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TECHNICAL NOTE TN-33

Why Did Geonics Limited Build the EM61-MK2? Comparison Between EM61-MK2 and EM61

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I. INTRODUCTION

This Technical Note provides, first of all, a short description of Geonics EM61 Time Domain Metal Detector, and its new version EM61-MK2, followed by a discussion on a concept and application of the apparent time-constant. In the second part of this paper several case histories are given over known targets, and comparison is made between the EM61-MK2 and the original EM61. Use and benefit of compressed amplitude scale is also discussed.

A Short Description of EM61

The EM61 is a high power time domain metal detector used for detection of ferrous and non-ferrous metallic targets for environmental, UXO and engineering applications. It comprises of a transmitter coil of dimensions 1 x 1 m that is energized by the pulses of current. The magnetic field caused by the transmitter current induces eddy currents in the target, which in turn produces a secondary magnetic field, that generates a signal in the receiving coil. The coil is coincident with the transmitter coil, and it is of the same size. The second receiver coil, parallel to the transmitter coil, is mounted 40 cm above the main receiver coil. The coil array is normally mounted on a set of wheels so that the bottom of the coil array is 43 cm above the ground level.

The main receiver coil is used for detection of targets by sampling the response decay at one time gate after termination of transmitter current pulse. The second receiver coil that has the sampling time gate at the same position as the main coil has the following functions: a) to reduce response from near surface unwanted targets, b) allows for calculation of depth to the target and c) can be used to reduce noise from external electromagnetic interference, like power and telephone lines. Data is normally recorded digitally on a small handheld data logger.

A short description of the EM61-MK2

The EM61-MK2 is an enhanced version of the EM61. The following are comments on the more important characteristics of the EM61-MK2 in comparison with the EM61.

1. Four Time Gates

The EM61-MK2 can provide output from the four time gates geometrically spaced in time in the range from 216 μs to 1,266 μs after termination of the transmitter pulse. This feature allows discrimination between different types of targets based on the time-decay rate of the response. This technique, that will be described in more detail later, is applicable only for the simple-geometry thin-wall targets with all three dimensions; height, width and length approximately equal, like 55 gallon drums or paint cans. For discrimination of targets with more complex geometry like UXO, plates, pipes and bars, Geonics EM63 fully time domain Metal detector can be used, as described in Geonics Technical Note TN-32.

The EM61-MK2 earliest gate provides an increase in output amplitude, in comparison with the EM61 output, for a factor between two to four depending on the target time-decay characteristic, which in turn depends on the target geometry and material. Figure 1 shows the time-decay response from a 105 mm projectile. The increase in signal from gate 3, gate equivalent to the EM61 gate, to gate 1, earliest EM61-MK2 gate, is about 4, a very significant factor especially for deeply buried targets detection.

2. Smaller Coil Array Geometry

The new 1 x 0.5 m coil size geometry, in comparison with the original 1 x 1 m, provides increased lateral resolution of detection, enhances response from near surface targets and with its smaller size simplifies the survey in a more wood-dense environment.

3. Computer Based Digital Logger

The new 486 ruggedized type field computer, that is used as a controller and data recorder for the EM61-MK2, provides for real-time graphical display for in-field quality control, allows over 10 records per second of data acquisition speed for faster survey, and provides storage for over 300,000 of data points sufficient for a full day of recording without need to damp.

4. Direct Interface with GPS

The EM61-MK2 system is fully equipped for simultaneous logging of GPS and EM data for most standard GPS receivers. This option provides for a significantly enhanced field procedure.

II APPARENT TIME-CONSTANT

The need for displaying target response in the apparent time-constant arises from the fact that it is always difficult to present meaningfully multi-parameter data that is generated in multi-time TDEM systems. The apparent time-constant data presentation normalizes the complete time-decay curve to a single number. It is based on the assumption that the target response, or part of it, is exponential. Although that assumption is rarely correct, it helps to normalize target response on the base of time-decay shape and removes the difference in the response magnitude. Since the fall-off of target response with depth is extremely high, up to power of six, it is, therefore, very difficult to recognize the similarity between the same type of targets at a different depth.

