USACE Participation in the Pole Mountain Advanced Classification Demonstration

Richard Grabowski, *U.S. Army Corps of Engineers, Omaha*

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14. ABSTRACT

This report describes in detail the procedures, methods, and resources used to complete the demonstration project at the former Pole Mountain Target and Maneuver Area. The objective of U.S. Army Corps of Engineers (USACE) participation was to learn to use advanced classification processes and apply them to making dig/no-dig decisions on munitions response sites. A total of 2,370 data files were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis Montaj software package. Once analysis was complete, theoretical ranked dig lists were submitted for scoring by the Institute for Defense Analyses. Dig list scoring was based on the number of targets of interest (TOIs) correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. The dig list submitted by USACE Omaha District correctly identified all of the TOI on site as TOI and the number of false positives was reduced by approximately 59%. A retrospective analysis was performed to examine ways of improving the results of the advanced classification. Results indicate that more aggressive use of a size parameter leads to a reduction of false positives by up to 77%.

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MetalMapper, UX-Analyze, UXO, Pole Mountain Target and Maneuver Area, discrimination, classification

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ACRONYMS

cm	centimeter
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
Geometrics	Geometrics, Inc
Geonics	Geonics, Inc
GPS	global positioning system
HE	high explosive
ID	identification
IDA	Institute for Defense Analyses
ISO	industry standard object
m	meter
mm	millimeter
Nfa	number of false alarms
PMTMA	Pole Mountain Target and Maneuver Area
Sky	Sky Research, Inc
SLO	San Luis Obispo
TDEM	time domain electromagnetic
TOI	target of interest
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
UXO	unexploded ordnance

EXECUTIVE SUMMARY

This report describes in detail the procedures, methods, and resources used to complete the demonstration project at the former Pole Mountain Target and Maneuver Area (PMTMA) (herein referred to as Pole Mountain) for Environmental Security Technology Certification Program (ESTCP) Project MR-201167 (USACE Participation in the Pole Mountain Advanced Classification Demonstration). The objective of U.S. Army Corps of Engineers (USACE) participation was to learn to use advanced classification processes and apply them to making dig/no-dig decisions on munitions response sites.

USACE's responsibilities on this project included only the processing and analysis of MetalMapper data collected at the Pole Mountain site by Sky Research, Inc (Sky). The MetalMapper is an advanced electromagnetic induction system developed by Geometrics, Inc (Geometrics), with support from the ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven tri-axial receiver antennas inside the Z (bottom) loop, allowing a total of 63 independent measurements of the transient secondary magnetic field when all transmitter coils are used. Sky personnel collected MetalMapper data over 2,370 targets in a static mode, preprocessed the data, and submitted background corrected .CSV files for each target to ESTCP, who then forwarded the files to the USACE.

The 2,370 data files were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis Montaj software package. Once analysis was complete, theoretical ranked dig lists (theoretical because all targets were intrusively investigated regardless of the indicated stop dig points) were submitted for scoring by the Institute for Defense Analyses (IDA). Dig list scoring was based on the number of targets of interest (TOIs) correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. Dig lists submitted by USACE were scored against the ground truth data generated during the intrusive investigation performed at the site following MetalMapper data collection.

The dig list submitted by USACE Omaha District correctly identified all of the TOI on site as TOI and the number of false positives was reduced by approximately 59%. A retrospective analysis was performed to examine ways of improving the results of the advanced classification. Results indicate that more aggressive use of a size parameter leads to a reduction of false positives by up to 77%.

1.0 INTRODUCTION

Remedial actions at Munitions Response Sites often involve the systematic surveying of the site with a geophysical sensor integrated with a global positioning system (GPS). This data is used to construct maps from which anomalous responses, otherwise known as anomalies, are identified. The locations of all anomalies are then dug. A substantial amount of time and money is spent excavating non-hazardous pieces of metal on munitions response sites. In some cases over 95% of the remedial action funds are expended digging fragments, clutter and cultural debris that could be left in the ground without adding inherent risk to the land users. Leaving non-hazardous material in the ground provides the potential for a significant cost saving.

Advanced classification as applied to munitions response refers to a process used to make a decision regarding whether the source of the anomalies are hazardous or not. Advanced classification is based on target parameters derived from fitting physics-based models to the observed geophysical sensor responses. Advanced classification takes advantage of more recent advanced electromagnetic induction (EMI) sensors, specifically the MetalMapper, TEMTADS and Berkley Unexploded Ordnance (UXO) Discriminator, which are capable of collecting static, high resolution, three-dimensional data over individual targets. This data is then inverted or modeled to produce polarizability curves that are inherent to the object. By clustering like curves and/or matching these curves to a library of know objects the processer can classify each target as a target of interest (TOI) or not.

The Environmental Security Technology Certification Program (ESTCP) initiated a Classification Pilot Program in 2007 to validate the application of a number of recently developed technologies in a comprehensive approach to munitions response. The goal of the program is to demonstrate that classification decisions can be made using an explicit approach, based on principled physics-based analysis that is transparent and reproducible. The former Pole Mountain Target and Maneuver Area (herein referred to as Pole Mountain) site is the sixth in a series of demonstration sites designed to showcase the use of advanced classification technologies in support of the Military Munitions Response Program.

1.1 OBJECTIVE OF THE DEMONSTRATION

The objective of the U.S. Army Corps of Engineers (USACE) participation in the advanced classification demonstration project was to learn to use advanced classification processes and apply them to making dig/no-dig decisions on munitions response sites. Initially, EMI data was collected by URS Corporation (URS) using a single-sensor Geonics, Inc (Geonics) EM61-MK2 in cart configuration as shown in **Figure 1**.

Figure 1: EM61-MK2 Cart Used to Collect Data at the Pole Mountain Site

The EM61-MK2 data was preprocessed by URS and a total of 2,370 anomalies were identified. A Geometrics, Inc (Geometrics) MetalMapper sensor was used by Sky Research, Inc (Sky) to perform cued interrogation on all the identified anomalies. The MetalMapper sensor was mounted to a Kubota All-Terrain Vehicle as shown in **Figure 2**.

Figure 2: MetalMapper Setup Used to Collect Data at the Pole Mountain Site.

The MetalMapper data was preprocessed by Sky through the stage of background correction, and then made available to the participants of this demonstration along with the EM61-MK2 data and the list of anomalies.

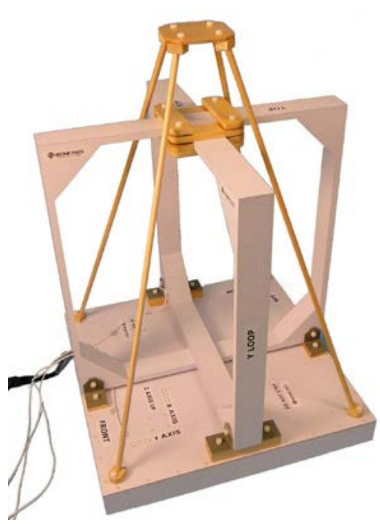
The MetalMapper data was processed by USACE using Oasis Montaj UX-Analyze algorithms. Dig/no-dig decisions were made by categorizing the target list based on specific parameters which are discussed below.

2.0 TECHNOLOGY

2.1 METALMAPPER TECHNOLOGY DESCRIPTION

The MetalMapper is an advanced EMI system developed by Geometrics, with support from the ESTCP. The MetalMapper system uses time domain electromagnetic (TDEM) principles to induce electrical currents in buried metallic objects and then measure the effects of those currents in receivers located on the ground surface. It has 3 orthogonal transmitter coils, each approximately 1 m x 1 m in size. One coil is oriented horizontally to generate vertical fields and the two other coils are mounted vertically orthogonal to each other as shown in **Figure 3**. Within the box containing the horizontal coil are 7 receiver cubes, each one containing 3 orthogonal coils to measure the fields, thus resulting in 21 different receiver coils. The receiver coils are oriented in the same manner as the transmitter coils.

