Appendix C
White Paper: Advanced Processing Methods for Reducing Anomalies

Advanced Processing Method for Reducing Anomalies

February 8, 2005

Introduction

A larger number of anomalies have been encountered during the Range 43-48 project than had been expected. While the anomaly density was originally estimated at approximately 30 anomalies per acre after analog removal, the actual density has averaged 250 anomalies per acre.

Objective

Parsons proposed an evaluation of several advanced processing techniques to address this problem. The objective of this effort was to identify a method to reduce the number of anomalies requiring reacquisition and intrusive investigation without increasing the chances of leaving items of interest in the ground. The goal of this effort was to reduce the number of anomalies by 5 percent.

Methodology

Currently, the determination of which anomalies to investigate is based solely on a threshold analysis. The threshold is a value where all anomalies above that instrument response value are investigated. Currently, the threshold value for this project is 3.0 mV in Channel 3.

The threshold method is the simplest analysis to apply and has proven to be fairly robust for a large number of sites. However, it does not take into account other characteristics of the anomalies, such as width and differences between the three different channels recorded by the EM61-MK2 that could be used to distinguish items of interest from small fragments or false positives. This evaluation focused on the lower amplitude anomalies (between 3 and 5 mV) with larger anomalies automatically selected for reacquisition.

Three additional methods of anomaly selection were evaluated and are described below. The geophysical data and the results of the intrusive investigations from the Range 43-48 project were used to set specific parameters for these methods and determine what percentage of anomalies were eliminated. After finalizing the specific parameters two of the methods were applied to a dataset collected over the Ordnance Detection and Discrimination Study (ODDS) seeded test site to ensure that the methods do not increase the chances of leaving items of interest in the ground.

Alternate Anomaly Selection Criteria Proposed for Evaluation

1) **Anomaly width selection –** An automatic calculation of the width of the anomaly can be performed within the Geosoft environment. The width can be based on either the width at which the anomaly is half the maximum amplitude or the width of the anomaly above a specified noise floor. The idea behind this selection

criteria is that as the depth of burial for an item increases, the anomaly amplitude generally decreases and the width of the anomaly should increase. Therefore, items buried near the maximum detection depth should have a low amplitude, but a wide anomaly width. Therefore, the number of selected anomalies with response values near the threshold could be limited by only investigating those low amplitude anomalies with sufficient width. This has the potential to reduce the number of items dug up, that are small and shallow. Software has been written for other Parsons MEC projects that can be adapted for use at Fort Ord that can automatically calculate the width of each anomaly.

2) **Anomaly Amplitude Decay –** Data acquired with the Geonics EM61-MK2 at Fort Ord includes measurements at three different times after current turn-off in the transmitter coil. The rate at which the signal decays over those three time channels is dependent on many factors including shape, burial depth, orientation and type of metal in the object. It has been shown that the information collected with the Geonics EM61-MK2 is not recorded over a wide enough time range to accurately characterize the object in terms of ordnance type, but results from other surveys conducted by Parsons show that this information can differentiate between objects made of different materials and wall thicknesses. This method would also take advantage of other work conducted by Parsons that can automatically obtain the data from all time channels and calculate the time constants for each anomaly. Another option for this type of analysis is to look not only at the amplitude decay at the anomaly peak, but also at the point where the anomaly strength is ½ of the original anomaly value. This type of analysis is somewhat more complicated than the first type proposed, but once implemented it would not significantly increase the burden on the geophysical processor.

3) **Inversion Analysis –** This analysis would use software developed by other DOD contractors to perform an inversion analysis that would attempt to characterize the item in terms of size, depth and orientation. While currently available methods do not have the ability to characterize an object using EM61-Mk2 data, they may be able to perform an inversion that is capable of distinguishing between larger, deeper buried objects with a low response value and smaller, shallow objects, or between items of different materials or construction. The status of the inversion software from other vendors is not clear and would also significantly increase the processing work required. There would have to be significant reductions in intrusive investigations as a result of this type of analysis in order for this to be recommended.

