

THE APPLICATION OF GPR IN FLORIDA FOR DETECTING FORENSIC BURIALS

Steven K. Koppenjan, Bechtel Nevada, Special Technologies Laboratory, Santa Barbara, CA
John J. Schultz, Anthony B. Falsetti, and Mary E. Collins, University of Florida, Gainesville, FL
Sashi Ono and Hua Lee, University of California, Santa Barbara, CA

Abstract

A study was performed at the University of Florida to measure ground penetrating radar (GPR) performance for detecting forensic burials. In controlled scenarios, 24 burials were constructed with pig cadavers. Two soils were utilized to represent two of the most common soil orders in Florida: an Entisol and an Ultisol. Graves were monitored on a monthly basis for time periods up to 21 months with grid data acquired with pulsed and swept-frequency GPR systems incorporating several different frequency antennas. A small subset of the graves was excavated to assess decomposition and relate to the GPR images during the test.

The grave anomalies in the GPR depth profiles became less distinctive over time due to body decomposition and settling of the disturbed soil (backfill) as it compacted. Soil type was a major factor. Grave anomalies became more difficult to recognize over time for deep targets that were within clay. Forensic targets that were in sandy soil were recognized for the duration of this study. Time elapsed imagery will be presented to elucidate the changes, or lack thereof, of grave anomalies over the duration of this study. Further analysis was performed using Synthetic Aperture Radar (SAR) reconstruction of images in 2-D and 3-D.

Introduction

Noninvasive geophysical methods have proved to be a valuable tool for forensic investigators in the search for clandestine graves. The use of geophysical tools, such as ground penetrating radar (GPR) can result in a significant time savings for evidence recovery teams. Additionally, being able to clear a suspected location so investigation resources can be directed elsewhere is extremely important.

The U.S. Department of Energy's Special Technologies Laboratory, operated by Bechtel Nevada, in support of the FBI Evidence Response Team, formed a collaborative, Forensic-GPR research project with the University of California, Santa Barbara, the University of Florida, and the University of Tennessee.

Previous research has tested the efficacy and applicability of different noninvasive geophysical technologies under controlled conditions in the detection of buried bodies, pig cadavers (70 kg average) and buried evidence (Davenport et al., 1988; Davenport et al., 1990; France et al., 1992; France et al., 1997). Conclusions from these studies indicate that GPR was the most important tool used to delineate graves and practical application by law enforcement investigators and geophysical contractors has confirmed these conclusions. Most recently, the Anthropological Research Facility operated by the Department of Anthropology at the University of Tennessee, Knoxville is using GPR to detect buried corpses in the ground and under concrete slabs (Freeland, et al., 2002; Miller, et al., 2002) and is associated with the Forensic-GPR collaborative effort.

There are several research topics that have not been addressed that pertain to forensic applications, one of which is the most relative to real-world situations, is the monitoring of control graves for durations longer than one year. Direct comparisons between soils and target size and depth are also important factors in grave detection. This study was designed to test the applicability of using GPR in Florida to detect buried bodies. There were three specific research objectives:

- Monitor the radar profile changes caused by decomposition of the cadaver and compaction of the backfill over time.
- Measure the effect of soil type and its effect on producing a distinctive anomalous response.
- Determine if pig cadaver size is a factor.

Initial findings from this study were reported at the GPR 2002 conference in Santa Barbara, California (Schultz, et al., 2002). This paper presents detailed results of a stepped-frequency GPR unit (Koppenjan, et al., 1998).

Test Site

The research site is located in northeast Alachua County, Florida. Two soils in the research area were chosen to represent very common soils in Florida: Entisols and Ultisols. The Entisol has a clay content that is very low (<5%), while it has a sand content extremely high (>95%). The amount of extractable cations are also low, averaging less than 5.0 cmol(+) / kg, and the pH is approximately 5.0. The upper portion (0 to 100 cm) of the Ultisol has similar soil properties. Below 1.0 meter in the Ultisol there is a clay layer that can have more than 15% clay, normally ranging about 20% to 30% clay. The amount of extractable cations and pH value are similar to the Entisol. All of these soil characteristics do not inhibit the penetration of the radar signal (Doolittle and Collins, 1995) and the GPR soil suitability index is between 0 and 3 indicating moderate to high GPR potential (Doolittle, et al., 2002).

Test Beds and Survey Design

Twenty-four burials were constructed with pig cadavers and divided equally into two groups of average weights (24.5 and 63.5 kg) and buried at depths of 50-60 cm or 100-110 cm. The pig cadaver sizes were chosen to represent children and small adults, while the depths were chosen to represent shallow and deep burials (Figure 1). Graves were monitored for durations up to 21 months with two GPR systems. In addition, ten control burials of similar dimensions as the pig burials were constructed at the same time as the pig burials and were monitored monthly (Figure 2). The majority of the control burials consisted of only backfill to determine the contribution of the disturbed soil to the grave anomaly. Grave monitoring with GPR began in 1999 using a commercial impulse system, the SIR 2000 by Geophysical Survey Systems, Inc., with 500 MHz and 900 MHz antennas. Data were acquired in length and width over the center of each target. Several test beds were excavated at various intervals to analysis the short-term decomposition.