Figure 3: Assembled MetalMapper Unit.



The transmitter coils are powered using a bi-polar half duty cycle and the time decay of the subsurface currents (transients) are measured during the off time of the transmitter coils. The transmitter coils are activated in sequence and measurements are recorded in all 21 receiver coils. In the case of Pole Mountain where all transmitter coils were used, this resulted in 63 different EM transients measured and recorded.

The MetalMapper has two modes of data collection, dynamic and static. Dynamic mode data are collected while the antenna platform is in motion. Static mode data collection is employed for cued surveys. As the name implies, the antenna platform remains static or motionless during the period of data acquisition. Depending on the acquisition parameters (e.g. sample period and stacking parameter) it can take tens of seconds to complete a single static measurement. The results of the static measurement are written into a binary data file containing only a single data point representing the average (stacked) result, usually over tens or even hundreds of repetitions of the transmitter's base frequency.

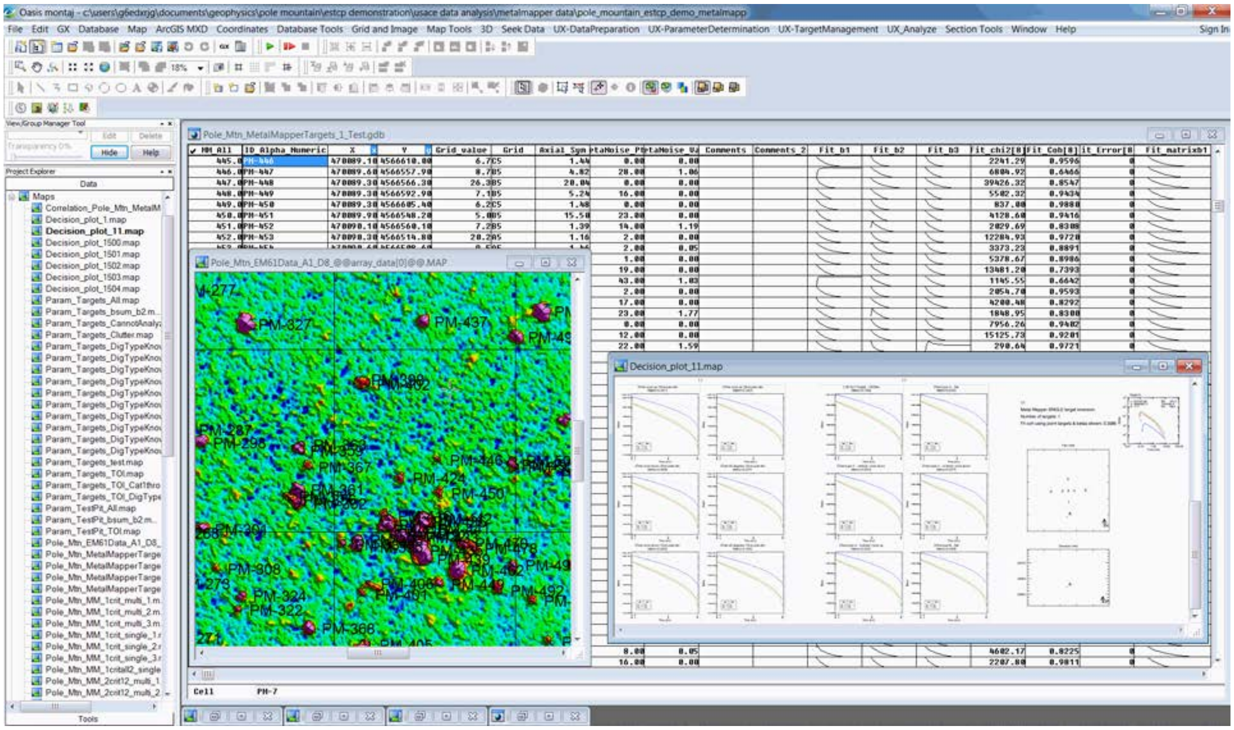
Data are acquired in time blocks that consist of a fixed number of transmitter cycle "repeats". Both the period and the repeat factor are operator selectable and are varied in multiplicative factors of 3. The MetalMapper also averages an operator-specified number of acquisition blocks (NStacks) together before the acquired data are saved to disk. The decay transients received during the off times are stacked (averaged) with appropriate sign changes for positive and negative half cycles. The decays in an individual acquisition block are stacked, and the decays in that block are averaged with other acquisition blocks (assuming the operator has selected NStack greater than 1). The resultant data are saved as a data point.

In its present (third generation) form, the MetalMapper technology has been demonstrated and scored at the Standardized UXO Technology Demonstration sites at Yuma Proving Grounds (Blind Grid only), at Aberdeen Proving Grounds (Blind Grid plus Direct Fire and Indirect Fire Areas), and most recently at Camp San Luis Obispo (SLO), Camp Butner, and Camp Beale in connection with 2009 through 2011 Classification Studies carried out by ESTCP. The performance of the MetalMapper at these sites is documented in formal reports issued by the Aberdeen Test Center and by the various demonstrators who analyzed the data collected at Camp SLO, Camp Butner, and Camp Beale.

2.2 UX-ANALYZE SOFTWARE TECHNOLOGY DESCRIPTION

The UX-Analyze module in Geosoft Oasis montaj software was the primary tool used to analyze MetalMapper data during USACE's participation in this advanced classification demonstration. UX-Analyze is a target selection, fitting and classification tool for UXO applications (**Figure 4**). During the course of several SERDP and ESTCP projects, AETC and Duke University developed various advanced processing procedures for improved detection of buried UXO and discrimination between UXO and clutter. Different procedures have been developed for use with magnetometer data and EMI sensor data. The procedures rely on physics-based models for the sensor response due to buried objects and estimate model parameters that correlate with target features or location to produce an optimal match between the modeled- and measured-sensor responses. Target location, depth, and magnetic dipole moment can be determined from magnetometer survey data, and the size of the target can be estimated from the dipole moment. These parameters have proven to be useful for discriminating between buried UXO and some clutter items. With proper processing, EMI sensor data collected above an unknown object can be used to determine eigenvalues of the magnetic polarizability tensor, which in turn can be used to determine information regarding the object's shape, size and burial depth. Robust, statistically efficient decision rules for target classification and discrimination then can be constructed using any of the target features.

Figure 4: Screen Snapshot of Computer Monitor during Data Analysis using UX-Analyze.



3.0 PERFORMANCE OBJECTIVES

The specific performance objectives for this demonstration are based on the objectives stated in the Project Demonstration Plan (U.S. Army Corps of Engineers, 2011) and are summarized in **Table 1**.

Table 1: Performance Objectives for this Demonstration.

Performance Objective	Metric	Data Required	Success Criteria
Correct classification of munitions	Number of UXO correctly identified	• Anomaly Classification List • Ground truth	Approach correctly identifies all UXO down to 30 cm as TOI and 97% of all UXO 57-mm or larger when deeper than 30 cm.
Maximize correct classification of non-munitions	Number of non-UXO correctly identified	• Anomaly Classification List • Ground truth	Approach correctly identifies 75% non-UXO anomalies as not TOI.
Stop dig threshold	Number of UXO recovered and number of false alarms eliminated	• Prioritized Dig List • Prioritized No- Dig List • Scoring reports from the IDA	Threshold between dig and no-dig places 50% of the master list of anomalies in the no-dig category while identifying all UXO 30 cm deep or shallower as TOI and 97% or more of UXO 57-mm or larger as TOI when deeper than 30 cm. (Assumes ~10% of all anomalies on master list are UXO.)
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Unable to apply decision rules".	• Demonstrator decision rules and parameters.	Reliable target parameters can be estimated and decision rules applied to 90% or more of anomalies on master anomaly list.
Correct estimation of target parameters	Accuracy of estimated target parameters.	• Calculated target parameters • Results of intrusive investigation	X, Y < 15 cm (1ó), Z < 10 cm (1ó), size ± 20%, symmetry estimate correct > 95% for anomalies processed

3.1 CORRECT CLASSIFICATION OF MUNITIONS

This is one of the two primary measures of the effectiveness. By collecting high-quality data and analyzing those data with advanced parameter estimation, we anticipate classification algorithms and rule-based decisions will correctly classify UXO targets in the TOI class.

