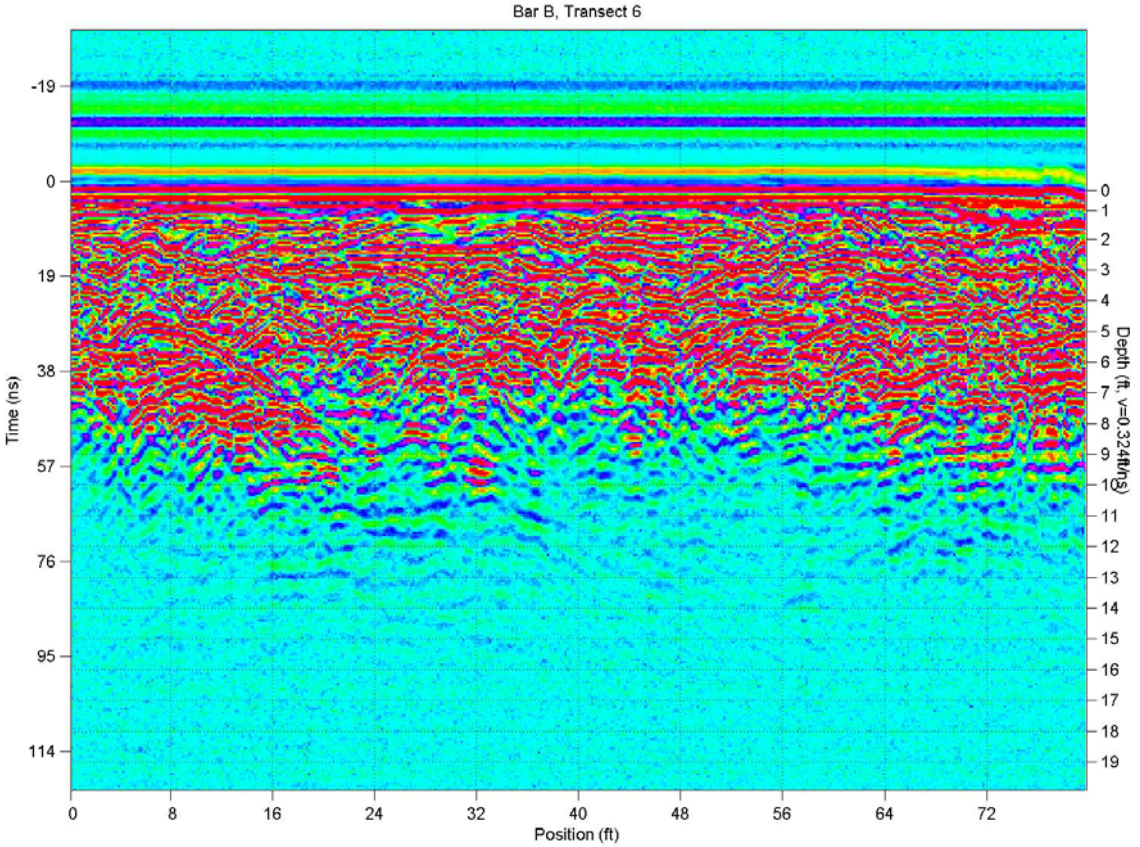
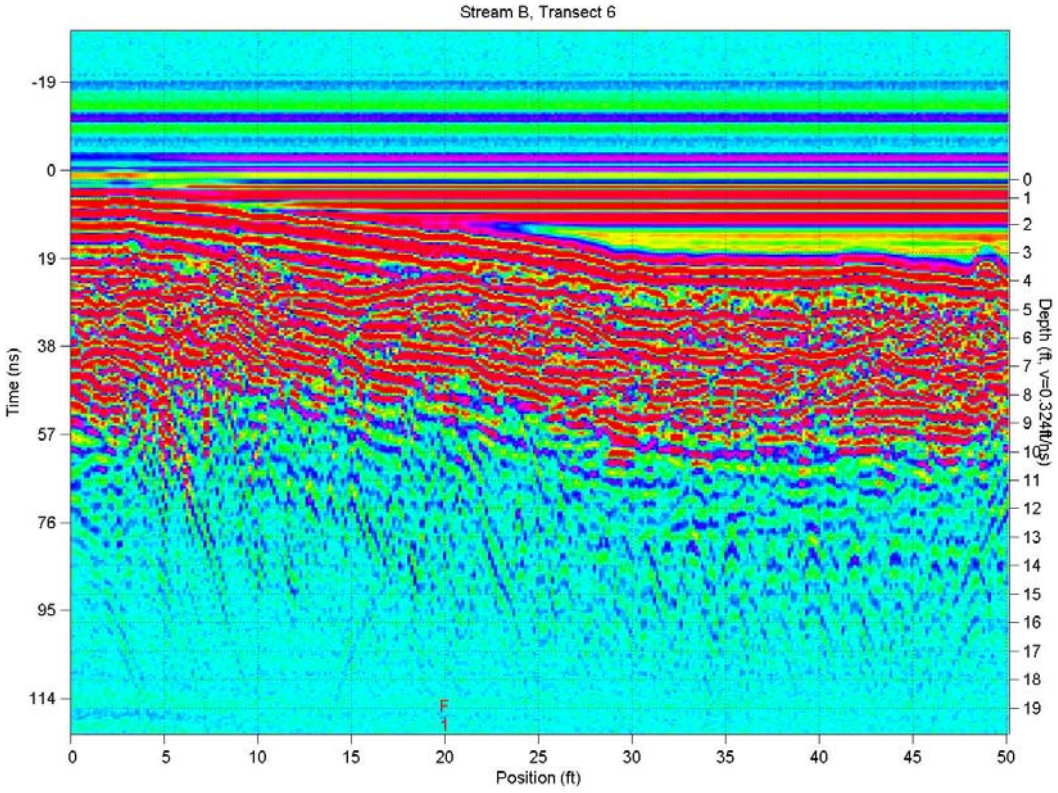
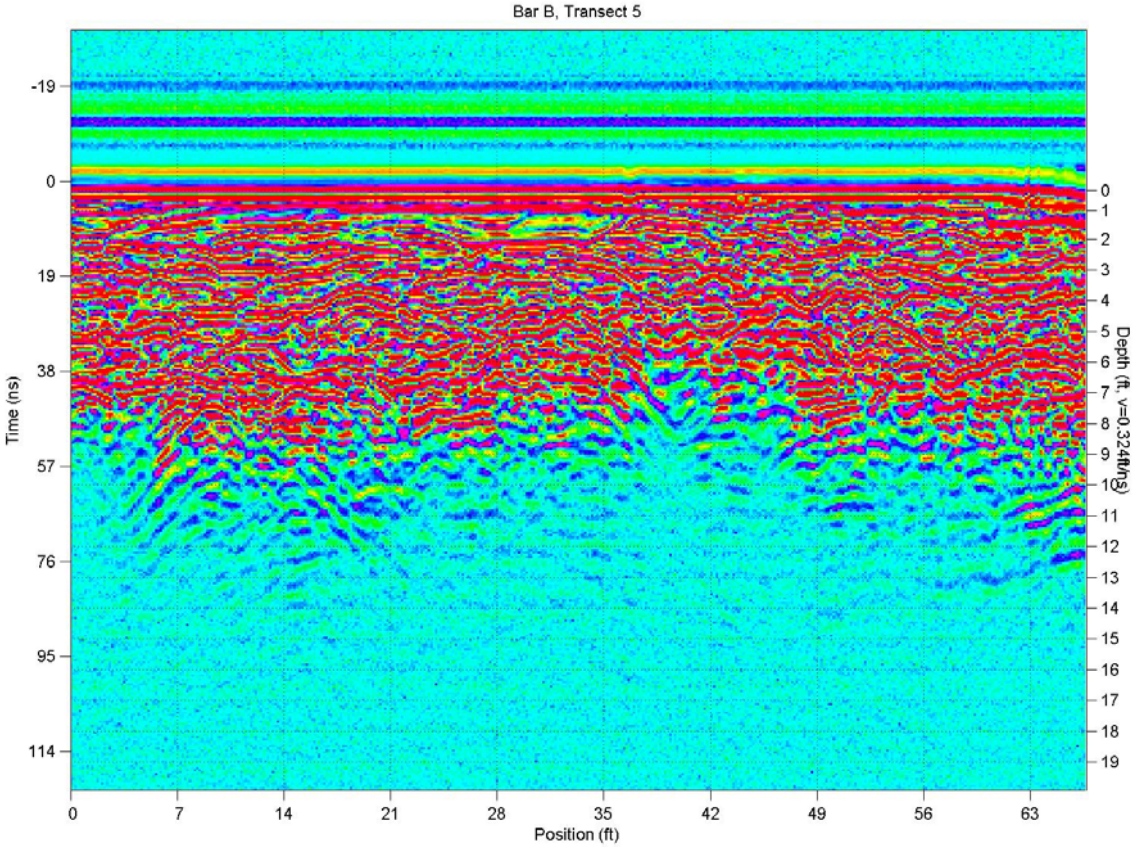
18
19


