United States Department of Agriculture	**Natural Resources Conservation Service**	**100 Campus Boulevard Suite 200 Newtown Square, PA 19087-4585**

Subject: ENG -- Geophysical Assistance **Date:** 14 October 2008

To: Jeff Burwell
State Conservationist
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Purpose:
Ground-penetrating radar (GPR) was used to estimate the depth to basalt along the route of the proposed Arcadia Pipeline in Fremont County, Idaho.

Principal Participants:
Kenneth Beckmann, Soil Conservationist, USDA-NRCS, St. Anthony, ID
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Glenn Hoffman, MLRA Project Leader, USDA-NRCS, Idaho Falls, ID
Paul Pedone, Geologist, USDA-NRCS, Portland, OR

Activities:
A GPR survey along the route of the proposed Arcadia Pipeline was completed on 17 and 18 September 2008.

Summary:

1. Approximately 14070 linear feet (2.66 miles) of GPR records were collected along portions of the route of the proposed Arcadian Pipeline.

2. Because of their clay content and mineralogy and the presence of some soluble salts, soils along the route of the Arcadia Pipeline are considered marginally suited to GPR. In these soils, with increasing depths, signal attenuation progressively weakened reflected signals to a point where subsurface interfaces were indiscernible. On most radar records, the underlying basalt was either not observed or was observed, but could not be traced laterally for great distances with any degree of confidence. In those soils where it was not observed, it could only be interpreted as being deeper than deepest subsurface interface identified on the radar records. In those soils where basalt bedrock was sporadically observed, its absence was presumed to reflect an occurrence at greater depths.

3. A number of soil interfaces were noticed in the upper parts of radar records. Typically these interfaces were closely spaced, segmented, with overlapping or superimposed reflections. As core observations were limited, only a few of these interfaces could be identified. Most were identified as either lenses having different grain- or particle-size distributions, or basalt bedrock. At greater soil depths, the faint and blurred reflections from lenses and basalt bedrock are easily confused. It is probably that in some places lithologic and stratigraphic layers were confused and misidentified.

4. Based on radar interpretations, the vast majority of soils along the route of the proposed Arcadia Pipeline are very deep (>150 cm) to bedrock. An area referred to as the *Middle Leg* contains the

greatest concentration of shallower (<150 cm) soils. A large portion of the *Middle Leg* occurs in a delineation of Jipper-Nayrib-Stipe complex, 1 to 6 % slopes.

5. A disk that contains the raw radar data files from this survey has been mailed to Paul Pedone under a separate cover letter.

It was my pleasure to work in Idaho and to be of assistance to you and your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH). [1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate (see Figure 2). An antenna with a center frequency of 200 MHz was used in this study. Daniels (2004) discusses the use and operation of GPR.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records. [1] Processing included: GPS option, header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, high-pass filtration, and migration (see Daniels (2004) for a discussion of these techniques).

The SIR-3000 system provides for the simultaneous use of a GPS receiver and serial data recorder (SDR). With this setup, each scan on a radar record can be georeferenced (position/time matched). Position data were recorded with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1] In RADAN, the coordinates for each radar scan are proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. In this study, on the GPR control unit, the scanning rate was set to 40 scans per second. As each scan of the radar is essentially georeferenced, the integration of GPS with GPR results in incredibly large data sets. Using the *Interactive Interpretation* module of the RADAN processing software, depths to subsurface features were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, depths, and other useful data).

Background:
The route of the proposed Arcadia Pipeline is located in southwestern Fremont County. This pipeline will cross soils having basalt parent rock at depths ranging from less than 25 cm to more than 200 cm. In a few places along this route, basalt can be seen to outcrop. The pipe will be placed in an excavated trench at a depth of about 150 cm. Soils with basalt within these depths will impact the costs and time required to construct this pipeline. Paul Pedone requested GPR assistance to help estimate the depth to basalt along the proposed route of the pipeline.

Study Sites:
The route of the proposed Arcadia Pipeline is located in south-central Fremont County. The pipeline is presently planned to essentially parallel Spring Creek between the southwestern ¼ of Section 13, T. 9 N., R. 41 E.; and the southwestern ¼ of Section 29, T. 9 N., R. 42 E. The track of this pipeline passes thru areas mapped as Jipper fine sandy loam, 1 to 6 % slopes (37); Jipper-Nayrib-Stipe complex, 1 to 6 % slopes (38); Snowshoe loamy fine sand, 1 to 6 % slopes (114); and St. Anthony gravelly loamy sands, 0 to 4 % slopes (121) (Web Soil Survey).

The well drained, very shallow (0 to 25 cm) Nayrib, moderately deep (50 to 100 cm) Stipe, and deep (100 to 150 cm) and very deep (>150 cm) Jipper soils formed in eolian deposits from mixed sources on basalt plains. The very deep, well drained St. Anthony soils formed in gravelly alluvium from mixed sources on stream terraces. The very deep, well drained Snowshoe soils formed on stabilized dunes. The taxonomic classifications of these soils are listed in Table 1.

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[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Table 1. Taxonomic classification of dominant soils mapped along the route of the proposed Arcadia Pipeline.

