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

Subject: Soil - Geophysical Investigation **Date:** 10 October 2007

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Purpose:
This study was conducted to determine whether sediment-filled wedges and mima-like mounds within the Laramie Basin could be detected and characterized with ground-penetrating radar (GPR).

Participants:
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Activities:
All field activities were completed on 1 October 2007.

Summary:

1. Two grids were established over areas with known relict permafrost features. One grid was established in an area of Tisworth-Gerdrum loams, 1 to 8 percent slopes, which contains sediment-filled wedges. One grid was established in an area of Alcova-Borollic Camborthids complex, 0 to 8 percent slopes, which contains mima-like mounds.

2. Because of their comparatively high clay contents and SAR, Tisworth and Gerdrum soils are poorly suited to GPR. Advanced signal processing techniques were used to improve radar image quality. These procedures are time consuming and, judging from the results, did not improve interpretations. No wedge-like features were evident on the radar records collected in this area of Tisworth and Gerdrum soils. As these features are known to occur in the grid site, their absence on radar records is attributed to high rates of signal attenuation, restricted penetration depths, and exceptionally high levels of background noise.

3. The 3D radar survey, which was conducted in an area of Alcova-Borollic Camborthids complex, 0 to 8 percent slopes, provided graphic information concerning the subsurface expression and geometry of a mima-like mound. These soils have lower soluble salt and clay contents that the Tisworth and Gerdrum soils and are more suitable for GPR soil investigations.

With kind regards,

James A. Doolittle
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Background:
During the late Pleistocene, much of Wyoming was a cold, wind-swept permafrost environment with relatively thin snow cover (Mears, 1987). This environment fostered the development of periglacial and permafrost features in Wyoming's high intermontane basins (Mears, 1987). These features include sediment-filled wedges and mima-like mounds.

Within the Laramie Basin, sediment-filled wedges generally occur on older terraces and fan aprons. While wedges are abundant in places, they tend to occur in clusters, which vary in number and size (Mears, 1987). Sediment-filled wedges deformed the host materials, which vary from gravels to bedrock. Typically, sediment-filled wedges extend into host materials to depths as great as 2 m, and form pattern ground with diameters ranging from 2 to 10 m (Mears, 1987). Most wedges contain a vertical structure, which consists of small veins about 1 to 1.5 cm wide that extend from the top to the bottom of the feature (Mears, 1981). Such fabrics are characteristic of relict sand-wedges (Black, 1976). The infilled materials of wedges usually do not contain significant accumulation of carbonates (Larry Munn personal communication). This contrasts with host soil materials, which commonly display strongly developed calcic horizon. Some wedges display a concave-downward slumping stratification that suggests subsidence into a melting ice wedge (Mears, 1981).

Small mounds formed by the upwelling of gravelly substrata induced by Late-Wisconsin cryostatic pressures are common in the Laramie Basin (Spackman and Munn, 1984). The upward intrusion of gravels occurred through larger sediment-filled wedges producing mound-like structures (Spackman and Munn, 1984). The larger of these mounds have diameters of about 6 to 7 m and heights of about 50 cm (Spackman and Munn, 1984). Soils formed on intermound areas have more strongly developed horizonation (Borollic Haplargids) than soils formed on mounds (Borollic Camborthids) (Spackman and Munn, 1984). Typically, intermound soils are calcareous and have well expressed argillic horizons. In general, mound soils are coarser-textured, have lower bulk density, and more soluble salts (Ca, Na, and Mg) (Spackman and Munn, 1984).

The recent advent of digital GPR output and the availability of more powerful computers and advanced data-processing software allow the geometry and structure of subsurface features recorded on radar traverses to be analyzed from a three-dimensional (3D) perspective. Compared with 2D GPR records, 3D images often provide greater resolution and detail (Grasmueck and Green, 1996) and improve our ability to identify weakly expressed subsurface features and patterns. To construct 3D images, relatively small areas (generally < 50-m on a side) are surveyed intensively using closely spaced (typically 10- to 100-cm) parallel GPR traverses. Data from the traverses are assembled to create 3D pseudo-images of the subsurface, allowing arbitrary cross-sections, insets, and time-slices to be extracted from the data set. This study explores the use of 3D GPR to identify and characterize relict permafrost features in the Laramie Basin.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR System-3000), manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[11] The SIR System-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 System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. Daniels (2004) discusses the use and operation of GPR. A 400 MHz antenna was used in this study.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program developed by GSSI.[1] Initial processing involved setting the initial pulse to time zero, header and marker editing, distance normalization, color table selection and transformation, and range gain adjustments. More sophisticated processing techniques, which included high pass filtration and signal stacking, were used to reduce

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

background noise. The Super 3D QuickDraw program developed by GSSI was used to construct 3D pseudo-images of radar records collected at each grid site.

