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

Subject: SOILS -- Ground-Penetrating Radar (GPR) Assistance **Date:** February 6, 2007

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Purpose:
Ground-penetrating radar (GPR) was used to investigate the area surrounding an "island" that recently emerged in a small lake located in south Georgia. It is hoped that GPR records will provide insight into the processes responsible for the formation of this emergent land mass.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Eric Brevik, Associate Professor, Department of Physics, Astronomy, and Geosciences, Valdosta State Univ., Valdosta, GA
Can Denizman, Assistant Professor, Department of Physics, Astronomy, and Geosciences, Valdosta State Univ., Valdosta, GA

Activities:
All field activities were completed on 25 January 2007.

Background (courtesy of Eric Brevik):
South Georgia is in an active karst zone, with fairly shallow limestone bedrock under primarily marine deposits. On the morning of October 13, 2006, the residents of a small private lake in south Georgia woke up to discover a new addition to their lake: a small "island" that had never before existed. Figure 1, shows the mass of earthen materials that emerged from the lake bottom and formed this strange phenomenon.

The lake's residents contacted the Geoscience Department at Valdosta State University to see if anyone there could explain what was going on, and what the potential consequences were for their lake. Dr. Can Denizman investigated the "island" in October, and was joined by Dr. Eric Brevik in early November. During these visits samples were collected from the "island". The two professors agreed that the "island" structure is most likely due to a collapse sinkhole on the lake bottom, but acknowledged that more information on the stratification and geometry of lake bottom was needed. It was agreed that a ground-penetrating radar (GPR) survey would be the best way to investigate this feature. Ground-penetrating radar (GPR) has been effectively used to map the topography and characterize the sediments along lake (Moorman and Michel, 1997; Mellett, 1995; Sellmann et al., 1992; Izbicki and Parker, 1991; Truman et al., 1991; and Haeni et al., 1987) and stream channels (Spicer et al., 1997) bottoms.

Figure 1. The "island" seen in this photograph emerged overnight from a south Georgia lake on October 13, 2007.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 ®, manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] 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. A 70 MHz antenna was used in this survey. The 70 MHz antenna is the lowest frequency antenna that is available to USDA-NRCS. This antenna provided adequate depth (greater than 10 m) and acceptable lateral resolution of subsurface features, even within the deeper portions of the lake.

Radar records contained in this report were processed with the RADAN for Windows ® (version 5.0) software program developed by GSSI.[1] Processing included setting the initial pulse to time zero, color transformation, header and marker editing, distance normalization, horizontal stacking, migration, filtration, and range gain adjustments.

An Allegro CE ® field computer (Juniper Systems, North Logan, Utah) and a Garmin Global Positioning System Map 76 ® receiver (with a CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack) (Garmin International, Inc., Olathe, Kansas) were used to record the coordinates of each reference station that was impressed on the radar record.[1] The Garmin GPS receiver was operated in the manual mode. Geodetic datum was WGS-84 (World Geodetic System of 1984). The Geographic (longitude/latitude) Coordinate system was used with units expressed in decimal degrees.

SURFER for Windows ® (version 8.0) (Golden Software, Inc., Golden, CO), was used to construct the images of the estimated depths to bottom sediments displayed in this report.[1] The grid of GPR depth estimates shown in this report was created using kriging methods with an octant search.

Survey Procedures:
The radar system was mounted in a fiberglass boat with the 70 MHz antenna. The fiberglass boat was towed behind a pontoon boat. GPR surveys were restricted to the portion of the lake near the "island". The "island" was closely approached, but emerged areas were not surveyed. The boats made eleven traverses across the area, each of different

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

lengths. Locations of traverse lines were arbitrary and were adjusted using identifiable features on the shore and "island". Reference points for both GPS and GPR were recorded simultaneously at intervals of 15 seconds.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, bedrock, 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 (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:

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

where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). For water, the E_r is 80 and the v is 0.033 m/ns. These parameters were used to depth scale the radar records.