Soil Series	Taxonomic Classification
Jipper	Coarse-loamy, mixed, superactive, frigid Calcic Pachic Haploxerolls
Nayrib	Loamy-skeletal, mixed, superactive, frigid Lithic Haploxerolls
Snowshoe	Coarse-loamy, mixed, superactive, frigid Typic Haploxerepts
St. Anthony	Loamy-skeletal, mixed, superactive, frigid Calcic Pachic Haploxerolls
Stipe	Coarse-loamy, mixed, superactive, frigid Calcic Pachic Haploxerolls

The very shallow to bedrock Nayrib soils and the sandy Snowshoe soils are considered well suited to GPR (http://soils.usda.gov/survey/geography/maps/GPR/index.html). Jipper, St. Anthony, and Stipe soils have higher clay contents, calcareous horizons, and are more attenuating and depth restrictive to GPR. These soils are considered only moderately suited to GPR. In these soils, GPR penetration depths were less than 1.5 m and subsurface interfaces generally provided weak reflections, which were difficult to interpret with confidence on even processed radar records.

A large segment of the proposed pipeline will cross areas of somewhat poorly to very poorly drained soils, which were not recognized in the soil survey of Fremont County. In addition, these soils, when observed in extracted cores, were stratified and had higher than anticipated clay contents. Because of the higher clay and moisture contents of these soils, the effective penetration depth (with a 200 MHz antenna) was estimated to be about 100 cm. Segments of these wetter, higher clay content soils are located in the northern ½ of Section 30 and the western ½ of Section 29, T. 9 N., R. 42 W. About 4900linear feet of radar records were collected in areas of these soils.

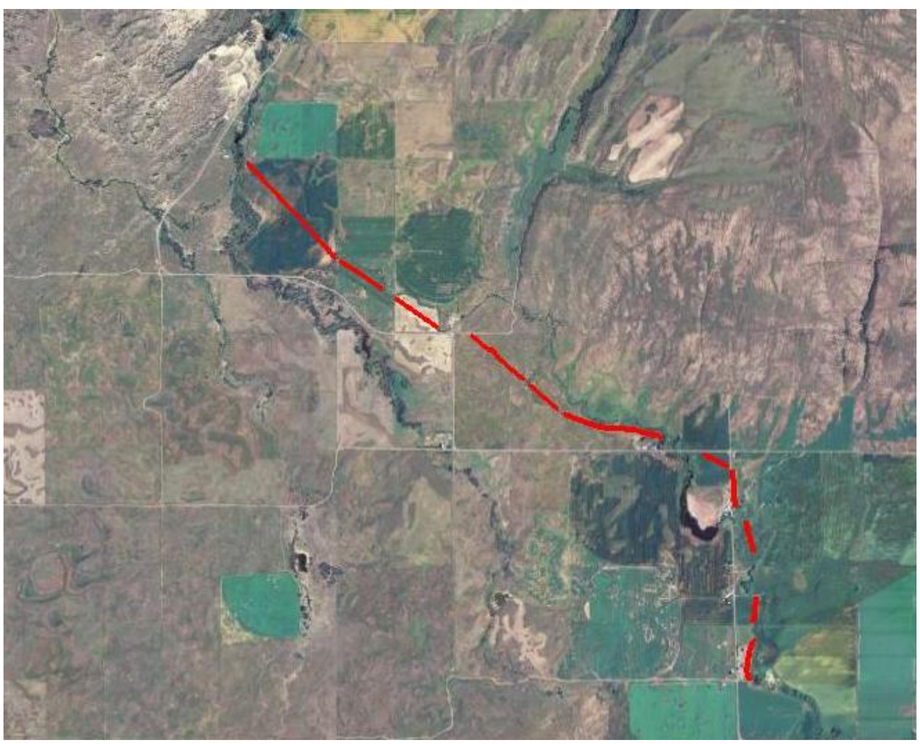

Figure 1. The sections of the proposed Arcadia Pipeline that were surveyed with GPR are shown on this Goggle Earth image.

Survey Procedures:
The proposed Arcadia Pipeline will be about 3.46 miles long. About 2.66 miles of the proposed route was surveyed with GPR (see Figure 1). One radar record was incorrectly formatted and the data were lost. Along most of this proposed route, pedestrian GPR traverses were conducted with a 200 MHz antenna (Figure 2). Typically, a radar traverse was started and ended at field boundaries. Each radar record was reviewed in the field. Soil cores were extracted at several locations for ground control and to verify the identities of some subsurface interfaces recognized on radar records.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., bedrock, soil horizon, stratigraphic layer) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (*v*) are described in equation [1] (after Daniels, 2004):

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

$$E_r = (C/v)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

Figure 2. Paul Pedone assists with a GPR survey along the route of the proposed Arcadia Pipeline.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (metal plate buried at 50 cm) or identified (through extracted soil cores) subsurface features (e.g., soil horizon, stratigraphic layer, bedrock contact), the *v* and E_r of the upper part of soil profiles were estimated using equations [1] and [2] for different segments of the survey. For the surface layers of Snowshoe soils, an estimated E_r of 4.92 resulted in a *v* of 0.1344 m/ns. For the surface layers of the slightly higher-lying and drier Jipper soils, an estimated E_r of 4.19 resulted in a *v* of 0.1456 m/ns. In wetter areas (northern ½ of Section 30 and the western ½ of Section 29, T. 9 N., R. 42 W), the surface layers had an estimated E_r of 6.73, which resulted in a *v* of 0.1148 m/ns. As soil properties are spatially variable, horizontal and vertical variations in *v* will exist and affect the accuracy of depth scales used on the radar records. Because of variations in these properties, radar interpretations were restricted to depths of 1.5 m. In addition, for many of the soils located along the *Last Leg* of the radar traverses, saturated soil conditions occur within depths of 70 to 100 cm. Depth scales will be more inaccurate below these depths. In areas of wetter soils, depth interpretations were restricted to the upper 100 cm of the soil profile.