Analysis

Ranges 43-48 anomalies with amplitudes between 3 and 5 mV on the third time gate (Channel 3) were evaluated to determine what characteristics could be used to eliminate anomalies caused by small fragments. The anomaly width and decay constants of each low amplitude anomaly were calculated, with the results plotted below.

Anomaly Width Analysis

The full-width of each anomaly was determined from the profile collected nearest the anomaly. The full-width was calculated at the half-maximum amplitude of the anomaly as shown in Figure 1.

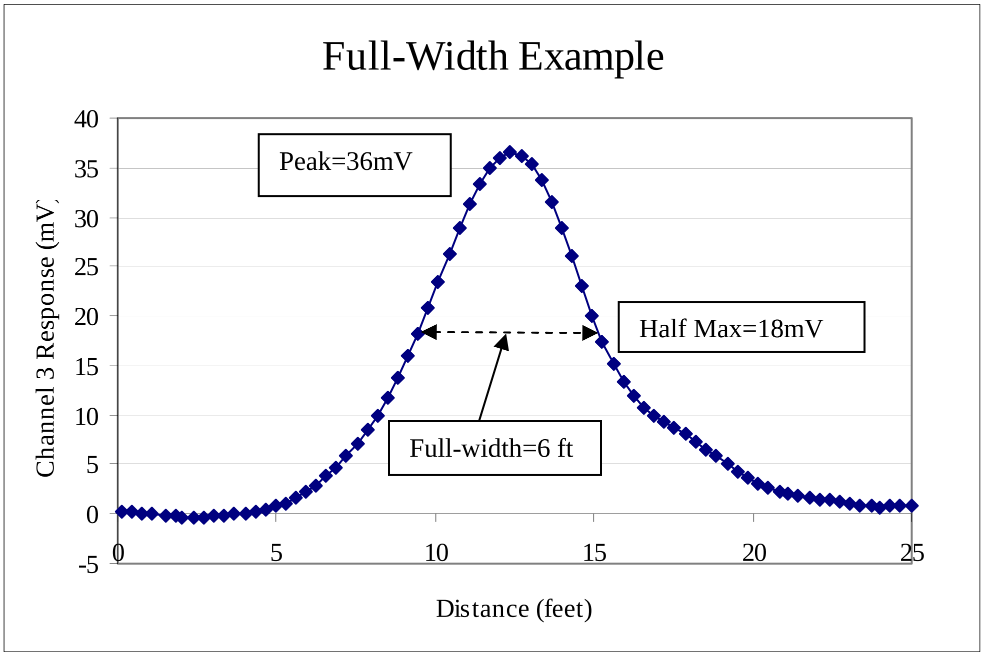

Figure 1. Example profile showing anomaly full-width at half-maximum.

The full width of an anomaly increases as the depth of burial increases. This relationship allows low amplitude anomalies caused by small, shallow items (i. e. fragments) to be distinguished from low amplitude anomalies caused by larger deeper items. Figure 2 displays two sample profiles, one wide profile over a 105mm Projectile at 48 inches bgs, and one over a small, near surface fragment. Both profiles are from the ODDS known seeded item plots.