Study Site:
Albany County is situated in the Laramie Basin, which has an averaged elevation of about 2200 m. Areas of mima-like mounds, sediment-filled wedges, and polygonal pattern ground have been identified on about 4 percent (97,320 acres) of the County. Several soil complexes have been established to cover areas that contain these unique features. These soil complexes have Borollic Camborthids as the minor, named component. Borollic Camborthids form on these features.

Two areas were selected for this study. Both sites are located southwest of Laramie and are in rangeland. The taxonomic classifications of the named soils that occur on these sites are listed in Table 1.

Table 1.
Taxonomic classification of soils.

Series	Taxonomic Classifications
Alcova	Fine-loamy, mixed, superactive, frigid Ustic Haplargids family.
Gerdrum	Fine, smectitic, frigid Torrertic Natrustalfs
Tisworth	Fine-loamy, mixed, superactive, frigid Ustic Natrargids

Study Site 1 is believed to contain sediment-filled wedges, which were identified in a nearby exposure. This study site is located in the western ½ of Section 16, T. 14 N., R. 74 W. The study site is located in an area of Tisworth-Gerdrum loams, 1 to 8 percent slopes (map unit 236). The very deep, well drained Tisworth and Gerdrum soils formed in alluvium derived from sodic shale and sandstone on alluvial fans, fan aprons, and terraces. Typically, the clay content ranges from 18 to 35 percent and the control section contains from 15 to 40 percent exchangeable sodium. Because of their high SAR, these soils are considered unsuited to GPR.

Study Site 2 is located in an area with conspicuous mima-like mounds (see Figure 1). The site is located in the SE ¼ of Section 36, T. 14 N., R. 75 W. The site is located in a polygon of Alcova-Borollic Camborthids complex, 0 to 8 percent slopes (map unit 102). The very deep, well drained Alcova soils formed in calcareous alluvium derived from mixed sources on older terraces, pediments, and dissected fan aprons. Depth to the loamy-skeletal materials ranges from 16 to 40 inches. The Bt horizon contains 20 to 35 percent clay.

Survey Procedures:
To collect the data required for construction of 3D GPR pseudo-images, survey grids were established at each site. Grids were established with axis lengths of 20 (Site 1) and 15 (Site 2) m. Along the two parallel axis lines, survey flags were inserted into the ground at a spacing of 50 cm (see Figure 1). A reference line was stretched between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along this reference line. The 400 MHz antenna was towed along the graduated rope on the soil surface and, as it passed each 100-cm graduation, a mark was impressed on the radar record. Following data collection along the line, the reference line was sequentially displaced 50-cm to the next pair of survey flags to repeat the process. A total of 41and 31 traverses were required to complete the GPR surveys at Sites 1 and 2, respectively.

