United States Department of Agriculture	**Natural Resources Conservation Service**	**11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: ENG -- Ground-Penetrating Radar (GPR) Assistance **Date:** 24 October 2005

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Purpose:
The purpose of this study was to use ground-penetrating radar (GPR) to help characterize the internal stratigraphy and depth to basalt beneath mima mounds within the Fairchild Air Force Base, which is located near Spokane, Washington.

Activities:
All field activities were completed on 9 and 10 October 2005.

Survey Area:
The site is located in an area of native grasses in the southeast portion of the airbase. At the time of the survey, soils were dry. The survey area consisted of mima mounds and inter-mound areas. The well drained, deep Deno and very deep Cheney soils are on the mounds. Typically these soils form in glaciofluvial deposits over basalt on the Channel Scablands. These soils have surface mantles of ash, loess and locally derived glaciofluvial sediments. At the Fairchild Air Force Base, soils form predominately in loess and volcanic ash with very little glaciofluvial deposits (Chris Miller, Soil Scientists, USDA-NRCS, personal communication). The shallow and very shallow, well drained Rockly soil is believed to occupy inter-mound areas. Table 1 lists the taxonomic classifications of these soils. Inter-mound areas also contain sections of exposed basalt parent rock. Where exposed, the surface of the basalt is highly pitted and has a very irregular micro-topography (see Figure 1).

Figure 1. The exposed basalt parent rock is pitted and has an irregular micro-topography. In this picture, two mima mounds may be seen in the background.

Table 1.
Taxonomic classification of soils

Series	Taxonomic classification
Cheney	Coarse-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Vitrandic Haploxerolls
Deno	Coarse-loamy, mixed, superactive, mesic Vitrandic Haploxerolls
Rockly	Loamy-skeletal, mixed, superactive, mesic Lithic Haploxerolls

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] Daniels (2004) discusses the use and operation of GPR. The SIR System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate. Calibration trials were completed with the 70, 200, and 400 MHz antennas. The 200 MHz antenna provided the best balance of penetration depth and resolution of subsurface features. The longer wavelength of the 70 MHz antenna provided poor resolution and did not provide substantially greater depths of penetration. In addition, radar records obtained with the 70 MHz antenna were cluttered with signal reverberations and unwanted background noise that masked subsurface interfaces. Signals from the 400 MHz were rapidly attenuated and depths of penetration were severely restricted in the comparatively high-loss soils that composed the mima mounds.

All radar records were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc)..[1] Processing included setting the initial pulse to time zero, color transformation, distance and surface normalization, signal stacking, background removal, migration, and range gain adjustments.

Survey Procedures:
Three mima mounds (identified as mounds A, B, and C) were selected for this investigation. These mounds were located near an access road and in an area that was approved for this study by the base command. Two orthogonal traverse lines were laid out across each mound. These lines were orientated in either a north to south or a west to east direction. Traverse lines varied in length from 20- to 25-m. The origin (0-m distance mark) of these lines was located, depending on orientation, at either the north or west ends. Along each line, survey flags were inserted in the ground at a 1-m interval and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Measured relief was 1.22, 1.31, and 1.09 m for mounds A, B, and C, respectively. Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum.

The radar survey was completed by pulling the 200 MHz antenna along the established traverse lines. As the antenna passed each of the flagged reference points, a vertical mark was impressed on the radar record.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time taken by electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, parent rock) 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 the following equation (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 the equation (Daniels, 2004):

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

In equation [2], C represents the velocity of propagation in a vacuum (0.299 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). The amount and physical state (temperature dependent) of water have the greatest effect on the E_r of earthen materials. Based on the depth to a known reflector, the E_r was estimated to be 5.7 in the upper part of the soil profile. This resulted in a propagation velocity of 0.13 m/ns. Substituting into Equation [1] an operating scanning-time of 70 ns and a propagation velocity of 0.13 m /ns, the maximum observation depth was (assuming a constant velocity) about 4.4 m

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

Interpretations:
Figures 2 thru 7 are the *terrain corrected* radar records from the survey. On each radar record, the surface has been *terrain corrected* to improve the visual presentation. Through a process known as *surface normalization*, elevations are assigned to each reference point and the image is corrected for changes in elevation. Surface normalization adjusts the vertical scale to correspond to changes in topography. On each of the radar records, scales are in meters. The vertical (depth) scale has been exaggerated relative to the horizontal (distance) scale. The depth scale (along left-hand margin) is based on a propagation velocity of 0.13 m/ns. The position of the depth scale has been adjusted in these figures so that the surface reflection along the left-hand margin of each radar record has a surface elevation of 0.0 m. This procedure has resulted in the truncation of the radar record in areas of lower elevation.