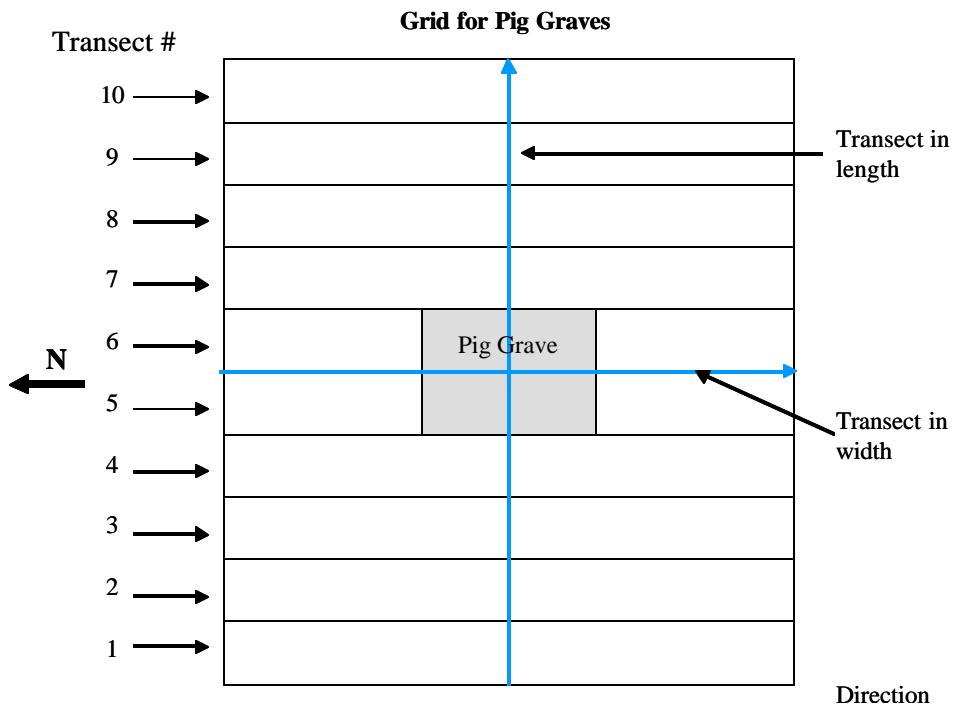


Figure 1. Data collection grid for pig graves.

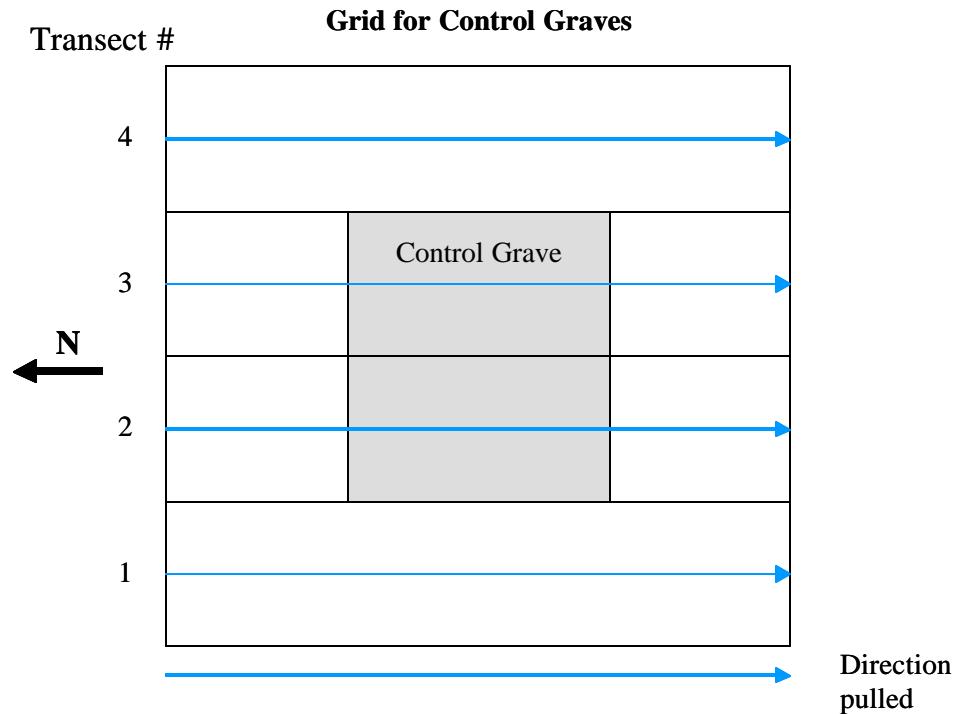


Figure 2. Data collection grid for control graves.

In 2001, field-testing with a lightweight stepped-frequency GPR began. It is a multi-frequency synthetic-aperture system that operates over the range of 200-700 MHz (Koppenjan, et al., 2000). A 6.1 meter by 4.9 meter grid was constructed for a subset of graves with the grave situated in the center of the grid. Ten transects were taken for each grave with the middle two transects crossing over the width of the grave. Data were acquired every 15 cm along each gridline, with 60 cm spacing of grid lines (Table 1). A 2.45 meter by 4.9 meter grid was used for the control plots. All of the test beds were excavated in July 2002. The GPR system acquiring data is shown in Figures 3 and 4.

Table 1. Stepped-Frequency GPR Data Collection.

Month	Date
June 2001	6-27-2001
July 2001	7-27-2001
August 2001	8-25-2001, 9-6-2001
September 2001	9-27-2001, 10-2-2001
October 2001	10-30-2001, 11-1-2001
November 2001	11-29-2001, 12-4-2001
December 2001	No data acquired
January 2001	1-22-2002, 1-27-2002
February 2001	2-11-2002, 2-19-2002
March 2001	3-19-2002, 3-26-2002
April 2001	4-23-2002, 4-24-2002
May 2002	No data acquired
June 2002	6-11-2002



Figure 3. GPR acquiring data.



Figure 4. Florida test site with data collection grid.

Results

Processing of Data

For the field analysis and display on the GPR unit, the stepped frequency data is converted into the time-domain pulse response equivalent using a narrow-beam reconstruction algorithm implemented with a fast Fourier transform (FFT). Initial laboratory processing used a 2-D, synthetic aperture radar (SAR) image reconstruction algorithm (Lee, et al., 1982). Using the 2-D SAR processing, the target resolution in the cross-range was 20% sharper when compared to standard FFT processing (Figure 5). The actual radar response of the pig cadaver is not a well-defined target when compared to a metal plate, but the improvement was consistent with the results of the SAR processed GPR data of buried metal plates (Koppenjan, et al., 2000).

Further analysis was performed using the full grid data (10 lines) over the test pit. The 2-D SAR algorithm was expanded for the 3-D case.