3.1.1 Metric

The metric for this objective is the number of items on the master anomaly list that are correctly classified as UXO and placed on the dig list.

3.1.2 Data Requirements

A list of anomalies from the master anomaly list classified as TOI and ground truth for those anomalies.

3.1.3 Success Criteria

The objective will be considered to be met if 100% of all UXO 30 cm deep (to center of mass) or shallower are correctly identified as TOI and if 97% or more of the UXO 57-mm in diameter or larger are correctly identified as TOI when deeper than 30 cm. Items smaller than 57-mm in diameter and deeper than 30 cm (to center of mass) are not anticipated. If these items are present but not selected in the TOI class, they will not be counted in this metric calculation.

3.2 MAXIMIZE CORRECT CLASSIFICATION OF NON-MUNITIONS

This is the second of the two primary measures of the effectiveness of this approach.

3.2.1 Metric

The metric for this objective is the number of anomalies from the master anomaly list that are correctly classified as not-TOI.

3.2.2 Data Requirements

A list of anomalies from the master anomaly list classified as not TOI and ground truth for those anomalies.

3.2.3 Success Criteria

The objective will be considered to be met if 75% or more of the non-munitions items are correctly labeled as not TOI.

3.3 STOP-DIG THRESHOLD

When all identified anomalies are excavated as in this type of demonstration, it is possible to tell the true classification capabilities of a classification process based solely on a prioritized dig list. In a real-world scenario, all targets may not be dug so the success of the approach would depend on the ability of an analyst to accurately specify a dig/no-dig threshold.

3.3.1 Metric

Percent of UXO correctly identified as TOI and numbers of false alarms, Nfa, at the threshold are the metrics for this objective.

3.3.2 Data Requirements

A list of ranked anomalies with a dig/no dig threshold as specified by the demonstrator. IDA personnel will use their scoring algorithms to assess the results.

3.3.3 Success Criteria

The objective will be considered to be met if the threshold between dig and no-dig places 50% of the master list of anomalies in the no-dig category while identifying all UXO 30 cm deep or shallower as TOI and 97% or more of UXO 57-mm or larger as TOI when deeper than 30 cm. This metric assumes approximately ten percent of all anomalies on the master anomaly list are UXO. If significantly more than ten percent are UXO it may be necessary to adjust this metric.

3.4 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated and dig/no-dig decision rules cannot be applied often must be placed in the dig category, thus reducing the effectiveness of the classification process.

3.4.1 Metric

The number of anomalies for which reliable parameters cannot be estimated and decision rules applied is the metric for this objective.

3.4.2 Data Requirements

A list of all target parameters along with a list of those anomalies for which parameters could not be reliably estimated and decision rules applied will be submitted by each demonstrator.

3.4.3 Success Criteria

The objective will be considered to be met if reliable parameters can be estimated and decision rules applied to 90% or more of the anomalies on the master anomaly list.

3.5 CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are estimated during anomaly analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately and verify some, or all of them with ground truth.

3.5.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.5.2 Data Requirements

A list of all target parameters will be submitted for each anomaly analyzed as part of this demonstration. IDA analysts will compare these estimated parameters to those measured during the intrusive investigation and determined via other means used by the ESTCP program office.

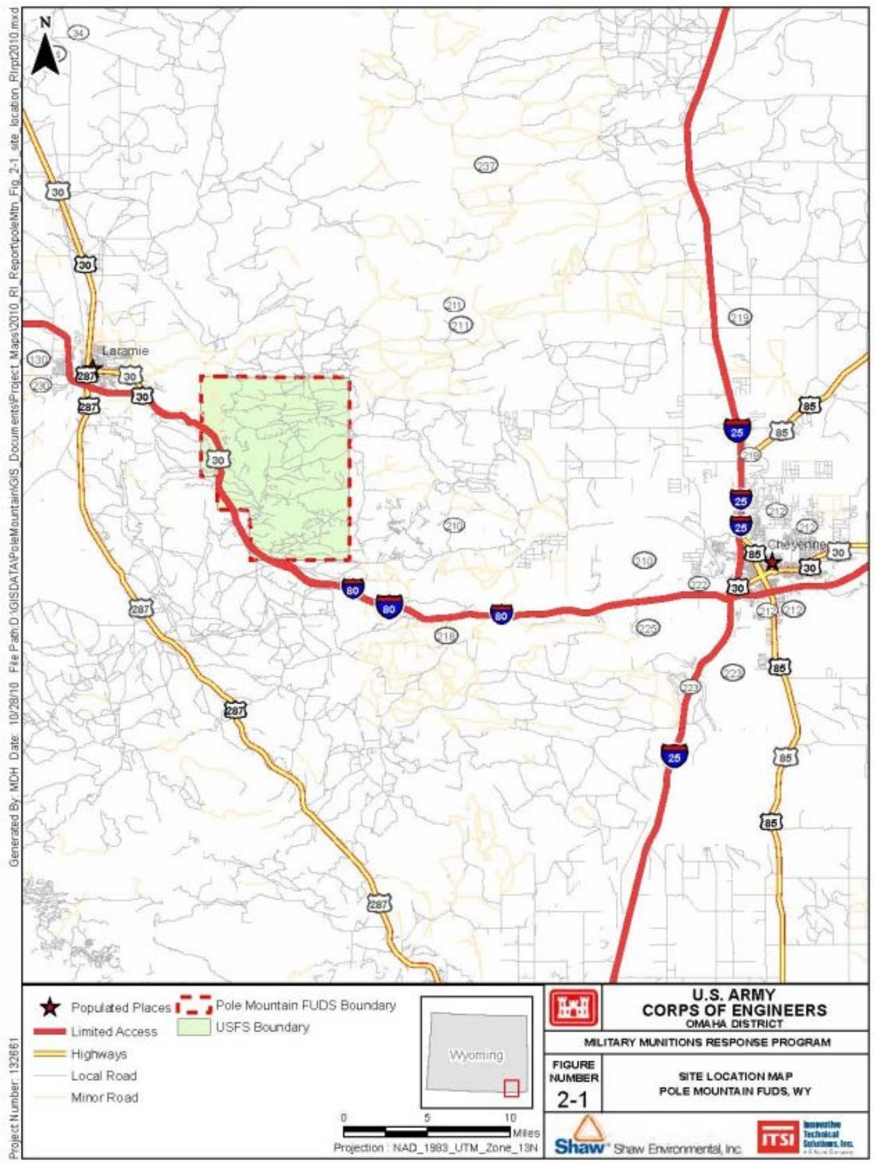
3.5.3 Success Criteria

The objective will be considered to be met if estimated size parameters are within ± 20%, estimated symmetry is correct for 95% of the cases, estimated X, Y locations are within 15 cm (1σ), and estimated depths are within 10 cm (1σ).

4.0 SITE DESCRIPTION

Pole Mountain is located in southeastern Wyoming, approximately 7 miles east of Laramie and 40 miles west of Cheyenne, Wyoming in the Pole Mountain Unit of the Medicine Bow National Forest as shown in **Figure 5**.

Figure 5: Site Location Map



Pole Mountain has been subdivided into 6 munitions response sites as shown in **Figure 6**. The demonstration site totals 50 acres and is located within the Bisbee Hill Maneuver Area as shown in **Figure 7**.