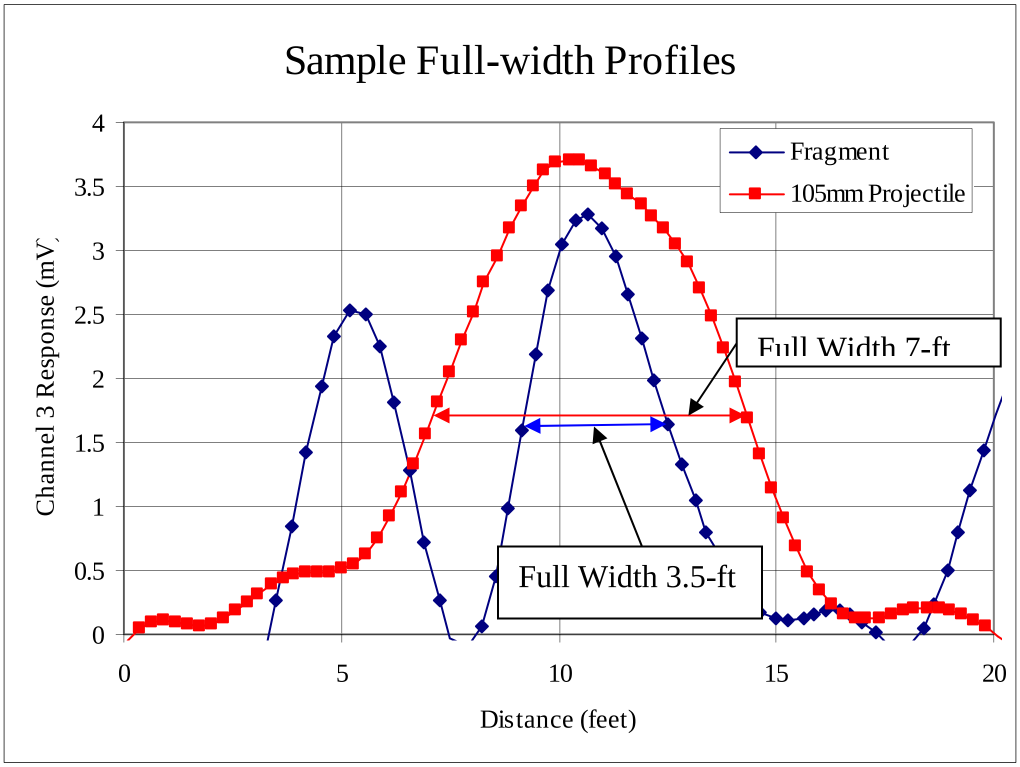

Figure 2. Sample profiles showing how the full-width of an anomaly can be used to distinguish between small near surface items and larger, deeper items.

Peak Time Decay Analysis

Using similar methods as the full-width analysis, time decay coefficients were determined for the peak value over the anomalies in Ranges 43-48. Two sample time decay curves are plotted in Figure 3 for the same two items shown above. The exponential decay from the early (Channel 1) through late (Channel 3) time gates is calculated using the following formula (Bosner, 2001):

$$\tau_{(m-n)} = \frac{t_n - t_m}{\ln(V_n - V_m)}$$

$\tau_{(m-n)}$ = time constant between channels m and n

m and n are gate numbers 1 to 4 (n>m)