The dimensions of the operations of the image reconstruction procedure (Chang, et al., 1994; Koppenjan, et al., 2000) are expanded for the 3-D case. Here we can summarize the image reconstruction procedure as:

- Step 1: Partition the data into coherent data sets based on the frequency index and regroup the data into N spatial data sets. Each spatial data set is associated with one unique frequency index. For the 2-D cases, the data set were only along the scan path. For the new version, the data sets will be 3-D over the 2-D aperture.
- Step 2: Convert the index from frequency to operating wavelength.
- Step 3: 2-D Fourier transform each spatial data set to represent the wave in the spatial-frequency domain.
- Step 4: Apply the backward propagation filter to the wave in the spatial-frequency domain. Note: The filter for the backward propagation operation will now be 3-D. (The three variables are (1) spatial frequency in x direction, (2) spatial frequency in y direction, and (3) depth z .) Since the formula of the backward propagation filter is wavelength dependent, each coherent spatial data set is processed by a unique backward propagation filter corresponding to its wavelength index. The wave gains an additional dimension by backward propagating in the range direction. Note that the backward propagated wave is now in the space domain in the range direction and in the spatial-frequency domain in cross-range directions.
- Step 5: Superimpose N backward propagated waves in 3-D, fx , fy , and z .
- Step 6: Inverse Fourier transform in the cross-range directions in 2-D, for fx and fy , to form the final image in the space domain with coordinates (x,y,z) .

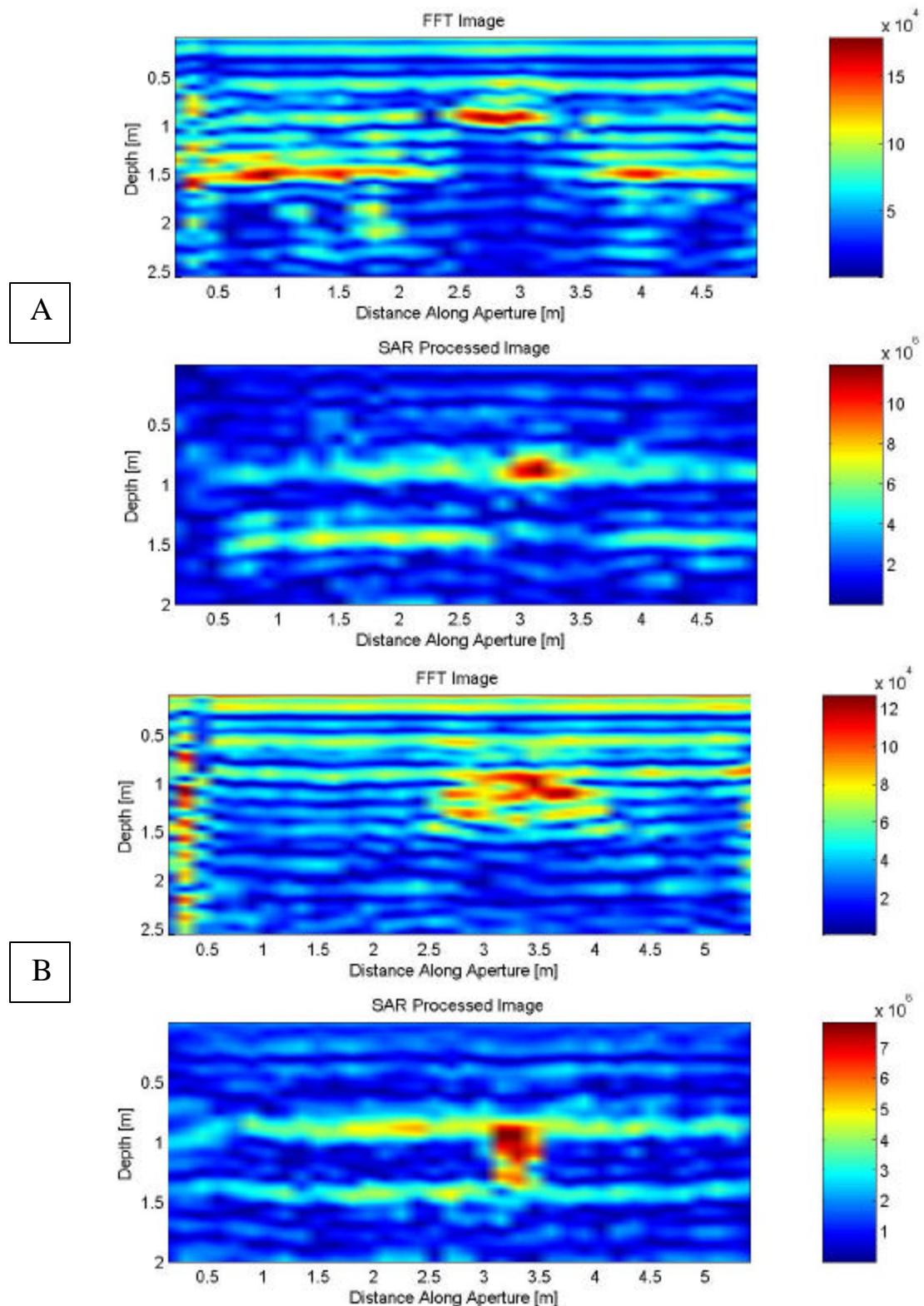


Figure 5. Comparison of GPR profile of pig cadaver target (FFT vs. SAR reconstruction). Shallow buried pig in Ultisol (A), deep buried pig in Entisol (B).

Data Analysis: Soil Type, Depth and Cadaver Size

The data for each month were processed using the 3-D SAR image reconstruction. A plan view map of the 30 square meter grid was created by integrating the data from just below the surface return (approximately 10 cm) to 150 cm depth. From the 3-D plot, selected vertical depth profiles (along the center line of the targets) and selected depth slices (at the burial depths of 50 cm and 100 cm) were analyzed. The relative level of return was calculated for the test pits and the control pits using the vertical depth profiles, the depth slice at maximum target return and the overall plan view map. This data from the four example test beds is plotted in Figure 6.