Figure 6: Munitions Response Site Map.

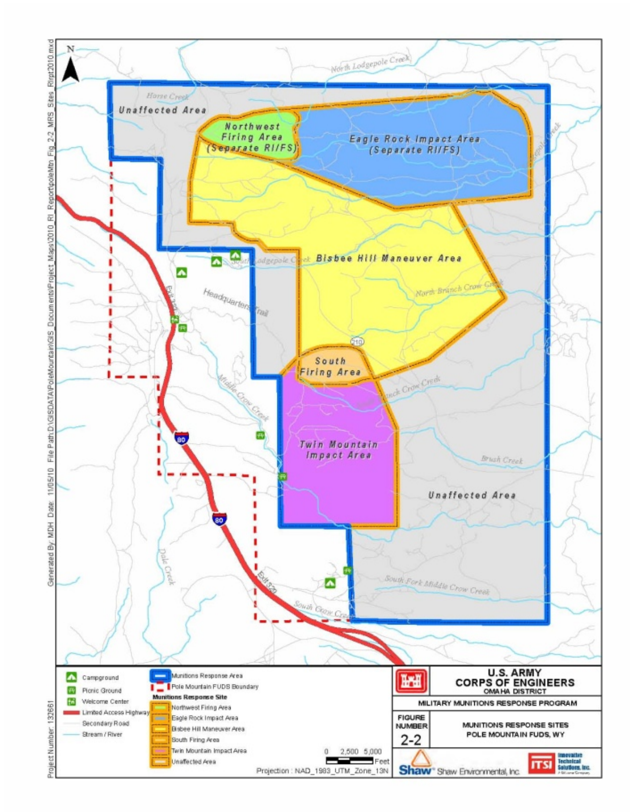
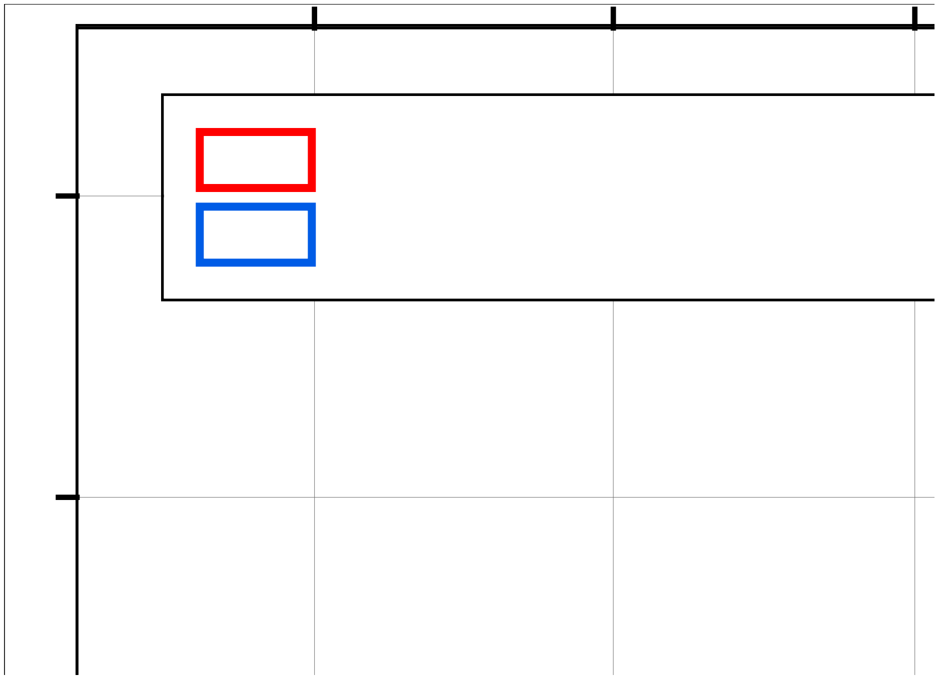


Figure 7: Site Location Map.



4.1 SITE HISTORY

Pole Mountain was established in 1879 as the Fort D.A. Russell Wood and Water Reserve. The land status alternated between national forest and military reservation from 1897 to 1925. Use of Pole Mountain fluctuated widely between 1925 and 1945, with some periods of almost no military use and other periods of heavy use. Pole Mountain, which has been known by a variety of names over the years, was extensively used as a target and maneuver area before 1959 by the Army, the Reserve Officers' Training Corps, the Citizens' Military Training Corps, various National Guard units, and the Department of the Air Force. Disposition of portions of Pole Mountain by the Department of Defense or its predecessor agencies included actions between 1945 and 1960. In July 1961, a Public Land Order terminated all military interests in the Pole Mountain District.

4.2 SITE GEOLOGY

Pole Mountain and the surrounding area consist of grassland, forest, and rock outcrops of the Sherman Mountains, a portion of the Laramie Range located within the Southern Rocky Mountains physiographic province. The topography of Pole Mountain is characterized by steep rock outcrops and broad rolling hills, which are dissected by drainages that principally flow in an easterly direction. The elevation ranges between approximately 7,500 and 9,050 feet above mean sea level.

The Laramie Range was formed by folding and faulting during the Laramide uplift in which Precambrian crystalline rocks are exposed in the core of the range. At Pole Mountain, the exposed core consists of 1.43-billion year-old rocks of the Sherman Granite, a coarse-grained, metaluminous biotite-hornblende granite.

4.3 SITE CONTAMINATION

A large variety of munitions have been reported as used at Pole Mountain. Physical evidence for the following items was discovered during the Remedial Investigation:

- Projectiles containing high explosive (HE) filler (37-mm to 155-mm, and 2.95-inch);
- Shrapnel projectiles (75-mm and 3-inch);
- 37-mm projectiles (inert and unfuzed)
- 3-inch Stokes mortars (practice, fuzed);
- 60-mm mortars containing HE filler; and
- Small arms ammunition (.30-caliber and .50-caliber)

5.0 TEST DESIGN

The objective of this program was to learn to use advanced classification processes and apply them to making dig/no-dig decisions on munitions response sites. The key components of this demonstration project are 1) collection of high quality geophysical data and principled selection of anomalous regions in those data, 2) analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties, and 3) the use of those parameters to construct a ranked anomaly list. In the course of participating in this demonstration, the USACE executed components 2 and 3 listed above. Target parameters were extracted during processing and passed through classification routines that were used to produce prioritized anomaly lists ordered from the item that the classification routine determined was most likely a munitions through the item regarded as the most likely to be nonhazardous.

The prioritized anomaly list was scored by the IDA, with emphasis on the number of items correctly labeled nonhazardous while correctly labeling all TOIs. The primary objective of the demonstration was to assess how well each demonstrator was able to order its ranked anomaly list and specify the threshold separating high-confidence clutter from all other items. The secondary objective was to determine the classification performance that could be achieved by each approach through a retrospective analysis.

5.1 SITE PREPARATION

USACE was not involved in site preparation for this project. Site set-up and logistics were performed by URS, and details regarding this aspect of the project should be contained in their report.

5.2 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. All MetalMapper data for this project were collected by Sky. Site-specific MetalMapper configuration should be discussed in detail in Sky's report.

5.3 CALIBRATION ACTIVITIES

All MetalMapper data for this project were collected by Sky. Any MetalMapper calibration activities performed on site should be discussed in detail in Sky's report.

5.4 DATA COLLECTION PROCEDURES

All MetalMapper data for this project were collected by Sky. Specific data collection activities performed on site should be discussed in detail in Sky's report.

5.5 VALIDATION

All anomalies on the master list were excavated by a team led by the URS. Each item encountered was identified, photographed, its depth measured, its location determined using centimeter-level GPS, and the item removed if possible. These ground truth data were used for evaluation of the dig lists submitted by various analysts.