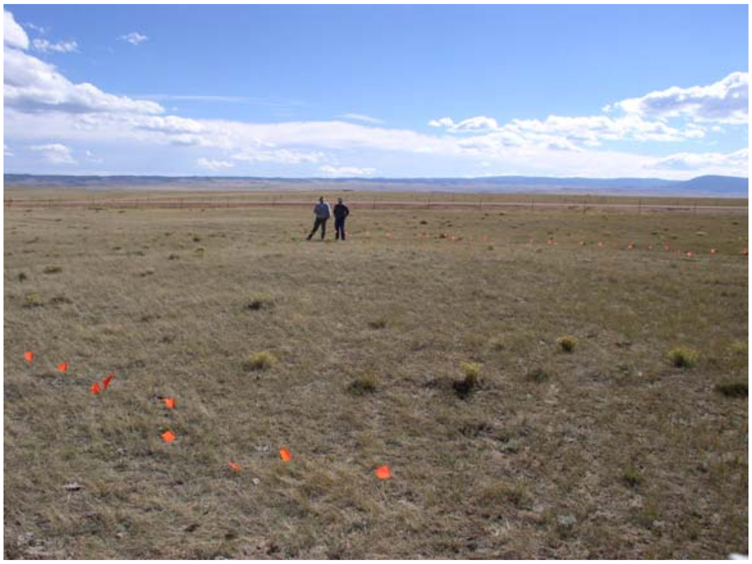

Figure 1. The two parallel and flagged lines form the boundaries of a grid established in an area of Alcova-Borollic Camborthids complex, 0 to 8 percent slopes, which contains prominent mima-like mounds.

Calibration:

Ground-penetrating radar is a time scaled system. This system measures the time it takes electromagnetic energy to travel from an antenna to an interface (e.g., 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 the following equation (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 the equation (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*.

Based on the measured depth and the two-way pulse travel time to a known, shallowly-buried reflector, and equation [1], the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profile was estimated. The estimated E_r was about 7.4 (v = 0.11m/ns). Soils were relatively dry at the time of this investigation.

Results:

<u>Site 1- Sediment-filled wedges</u>:

Radar records collected in this grid area were exceedingly depth restricted and plagued by high levels of background noise, which obscured subsurface reflectors. Figure 2 contains a relatively unprocessed (upper) and processed (lower) radar record from the grid site. The upper record has been subjected to setting the initial pulse to time zero, distance normalization, color table and transformation selections, and range gain adjustments. The lower radar record has been subjected to signal stacking and high pass horizontal filtration. Parallel bands of noise overwhelmed the upper part, while high frequency (snow-like) noise beset the lower part of the unprocessed radar record (upper record). Several high-amplitude (colored white, grey, blue, and purple) reverberations are evident on the radar records shown in Figure 2. These reverberations occur near the 0, 2, 4.5, and 8 m distance marks and extend from the soil surface downwards. These reverberations are caused by the jarring of the antenna as it was pulled over features on the soil surface, such as clumps of grasses. No distinct structures are evident on the unprocessed record. Sediment-filled wedges are not evident on this radar record.

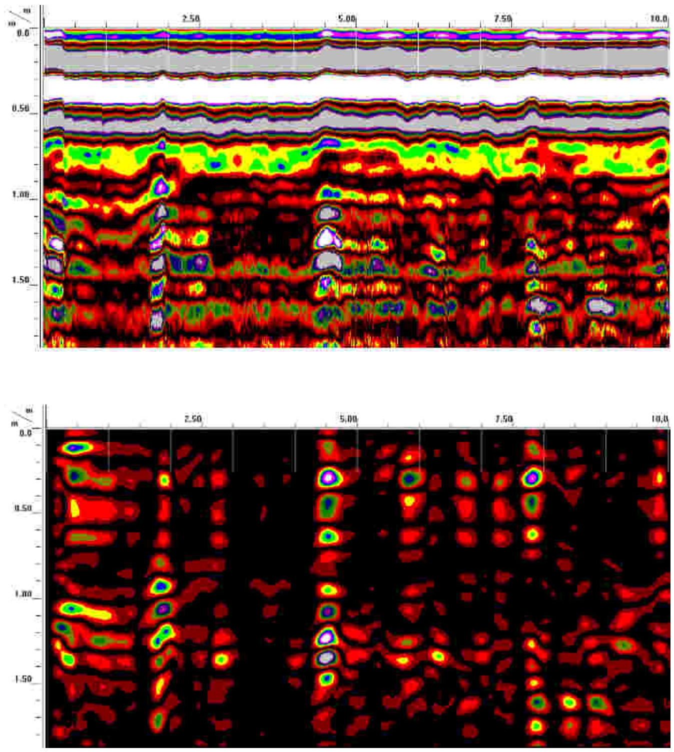

Figure 2. The relatively unprocessed (upper) and processed (lower) radar record from Grid Site 1 illustrate the affects of background noise removal.