For the exponential time-decay the following can be written:

$$V(t) = k\, e^{-t/\tau}$$

where: V(t) = output signal as function of time in mV at time t in μs

τ = characteristic time-constant in μs

k = constant

From four outputs measured with the EM61-MK2 at four time gates, six different time-constants can be derived in the following way:

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

where: τ_{m-n} is time-constant between channels m and n

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

V_m and V_n are gate output at time t_m and t_n

For illustration Figure 1 shows the time-decay response of a 105 mm projectile in horizontal position in time range from 10 μs to 100 ms. Figure 2 shows a section of decay with indication of EM61-MK2 gate position.

In this example (Figure 2) calculation of apparent time-constant can be performed:

$$\tau_{1-3} = \frac{t_3 - t_1}{\ln\frac{V_1}{V_3}} = \frac{660-216}{\ln\frac{110}{48}} = 535 \mu s$$

If the target response is thoroughly exponential all six time-constants will be the same. For the non-exponential response time-constants will be different, or partially different, depending on the decay curve departure from the exponential. From the same target at the different depth, and, therefore, different response magnitude, corresponding time-constant will be similar.

In practice it is a good idea to calculate, process automatically performed in the EM61 program DAT61W, apparent time-constants with two different time sets, let's say τ_{1-3} and τ_{2-4} and then compare results. If the two calculated time-constant for the different targets are the same, it would suggest that these targets are most likely of the same type. Caution has to be exercised when applying this technique since this simplified approach will work only for a simple-geometry thin-wall targets, where all three dimensions of targets are approximately equal, like in the case of drums or paint cans, or when the coupling orientation between target and coil array is not changing from target to target, like in the case of horizontal plates.

The apparent time-constant concept can also be employed to separate small near surface targets from deeper larger targets. Typically small targets, like pop cans or a set of nails, have apparent time-constant in range of 100 μs or less, while larger targets produce response typically with time-constant in the range of several hundreds to several thousands of microseconds.

Example presented later in this note demonstrates the use of apparent time-constant for targets identification.

III. CASE HISTORY WITH EM61-MK2

1. Miscellaneous UXO Targets

Figures 3 to 6 show the profile response over a set of six UXO targets on the surface, equally spaced at 5 meters a part, on a single 40 m long line. Figures 3 and 4 are plots with targets long axes perpendicular to the profile line. Figure 5 shows results of the test with targets in the vertical position, while Figure 6 is results with target long axes parallel to the survey line.

The following comments can be made in the observation:

a) Response differs in amplitude and shape for the same target at three different orientations.

Figure 4 shows the same data as Figure 3, but in a compressed scale. In order to reduce a large dynamic range of amplitude response, that is typical for TDEM, data is plotted in compressed scale produced by taking the square-root of the original amplitude. This approach compresses larger signals and accentuates small values, without introducing a significant profile shape distortion, somewhat less than more conventional log type of compression.

b) The largest response is with the target in the vertical position. This is partly due to the fact that in this orientation targets are closer to the coil array and partly due to the full effect of magnetic induction response (see paper, "Application of TDEM to UXO Detection", by McNeill and Bosnar, proceeding UXO Forum 1996).

c) Response at the first gate is up to four times larger than the response at gate three, gate equivalent to the EM61 output.

d) Figure 6 shows double peak response. In case of in-line target orientation, due to the maximum coupling between the long axes of target and the coil array that happens just slightly before and after the array crosses the target center, magnetic induction is a predominant effect at the peak response points, producing larger response than eddy current effect that is maximum over the target center.

2. Various Ferrous and Non-ferrous Balls

A set of six balls are equally spaced at five meters on the ground's surface. The targets 1 to 3 are iron balls, while targets 4 to 6 are aluminum. The following comments on the results of the test can be made:

a) Response from iron (ferrous) balls is considerably larger than response from the equivalent size aluminum ball. The reason for this is that the response, in case of iron ball, comes from two effects: eddy current and magnetic induction (permeability) effect, while in the case of aluminum ball only eddy currents effect contributes to the response.

b) The ratio between gates 1 and 3, EM61 equivalent gate, for aluminum ball is about two, while in the case of the 12.5 cm diameter steel ball ratio is about four.

3. Miscellaneous Metallic Objects

Figure 8 shows the response from various small metallic objects lying on the surface of the ground, spaced five meters apart.