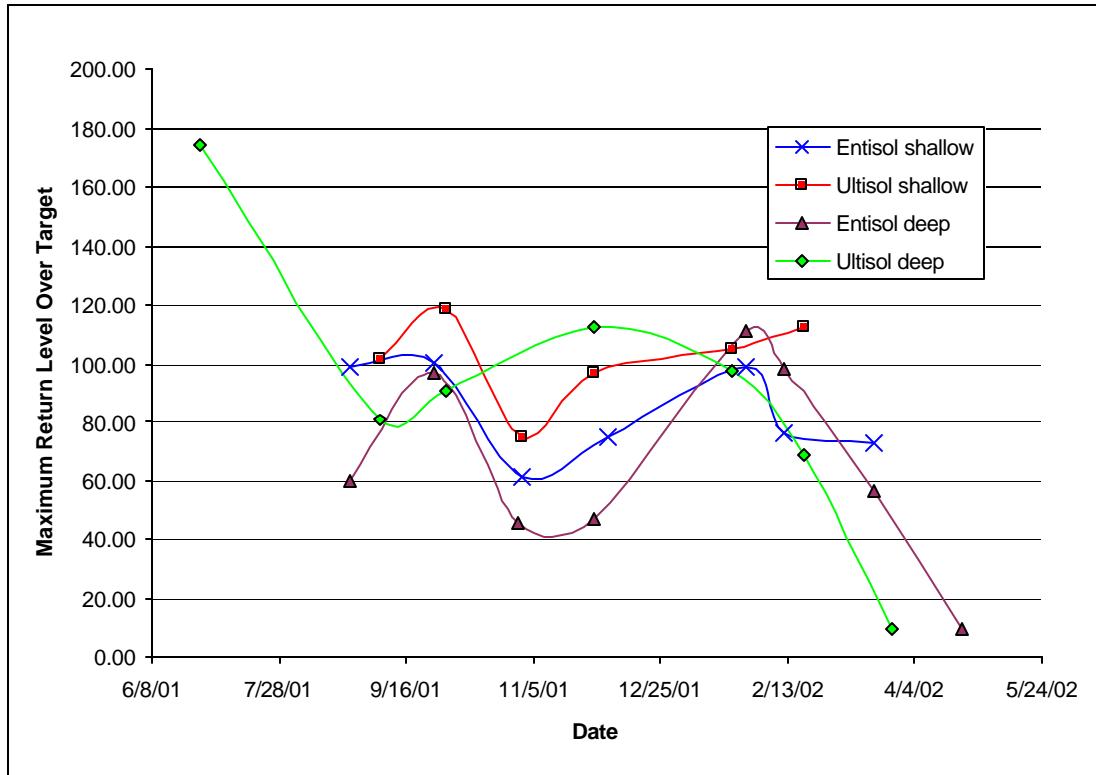


Figure 6. Maximum return level over target vs. time.

Figures 7 through 10 show time sequence depth profiles over the target for the test beds. A 3-D plot of a burial site (large pig, deep burial, Ultisol, 10 months) is shown in Figure 11. Figure 12 is the horizontal slice at 60 cm from the 3-D plot.

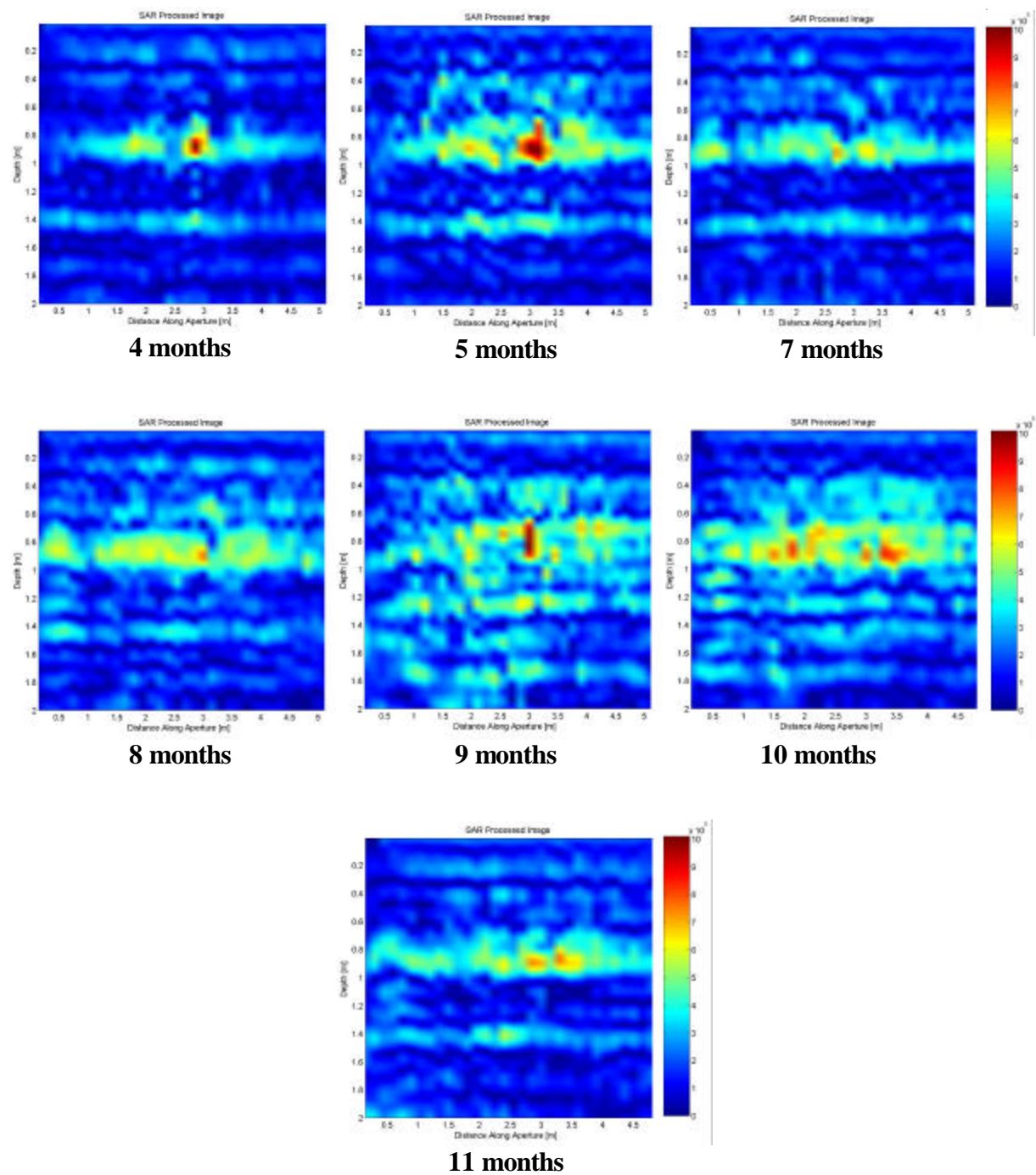


Figure 7. Depth profiles from 4 to 11 months of a small pig, shallow burial in Entisol.