Advanced processing techniques were used to reduce background noise. In the lower radar record (see Figure 2), high pass horizontal filtration and signal stacking have been used to remove low and high frequency noise, respectively. These processing techniques were use to improve signal-to-noise ratios and interpretations. Even after processing, reverberations are still evident on the lower radar record. These undesired reflections could be mistaken for sediment filled wedges. In the lower part (100 to 150 cm) of the processed radar record, higher amplitude planar reflections suggest the presence of a soil horizon or contact. These reflections are believed to be an artifact resulting from the exponential increase in range gain amplification with depth. Because of the high rates of signal attenuation experienced by the 400 MHz antenna in these soils, the range gain was over amplified.

Figure 3 is a three-dimensional GPR pseudo-image of the grid site. In this pseudo-image, a 15 by 12 by 0.9 m cube has been removed. Several reverberations are evident in the side of the cutout cube and the cube itself. These reverberations are irregularly space and do not form a continuous pattern on the base of the cutout, which would suggest sediment filled wedges and polygonal pattern ground.

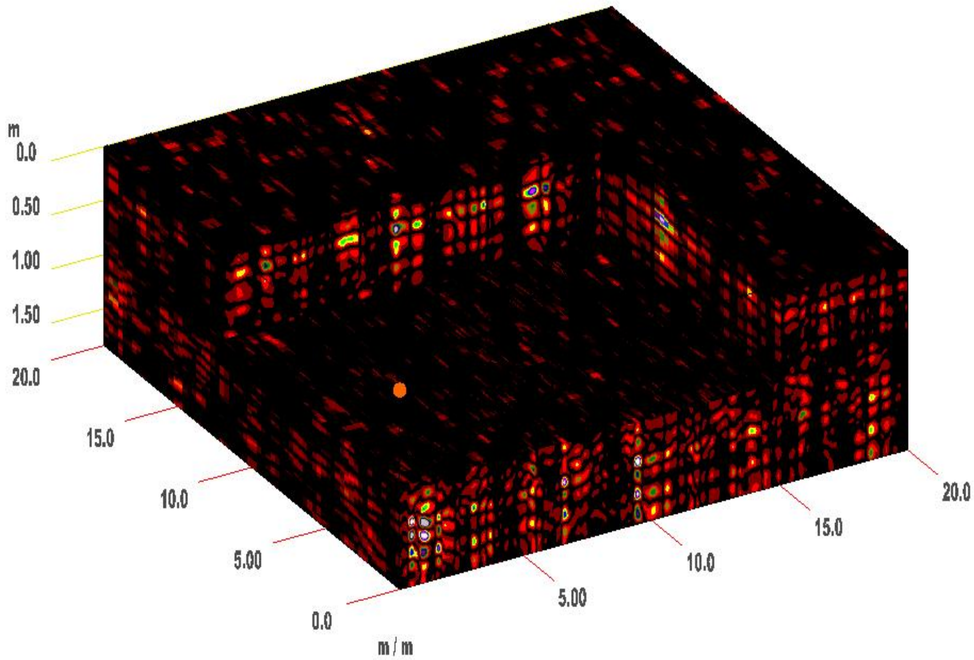

Figure 3. A 3D GPR pseudo-image from the Study Site 1. In this image of a 20 by 20 m survey area, a 15 by 12 by 0.90 m volume has been removed.

Because of their comparatively high SAR, Tisworth and Gerdrum soils are considered poorly suited to GPR. Advanced signal processing techniques are time consuming to perform. Judging from the presented results, these techniques are considered ill-advised on these soils. No wedge-like features were evident on the radar records collected in this area of Tisworth-Gerdrum loams, 1 to 8 percent slopes. As these features are known to occur in the grid site, their absence is attributed to high rates of signal attenuation, restricted penetration depths, and exceptionally high levels of background noise.

<u>Site 2- Mima-like mounds:</u>
The lower clay and soluble salt contents of the Alcova-Borollic Camborthids complex greatly improved penetration depths and improved the signal to noise ratio. Figure 4 contains a relatively unprocessed (upper) and processed (lower) radar record from Grid Site 2. In Figure 4, the upper record has been subjected to minor processing, which included: setting the initial pulse to time zero, distance normalization, color table and transformation selections, and range gain adjustments. Once again, parallel bands of noise overwhelmed the upper part, while high frequency (snow-like) noise beset the lower part of this slightly processed radar record.