Results:

<u>The *First Leg*</u>:

Along the First L*eg* (see Figure 3), the radar traverses cut across mapped areas of Snowshoe loamy fine sand, 1 to 6 % slopes, and Jipper fine sandy loam, 1 to 6 % slopes. In general, attenuation rates increased, penetration depths decreased, and interpretations became more unclear with increasing distance from the start of this leg. In these soils, below a depth of about 150 cm, radar signals were severely attenuated, signal-to-noise ratios were lower, meaningful imagery was faint and ambiguous, and interpretations could not be made with confidence. Along the *First Leg*, the depth to basalt was interpreted to be mostly greater than 150 cm (see Figure 3).

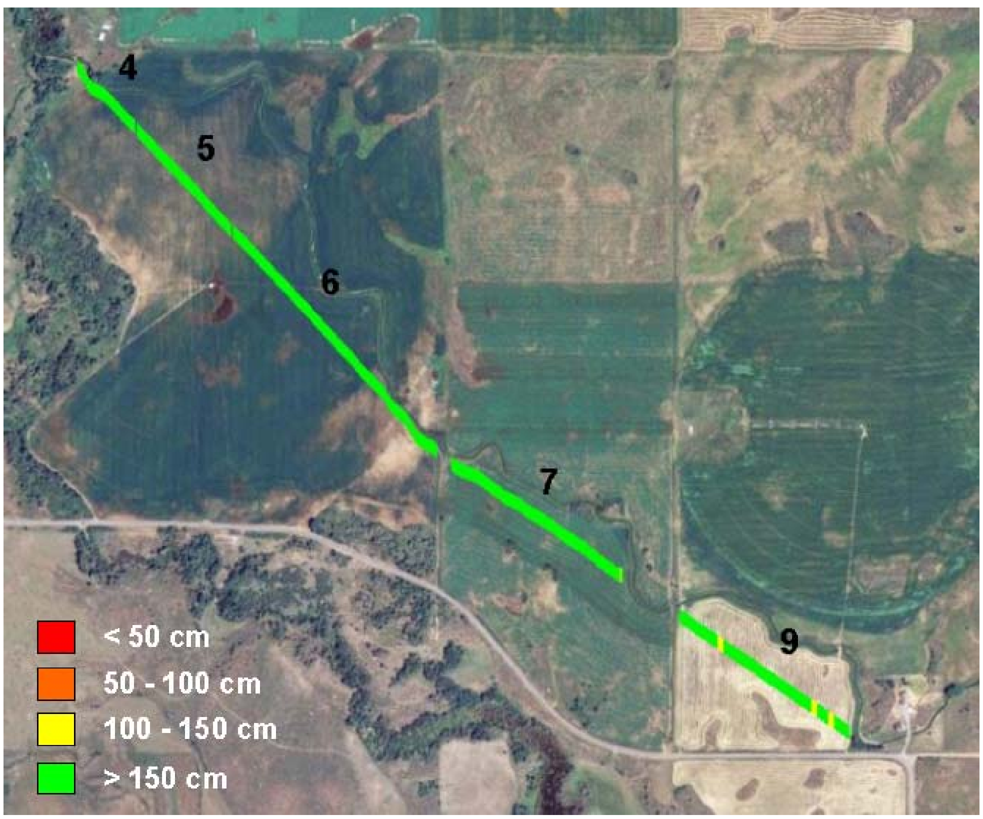

Figure 3. The depth to basalt bedrock as interpreted from radar record collected along the First Leg of the route for the proposed Arcadia Pipeline. Numbers identify radar files and traverses.

Figure 4 provides a relatively unprocessed (upper) and processed (lower) images of the same radar record, which was collected along GPR traverse line 4 (see Figure 3), in an area of Snowshoe loamy fine sand, 1 to 6 % slopes. The low clay and moisture contents of Snowshoe soils provide a medium that is well suited to GPR. Low rates of signal attenuation resulted in well-expressed features evident on the radar record to estimated depths as great as 6 m. In the lower plot of Figure 4, signal stacking and high-pass filtration were used to reduce both high (appears as snow) and low (appears as parallel, horizontal bands) frequency noise. These processing steps improved the signal-to-noise ratio and enhanced the interpretability of the radar record. In Figure 4, a red-colored, segmented line has been used to identify a moderately deep and deep, contrasting subsurface layer. A green-colored, segmented line has been used to identify a very deep, unidentified subsurface interface. Based on the interpretation of this radar record, the depth to basalt is greater than 150 cm along the entirety of GPR traverse line 4.