6.0 DATA ANALYSIS PLAN

The MetalMapper was used to collect static data over 2,370 targets identified at Pole Mountain based on EM61-MK2 data. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 PREPROCESSING

Raw MetalMapper data are collected and stored as .TEM files. The MetalMapper acquisition software uses a convention for assigning a unique name to each data file without the need to manually enter the name. The operator supplies a prefix for the root name of the file (e.g., “Static”). The acquisition software then automatically appends a five-character numerical index to the filename prefix to form a unique root name for the data file (e.g., Static00001). The index is automatically incremented after the file has been successfully written. Although the Target identification (ID) is not used as the file name in the .TEM file, the Target ID is stored in the file according to name of the target highlighted on the MetalMapper screen during collection. Pre-processing of the .TEM files was performed by Sky personnel and consisted of removing background values from the data, converting the points from the geographic coordinate system used for collection to the Universal Transverse Mercator Zone 13N coordinate system used for processing, and exporting the resulting data to a .CSV file that could be imported into the UX-Analyze package in Geosoft’s Oasis Montaj software. The exported .CSV file name contained both the collection ID and the Target ID (e.g., 2621_Static00001_2621).

6.2 PARAMETER ESTIMATION

All MetalMapper data points were inverted using UX-Analyze to determine modeled parameters for each target. These parameters included the location, size, and orientation of the source object; the polarizability of each axis of the object; and information regarding the quality of the data and the relative match between the inverted data and the expected model.

All target inversion was performed using the UX-Analyze batch processing mode using both the single and multiple object solvers. The single object and multiple object results were run through the classification scheme to determine which method returned a result more indicative of TOI. Although the multiple object result may have approximated the expected model to a higher degree, the result more indicative of potential TOI was used for target ranking to be conservative.

6.3 CLASSSIFICATION AND TRAINING

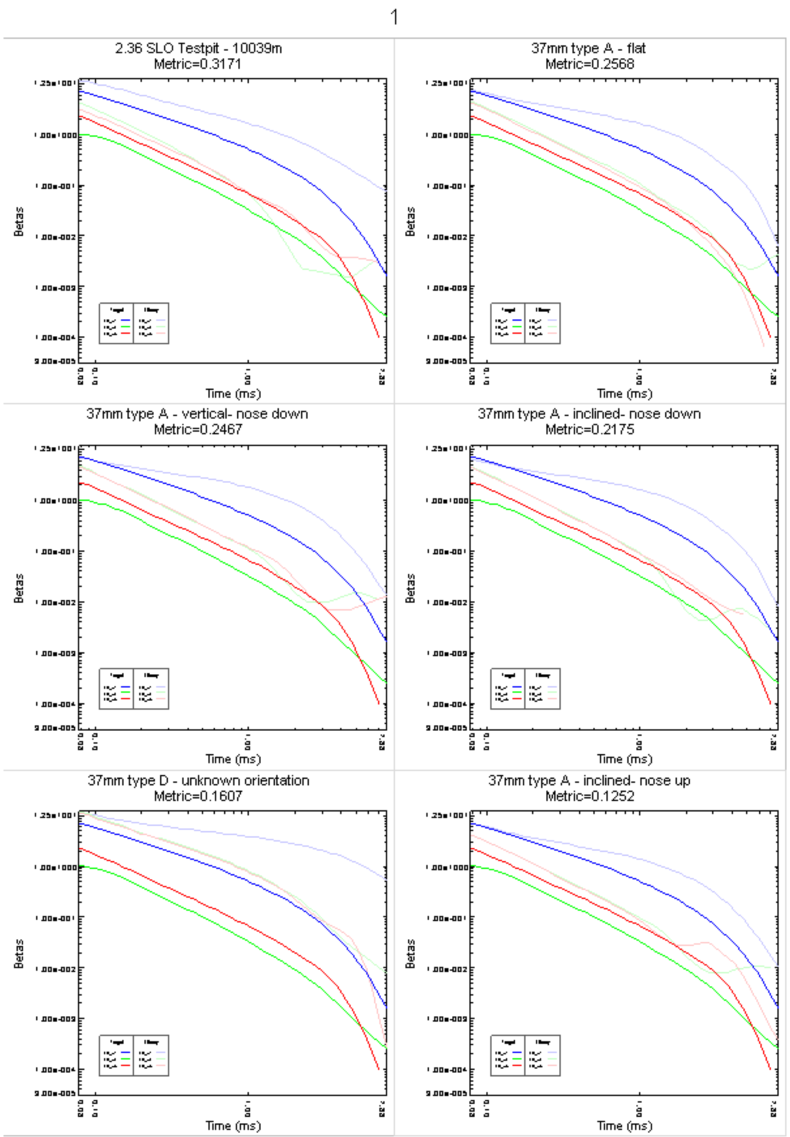
The polarizability curves developed for each target were compared to a library of known polarizability curves from the following sources:

- Library of response parameters for UXO specific to Pole Mountain, to include 37-mm, 57-mm and 75-mm projectiles, stokes mortars, and small industry standard objects (ISOs). This library was derived from test pit data collected during the course of the Metal Mapper data acquisition for this demonstration.

- Library of response parameters for UXO from previous advanced classification demonstrations. The list includes a multitude of UXO items from 37-mm and up in size and small ISOs. This library was supplied by SAIC.

All three possible combinations of the primary and secondary polarizability curves were used when matching to the SAIC library; however, only two of the three combinations were used when matching to the Pole Mountain specific library. Example polarizability curves generated for this demonstration project are shown in **Figure 8**.

Figure 8: Typical Polarizability Curves



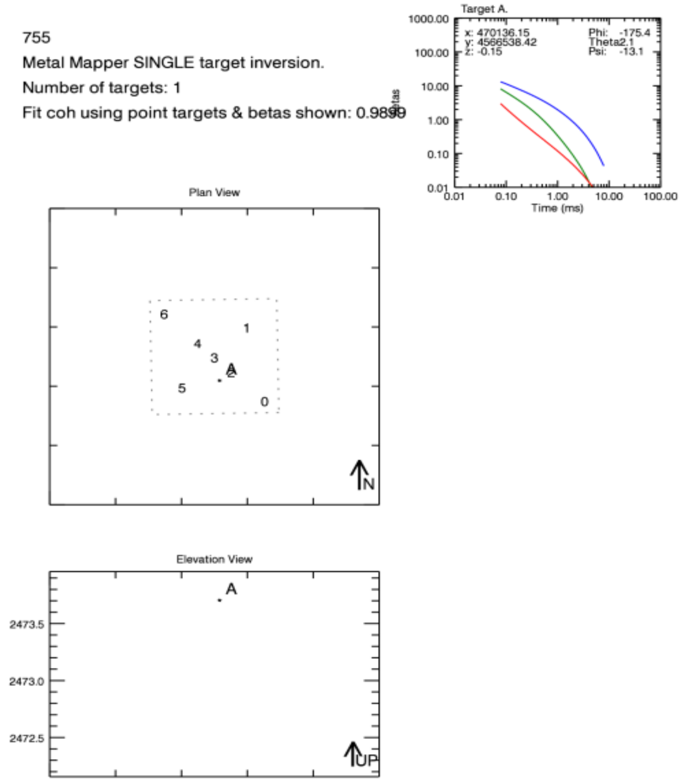
Following generation of the polarizability curves, the single object and multiple object solver target lists were ranked separately using the decision rules shown in **Table 2**.