Bar B, Transect 7
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
0
9
18
27
36
45
54
63
72
81
Position (ft)


Stream B, Transect 7
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1
0
6
12
18
24
30
36
42
48
54
Position (ft)


Bar B, Transect 6
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
0
8
16
24
32
40
48
56
64
72
Position (ft)


Stream B, Transect 6
Time (ns)
-19
0
19
38
57
76
95
114
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
F
1
0
5
10
15
20
25
30
35
40
45
50
Position (ft)


Bar B, Transect 5
Time (ns)
-19
0
19
38
57
76
95
114
Position (ft)
0
7
14
21
28
35
42
49
56
63
Depth (ft, v=0.324ft/ns)
0
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3
4
5
6
7
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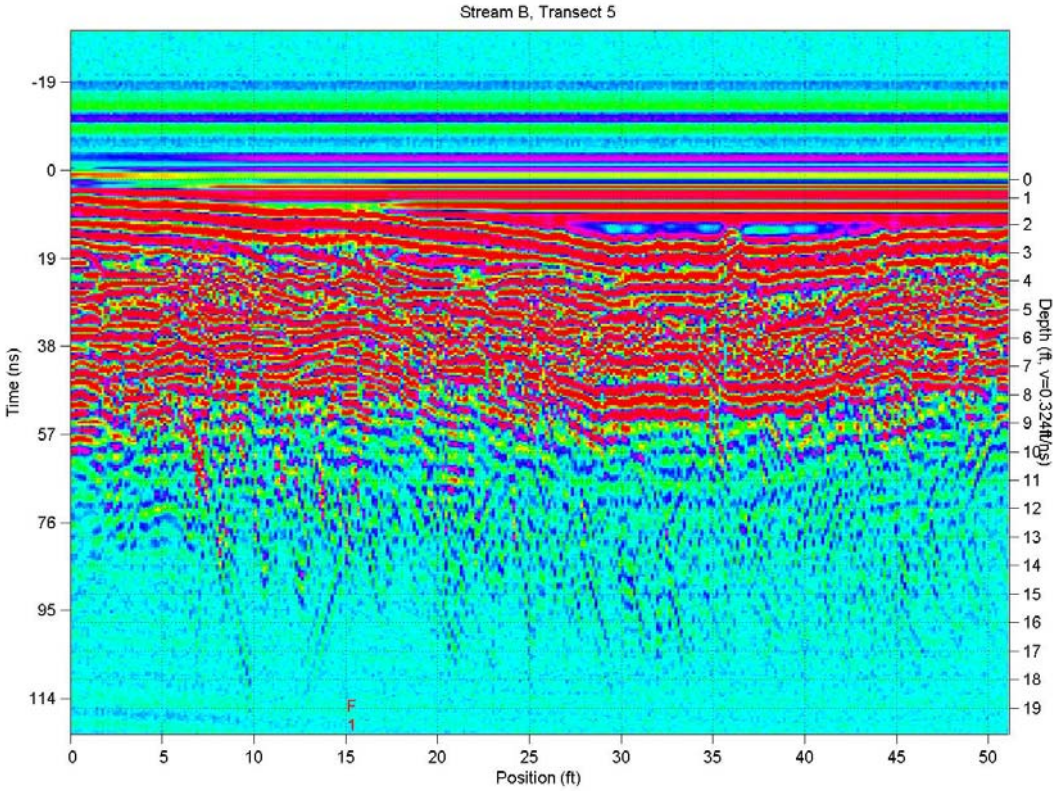
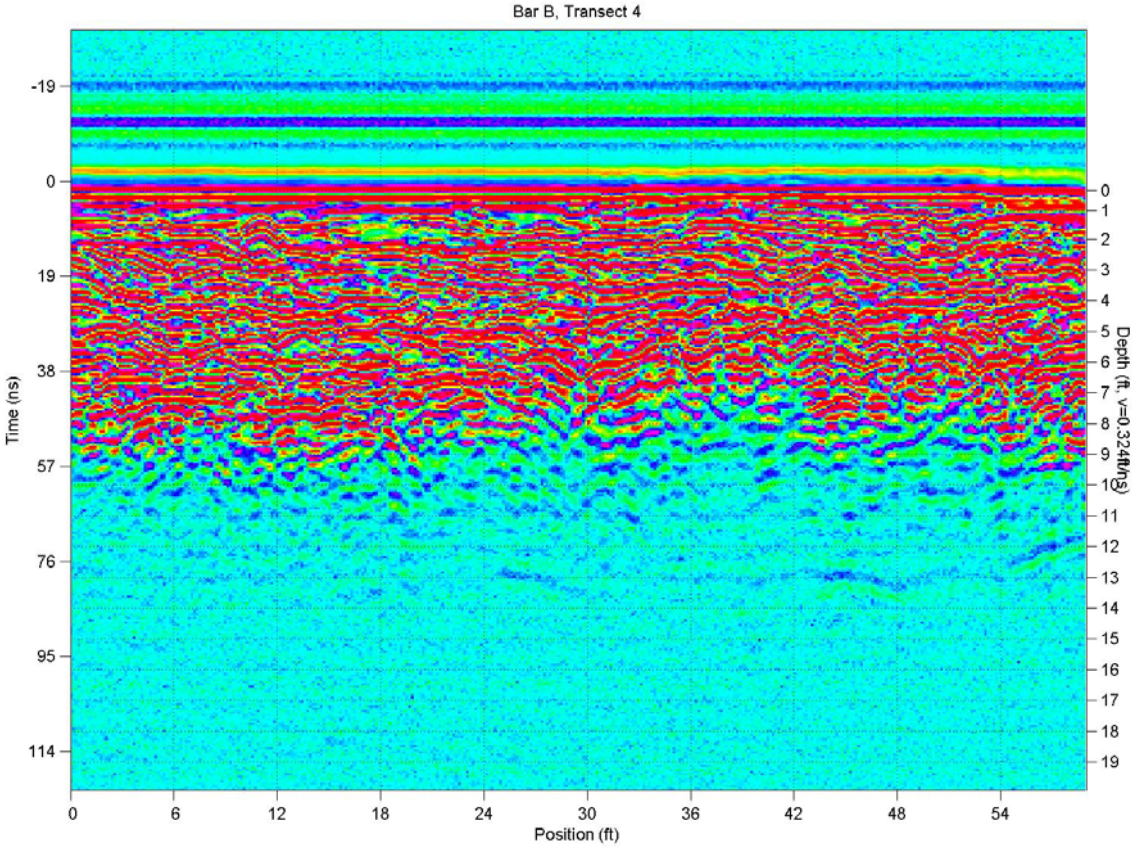