The following comments can be made:

a) Response signature from ferrous material is spatially wider due to the combination of eddy current and magnetic induction effect.

b) It is interesting to observe that aluminum plate, target 3, gives larger response than equivalent size steel plate, target 2. A simple explanation for this is that unlike in case of balls, magnetic induction effect is not sufficiently large to compensate for the difference in the electrical conductivity, related to the eddy current effect, between aluminum and steel.

c) The ratio between channels 1 and 3 is between two to three for iron plates and somewhat less than two for aluminum targets.

4. Columbia Test Site - University of Waterloo

Figure 9 shows the survey site with location and description of different metallic targets buried at the site.

Figure 10 shows the seven profiles over targets to demonstrate a huge dynamic range in amplitude from different targets, and from similar targets at the different depth.

Figure 11 shows the contour map of the site using gate no. 1 as an input. From results present in this form it would be difficult to guess the nature of the targets. For example, the response from the drum at 0.5 meters below surface is about 3 orders of magnitude larger than the response from the drum at 2 meters depth.

Figure 13 shows the same data, but now presented in the apparent time-constant form using output from gates 2 and 4, as discussed earlier in this note. The vertical time scale represents apparent time-constant in μs. Note that all responses from drums, including a group of nine, shows the same time-constant of about 900 μs Similarly, three pipes at different depths and all steel plates show time-constant of 550 μs and 700 μs respectively. Signal from pipe at the 2 m depth is too small for accurate calculation of time-constant.

Figure 12 is the same as Figure 10, here for an easier compression for differences in amplitude and similarity in apparent time-constant between targets.

This case history demonstrates that the apparent time-constant, a simple approach for data transformation can be an effective method to help in target discrimination and classification.

Once more, it has to be emphasized that this method is effective only for a simple-geometry target, as defined earlier.

References

1. J.D. McNeill, M.Bosnar, "Application of Time Domain Electromagnetic Techniques to UXO Detection", proceeding, UXO Forum 1996.

2. Geonics Limited, Technical Note TN-32, "Application of TDEM Techniques to Metal Detection and Discrimination: A Case History with the New Geonics EM-63 Fully Time-Domain Metal Detector", J.D. McNeill, M. Bosnar, April 2000.