Table 2: Initial Rule Based Decision Logic

Category 0: Cannot Analyze	Category 1: TOI	Category 2: Cannot Decide	Category 3: Clutter
Poor fit coefficients	Library metric > threshold	Distance from flag > threshold	Library metric < threshold
Unreasonable depth		Distance from array > threshold	
Negative betas (β1,β2,β3)		Low amplitude	
		Noisy betas (β1,β2,β3)	

The classification results for each target in Categories 1 and 2 were then examined by the data processor. This examination was performed to determine the usability of the decision rule logic. The decision rule logic would be deemed usable if the data processor identified three reasonable looking polarization curves and the primary polarization axis (β1) did not match the two secondary axes (β2/β3) for the Category 1 targets. In addition, the decision rule logic would also require that any Category 1 target did not visually appear to belong in Category 2. None of the Category 3 or 4 polarization curves were examined as the decision rule logic was considered set for these two categories. **Figure 9** shows an example of a polarization curve where the initial decision logic placed this target in the Category 1 list; however, it is plainly evident that this item does not have the symmetry pattern usually associated with a TOI.

Figure 9: Example Fit Results for Target Incorrectly Identified as TOI



Subsequent to the visual inspection and the determination that the decision rules were incorrectly assigning targets to Category 1, training data was requested for targets predominantly flagged as Category 1 that visually did not appear to be TOIs, and some targets flagged as Category 3 to confirm certain type curves as non-TOI. **Table 3** lists all the training data along with notes on the polarization data, which formed the basis for changing the rule based decision logic. The data processor made the decision not to further refine the cutoff values of the rule based decision logic; however, to concentrate on reducing the dig list of Category 1 targets by using the geometric relationships between the three polarizations. None of the requested targets were identified as a TOI so the original Pole Mountain library was not modified based on the results of the training data.

Table 3: List of Anomalies for Training Data Request

Anomaly ID	Identification	Dig Type	Category/Subcategory	Polarization Notes	Decision Rule Notes 1	Decision Rule Notes 2
PM-95	Wire	CD	Cat 1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9043
PM-95	Other	CD				
PM-95	Other	CD				
PM-95	Other	CD				
PM-95	Other	CD				
PM-90	Other	CD	Cat1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9382
PM-90	Other	CD				
PM-90	Other	CD				

Anomaly ID	Identification	Dig Type	Category/Subcategory	Polarization Notes	Decision Rule Notes 1	Decision Rule Notes 2
PM-90	Wire	CD				
PM-90	Wire	CD				
PM-871	Frag (light)	MD	Cat 3, Sub 1	Correct classification		
PM-830	Horseshoe	CD	Cat 1, Sub 4			
PM-830	Other	CD				
PM-830	Other	CD				
PM-830	Nail	CD				
PM-830	Nail	CD				
PM-77	Frag (light)	MD	Cat 1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9127
PM-77	Horseshoe	CD				
PM-755	Other	CD	Cat 1, Sub 5	b1 nearly equal to b2, b3 much less and betas cross over	cutlow3 too low at 0.80	actual = 0.8987
PM-696	Frag (heavy)	MD	Cat 1, Sub 3	3 moderately spaced betas	middle of cutlow3 and cuthi3	actual = 0.8584
PM-625	Frag (light)	MD	Cat 3, Sub 1	Correct classification		
PM-507	Frag (medium)	MD	Cat 3, Sub 1	Correct classification		
PM-507	Frag (light)	MD	Cat 3, Sub 1	Correct classification		
PM-503	Nail	CD	Cat 1, Sub 7	3 widely spaced betas	cuthigh1 too low at 0.97	actual = 0.9798
PM-491	Other	CD	Cat 1, Sub 7	b1<b2 or b3	cuthigh1 too low at 0.97	actual = 0.9847
PM-463	Frag (light)	MD	Cat 1, Sub 7	odd decay - visually never would pick	cuthigh1 too low at 0.97	actual = 0.9835
PM-433	Other	CD	Cat 1, Sub 6	3 widely spaced betas	cutlow2 too low at 0.90	actual = 0.9317
PM-433	Nail	CD				
PM-415	Other	CD	Cat 1, Sub 6	3 widely spaced betas	cutlow2 too low at 0.90	actual = 0.9059
PM-350	Frag (medium)	MD	Cat 1, Sub 7		cuthigh1 too low at 0.97	actual = 0.9734
PM-320	Other	CD	Cat 3, Sub 1	Correct classification		
PM-315	Horseshoe	CD	Cat 1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9945
PM-2319	Other	CD	Cat 1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9804
PM-225	Frag (light)	MD	Cat 3, Sub 1	Correct classification		
PM-2208	Frag (light)	MD	Cat 1, Sub 5	3 very closely spaced betas, b1<b2 or b3	cutlow3 too low at 0.80	actual = 0.8050
PM-2208	Frag (light)	MD				
PM-2208	Frag (light)	MD				
PM-2208	Frag (light)	MD				
PM-2208	Frag (light)	MD				

Anomaly ID	Identification	Dig Type	Category/Subcategory	Polarization Notes	Decision Rule Notes 1	Decision Rule Notes 2
PM-2180	Frag (light)	MD	Cat 1, Sub 5	3 very closely spaced betas, b1<b2 or b3	cutlow3 too low at 0.80	actual = 0.8036
PM-2180	Frag (light)	MD				
PM-2180	Frag (light)	MD				
PM-2180	Frag (light)	MD				
PM-2180	Frag (light)	MD				
PM-2101	Frag (light)	MD	Cat 1, Sub 5	3 very closely spaced betas, b1<b2 or b3	cutlow3 too low at 0.80	actual = 0.8737
PM-2101	Frag (light)	MD				
PM-2101	Frag (light)	MD				
PM-2101	Frag (light)	MD				
PM-2101	Frag (light)	MD				
PM-2098	Frag (light)	MD	Cat 1, Sub 5	3 equally spaced betas	cutlow3 too low at 0.80	actual = 0.8140
PM-2098	Frag (light)	MD				
PM-2098	Frag (light)	MD				
PM-2098	Frag (light)	MD				
PM-2098	Frag (light)	MD				
PM-2086	Frag (heavy)	MD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.8979
PM-2083	Frag (light)	MD	Cat 1, Sub 6	3 equally spaced betas	cutlow2 too low at 0.90	actual = 0.9461
PM-2012	Frag (light)	MD	Cat 1, Sub 6	3 equally spaced and wide apart betas	cutlow2 too low at 0.90	actual = 0.9201
PM-1996	Frag (medium)	MD	Cat 1, Sub 5	3 equally spaced close anomalies	cutlow3 too low at 0.80	actual = 0.8429
PM-1992	Frag (light)	MD	Cat 1, Sub 3		low of of cutlow3 and cuthi3	actual = 0.8104
PM-194	Fuze/Fuze Components	MD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.9423
PM-1816	Wire	CD	Cat 1, Sub 6	b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9031
PM-180	Frag (medium)	MD	Cat 1, Sub 5	b2 and b3 spaced a little too far apart	cutlow3 too low at 0.80	actual = 0.8705
PM-1743	Frag (light)	MD	Cat 1, Sub 4	3 relatively close equally spaced betas	low of cutlow 2 and cuthi2	actual = 0.9103
PM-1743	Frag (light)	MD				
PM-1743	Frag (light)	MD				
PM-1743	Frag (light)	MD				
PM-1743	Frag (light)	MD				
PM-1624	Horseshoe	CD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.8811
PM-1624	Can Fragments	CD				
PM-1624	Other	CD				
PM-1624	Other	CD				
PM-1624	Other	CD				
PM-1496	Horseshoe	CD	Cat 1, Sub 4	b1<b2 or b3	low of cutlow 2 and cuthi2	actual = 0.9020
PM-136	Horseshoe	CD	Cat 1, Sub 7	b1<b2 or b3	cuthigh1 too low at	actual = 0.9969