On radar records, reflections from interfaces spaced closer than one-half wavelength apart are indistinguishable due to constructive and destructive interference (Daniels, 2004). Daniels (2004) used the following equation to show the relationship between velocity of propagation (v), antenna center frequency (f), and wavelength (λ):

$$\lambda = v/f \qquad [3]$$

Equation [3] shows that the propagated wavelength will decrease with decreasing propagation velocity and increasing antenna frequency. Using equation [3] and the velocity of pulse propagation through water (0.033 m/ns) results in a wavelength of about 47 cm for the 70 MHz antenna. With the 70 MHz antenna, submerged layers spaced closer (vertically) than about 25 cm are therefore indistinguishable on radar records.

With the 70 MHz antenna the lake-bottom sediments were penetrated. Variations in sediments are distinguishable on radar records. However, the compositions of these layers are unknown. As no borings were made through these sediments at the time of this survey, the identity of these layers can not be verified nor their thickness accurately estimated.

Interpretation of GPR Data:

Radar records were of excellent interpretative quality. Figure 2 is a portion of the radar record from traverse line 6 (see Figure 4 for location). This traverse line crosses the impacted area in an east-northeast to west-southwest direction. In Figure 2, the depth scale is meters. Although the radar provides a continuous profile of the lake, measurements of the water depth were restricted to reference points (white, vertical lines at the top of the radar record). On this radar record, these lines appear at a time interval of about 30 seconds. In Figure 2, the emergent "island" is most closely approached between reference points 5 and 6.

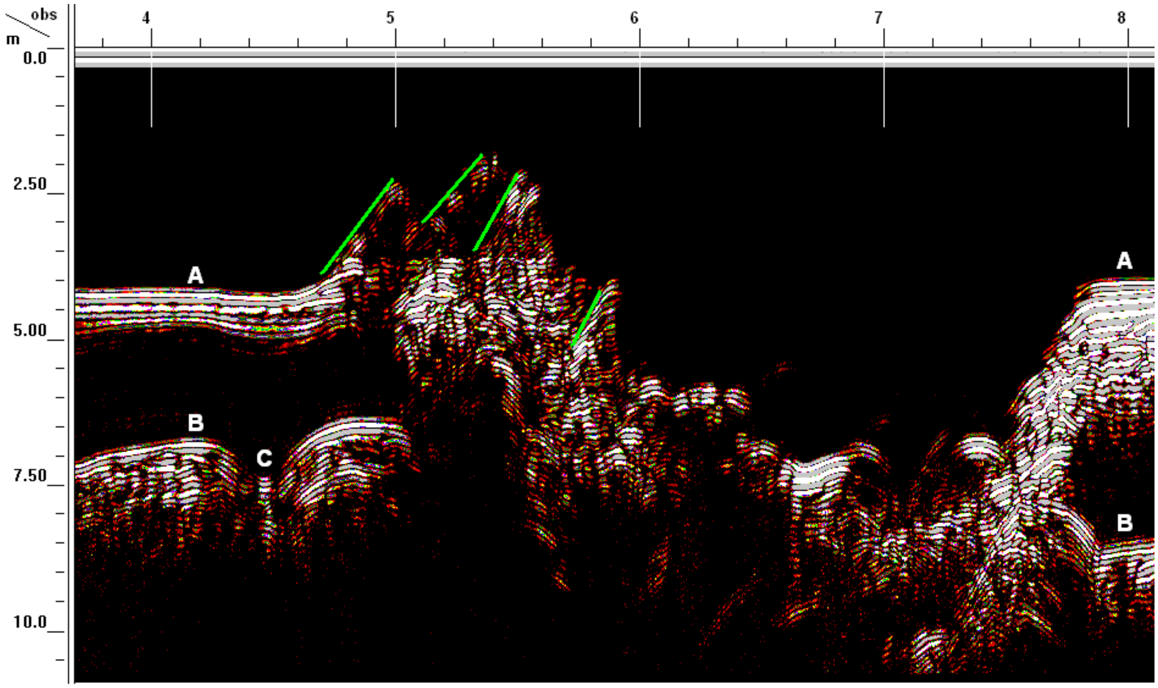

Figure 2. A deep crater-like feature and shoved, elevated lake-floor sediments are evident in this portion of the radar record from traverse line 6.