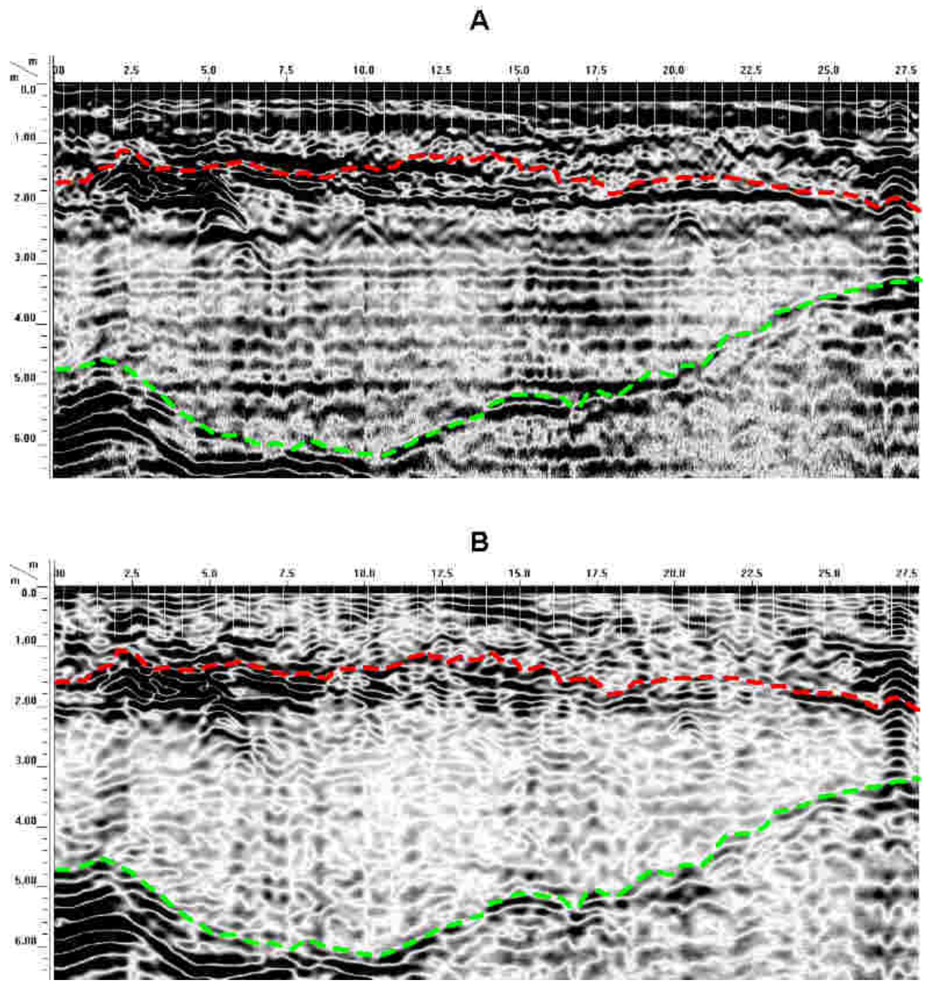

Figure 4. This unprocessed (A) and processed (B) radar record is from GPR traverse line 4, which was collected in an area of Snowshoe loamy fine sand, 1 to 6 % slopes.

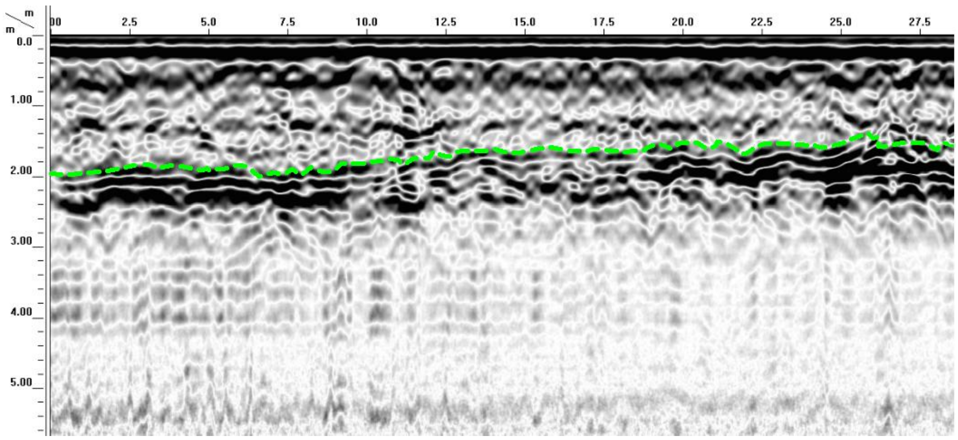

Figure 5. This radar record is from is from GPR traverse line 5, which was collected in an area of Jipper fine sandy loam, 1 to 6 % slopes. In this area, Jipper soils have a loamy substratum (marked with green-colored line).

The second thru fifth GPR traverse lines (in Figure 3, lines 5 thru 9) were conducted in an area of Jipper fine sandy loam, 1 to 6 % slopes. The higher clay and calcium carbonate contents of Jipper soils increased the rates of signal attenuation. This resulted in reduced penetration depths, lower signal-to-noise ratios, poorer image quality, and lower confidence in interpretations. With each succeeding GPR traverse line, signal-to-noise ratios became lower; subsurface reflections became weaker, more indistinct and segmented; and radar interpretations became less clear and more uncertain. However, depths to basalt bedrock could be interpreted (based on site condition, core observations, and radar interpretations) to depths of at least 150 cm along these GPR traverse lines.

Figure 5 is a relatively unprocessed radar record that was collected along GPR traverse line 5 (see Figure 3), in an area of Jipper fine sandy loam, 1 to 6 % slopes. The higher clay and calcium carbonate contents of Jipper soils provide a medium that is only moderately suited to GPR. These properties fostered higher rates of signal attenuation, which resulted in lower signal-to-noise ratios and reduced penetration depths (about 2 to 2.5 m). In Figure 5, a green-colored, segmented line has been used to identify a very deep, contrasting subsurface layer. Based on core observations, this subsurface layer was identified as a higher clay content stratum. Based on the depth to this interface, the depth to the underlying basalt, though not observed, must be interpreted to be greater than 150 cm along the entirety of GPR traverse line 5 (see Figure 3).