Soils were attenuating and depth restrictive to GPR. A high gain display setting was used in each of these figures to enhance weaker, subsurface interfaces. This procedure resulted in an over-amplification of the soil surface reflections on each of the radar records.

In areas that are shallow to parent rock, the soil/bedrock interface is masked by the strong surface reflection and its multiples. In general, the 200 MHz antenna provided an averaged penetration depth of about 2 m through the basalt. Parallel bands of low frequency noise are evident in the lower part of most radar records. These parallel bands of noise testify to a high-loss environment and the over gaining and ringing of the radar pulse in these earthen materials. These bands of noise should not be confused with reflections from subsurface interfaces.

The basalt parent rock is characterized by multiple horizontal reflectors. These planar reflectors are believed to represent beds or columns of basalt. In places, these reflectors appear segmented. Segmentation is a result of narrow, vertical columns or zones of no signal returns. These vertical columns may represent fractures or breaks in the basalt. Within these zones, the radar signal is scattered and reflected away from the antenna from the vertical bedrock interface and therefore not received.

In each radar record, point reflectors may be identified by their characteristic hyperbolic patterns (∧). These hyperbolic patterns have different shapes and sizes. Point reflectors are believed to represent local inhomogeneities with the parent rock such as fractures or air-filled voids or objects within the soil such as animal burrows or rock fragments.

The soil/parent rock interface provides an abrupt interface that separates highly contrasting materials. As a result, this interface has the potential of producing high amplitude (colored in shades of white, gray, purple, blue, and green) reflections. However, on each of the attached radar records, this interface often appears segmented and poorly expressed. In addition, this interface is expressed in a wide range of signal amplitudes. These characteristics are related to the highly pitted and irregular bedrock surface (see Figure 1). The irregular and pitted bedrock surface scatters the reflected radar energy. As a consequence, much of the reflected energy is directed away from the antenna. This “poor reception” results in the segmented and poorly expressed appearance of the soil/parent rock interface on portions of the radar records. In each of the attached radar records, the interpreted soil/parent rock interface has been identified with a white line (see Figures 2 thru 7).

Very weak evidence of soil horizon development or stratigraphic layering within the mounds is evident on the radar records (see Figures 2 thru 7). Above the soil/bedrock interface, low amplitude (colored in shades of red and yellow) reflections distinguish features with weak or gradational boundaries. Where evident, these soil interfaces appear segmented and wavy to slightly incline. Had the 400 MHz antenna been less depth restricted in the mound materials, it would have provided improve resolution and definition of these features. High amplitude, point reflectors within the mound materials are believed to represent rock fragments, animal borrows, or artifacts.