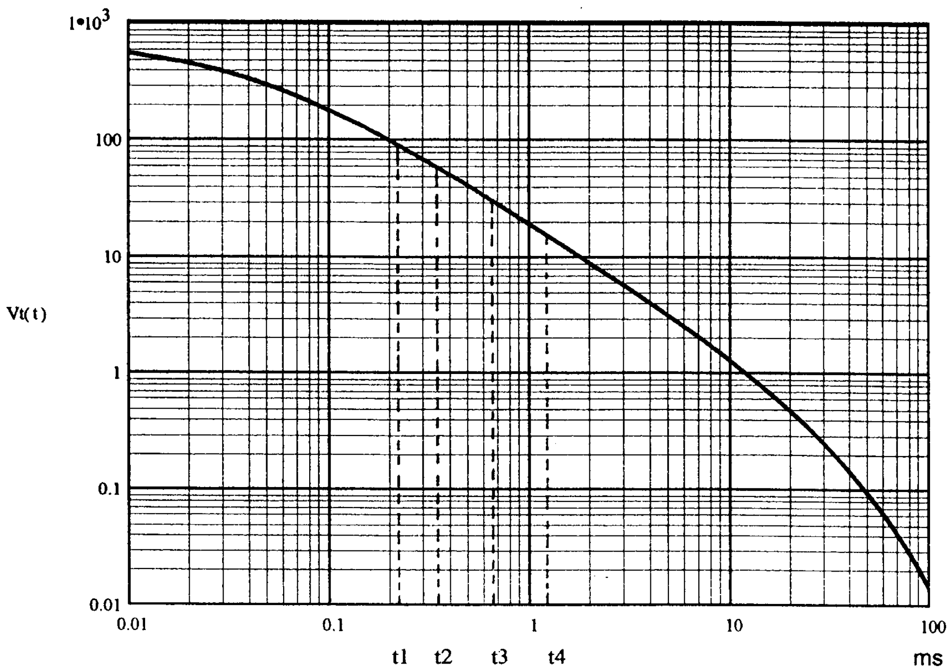

Figure 1

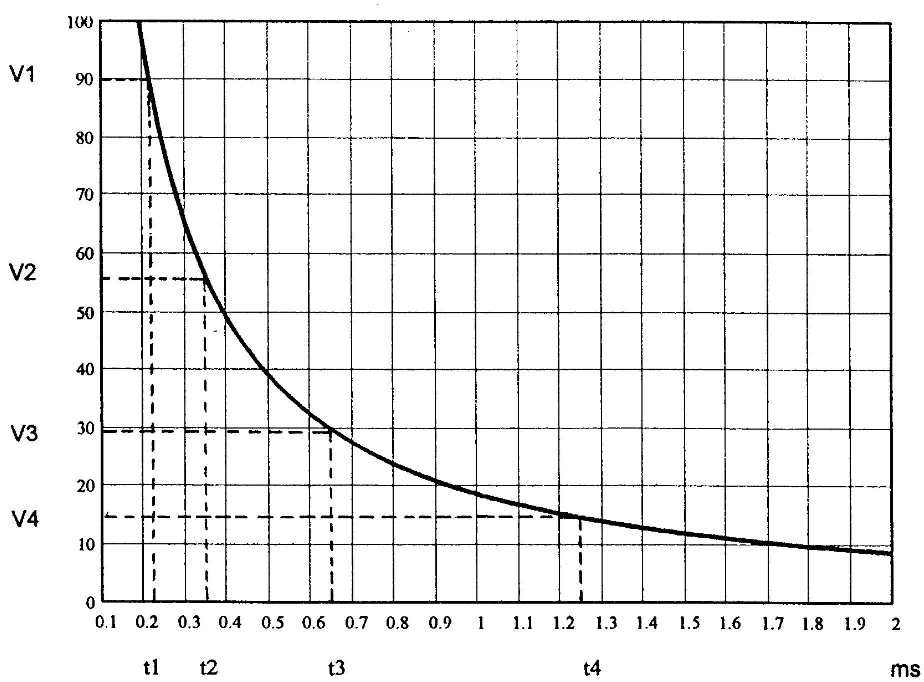

Figure 2

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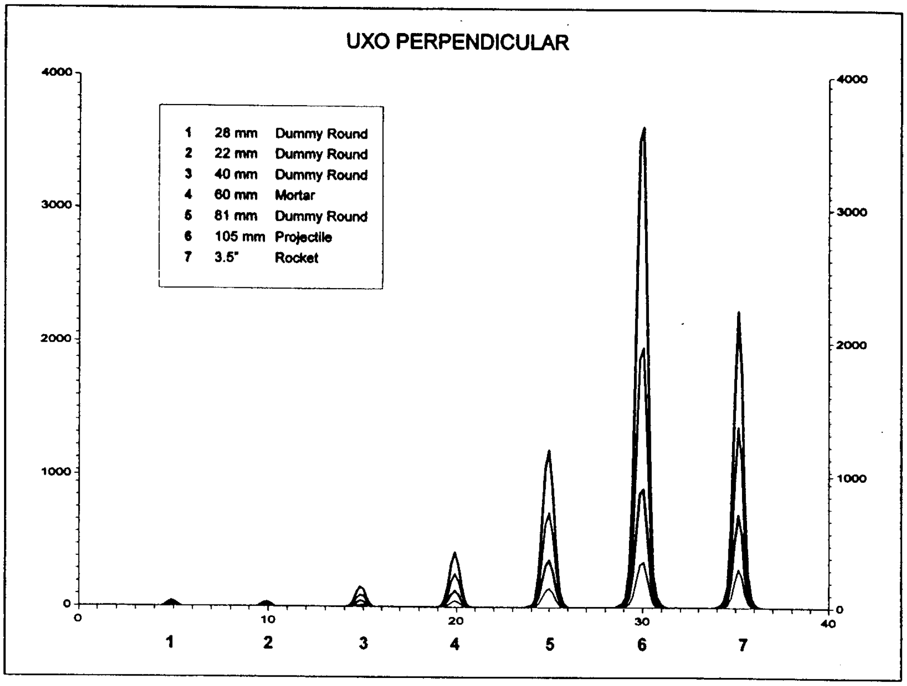