Figure 6 illustrates a relatively unprocessed (upper) and processed (lower) image of the same radar record, which was collected along GPR traverse line 6 (see Figure 3), in an area of Jipper fine sandy loam, 1 to 6 % slopes. Noticeably higher rates of signal attenuation reduced the amount of energy reflected from subsurface interfaces and further limited the effective penetration depth. Because of the higher rates of signal attenuation and lower signal-to-noise ratios, interpretations could not be made with confidence below depths of about 1.8 m. In Figure 6, the beneficial effects of signal stacking and high-pass filtration on soil interpretations can be seen in the lower plot. These processing techniques were used to lowered unwanted background noise and help improve the interpretability of the radar record. In general, these techniques helped to improve interpretations only in the upper 1.8 m of the soil profile. Below this depth, signal-to-noise ratios were low and subsurface reflections were too weak, ill-defined, and segmented for identification. In this plot, a green-colored segment line has been used to approximate the depth to the lower-most interpreted soil interface. Nearby ground-truth cores indicate that this interface does not represent the underlying basalt.

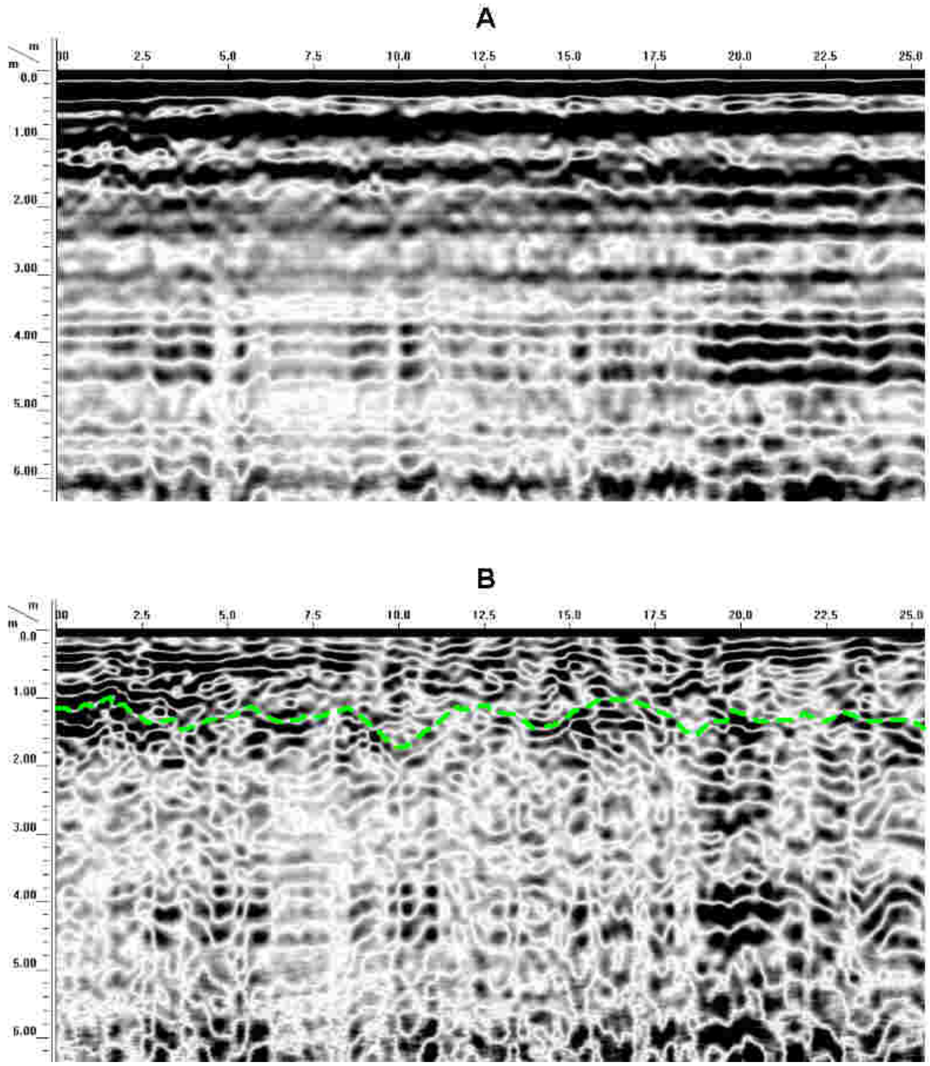

Figure 6. This unprocessed (A) and processed (B) radar record is from an area of Jipper soils.

<u>The *Middle Leg*:</u>

The M*iddle Leg* of GPR traverses is about 4000 feet long (see Figure 7). This leg began in an area of rangeland that had been mapped as Jipper-Nayrib-Stipe complex, 1 to 6 % slopes. Within this unit, basalt was known to occur at relatively shallow depths and outcrops are evident along portions of GPR traverse lines 10 and 13. Along this leg, the second and third (files 13 and 14) GPR traverses were conducted across areas of the St. Anthony gravelly loamy sands, 0 to 4 % slopes; and Jipper fine sandy loam, 1 to 6 percent slopes. In general, interpretations could still be made on radar records to depths as great as 150 cm (see Figure 8). However, because of relatively high rates of signal attenuation, most subsurface reflectors, including the soil/bedrock contact, were weakly expressed, discontinuous, and difficult to trace laterally with confidence. Soil cores obtained along the last traverse line of this leg (file 14) revealed soils with increasing clay (clay loams) and moisture contents (a water table was observed within depths of 150 cm in one core).