Anomaly ID	Identification	Dig Type	Category/Subcategory	Polarization Notes	Decision Rule Notes 1	Decision Rule Notes 2
					0.97	
PM-136	Horseshoe	CD				
PM-136	Horseshoe	CD				
PM-1344	Other	CD	Cat 1, Sub 5		cutlow3 too low at 0.80	actual = 0.8658
PM-1340	Other	CD	Cat 1, Sub 5		cutlow3 too low at 0.80	actual = 0.8350
PM-1300	Fuze/Fuze Components	MD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.9201
PM-1251	Frag (medium)	MD	Cat 1, Sub 6	3 widely spaced betas, b1<b2 or b3	cutlow2 too low at 0.90	actual = 0.9416
PM-1225	Fuze/Fuze Components	MD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.9106
PM-119	Nail	CD	Cat 1, Sub 5		cutlow3 too low at 0.80	actual = 0.8034
PM-119	Frag (light)	MD				
PM-1119	Other	MD	Cat 1, Sub 5	3 very closely spaced anomalies	cutlow3 too low at 0.80	actual = 0.9065
PM-1003	Wire	CD	Cat 1, Sub 5	3 very closely spaced betas	cutlow3 too low at 0.80	actual = 0.8422

A method was devised for calculating the average polarizability at 2 locations along each of the three polarization curves for each target. Early beta calculations were centered on time gate 11 and late beta calculations were centered on time gate 30, each with a window width of 8 time gates. A new decision logic rule was established based on the ratio of the ratios of the three betas at both early and late times in the polarizability curves. The final decision logic is shown in **Table 4**.

Table 4: Final Rule Based Decision Logic

Category 0: Cannot Analyze	Category 1: TOI	Category 2: Cannot Decide	Category 3: Clutter
Poor fit coefficients	Library metric > threshold	Distance from flag > threshold	Library metric < threshold
Unreasonable depth	Beta ratios >< threshold	Distance from array > threshold	
Negative betas (β1,β2,β3)		Low amplitude	
		Noisy betas (β1,β2,β3)	

Final classification for the PMTMA project was accomplished by combining the single and multiple object lists into one master list, and using the revised decision rules generated after analysis of the training data. Confidence metrics generated for each target during the comparison to the various library data were used to rank the anomalies in each category from highest to lowest confidence metric.

The final dig list was submitted with the following parameters:

- Training Data: 43 items selected

- Cannot Analyze (Category 0): 41 items selected
- Likely TOI (Category 1): 884 items selected
- Cannot Decide (Category 2): 411 items selected, all which were assigned a no-dig status
- Likely Clutter (Category 3): 987 items selected

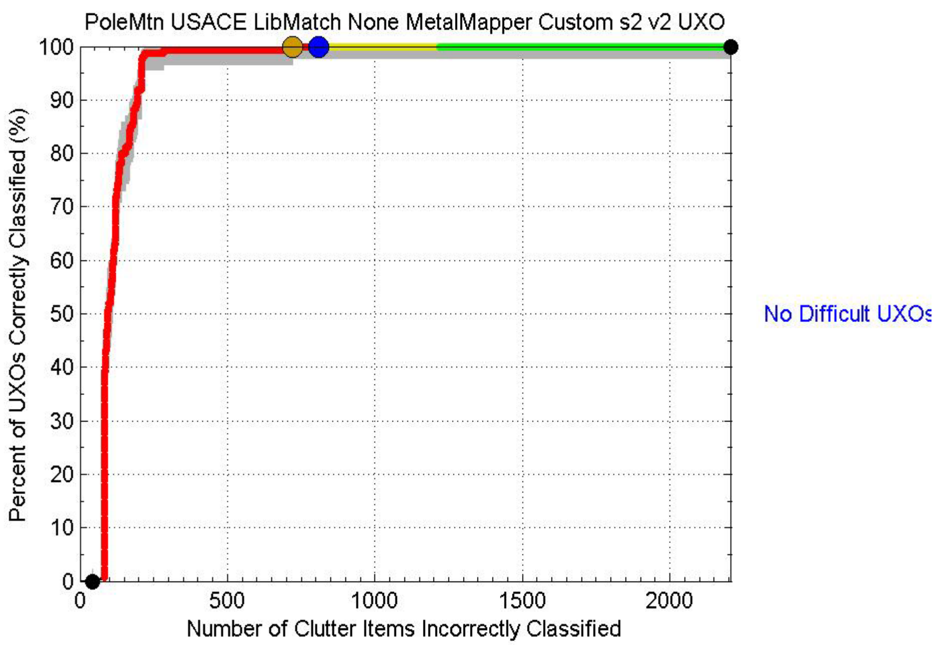
7.0 PERFORMANCE ASSESSMENT

7.1 CORRECT CLASSIFICATION OF MUNITIONS

The IDA compared the submitted dig list to ground truth data from Pole Mountain. The results were judged according to performance objectives identified for this project in the Demonstration Plan (U.S. Army Corps of Engineers, 2011).

Figure 10 shows the receiver operating characteristics (ROC) curve for the final dig list. As indicated in the figure, all TOI were correctly identified and this performance objective was met.

Figure 10: ROC Curve for Final Dig List



7.2 MAXIMIZE CORRECT CLASSIFICATION OF NON-MUNITIONS

A few of the 2,370 targets for which data were collected at Pole Mountain ended up being multiple picks on the same source, so a total of 2,368 digs were performed during the project. The small reduction in targets means that there were 2,208 true clutter items in the data set. The metric set prior to the demonstration was to correctly identify 75% of the non-TOI anomalies. The final dig list correctly identified 987 items (44.7%) of the clutter items as clutter. This metric was not met due to the large number of anomalies classified as “Can’t Analyze” which resulted in additional digs.

7.3 STOP DIG THRESHOLD

For the final dig list submitted, all TOI at the site were correctly identified as TOI, and the number of false positives was reduced by more than 50 percent of the total number of false positives (59%). This exceeds the performance objectives for the dig threshold and passes this performance criterion.

7.4 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

The final dig list contained 41 targets categorized as “Cannot Analyze”. This corresponds to 1.7% of the targets at the site and exceeds the performance metric established.

7.5 CORRECT ESTIMATION OF TARGET PARAMETERS

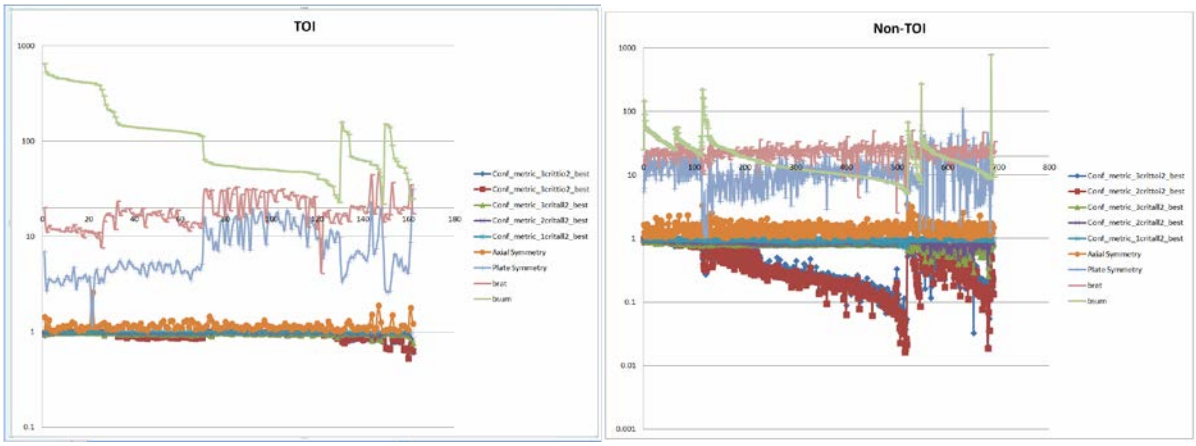
Target parameters were not submitted for analysis. Positioning may have been a problem with the data, as 15% of the anomalies had offsets from their model positions greater than 0.5m and were subsequently classified as “Can’t Analyze.”