Stream B, Transect 5
Time (ns)
-19
0
19
38
57
76
95
114
F
1
Position (ft)
0
5
10
15
20
25
30
35
40
45
50
Depth (ft, v=0.324ft/ns)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19


Bar B, Transect 4
Time (ns)
-19
0
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38
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95
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Position (ft)
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12
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Depth (ft, v=0.324ft/ns)
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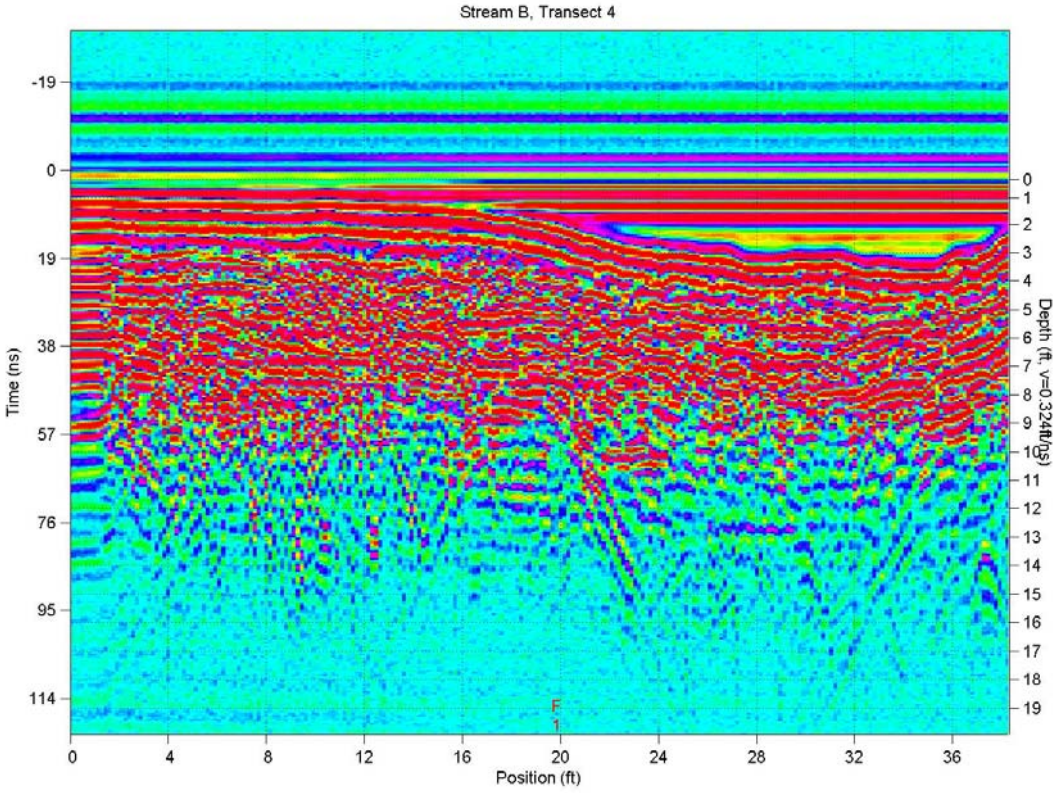
Stream B, Transect 4
Time (ns)
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Position (ft)
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Depth (ft, v=0.324ft/ns)