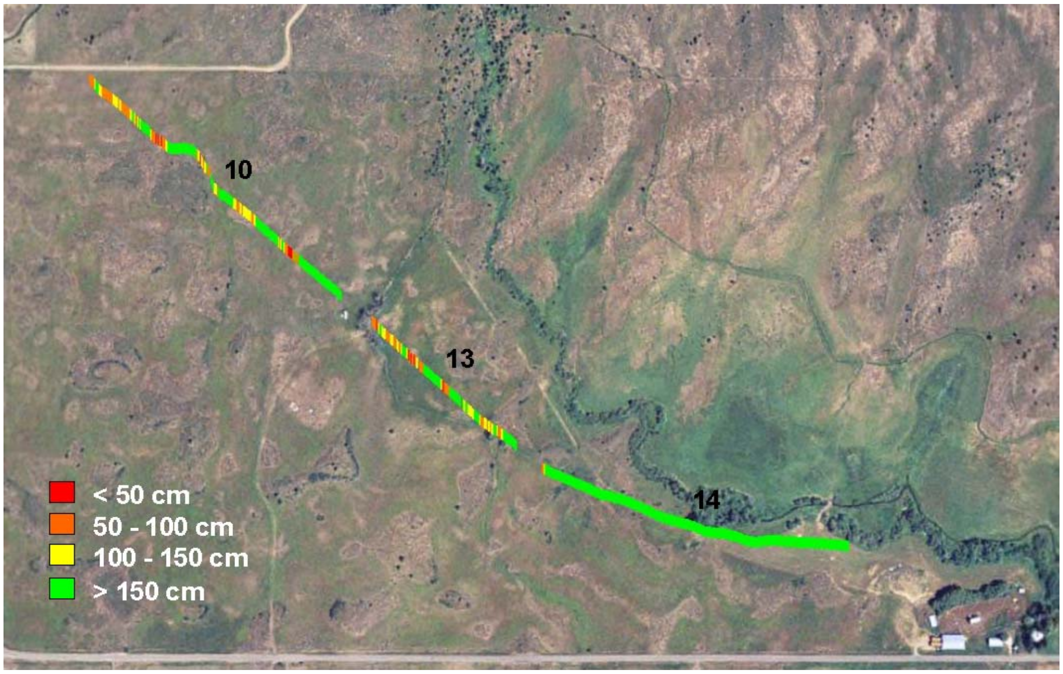

Figure 7. The depth to basalt bedrock as interpreted from radar record collected along the Middle Leg of the route for the proposed Arcadia Pipeline.

Figure 8 contains a relatively unprocessed (A) and processed (B) image of the same portion of a radar record (collected along GPR traverse line 10). This radar record was collected in an area of Jipper-Nayrib-Stipe complex, 1 to 6 % slopes. In the lower plot, a green-colored line approximates the interpreted soil/bedrock interface. As can be seen in these plots, signal processing was useful in removing most bands of low-frequency background noise, which plagued the unprocessed radar record and obscured some subsurface interfaces. However, even on the processed radar record, meaningful interpretations are generally restricted to depths of less than 150 cm. Interpretations could be extended to slightly greater depth, but with less confidence.

Even in areas where the soil/bedrock interface was known to be within depths of 2 m, it seldom produced a reflector that could be traced laterally across a radar record. The soil/bedrock interface was variable in depth and produced a wide range of reflections amplitudes. The poor continuity and strength of reflected signals from this interface are associated with higher rates of signal attenuation in these soils. Reflected signal amplitudes are dependent on depth and subsurface topography of the basalt, presence of other scattering bodies or layers (rock fragments and gravel layers were observed in soil cores), and properties (clay, moisture, calcium carbonate contents) of the overlying soil materials.