In Figure 2, the horizontal, high-amplitude (colored white and grey) reflector at the top of the radar record represents the reflection from the lake's surface. Below the surface reflection, the first series of high-amplitude reflections represents the lake bottom (in Figure 2, see "A"). On this portion of the radar record, this interface varies in depth from about 1.78 to 7.64 m. Between reference marks 5 and 6, reflections from this interface are noticeably mixed, lower in signal amplitude (colored red, yellow, and blue), segmented, and inclined downwards towards the east and away from a deep crater-like feature that is evident between reference marks 6 to 8. In Figure 2, green-colored lines have been drawn to draw attention to the downward dipping reflections from layers of former sub-bottom sediments, which have been moved upwards along the eastern rim of the crater-like feature. A "hinge-line" is evident near reference point 8. Here, downward bending bands of reflectors suggest the collapse of sediments into the crater-like feature. Though not verified, it is suspected that the high-amplitude planar reflector at "B" represents the upper boundary of the underlying limestone bedrock. If so, a cavity in this surface is evident at "C".

Figure 3 is a portion of the radar record from traverse line 11(see Figure 4 for location). This traverse line crosses to the west of the emergent "island" and across the crater-like feature from south to north. This traverse line is orthogonal to traverse line 6 (shown in Figure 2). The depth scale is meters. The white, vertical lines at the top of the radar record represent reference marks and are spaced at a time interval of about 30 seconds. In Figure 3, the emergent "island" is most closely approached between reference points 6 and 8.

In Figure 3, the horizontal, high-amplitude reflector at the top of the radar record represents the reflection from the lake's surface. Below the surface reflection, the first series of high-amplitude reflections represents the lake bottom (in Figure 3, see "A"). On this portion of the radar record, this interface is essentially horizontal on either side of the crater-like feature, but is slightly lower (about 4.05 to 4.10 m) on the left-side (south) and slightly higher (about 3.9 m) on the right-side (north). In Figure 3, two conspicuous, high-amplitude, planar, subsurface reflectors (see "B" and "C") separate distinct, sub-bottom sedimentary and/or lithologic facies. Each GPR facies is characterized by unique graphic signatures. Methods of GPR facies analysis are described for unconsolidated sediments by Beres and Haeni (1991).