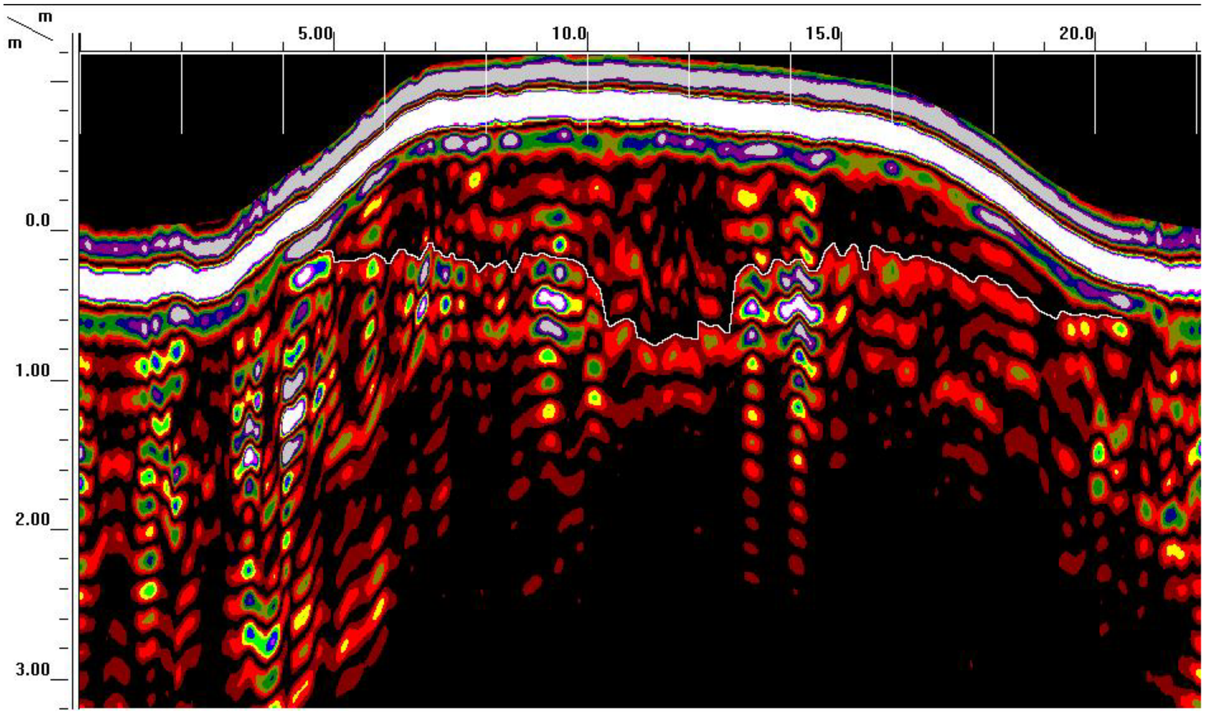

Figure 2. Radar record collected along a traverse line that trended in a north to south direction across Mound A.

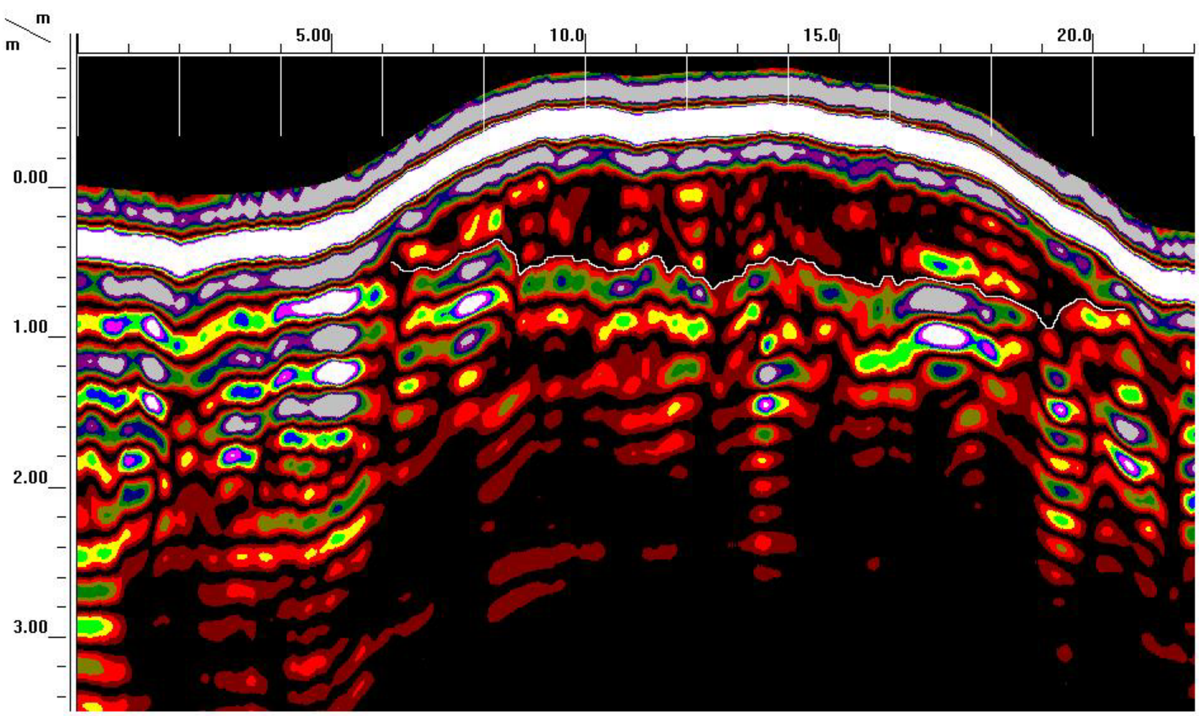

Figure 3. Radar record collected along a traverse line that trended in a west to east direction across Mound A.