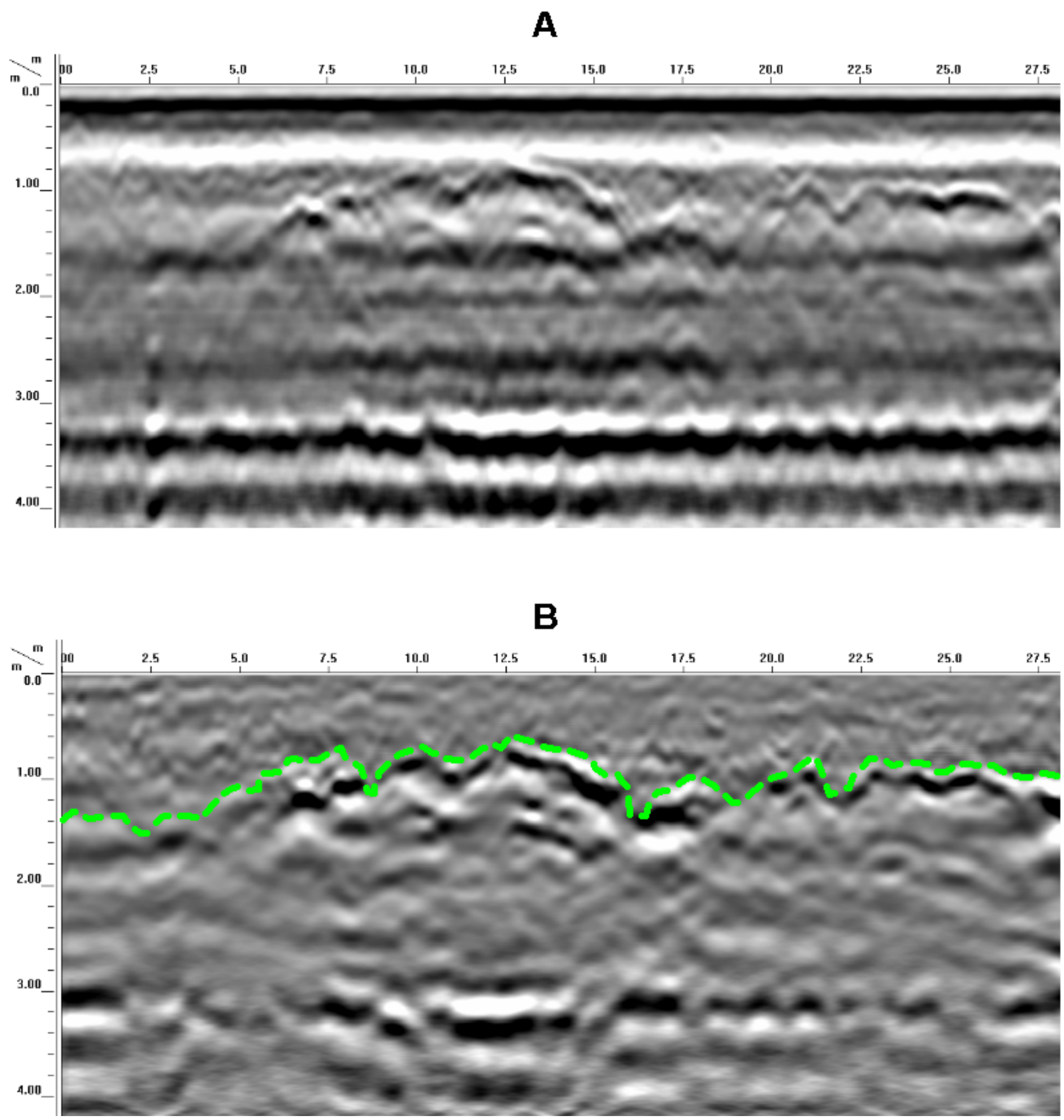

Figure 8. This unprocessed (A) and processed (B) radar record is from GPR traverse line 10, which was collected in an area of Jipper-Nayrib-Stipe complex, 1 to 6 % slopes. In the lower plot, a green-colored line approximates the interpreted soil/bedrock interface.

<u>The *Last Leg*:</u>

The *Last Leg* of GPR traverses is about 4900 feet long (see Figure 9). This leg transitioned from an area mapped as St. Anthony gravelly loamy sands, 0 to 4 % slopes, to an area mapped as Jipper fine sandy loam, 1 to 6 percent slopes. As noted earlier in this report, these delineations are improperly named. The soils along the traverses shown in Figure 9 are wetter and contain higher clay content strata than allowed by these soil series. These properties produced higher rates of signal attenuation and more variable E_r and v profiles. These factors severely limited the depth of signal penetration, increased the levels of unwanted background noise, reduced the clarity of subsurface reflectors, and lowered confidence in interpretations. As a consequence, along these traverse lines, radar interpretations were restricted to the upper 100 cm of the soil profile.