In the lower radar record (se Figure 4), advanced signal processing techniques, which included high pass horizontal filtration and signal stacking, have been used to remove low and high frequency noise, respectively. These processing techniques improved the signal-to-noise ratios and interpretations. Wavy, segmented, planar reflectors are evident in the lower part of the processed radar record. These reflectors are assumed to represent strata in the underlying sands and gravels of Alcova soils. The upper part of the radar record is comparatively free of reflectors. This would indicate less contrasting materials with gradational boundaries. The argillic horizon is not evident on either radar record shown in Figure 4. The argillic horizon is too close to the soil surface and has been masked by the reverberations of the strong surface pulse and/or has been effectively removed by signal processing.

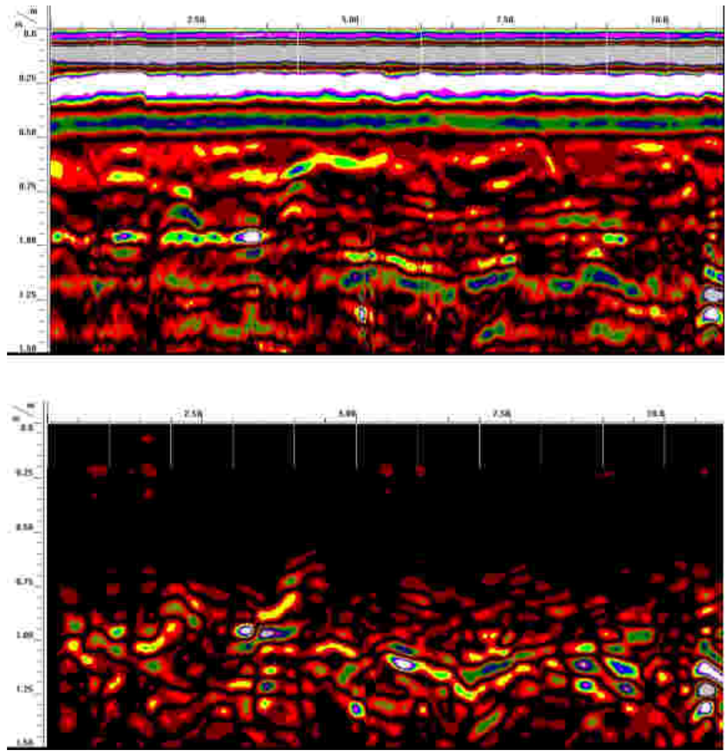

Figure 4. *Two identical radar records; upper record is unprocessed while the lower record has been processed to reduce background noise.*

Figure 5 consists of three stacked, 3D pseudo-images of the Alcova-Borollic Camborthids grid site. The upper plot consists of a 3D cube without cutout inset of the grid site. All radar traverses were conducted parallel to the X axis (right foreground), which was orientated in essentially a north-south direction. Radar traces were more continuously sampled in this direction and reflectors are more strongly expressed, with little distortion to the data in this direction. Along the Y axis, however, data were not continuously recorded but interpolated over a 50-cm interval (the distance between radar traverses). As a result, some subsurface information was lost during interpolation and data along the Y-axis appear noticeably smudged, less resolved, and more generalized.

The interface separating the loamy mantle from the stratified sand and gravel deposits provides a highly contrasting boundary. Stratifications within the sands and gravels are evident. These strata appear to have complex and variable compositions (judged by variations in signal amplitudes) and geometries.

In Figure 5, the middle pseudo-image of the grid site has a 13.25- by 13.50- by 0.45-m inset graphically removed from the 3D cube. Along the base of the cutout inset, the up-turned strata of the mima-like mound form a concentric circle, which defines the location of this feature.

In the lower pseudo-image shown in Figure 5, an 11.0- by 10.5- by 1.0-m inset has been graphically removed from the 3D cube. Along the sidewalls of the cutout inset, the upwelling of gravelly substrata, which was produced by former cryostatic pressures, is evident. These strata of coarser-textured materials are inclined upwards and approach the soil surface on the mima-like mound. These strata are deeper inter-mound areas. At this site, the 3D radar survey provided information on the subsurface expression and geometry of this mima-like mound.