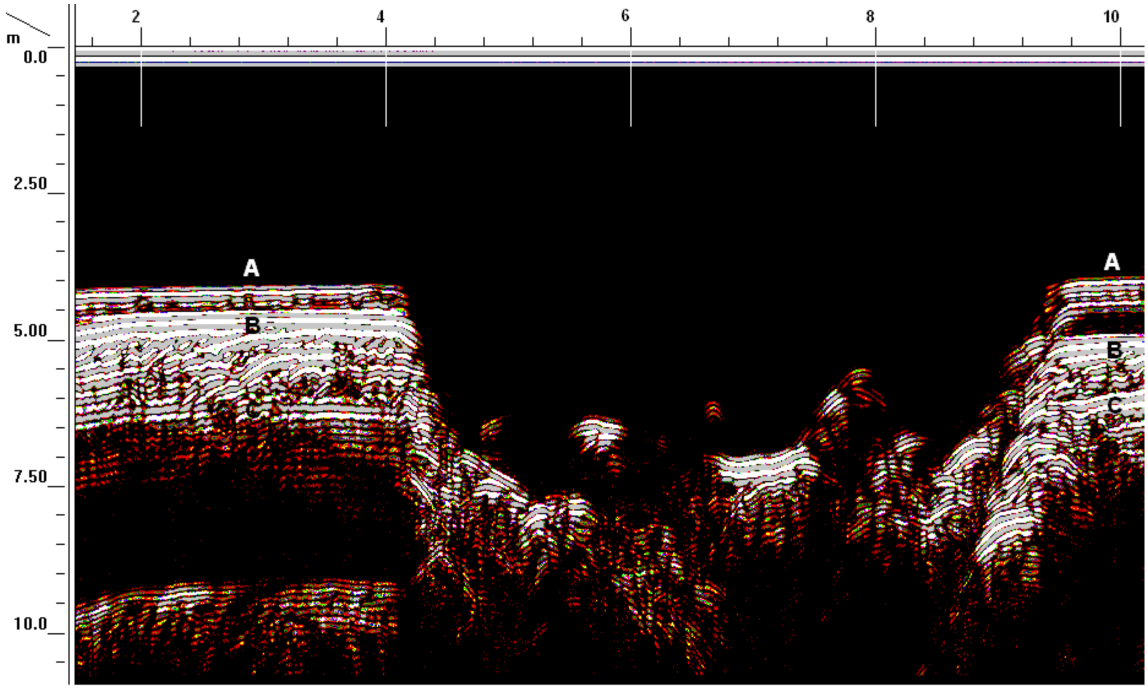

Figure 3. Portion of the radar record from traverse line 11 showing the crater-like feature and collapsed lake-floor sediments.

In Figure 3, a "hinge-line" is evident on the northern expression (right-hand side) of the crater-like feature near reference point 10. Here, downward bending bands of reflectors suggest the collapse of sediments into the crater-like feature. On the south side (left-hand side) of the crater-like feature, below reference mark 4, down-turned bands of reflectors are less evident and the abrupt truncation of reflectors suggests a much sharper break.

Depth Estimates and Contouring:
The radar survey was completed in 1/2 day. The depths to bottom sediments were recorded at 169 points using GPR and GPS. The average depth to bottom sediments within the survey area is 3.96 m with a range of 1.09 to 6.96 m. At one half of the reference points, depths to bottom sediments were between 3.77 and 4.21 m. While these statistics are useful, two- and three-dimensional plots of the depth estimates provide a more coherent picture of the emergent "island" area. In the subsequent plots, it must be emphasized that data were collected only in areas covered with water, where boat steerageway could be maintained. No measurements were collected on the emergent "island". Figure 4 is a two-dimensional contour map of the lake bottom. In this plot, the contour interval is 50 cm. Colors have been used to help express the contours. In Figure 4, portions of the "island" emerge from the lake near points labeled "A". Figure 5 is a raster image map of the study area. In this 3D map, depths are represented by different colors. Once again the contour interval is 50 cm.