7.6 RETROSPECTIVE ANALYSIS

The ROC curve portrayed in **Figure 10** indicates three areas where improvements to the advanced classification analysis could be made. Above approximately 95% of UXO correctly classified, the classification scheme results in a large number of debris (munitions and cultural) being incorrectly classified. The second issue is the last TOI correctly identified falls very far down the list. Lastly, the number of “cannot decide” items is quite substantial. The first two issues are mainly related to the use of a target library which contains many more munitions items than has been found at the Pole Mountain Site and the fact that the classification scheme iteratively looks for these anomaly types much later in the routine.

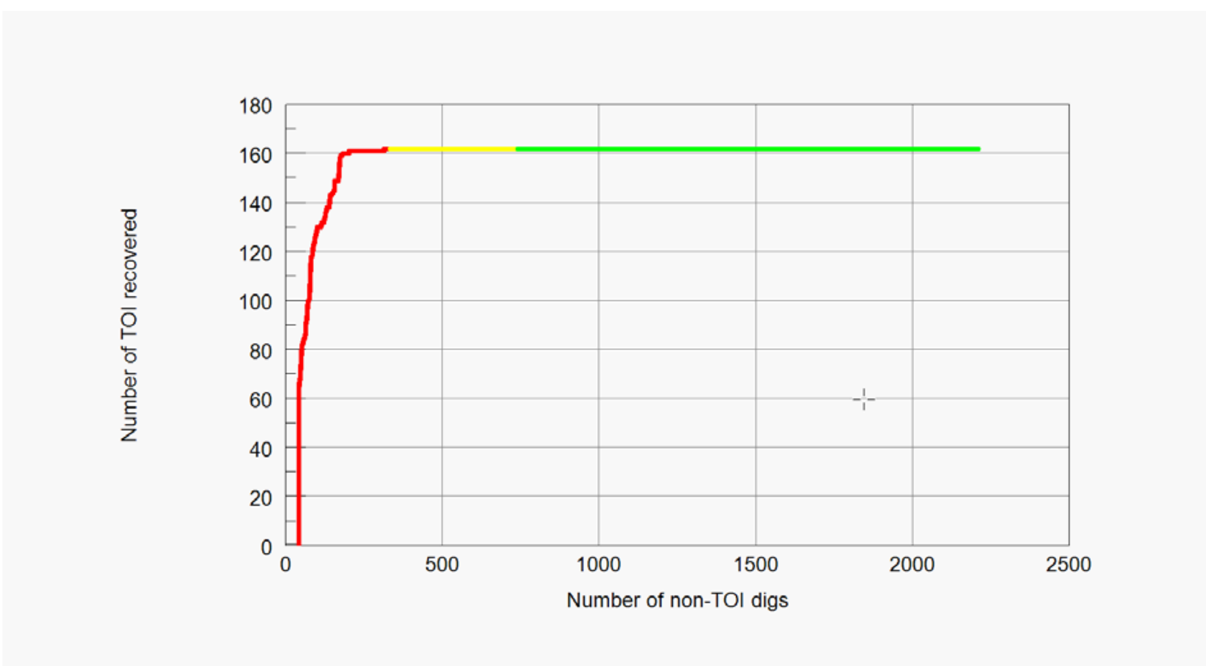
In keeping with the classification approach which did not include feature space analysis, the data for a select number of key attributes (axial and plate symmetry, brat, bsum, etc) were plotted by classification type **(Figure 11)** to look for a trend which may help correct the issues identified above.

Figure 11: Parameter Trend Analysis



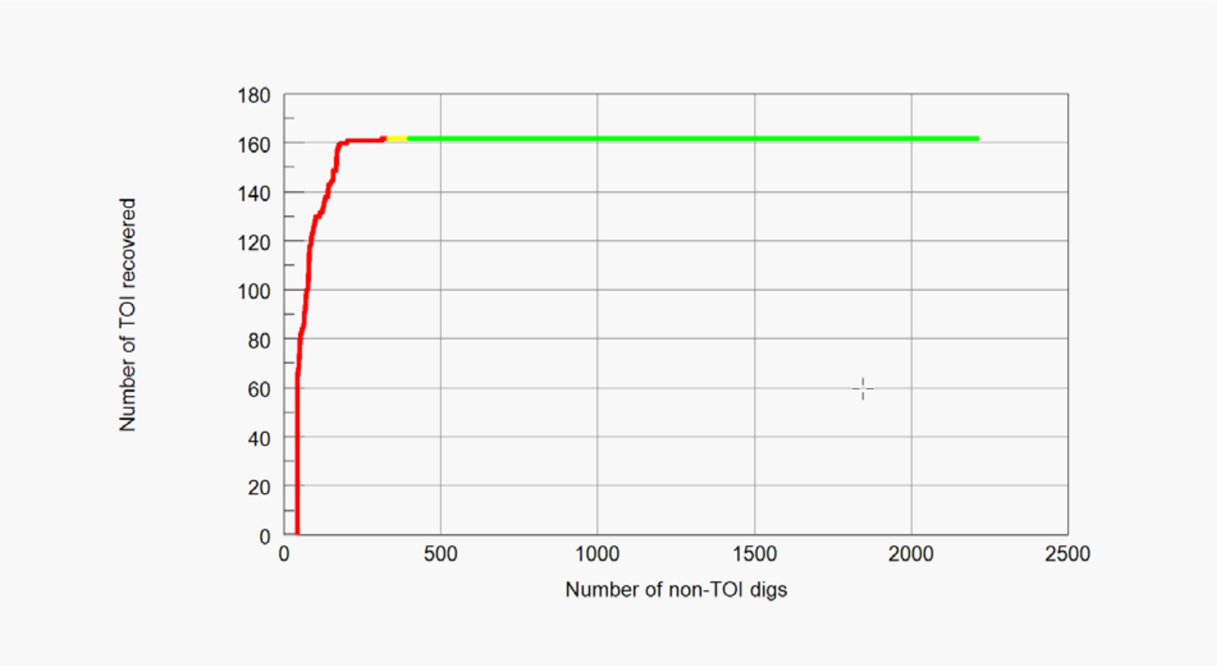
It is evident that the bsum parameter, which is related to the size of the item, had a cutoff set way too low. By appropriately adjusting this parameter, the last TOI correctly classified can be found much earlier in the dig list and the number of incorrectly identified TOI are also reduced as shown in **Figure 12**.

Figure 12: ROC curve for conservative readjustment of bsum parameter



By using the most aggressive classification scheme by applying the new bsum cutoff to all anomalies, the number of “cannot decide” items is also greatly reduced as shown in Figure 13.

Figure 13: ROC curve for most aggressive readjustment of bsum parameter



The dig list for the ROC curve shown in **Figure 13** had the following statistics:

- Training Data: 43 items selected
- Cannot Analyze (Category 0): 41 items selected
- Likely TOI (Category 1): 453 items selected
- Cannot Decide (Category 2): 66 items selected, all which were assigned a no-dig status
- Likely Clutter (Category 3): 1763 items selected

8.0 COST ASSESSMENT

Costs were broken down into three categories: Learning, Analysis and Application, and Reporting. Learning includes all activities undertaken to understand and implement the new advanced classification tools, and includes a 3-day trip to Ft. Ord for hands-on MetalMapper training.

Analysis and Application includes the time required to perform inversions using UX-Analyze and to create decision plots for each target, examine the polarization curves, identify unknown items for training data request, and finalize the classification scheme.

Table 5: Cost Assessment Table

Cost Element	Cost/Quantity
Learning	$3.91/anomaly
Analysis and Application	$7.17/anomaly
Reporting	$1.69/anomaly

REFERENCES

U.S. Army Corps of Engineers. 2011. *Abbreviated Demonstration Plan, USACE Participation in Camp Beale and Pole Mountain Advanced Classification Demonstrations, ESTCP Project No. MR-201167*. Version 1, May.