V_m and V_n are the measured gate voltages at times t_m and t_n

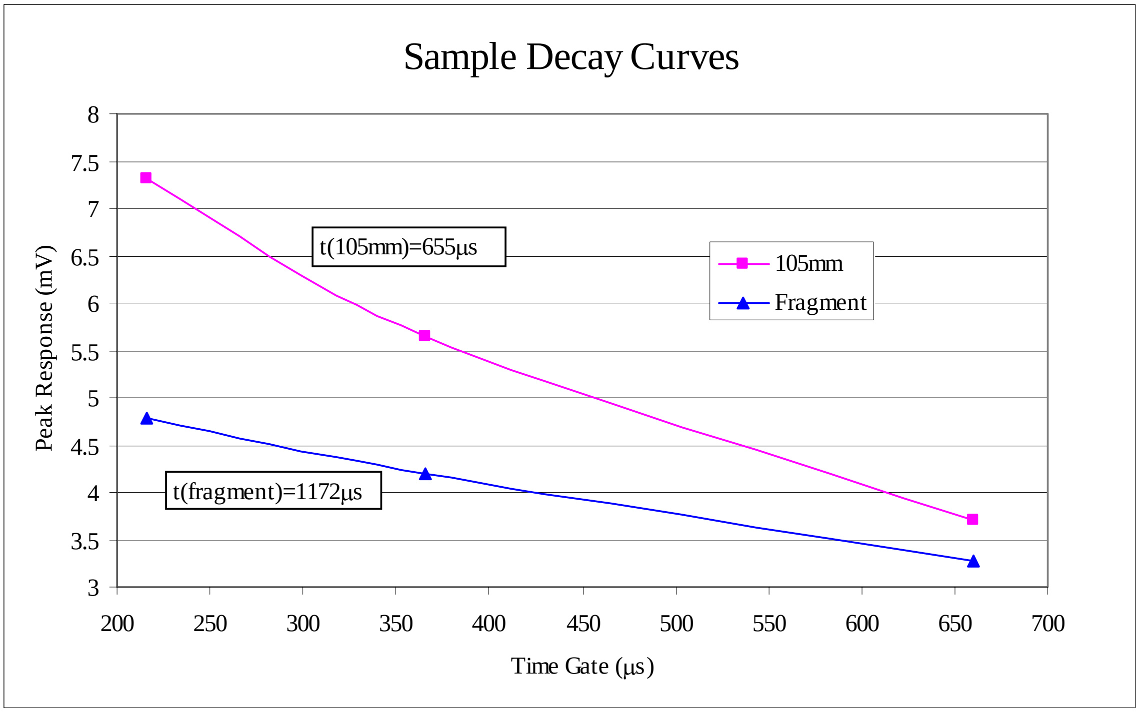

Figure 3. Sample decay curves of the 105mm projectile and near surface fragment shown in Figure 2 with very different decay constants.

Full-Width decay constant analysis

Properties of the decay constant at the half-maximum point for an anomaly (offset by one half-width from the peak) could provide an opportunity to further reduce the number of anomalies. These ratios were calculated for anomalies in the ranges 43-48 area, but the results did not add much benefit beyond the reductions from the full-width and peak decay constant analysis described below.

Inversion Analysis

Inversion software developed by other DoD contractors was investigated for use with the data being collected in the Ranges 43-48 area. Two such software packages exist: a Geosoft based package developed by AETC, and a Matlab based package developed at UBC (University of British Columbia). The AETC software is not yet available but is expected to be released in beta test stage in the first quarter of 2005. The UBC software is currently available and one of the developers was contacted to determine if it would offer advantages over the methods described above. However, reliable inversions require very high quality positioning data and a very dense dataset. The process being employed at Ranges 43-48 (data transects every 2 feet) does not provide adequate inputs to take advantage of the recent developments in inversion algorithms. The UBC software would likely not provide significant anomaly reduction after the methods described above. The cost of the software and additional processing time required to use it would likely offset any benefits gained from using this software on the Ranges 43-48 dataset.

Intrusive Investigation Reduction Analysis

To analyze the potential of this selection method to reduce anomaly selection for intrusive investigations, a program was written to extract the additional anomaly attributes from the data. It is in the form of a Geosoft Executable (GX) that runs within the Geosoft Oasis montaj processing environment currently used at Ft. Ord. The GX goes through all the anomalies selected by the processor for a grid block. The following process is then computed for each anomaly point:

1. Find the closest point in the acquired data to the picked anomaly point
2. Search forward and backward along the line in the data to find the actual data point that represents the peak of the anomaly in Channel 3.
3. Store that value as well as the Channel 2 value at the same location.
4. Search backwards and forwards for the peak in the Channel 1 data.
5. Store the Channel 1 value and compute the apparent time decay constant between Channels 1 and 3.
6. The GX then searches backwards and forwards along the line for the full-width points for the Channel 3 profile and computes the anomaly full-width and stores that information.
7. The GX then also retrieves the Channel 1 and Channel 2 data at the two points where the anomaly is half the peak value and computes the apparent decay time constant for those two points as well.

This GX was run over all data sets acquired within the Range 43-48 area where UXO or QC items were found. Only point anomalies were analyzed and not polygon anomalies. This resulted in the GX being run over 46 different datasets collected at Range 43-48 with 6,885 anomalies being extracted. During this process one software error was discovered and fixed.