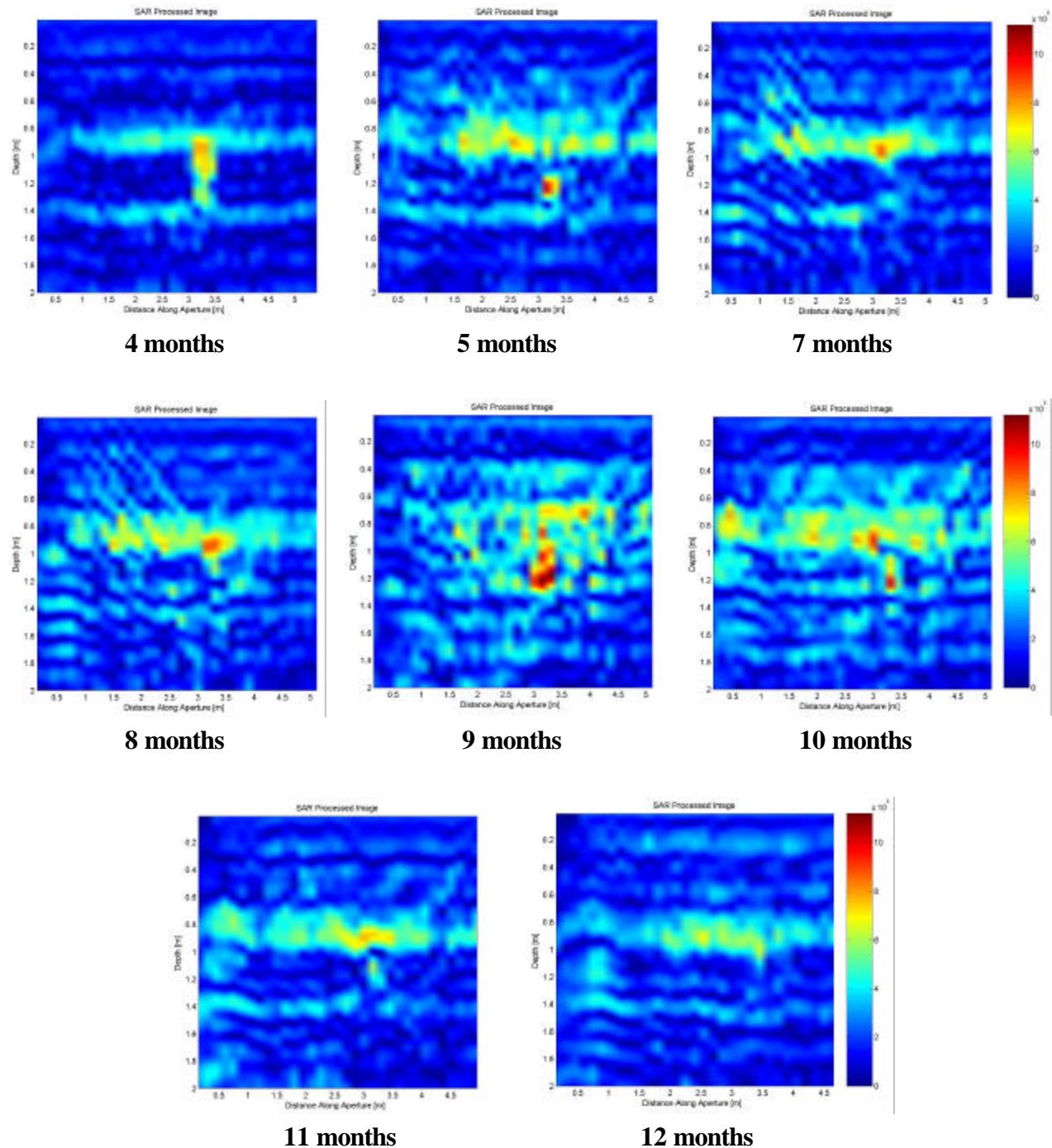


Figure 8. Depth profiles from 4 to 12 months of a small pig, deep burial in Entisol.