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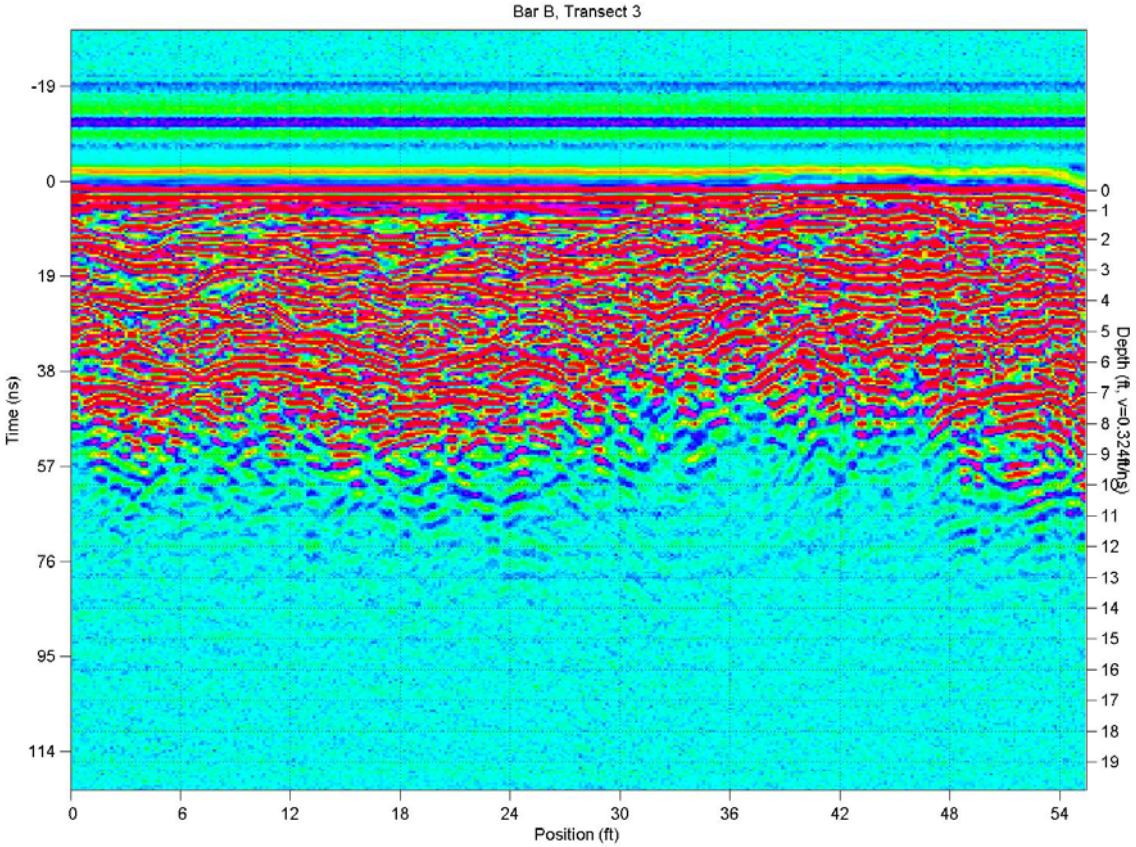
Bar B, Transect 3
Time (ns)
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114
Position (ft)
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Depth (ft, v=0.324ft/ns)
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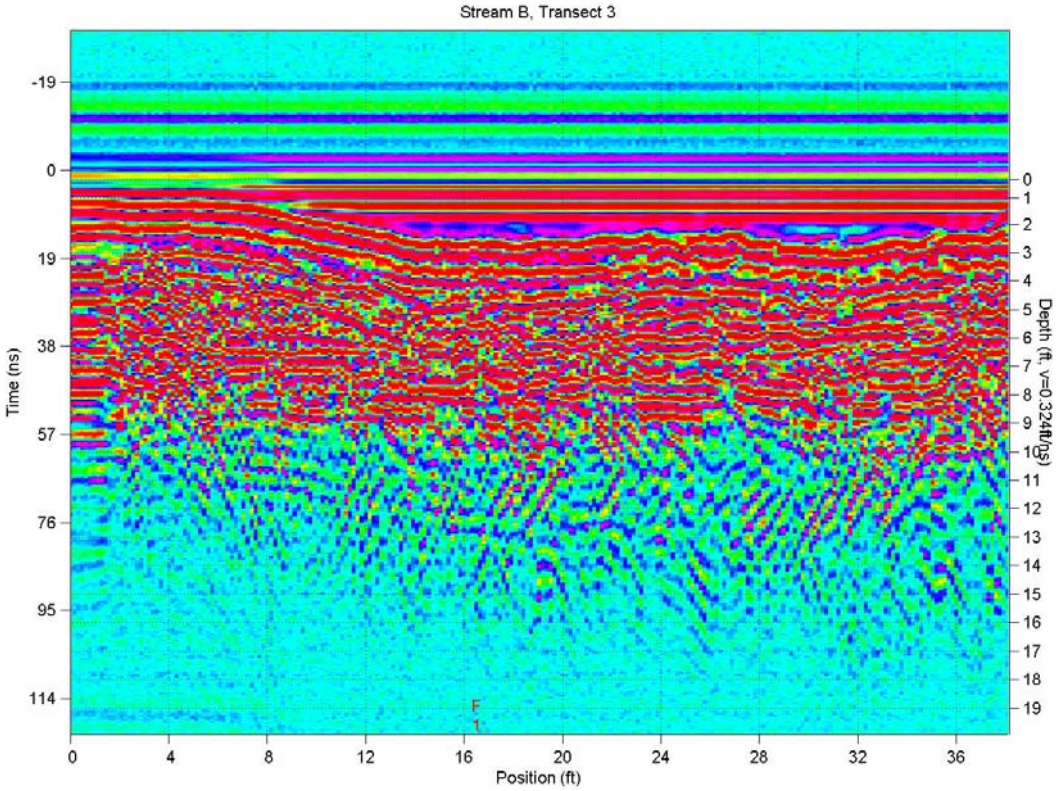
Stream B, Transect 3
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Position (ft)
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Depth (ft, v=0.324ft/ns)
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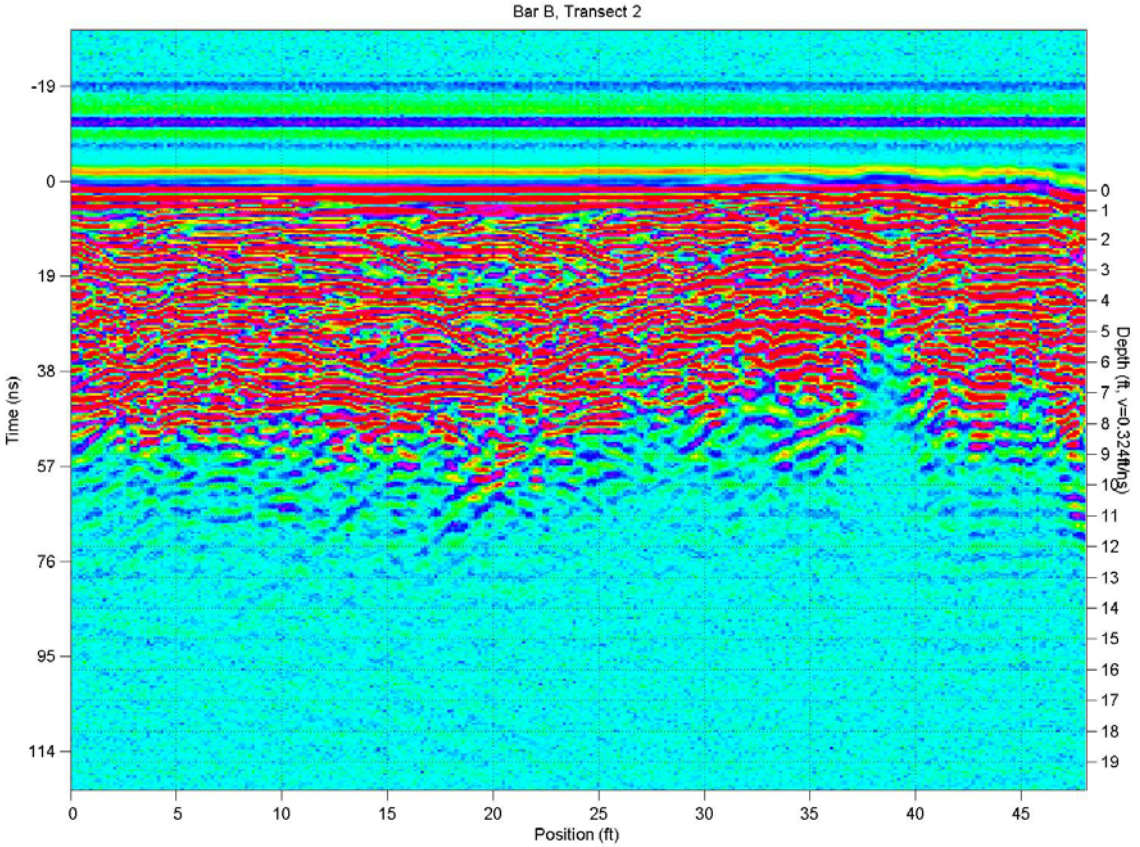
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Time (ns)
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38
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Position (ft)
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Depth (ft, v=0.324ft/ns)