Figure 3

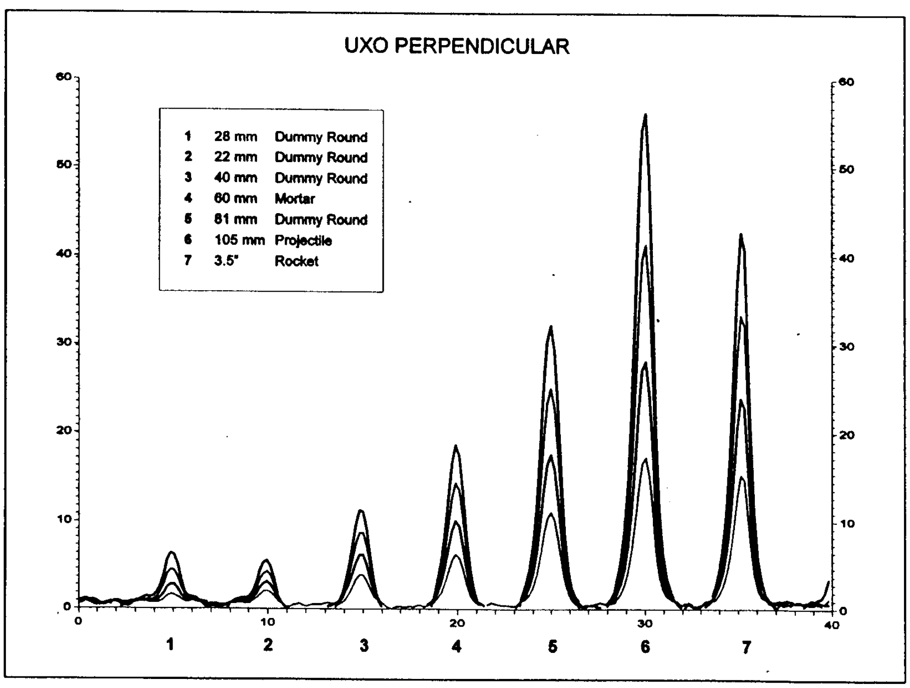

Figure 4

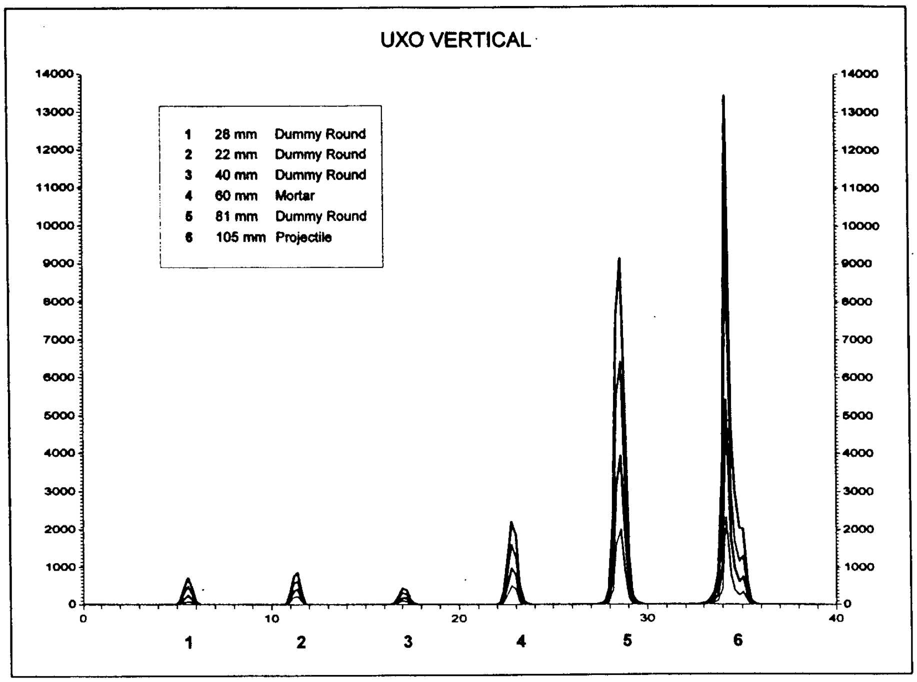