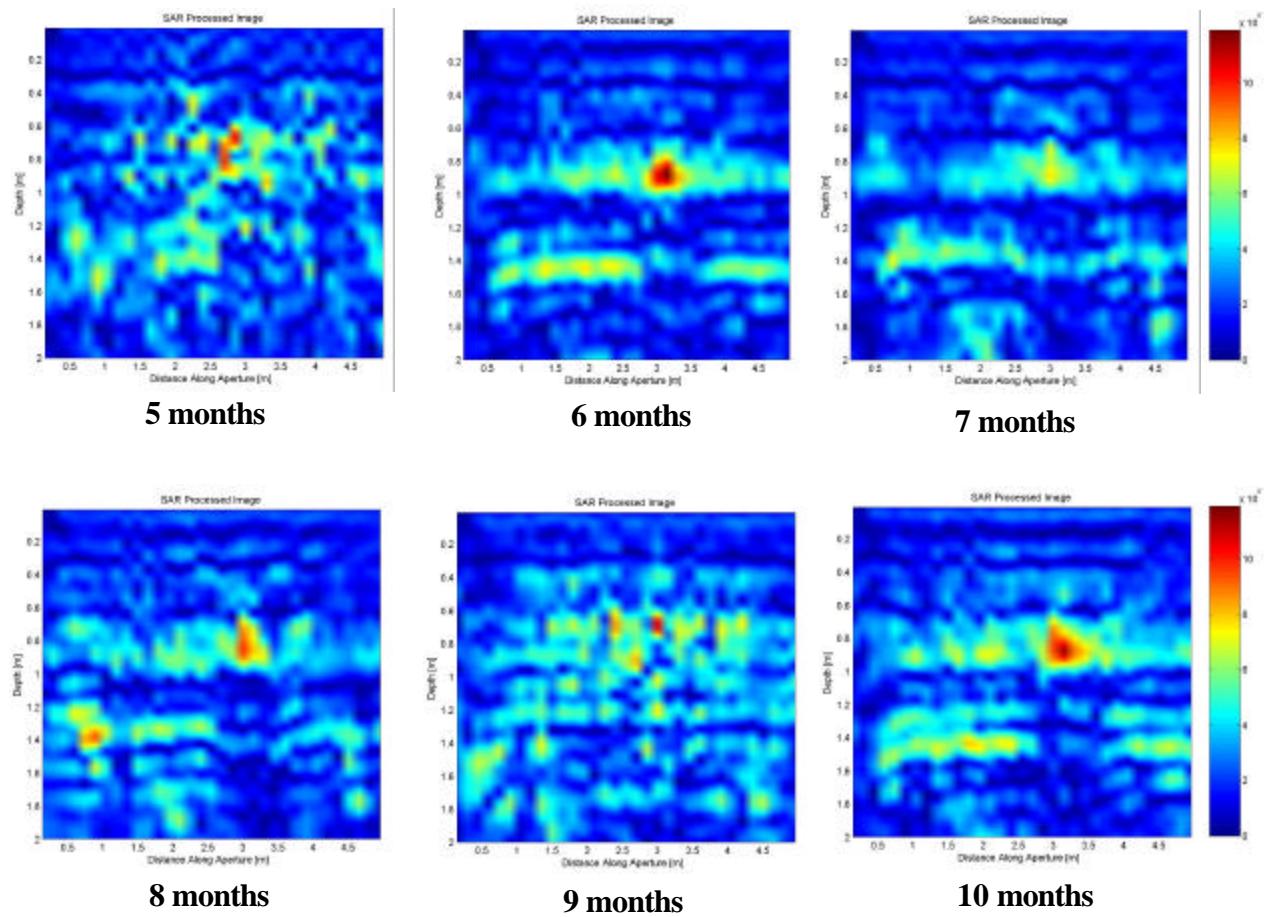


Figure 9. Depth profiles from 5 to 10 months of a large pig, shallow burial in Ultisol.

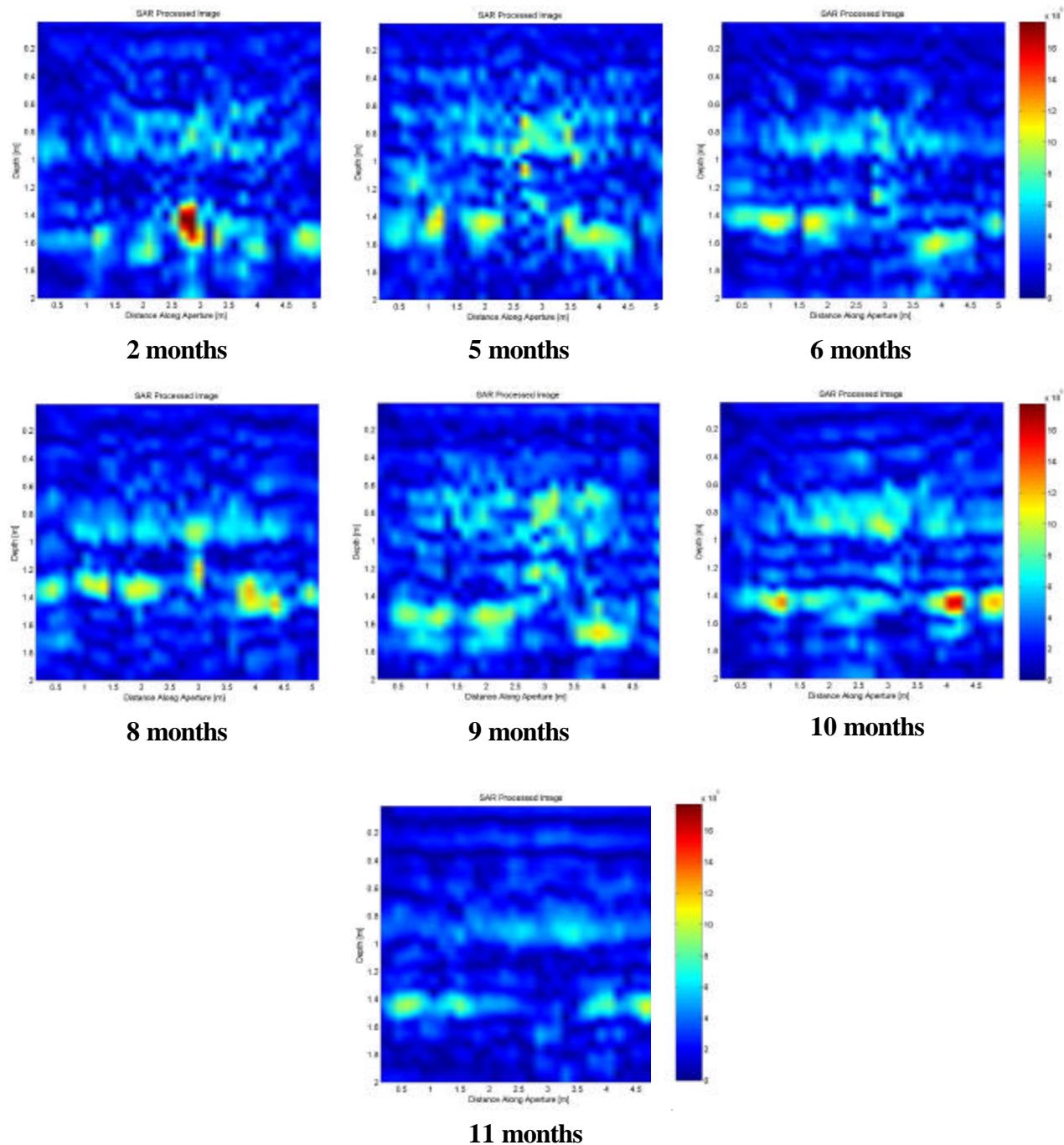


Figure 10. Depth profiles from 2 to 11 months of a large pig, deep burial in Ultisol.