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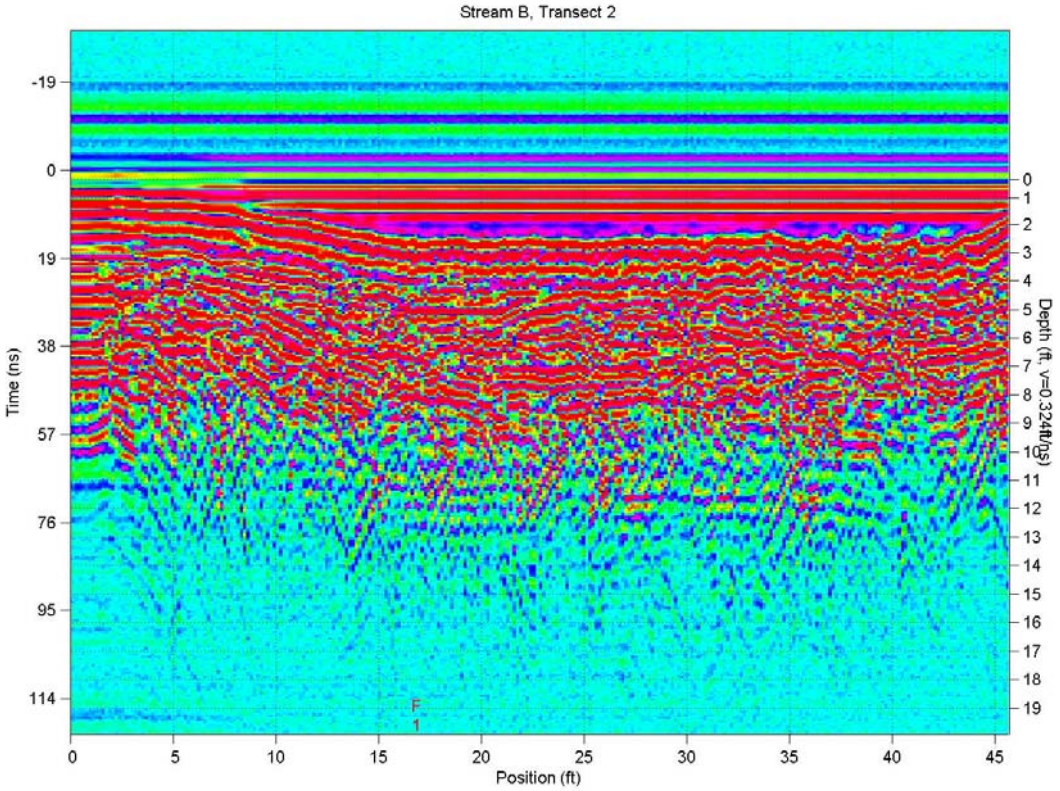
Stream B, Transect 2
Time (ns)
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Position (ft)
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Depth (ft, v=0.324ft/ns)
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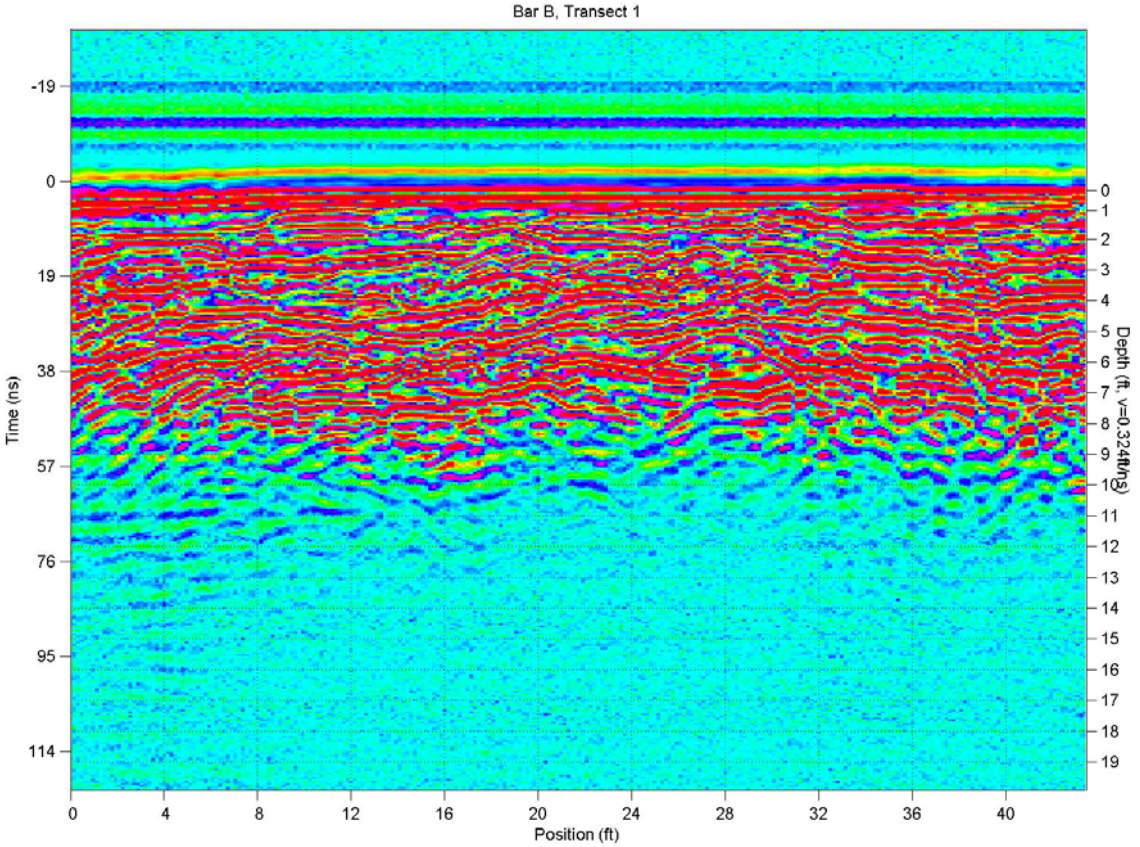
Bar B, Transect 1
Time (ns)
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Depth (ft, v=0.324ft/ns)
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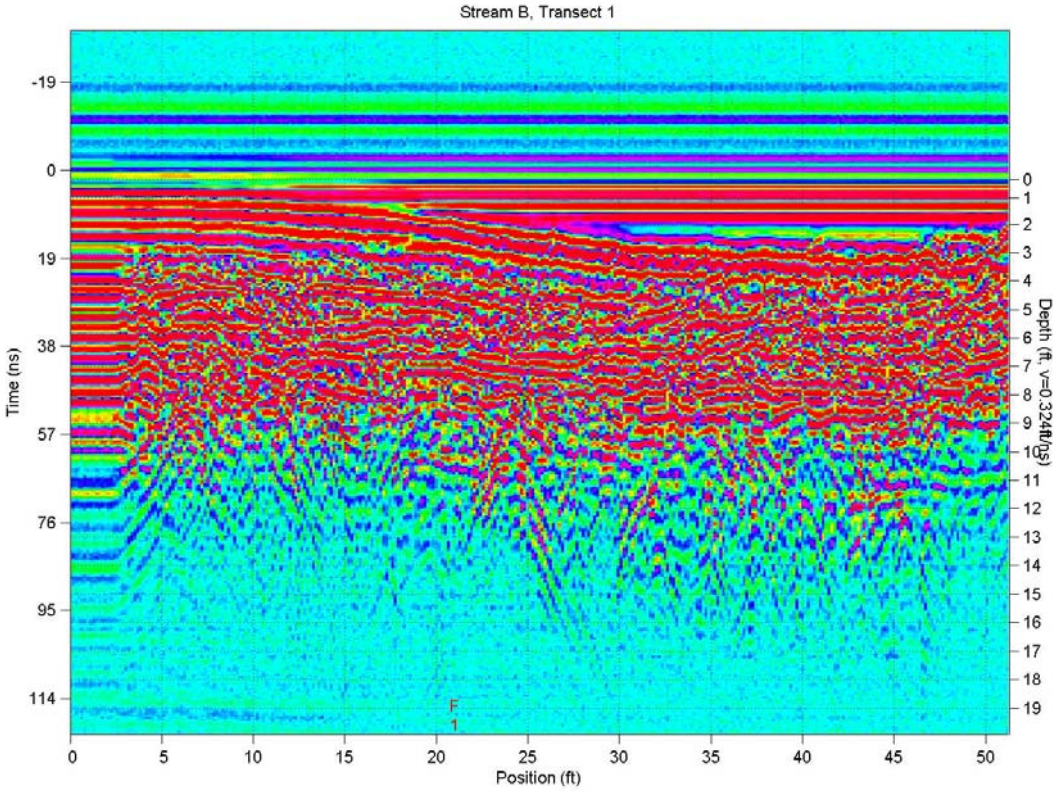
Stream B, Transect 1
Time (ns)
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Position (ft)
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Depth (ft, v=0.324ft/ns)
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Appendix B