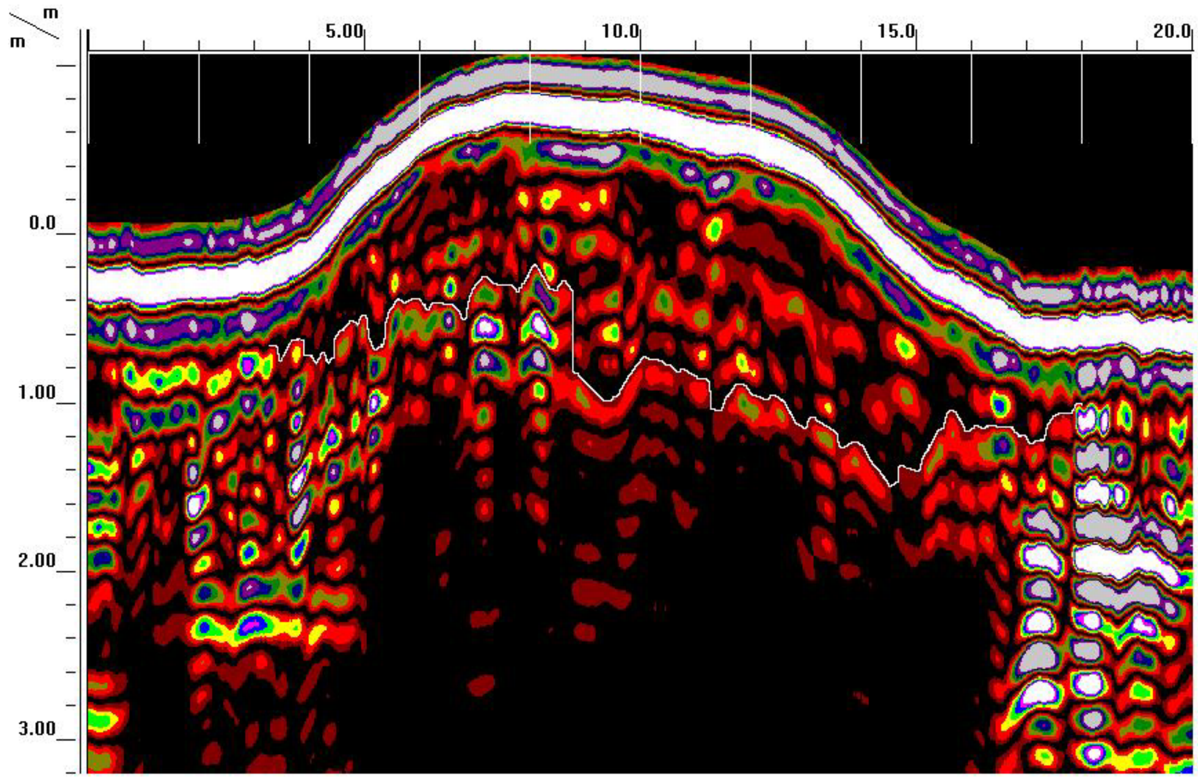

Figure 4. Radar record collected along a traverse line that trended in a north to south direction across Mound B.