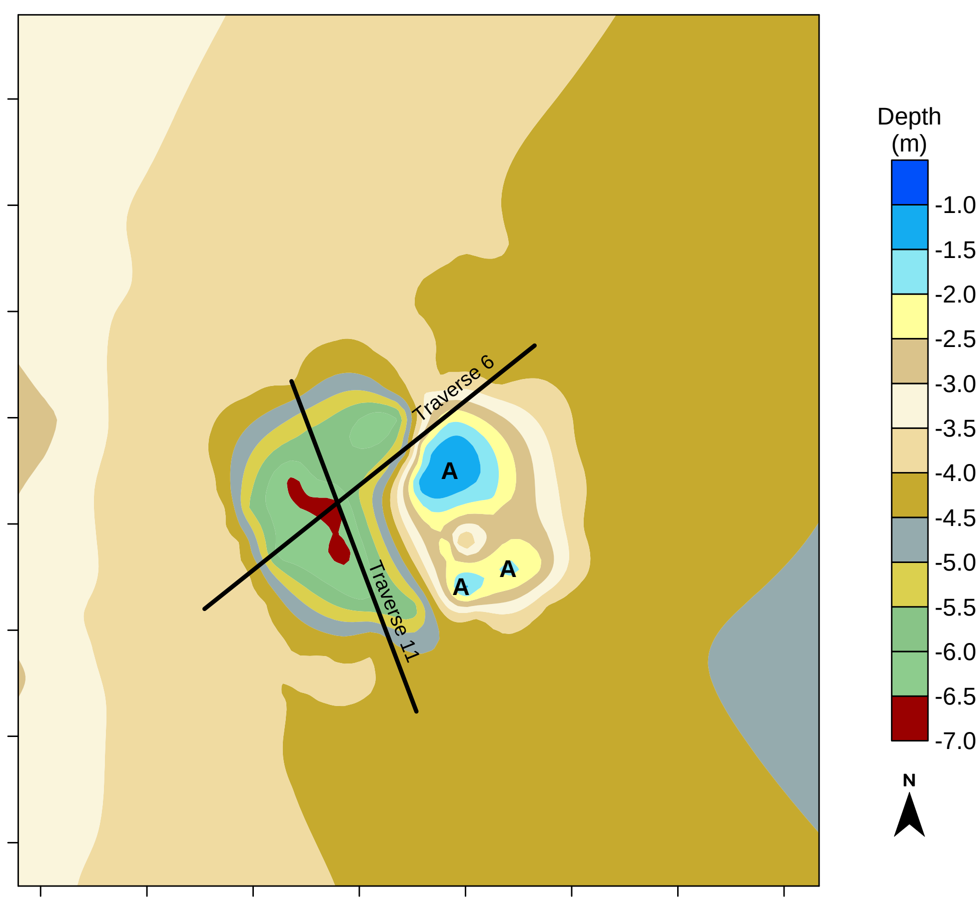

Figure 4. The locations of emergent land are denoted by the letter "A" in this two-dimensional contour map of the study area. The locations of the segments of the radar records shown in Figures 2 and 3 are also indicated.

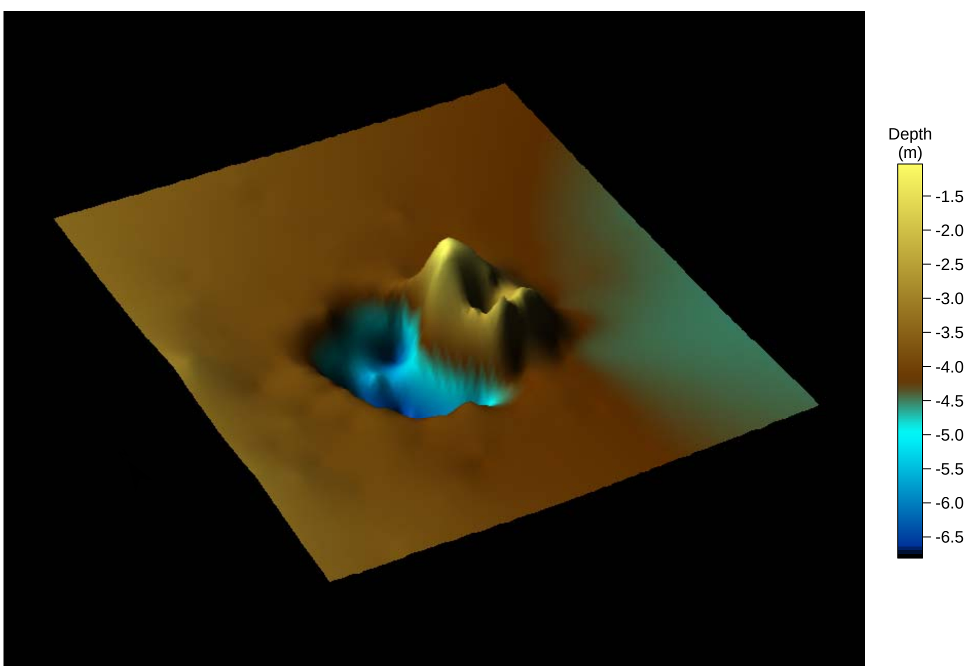

Figure 4. This three-dimensional image map shows the crater-like feature and a seemingly "thrusted" mound of sub-bottom sediments.

All GPR files have been prepared in bitmap format and will me mailed to you along with the GPR estimated data on the depth to bottom sediment and coordinates of each observation point. It was my pleasure to be of assistance to you and Dr Denizman in this investigation

With kind regards,

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