ANOVA Using Metals Between Controls vs. Bar A and Bar B

One Way Analysis of Variance Friday, May 30, 2008, 7:50:59 AM

Data source: Lead Controls vs Bar A and B

Dependent Variable: Col 2

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 7:50:59 AM

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
Controls	3	0	28.881	20.808	35.511
Bar A	20	0	705.585	625.170	811.410
Bar B	20	0	643.737	570.111	731.202

H = 9.301 with 2 degrees of freedom. (P = 0.010)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.010)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Bar A vs Controls	23.600	3.036	Yes
Bar A vs Bar B	4.200	1.058	No
Bar B vs Controls	19.400	2.495	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Friday, May 30, 2008, 7:52:55 AM

Data source: Cadmium Controls vs Bar A and B

Dependent Variable: Col 4

Normality Test: Passed (P = 0.106)

Equal Variance Test: Passed (P = 0.882)

Group Name	N	Missing	Mean	Std Dev	SEM
Controls	3	0	5.134	3.162	1.825
Bar A	20	0	11.408	3.959	0.885
Bar B	20	0	13.226	4.049	0.905

Source of Variation	DF	SS	MS	F	P
Between Groups	2	177.061	88.530	5.628	0.007
Residual	40	629.202	15.730		
Total	42	806.263			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.007).

Power of performed test with alpha = 0.050: 0.755

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor: **Col 1**

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
Bar B vs. Controls	8.092	3.296	0.00206	0.017	Yes
Bar A vs. Controls	6.274	2.555	0.0145	0.025	Yes
Bar B vs. Bar A	1.818	1.450	0.155	0.050	No

One Way Analysis of Variance Friday, May 30, 2008, 7:54:03 AM

Data source: Zinc Controls vs Bar A and B

Dependent Variable: Col 6

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 7:54:03 AM

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
Controls	3	0	38.617	37.442	43.061
Bar A	20	0	368.232	348.565	406.732
Bar B	20	0	339.897	280.121	428.220

H = 9.098 with 2 degrees of freedom. (P = 0.011)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.011)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Bar A vs Controls	23.400	3.010	Yes
Bar A vs Bar B	3.800	0.957	No
Bar B vs Controls	19.600	2.521	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Appendix C

ANOVA Control Particle Sizes vs. Test Particle Sizes Using Metals Concentrations

One Way Analysis of Variance Friday, May 30, 2008, 10:19:48 AM

Data source: Lead Control vs Test by Particle Size

Dependent Variable: Col 32

Normality Test: Passed (P = 0.706)