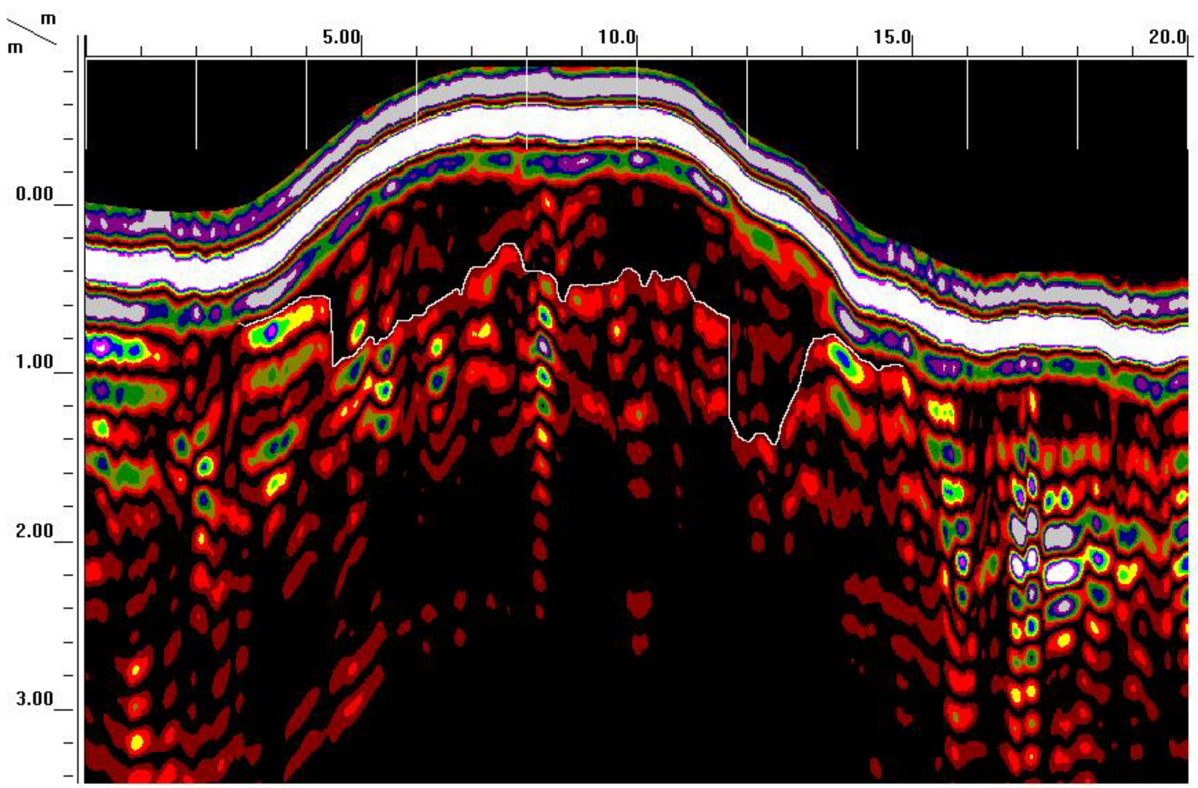

Figure 5. Radar record collected along a traverse line that trended in a west to east direction across Mound B.