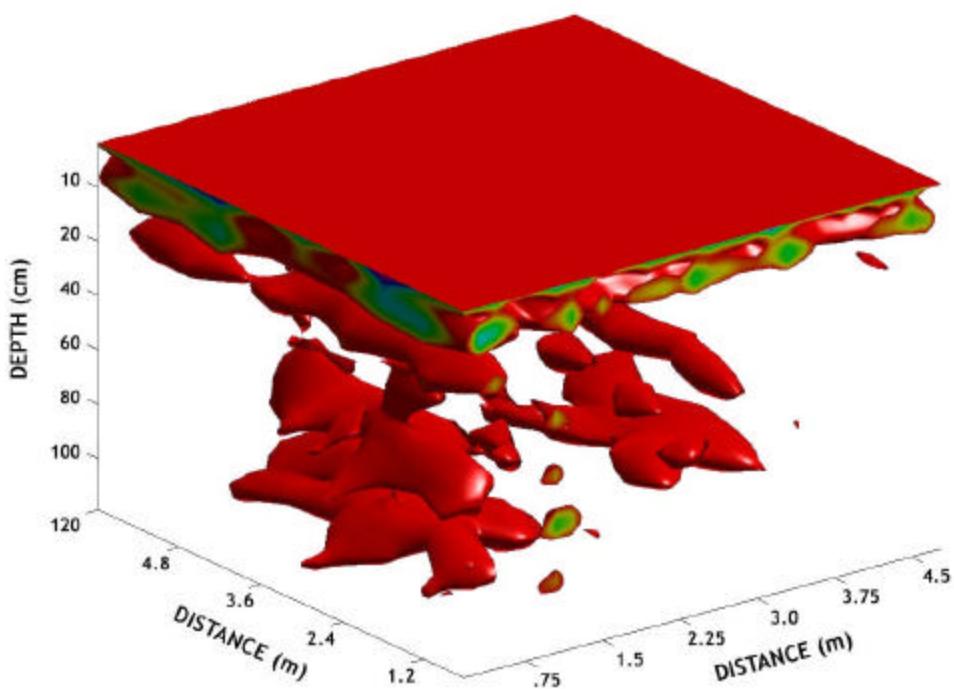


Figure 11. 3-D SAR reconstruction plot of a grave with a large pig, deep burial in Entisol, at 10 months.

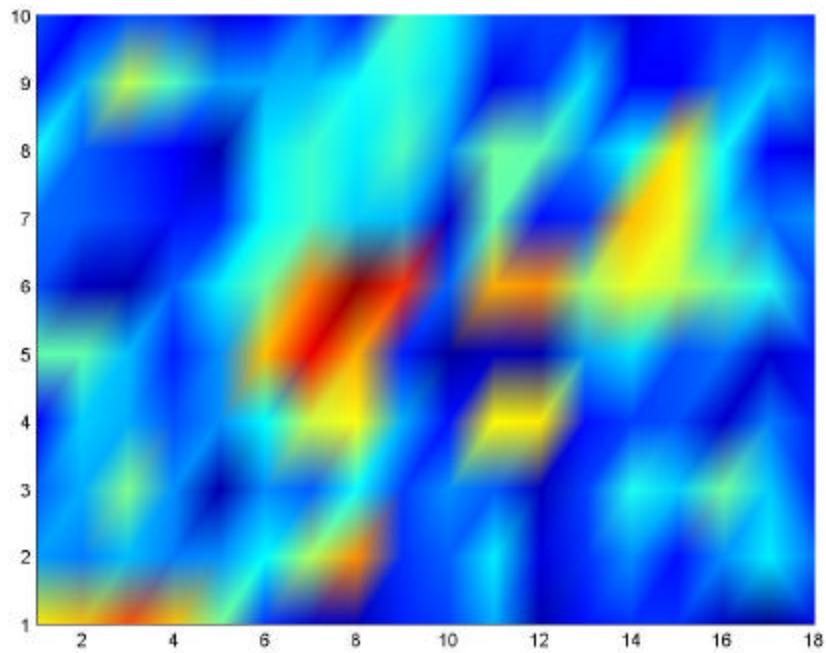


Figure 12. Horizontal slice (60 cm) from the 3-D SAR reconstruction plot of a grave with a large pig, deep burial in Entisol, at 10 months.

Excavations were conducted to correlate decomposition state of the pig cadavers with imagery characteristics. However, once the pigs were excavated, they were no longer monitored with GPR. The return of the shallow pig cadaver in Entisol, (Figures 7 and 8), is easily detectable and changes slightly over 12 months as the fleshed cadaver transitioned to a skeleton. Although the pigs buried at 110 cm still retained mummified soft tissue and hide, they were still discernable for the duration of the study. Overall, the return diminished in later months, but the pig cadavers were still detectable for the duration of the study. Soil moisture was not a major factor for the burials in the sandy soil.

In Figure 9 the return from the pig cadaver is detectable for the shallow burials in Ultisol over the test period. These pigs exhibited a similar transition to a skeleton state as those in Entisol. Soil moisture was a slight factor during the wet months (month 7 to 9). The return from the argillic horizon is very apparent below 100 cm, but is masked by the pig cadaver (Figure 9, 6 months).

Clay was a significant factor in detecting a return from the pig cadaver. For the deeper burials in the Ultisol at the level of the argillic horizon, the return from the pig diminishes significantly over the first few months (Figure 10). Even though the cadaver has undergone almost no decomposition, the return diminishes significantly reducing the chance of grave detection (Schultz, 2003). The clay acted to mask the grave by limiting the contrast of the pig cadaver (Schultz et al., 2002). Over time the relative dielectric permittivity of the cadaver was very similar to that of the soil. Disturbances in the soil above and at the argillic horizon were detected through out the test period.

The cadaver size was not a factor with detection using the 200 – 700 MHz, FM-CW GPR. This was similar to both the 500 MHz and 900 MHz pulsed GPR results. The depth profiles exhibited similar responses for both size cadavers, though the anomalies were smaller for the 24.5 kg pigs.

The 3-D SAR reconstruction plots (Figure 11) were useful for data analysis, but the visual representation did not add much value when compared to the 2-D SAR reconstruction plots. A horizontal slice from the 3-D SAR reconstruction plot (65 cm depth) of a grave with a large pig, deep burial in Entisol, at 10 months, depicts an anomaly in the location of the cadaver (Figure 12). The 60 cm spacing of the grid lines was found to be too coarse for the algorithm processing and resulted in increased interpolation. The grid lines should be reduced in future surveys when time permits. A spacing of 15 cm would improve the reconstruction resolution, but would quadruple the collection time and amount of data.