The data for all these anomalies was then exported as a CSV file and imported into an Access database. The geophysical anomaly attributes were then merged with the information from the reacquisition and digital excavation results based on the unique Target-ID's for each anomaly. Because not all the anomalies had been intrusively investigated, the final total of anomalies where the geophysical attributes could be compared to the intrusive results was 4,717 anomalies. This anomaly set was then used for evaluating the anomaly selection criteria results.

The full-width and peak decay constant methods appear to offer the largest opportunity for anomaly reduction and will require minimal additional processing effort. Figure 4 displays a crossplot of the peak time constant vs. the full-width for the selected 4,717 anomalies in Ranges 43-48.

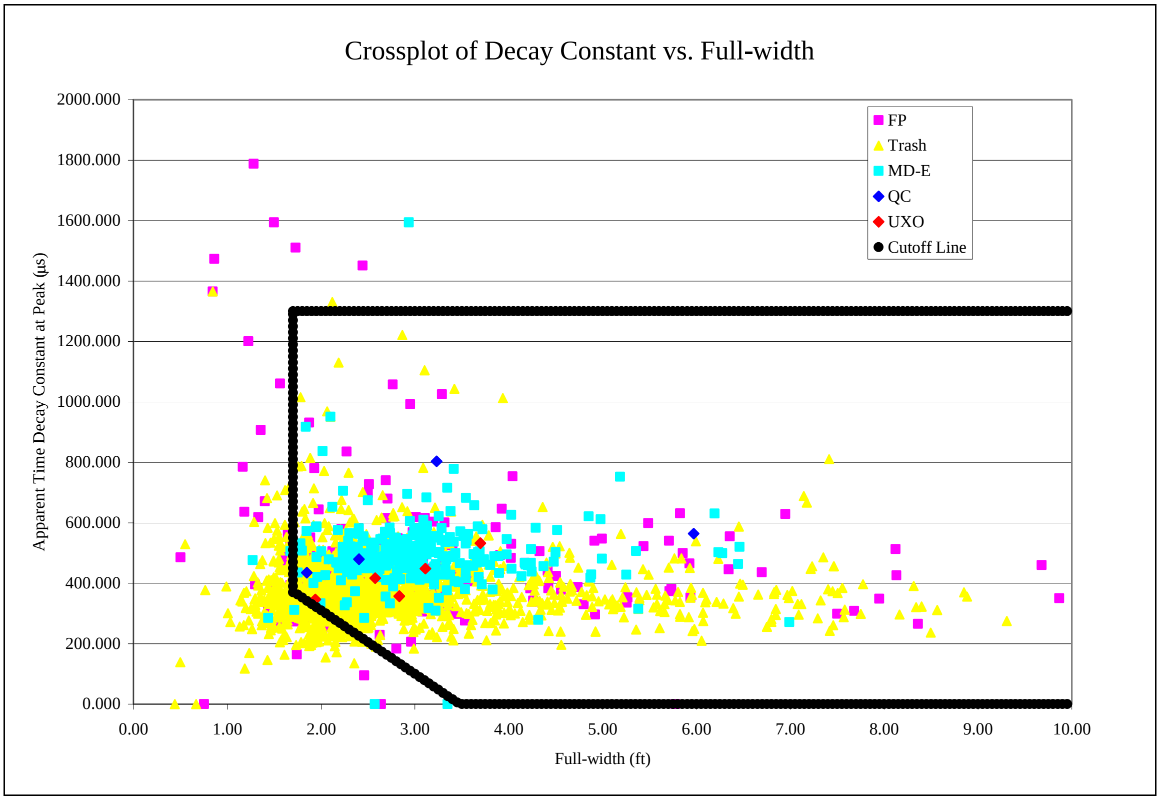

Figure 4 – Anomaly Peak Decay Time Constant plotted vs. Full-Width for Anomalies with a Channel 3 Peak value less than 5 mV – Range 43-48 points anomalies.