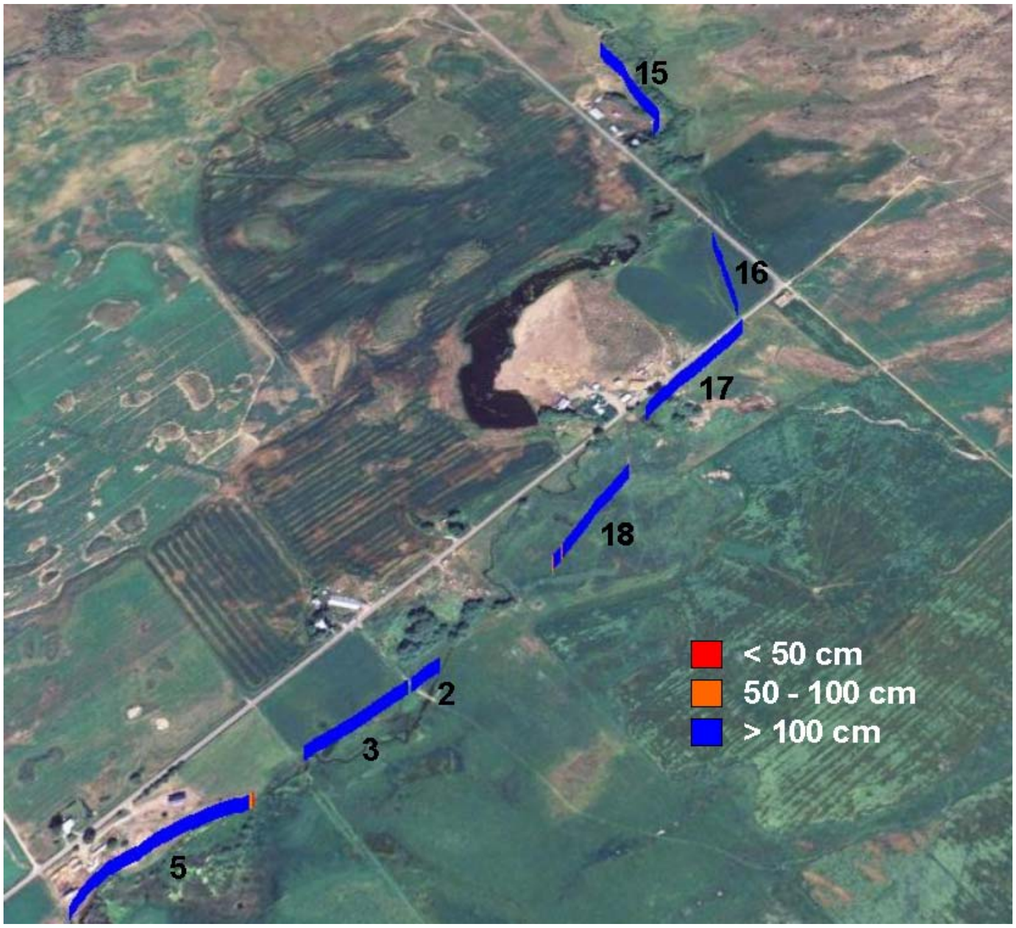

Figure 9. The depth to basalt bedrock is interpreted from radar record files collected along the set of radar traverses conducted along the wetter and finer-textured southern portion of the proposed route for the Arcadia Pipeline.

Portions of radar traverse lines 17 and 5 crossed areas with remnants of former farm structures and/or that contained high concentrations of surficial and/or shallowly buried *cultural features* (i.e., machinery parts, foundation stones, pipes). These *cultural features* produced unwanted reflections, which obscured subsurface interfaces and confounded interpretations of the basalt bedrock. Only traverse lines 18 and 5 (see Figure 9) contained subsurface interfaces that could be identified as bedrock within depths of 100 cm. For the remaining traversed areas along the *Last Leg*, the depth to bedrock was interpreted to be greater than 100 cm.

Summary:

A majority of the soils along the route of the proposed Arcadia Pipeline are marginally suited to GPR investigations. On most radar records, the underlying basalt was either not observed or was observed, but could not be traced laterally for great distances with any degree of confidence. In those portions where it was not observed, it was assumed to be deeper than the deepest subsurface interface identified on the radar record. In those portions where it was sporadically observed, its absence was presumed to reflect an occurrence at greater depths. With increasing soil depths signal attenuation progressively weaken reflected signals to a point where interfaces are indiscernible. A number of soil interface were noticed in the upper parts of some radar records. Typically these interfaces were closely spaced, segmented, with overlapping or superimposed reflections. As core observations were limited, only a few of these interfaces were identified. Identified interfaces were either lenses having different grain- or particle-size distributions or bedrock. At greater soil depths, faint and blurred reflections from lenses and bedrock can be easily confused. It is therefore probably that, in some places, stratigraphic and lithologic layers were confused and misidentified.

Acknowledging these limitations, the following tables summarize the radar interpretations. Tables 2, 3, and 4 summarize radar interpretations on the depth to bedrock for the *First*, *Middle*, and *Last Legs*, respectively. Within each table, GPR traverses are organized by file number. For each radar traverse, the estimated length and the frequency distribution of depth interpretations (according to soil depth classes) are listed (see Figures 3, 7, and 9 for the locations of traverse lines). The soil depth classes are shallow (< 50 cm; < 20 inches), moderately deep (50 to 100 cm; 20 to 40 inches), deep (100 to 150 cm; 40 to 60 inches) and very deep (> 150 cm; > 60 inches).

Table 2. Frequency distribution of radar interpretations of the depth to basalt for the First Leg of radar traverses. Interpretations are grouped according to soil depth classes.

File	**4**	**5**	**6**	**7**	**9**
Length (ft)	*482*	*775*	*1682*	*1151*	*1166*
shallow	0.00	0.00	0.00	0.00	0.00
moderately deep	0.00	0.00	0.00	0.00	0.00
deep	0.00	0.00	0.00	0.00	0.11
very deep	1.00	1.00	1.00	1.00	0.89

Table 3. Frequency distribution of radar interpretations of the depth to basalt for the Middle Leg of radar traverses. Interpretations are grouped according to soil depth classes.

File	**10**	**13**	**14**
Length	*1158*	*875*	*1463*
shallow	0.03	0.04	0.00
moderately deep	0.26	0.30	0.02
deep	0.19	0.25	0.00
very deep	0.51	0.41	0.98

Table 4. Frequency distribution of radar interpretations of the depth to basalt for the Last Leg of radar traverses. Interpretations are grouped according to soil depth classes. Because of the restricted penetration depth and ambiguities in interpretations, the very deep and deep soil depth classes have been combined.

File	**15**	**16**	**17**	**18**	**2**	**3**	**5**
Length	*904*	*611*	*852*	*722*	*190*	*615*	*1021*
shallow	0.00	0.00	0.00	0.00	0.00	0.00	0.01
moderately deep	0.00	0.00	0.00	0.03	0.00	0.00	0.02
deep and very deep	1.00	1.00	1.00	0.97	1.00	1.00	0.97

References:

Daniels, D. J. 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.