Summary and Conclusions

This study demonstrated the ability of GPR to detect graves in typical, Florida soil and validated the GPR soil suitability index for the area. Soil type can be a factor for long-term burials when the grave intrudes the clay horizons. It was possible to detect a fleshed cadaver, partially decomposed cadaver, and skeleton remains in the sand soil for a variety of depths. The shallow and deep graves were detected in sand soil throughout the study. The deep graves in clay became difficult to discern over time even though the cadavers had undergone little decomposition. The stepped-frequency results were similar to the 500 MHz pulsed GPR data, both of which were better than the 900 MHz data (Schultz, et al., 2002).

Future Plans

Forensic analysis of the bones and decomposition rates will be performed and further correlated to the GPR data profiles and responses. Over the 21 months, several graves were excavated during the study. At the end of the study all graves were excavated. The decomposition data will be compared to GPR profile data and reported in a future publication. Soil analysis will be performed to determine its effect on the rate of decomposition. Additionally the data acquired during this study will be used as a database for developing neural network processing for “forensic target” identification.

Acknowledgements

The authors are thankful for the cooperation of the IFAS - Animal Science Research and Education Center at the University of Florida for the use of a research field site. This study was funded by the 1999 *Connective Tissue* research award (JJS), and a 2000-2001 Forensic Sciences Foundation Lucas Grant (JJS). In addition, the authors would like to thank Todd McCall, FBI-Evidence Response Team, for project funding and DOE/Applied Technologies Program for use of the GPR unit. This work was supported by the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office, under Contract No. DE-AC08-96NV11718. **DOE/NV/11718--739.**

References

1. Chang, M., Akiyama, I., and Lee, H., 1994, “Image reconstruction and enhancement for subsurface radar imaging using wavefield statistics,” Proceedings of the 28th Annual Asilomar Conference on Signals, Systems, and Computers, pp. 1200-1204.
2. Collins, M.E., Ovalles, F.A., Keuhl, R.J., Kurtz, J.L., Miller, B.K., Kostaanch, P., 1996. Characterization and Comparison of Soils for Ground Penetrating Radar Measurements, GPR Technical Report to MIT/Lincoln Laboratory and the Army Research Laboratory, University of Florida, Gainesville, p. 90.
3. Davenport, C.G., Lindemann, J.W., Griffin T.J., and Borowski, J.E., 1988. Geotechnical Applications 3: Crime Scene Investigation Techniques, *Geophysics: The Leading Edge of Exploration*, Vol., 7, No., 8, pp. 64-66.
4. Davenport, C.G., Griffin, T.J., Lindemann, J.W., and Heimmer, D., 1990. Geoscientists and Law Officers Work Together in Colorado, *Geotimes*, Vol., 35, No., 7, pp. 13-15.
5. Doolittle, J.A. and Collins, M.E., 1995. Use of Soil Information to Determine Application of Ground Penetrating Radar, *Journal of Applied Geophysics*, Vol. 33, pp. 101-108.
6. Doolittle, J.A., Minzenmayer, F.E., Waltman, S.W., and Benham, E.C., 2002. Ground Penetrating Radar Soil Suitability Map of the Conterminous United States, *Ninth International Conference on Ground Penetrating Radar*, Santa Barbara, California, USA, April 30-May 2, pp. 7-12.
7. France D.L., Griffin, T.J., Swanburg, J.G., Llindemann, J.W., Davenport, G.C., Trammell, V., et al., 1992. A Multidisciplinary Approach to the Detection of Clandestine Graves, *Journal of Forensic Science*, Vol. 37, pp. 1445-1458.
8. France D.L., Griffin, T.J., Swanburg, J.G., Llindemann, J.W., Davenport, G.C., Trammell, V., et al., 1997. NecroSearch Revisited: Further Multidisciplinary Approaches

to the Detection of Clandestine Graves. In: Haglund W.D., Sorg M.H., editors. *Forensic Taphonomy: The Postmortem Fate of Human Remains*. Boca Raton, Florida: CRC Press, pp. 497-509.

9. Freeland, R.S., Yoder, R.E., Miller, M.L., and Koppenjan, S.K., 2002. Forensic Application of Sweep-Frequency and Impulse GPR, *Ninth International Conference on Ground Penetrating Radar*, Santa Barbara, California, USA, April 30-May 2, pp. 533-538.
10. Lee, H., Wade, G., and Noorbehesht, B., 1982, "The Transfer Functions of Electrostatics Problems," *IEEE Transactions on Education*, vol. E-25, no. 3, pp. 111-112.
11. Miller, M.L., Freeland, R.S., and Koppenjan, S.K., 2002. Searching for Concealed Human Remains using GPR Imaging of Decomposition, *Ninth International Conference on Ground Penetrating Radar*, Santa Barbara, California, USA, April 30-May 2, pp. 539-544.
12. Koppenjan, S.K., Allen, C.M., Gardner, D., and Wong, H.R., 1998. Lightweight Ground Penetrating Radar, *Seventh International Conference on Ground Penetrating Radar*, Lawrence, Kansas, USA, May 27-30, pp. 771.
13. Koppenjan, S.K., Allen, C.M., Gardner, D., and Wong, H. R., Lee, H., and Lockwood, S.J., 2000. Multi-Frequency Synthetic-Aperture Imaging with a Lightweight Ground Penetrating Radar System, *Journal of Applied Geophysics*, Vol 43, pp. 251-258.
14. Schultz, J.J., Falsetti, A.B., Collins, M.E., Koppenjan, S.K., and Warren, M.W., 2002. The Detection of Forensic Burials in Florida using GPR, *Ninth International Conference on Ground Penetrating Radar*, Santa Barbara, California, USA, April 30-May 2, pp. 443-448.
15. Schultz, J.J. 2003, The Detection of Buried Remains Using Ground Penetrating Radar and Taphonomy of Burials, Ph.D thesis, Department of Anthropology, University of Florida.

This report was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty or representation, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

DISTRIBUTION LIST

U.S. Department of Energy 1 copy
National Nuclear Security Administration
Nevada Operations Office
Technical Library
P.O. Box 98518
Las Vegas, NV 89193-8518

U.S. Department of Energy 1 copy
National Nuclear Security Administration
Nevada Operations Office
Public Reading Facility
P.O. Box 98518
Las Vegas, NV 89193-8518

U.S. Department of Energy 1 electronic copy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062