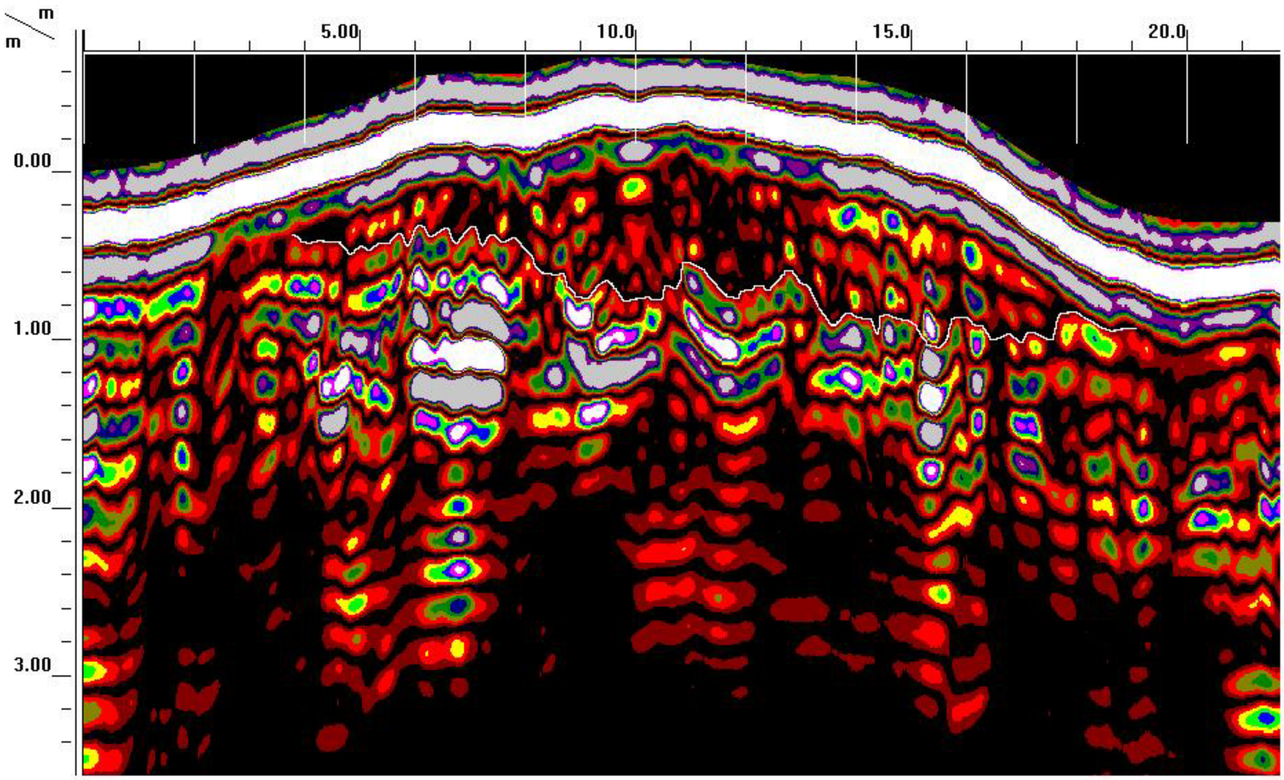

Figure 6. Radar record collected along a traverse line that trended in a north to south direction across Mound C.

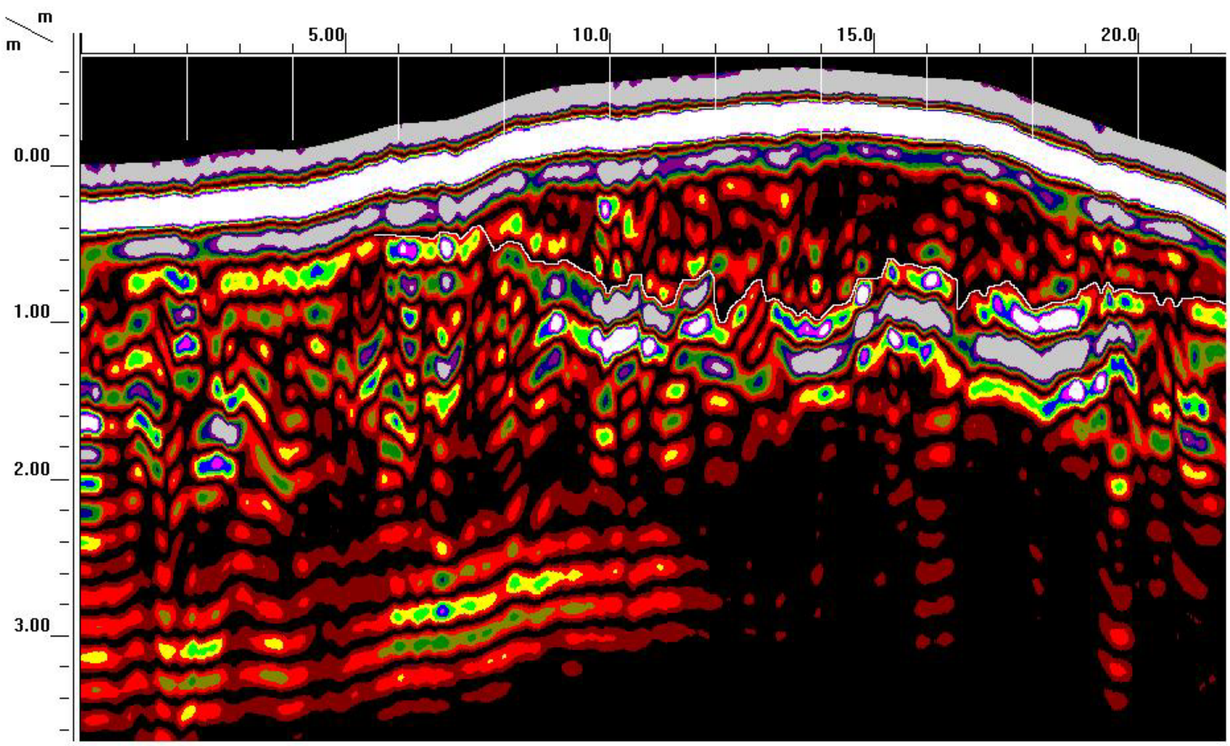

Figure 7. Radar record collected along a traverse line that trended in a west to east direction across Mound C.

It was my pleasure to work on mima mounds and to assist you in this project.

With kind regards,

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References

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