Based on these data, criteria for the decay constant and minimum full-width cutoff values were established to identify anomalies that do not contain UXO or QC items of interest and therefore don't have to be intrusively investigated. The following criteria were selected to remove the maximum number of anomalies while not removing any UXO or QC items of interest. Only anomalies with peak values less than 5mV on Channel 3 were considered for elimination.

1) Anomalies with full-widths less than 1.7-ft or
2) Decay constants greater than 1300µ or
3) A Cut-Off line was computed that eliminated additional targets with full-widths greater than 1.7-ft and lower time constants. The parameters for this cut-off line are:

   time constant = 730 – 210*full-width.

   Any anomalies for which the measured time constant was less than the time constant computed with this formula were eliminated as well.

A graphical representation of the criteria described above is also shown on Figure 4. Applying the criteria discussed above results in the elimination of 431 anomalies (those anomalies outside of the box) of a total of 4,717 or 9.1% of the total anomalies (not including the polygon anomalies). A majority of the anomalies that were excluded were classified as Munitions Debris – Fragment and false positives. In addition, there were several anomalies that were designated as munitions debris expended (MD-E). These items consisted of 22 mm subcaliber and 14.5 mm subcaliber munitions. These items are smaller than the smallest item of interest – a 37 mm projectile. The 9.1% reduction is significantly above the 5% reduction set as a goal for this initiative. No UXO or QC items larger than the smallest item of interest were excluded using these criteria.

To check these values on a different dataset, the process described above was applied to the dataset collected over the ODDS seeded plots. The criteria discussed above eliminated a total of 29 anomalies out of a total of 383 anomalies - a reduction of 7.6%, without eliminating any items of interest larger than the 37 mm.

A GX was also written that automates the use of these criteria, so that the operator can quickly determine which anomalies should be deselected. As an additional step, the operator can review the deselected anomalies and ensure that the selection process was performed correctly. Based on the number of datasets on which we have tested this GX, we believe it is ready for implementation into the production environment.

Conclusion

Based on the analysis performed it is believed that the number of anomalies selected for intrusive investigation in the Range 43-48 of Fort Ord could be reduced by approximately 8-10% by applying these thresholds to the anomaly full-width and peak time decay constant. Applying this type of analysis to the data would not result in an increased chance of leaving items of interest in the ground. This method can be easily integrated into the existing geophysical data processing flow and could provide cost savings to the Fort Ord clearance effort.

Quality Control

Additional quality control steps will be implemented to ensure that the selected advanced processing techniques are effective and being followed. A percentage of anomalies with peak Channel 3 values over 3 mV, but which have been eliminated by the advanced processing, will be reacquired. The results from excavation of these anomalies will be reviewed to ensure that none are items of interest. The percentage of anomalies to be checked will start at 10%, but may be reduced at a later date if these QC anomalies do not result in items of interest.

Future Improvements

There are several possible areas where additional anomalies could be eliminated, listed below:

1) Change the use of Channel 4 on the EM61MK2 from recording data from the top coil to recording the fourth time gate at 1266 µs. Generally, the later in time you

record, the better chance you have of discriminating between different types of objects. This will depend of whether there is enough signal-to-noise in the late time gate data to obtain accurate decay time constants. Currently there is no data set over which we could analyze the potential for later time gate data at Ft. Ord. However, experience at other sites has shown that the best discrimination results were obtained with decay time constants that included the last time gate. A suggested approach might be to start recording the later time gate and then evaluate the use of the data as the intrusive results become available.

2) Acquire additional data during the reacquisition phase to perform additional dig/nodig decisions after analysis of additional data acquired during reacquisition. The additional data could include more accurate data readings directly over the peak of the anomaly with the EM61-MK2 or possibly the EM63 –which has 20 time gates that extend over a much wider time range. Additional data could include the use of an EM61 with a GPS unit on reacquisition that would collect several lines over each anomaly in orthogonal directions and then an inversion or more detailed analysis could be performed.

Reference

Bosner, Miro, 2001, Technical Note 33 (TN-33), Why did Geonics build the EM61-MK2?, Geonics, Ltd.