Equal Variance Test: Passed (P = 0.119)

Group Name	N	Missing	Mean	Std Dev	SEM
Control Sand	3	0	37.752	15.617	9.017
Sand	40	0	663.913	165.750	26.207

Source of Variation	DF	SS	MS	F	P
Between Groups	1	1094169.112	1094169.112	41.850	<0.001
Residual	41	1071937.346	26144.813		
Total	42	2166106.458			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor: **Col 30**

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
Sand vs. Control Sand	626.161	6.469	0.0000000931	0.050	Yes

One Way Analysis of Variance Friday, May 30, 2008, 10:20:05 AM

Data source: Cadmium Control v Test by Particle Size

Dependent Variable: Col 33

Normality Test: Passed (P = 0.630)

Equal Variance Test: Passed (P = 0.284)

Group Name	N	Missing	Mean	Std Dev	SEM
Control Sand	3	0	5.777	3.877	2.238
Sand	40	0	18.528	9.098	1.438

Source of Variation	DF	SS	MS	F	P
Between Groups	1	453.767	453.767	5.710	0.022
Residual	41	3258.070	79.465		
Total	42	3711.837			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.022).

Power of performed test with alpha = 0.050: 0.558

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor: **Col 30**

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
Sand vs. Control Sand	12.751	2.390	0.0215	0.050	Yes

One Way Analysis of Variance Friday, May 30, 2008, 10:20:23 AM

Data source: Zinc Control vs Test by Particle Size

Dependent Variable: Col 34

Normality Test: Passed (P = 0.615)

Equal Variance Test: Passed (P = 0.063)

Group Name	N	Missing	Mean	Std Dev	SEM
Control Sand	3	0	52.139	2.429	1.403
Sand	40	0	344.488	108.433	17.145

Source of Variation	DF	SS	MS	F	P
Between Groups	1	238515.679	238515.679	21.326	<0.001
Residual	41	458564.446	11184.499		
Total	42	697080.125			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001).

Power of performed test with alpha = 0.050: 0.997

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor: **Col 30**

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
Sand vs. Control Sand	292.349	4.618	0.0000380	0.050	Yes

One Way Analysis of Variance Friday, May 30, 2008, 10:22:21 AM

Data source: Lead Control vs Test by Particle Size

Dependent Variable: Col 40

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 10:22:21 AM

Data source: Data 1 in control v particle size

Group	N	Missing	Median	25%	75%
Control Gravel	3	0	31.730	23.183	35.827
Gravel	40	0	842.682	720.110	1103.838

H = 8.182 with 1 degrees of freedom. (P = 0.004)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.004)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Gravel vs Control Gravel	21.500	2.860	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Friday, May 30, 2008, 10:22:38 AM

Data source: Cadmium Control vs Test by Particle Size

Dependent Variable: Col 41

Normality Test: Passed (P = 0.576)

Equal Variance Test: Passed (P = 0.914)

Group Name	N	Missing	Mean	Std Dev	SEM
Control Gravel	3	0	8.210	7.114	4.107
Gravel	40	0	12.578	8.297	1.312

Source of Variation	DF	SS	MS	F	P
Between Groups	1	53.247	53.247	0.784	0.381
Residual	41	2786.010	67.951		
Total	42	2839.257			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.381).

Power of performed test with alpha = 0.050: 0.047

The power of the performed test (0.047) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

One Way Analysis of Variance Friday, May 30, 2008, 10:23:00 AM

Data source: Zinc Control vs Test by Particle Size

Dependent Variable: Col 42

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 10:23:00 AM

Data source: Data 1 in control v particle size

Group	N	Missing	Median	25%	75%
Control Gravel	3	0	40.853	33.453	48.946
Gravel	40	0	369.535	290.970	460.300

H = 8.182 with 1 degrees of freedom. (P = 0.004)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.004)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Gravel vs Control Gravel	21.500	2.860	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Friday, May 30, 2008, 10:15:11 AM

Data source: Lead Control vs Test by Particle Size

Dependent Variable: Col 25

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 10:15:11 AM

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
Control Pebble	3	0	18.893	12.931	21.078
Pebble	40	11	410.247	284.057	544.762

H = 7.909 with 1 degrees of freedom. (P = 0.005)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.005)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Pebble vs Control Pebble	16.000	2.812	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Friday, May 30, 2008, 10:15:32 AM

Data source: Cadmium Control vs Test by Particle Size

Dependent Variable: Col 26

Normality Test: Failed ($P < 0.050$)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 10:15:32 AM

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
Control Pebble	3	0	0.000	0.000	3.182
Pebble	40	11	0.170	0.000	3.357

$H = 0.269$ with 1 degrees of freedom. ($P = 0.604$)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference ($P = 0.604$)

One Way Analysis of Variance Friday, May 30, 2008, 10:15:48 AM

Data source: Zinc Control vs Test by Particle Size

Dependent Variable: Col 27

Normality Test: Failed ($P < 0.050$)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Friday, May 30, 2008, 10:15:48 AM

Data source: Data 1 in Notebook 1

Group	N	Missing	Median	25%	75%
Control Pebble	3	0	26.463	25.858	28.071
Pebble	40	11	318.077	247.005	430.331

$H = 7.909$ with 1 degrees of freedom. ($P = 0.005$)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference ($P = 0.005$)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
Pebble vs Control Pebble	16.000	2.812	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

Appendix D

ANOVA Using Metals Means Between Particle Sizes

One Way Analysis of Variance Thursday, April 03, 2008, 7:13:59 AM

Data source: LEAD by Particle Size wo control

Dependent Variable: Col 6

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, April 03, 2008, 7:13:59 AM

Data source: Data 1 in size wo control tests

Group	N	Missing	Median	25%	75%
<2	40	0	639.525	558.053	789.893
2.000	40	0	842.682	720.110	1103.838
12.500	40	11	410.247	284.057	544.762

H = 42.373 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
2 vs 12.5	50.037	6.490	Yes
2 vs <2	24.150	3.417	Yes
<2 vs 12.5	25.887	3.358	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Thursday, April 03, 2008, 7:16:19 AM

Data source: CADMIUM by Particle Size wo control

Dependent Variable: Col 8

Normality Test: Passed (P = 0.077)

Equal Variance Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, April 03, 2008, 7:16:19 AM

Data source: Data 1 in size wo control tests

Group	N	Missing	Median	25%	75%
<2	40	0	19.195	10.404	25.710
2.000	40	0	11.378	7.090	18.127
12.500	40	11	0.170	0.000	3.357

H = 49.138 with 2 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method):

Comparison	Diff of Ranks	Q	P<0.05
<2 vs 12.5	53.478	6.937	Yes
<2 vs 2	16.750	2.370	No
2 vs 12.5	36.728	4.764	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.