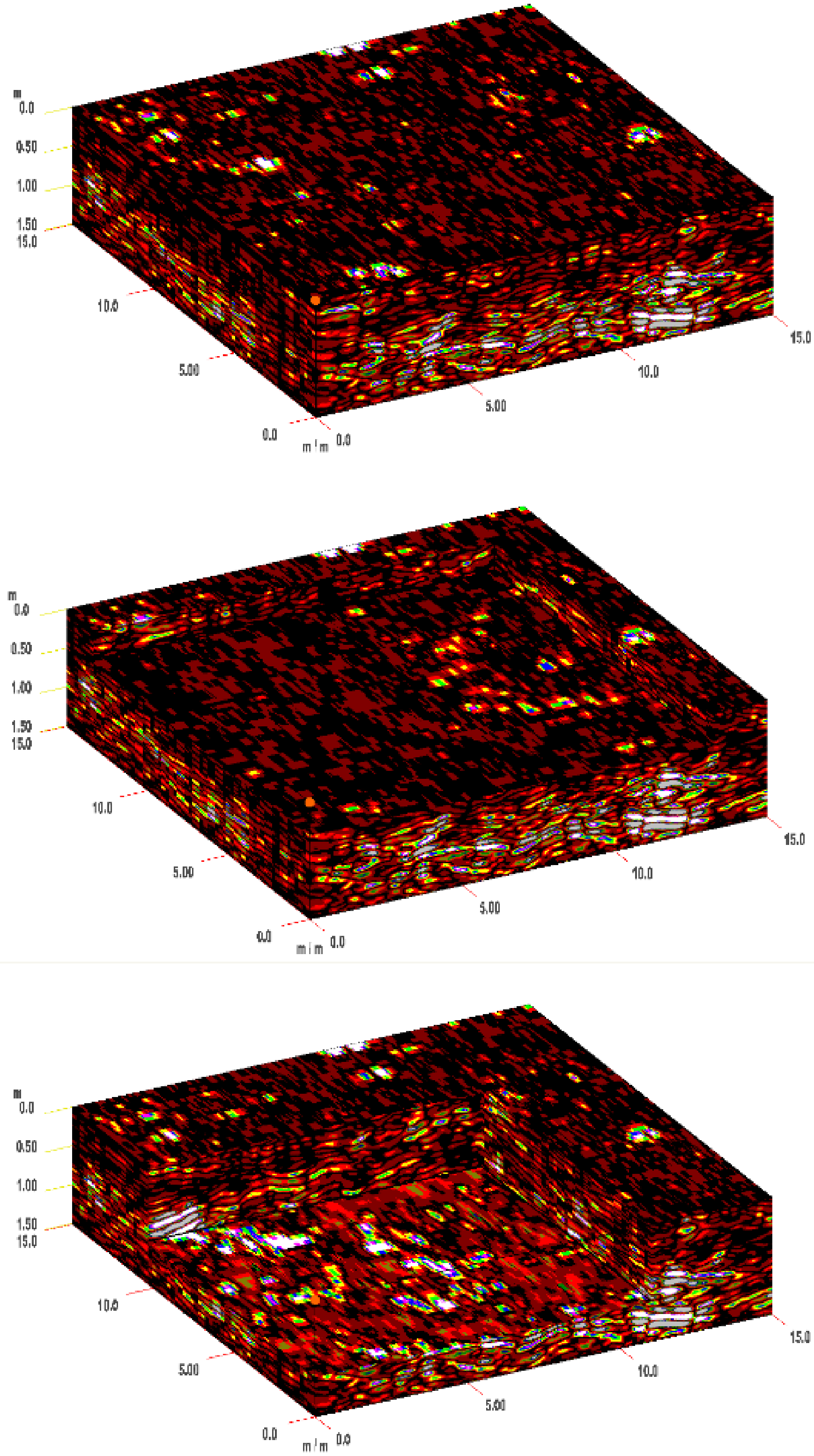

Figure 5. Three 3D pseudo-images of the Alcova-Borollic Camborthids grid site showing the subsurface geometry of a mima-like mound.

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