One Way Analysis of Variance Thursday, April 03, 2008, 7:17:36 AM

Data source: ZINC by Particle Size wo control tests

Dependent Variable: Col 10

Normality Test: Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks Thursday, April 03, 2008, 7:17:36 AM

Data source: Data 1 in size wo control tests

Group	N	Missing	Median	25%	75%
<2	40	0	324.475	257.483	423.892
2.000	40	0	369.535	290.970	460.300
12.500	40	11	318.077	247.005	430.331

H = 3.465 with 2 degrees of freedom. (P = 0.177)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.177)

Appendix E

T-tests Between Washed vs. Not Washed Samples and Dataset

Paired t-test: Wednesday, January 23, 2008, 7:32:21 AM

Data source: Sieve Test Washed vs Not Washed – Pebble Size Material

Normality Test: Failed ($P < 0.050$)

Test execution ended by user request, Signed Rank Test begun

Wilcoxon Signed Rank Test Wednesday, January 23, 2008, 7:32:21 AM

Data source: tat wash v not

Group	N	Missing	Median	25%	75%
pebble	36	0	316.500	201.500	627.000
pebble wash	36	0	452.000	263.000	783.000

W = 104.000 T+ = 385.000 T- = -281.000
Z-Statistic (based on positive ranks) = 0.817
(P = 0.418)

The change that occurred with the treatment is not great enough to exclude the possibility that it is due to chance (P = 0.418).

Paired t-test: Wednesday, January 23, 2008, 7:31:03 AM

Data source: Sieve Test Washed vs Not Washed- Gravel Size Material

Normality Test: Passed (P = 0.229)

Treatment Name	N	Missing	Mean	Std Dev	SEM
gravel	36	0	994.139	831.063	138.511
gravel wash	36	0	912.861	610.710	101.785
Difference	36	0	81.278	996.587	166.098

t = 0.489 with 35 degrees of freedom. (P = 0.628)

95 percent confidence interval for difference of means: -255.919 to 418.474

The change that occurred with the treatment is not great enough to exclude the possibility that the difference is due to chance (P = 0.628)
Power of performed test with alpha = 0.050: 0.050
The power of the performed test (0.050) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Appendix E: Data Table-Raw numbers used to generate t-test

number raw	2	2 wash	12.5	12.5 wash
H0602928	479	1015	111	390
B5.51.0	657	555	2092	965
	493	548	824	575
2932	962	925	359	821
B1.29.0	475	701	679	630
	1054	881	394	442
2901	994	812	78	322
B7.12.2	627	326	924	90
	2092	758	121	487
2919	680	931	430	247
B14.33.0	140	1266	526	417
	713	216	275	592
2912	514	861	281	466
Native 2	1295	1049	288	279
	1180	447	77	745
2908	368	923	884	435
B10.44.2	244	731	507	53
	211	1145	575	190
2909	256	387	547	144
B10.44.1	2396	99	563	44
	807	1084	220	1138
2904	948	1149	83	371
Native 2.1	4670	1403	161	216
	635	852	1321	462
2939	1586	1149	856	212
A14.63.0	1201	537	800	671
	592	366	345	563
2940	436	1008	248	288
A13.39.0	1684	1040	202	365
	1125	3770	125	1030
2910	362	623	265	6316
Native 3.0	558	1638	274	856
	1319	932	150	44
2911	1722	716	276	1286
Native 2.0	1526	377	201	1592
	788	1643	1261	1636

Appendix F

ANOVA Using Metals Means on the Vertical Extent

One Way Analysis of Variance Tuesday, May 20, 2008, 8:13:26 AM

Data source: Lead Concentration by Depth

Dependent Variable: Col 6

Normality Test: Passed (P = 0.612)

Equal Variance Test: Passed (P = 0.945)

Group Name	N	Missing	Mean	Std Dev	SEM
0 (surface)	12	0	672.598	341.853	98.684
1 foot	12	0	844.944	369.988	106.806
2 feet	9	0	720.519	310.643	103.548
3 feet	6	0	785.722	467.870	191.007

Source of Variation	DF	SS	MS	F	P
Between Groups	3	194891.006	64963.669	0.488	0.693
Residual	35	4657797.969	133079.942		
Total	38	4852688.974			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.693).

Power of performed test with alpha = 0.050: 0.049

The power of the performed test (0.049) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

One Way Analysis of Variance Tuesday, May 20, 2008, 8:14:53 AM

Data source: Cadmium Concentration by Depth

Dependent Variable: Col 8

Normality Test: Passed (P = 0.143)

Equal Variance Test: Passed (P = 0.574)

Group Name	N	Missing	Mean	Std Dev	SEM
0 (surface)	12	0	10.843	10.474	3.024
1 foot	12	0	10.978	8.098	2.338
2 feet	9	0	14.110	11.919	3.973
3 feet	6	0	12.217	11.848	4.837

Source of Variation	DF	SS	MS	F	P
Between Groups	3	68.071	22.690	0.211	0.888
Residual	35	3766.441	107.613		
Total	38	3834.512			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.888).

Power of performed test with alpha = 0.050: 0.049

The power of the performed test (0.049) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

One Way Analysis of Variance Tuesday, May 20, 2008, 8:16:09 AM

Data source: Zinc Concentration by Depth

Dependent Variable: Col 10

Normality Test: Passed (P = 0.174)

Equal Variance Test: Passed (P = 0.773)

Group Name	N	Missing	Mean	Std Dev	SEM
0 (surface)	12	0	331.257	119.440	34.479
1 foot	12	0	535.565	197.378	56.978
2 feet	9	0	400.700	161.434	53.811
3 feet	6	0	385.510	166.594	68.012

Source of Variation	DF	SS	MS	F	P
Between Groups	3	265167.215	88389.072	3.317	0.031
Residual	35	932717.308	26649.066		
Total	38	1197884.523			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.031).

Power of performed test with alpha = 0.050: 0.528

All Pairwise Multiple Comparison Procedures (Holm-Sidak method):
Overall significance level = 0.05

Comparisons for factor: **Col 2**

Comparison	Diff of Means	t	Unadjusted P	Critical Level	Significant?
1.000 vs. 0.000	204.308	3.066	0.00417	0.009	Yes
1.000 vs. 2.000	134.865	1.874	0.0694	0.010	No
1.000 vs. 3.000	150.055	1.838	0.0745	0.013	No
2.000 vs. 0.000	69.442	0.965	0.341	0.017	No
3.000 vs. 0.000	54.252	0.665	0.511	0.025	No
2.000 vs. 3.000	15.190	0.177	0.861	0.050	No