Figure 5

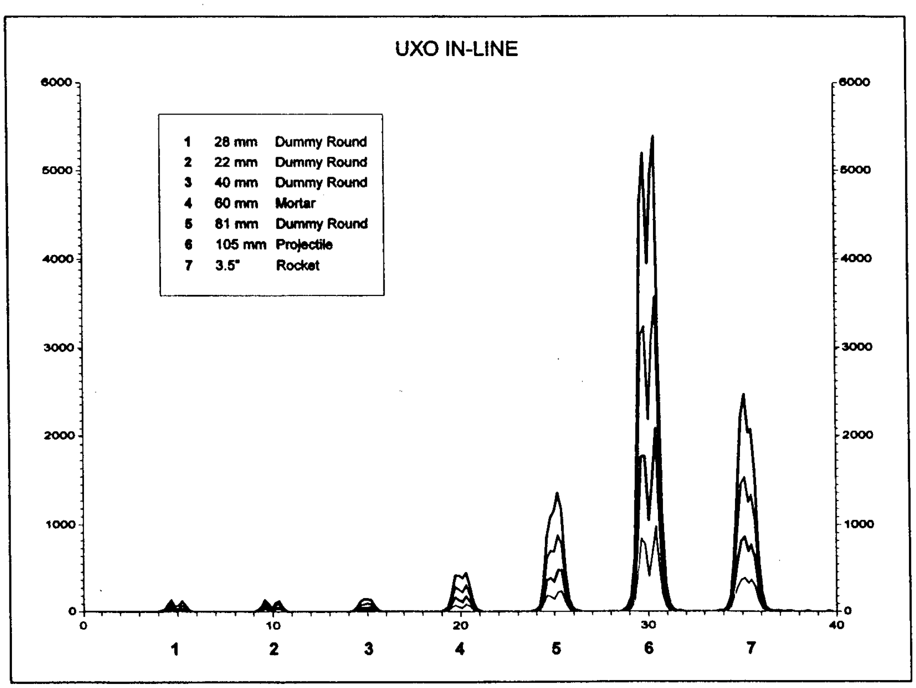

Figure 6

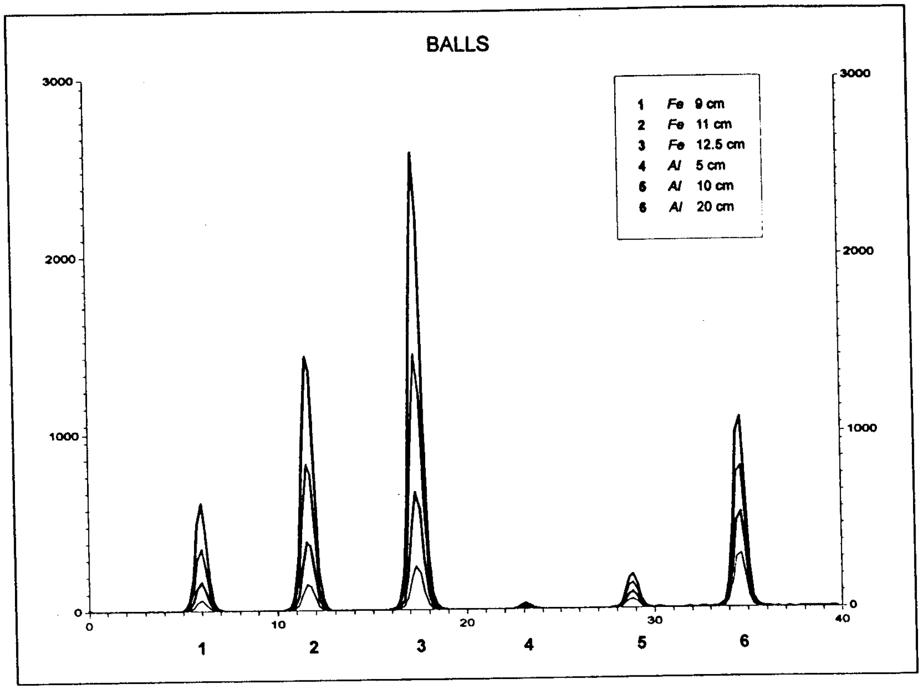

Figure 7

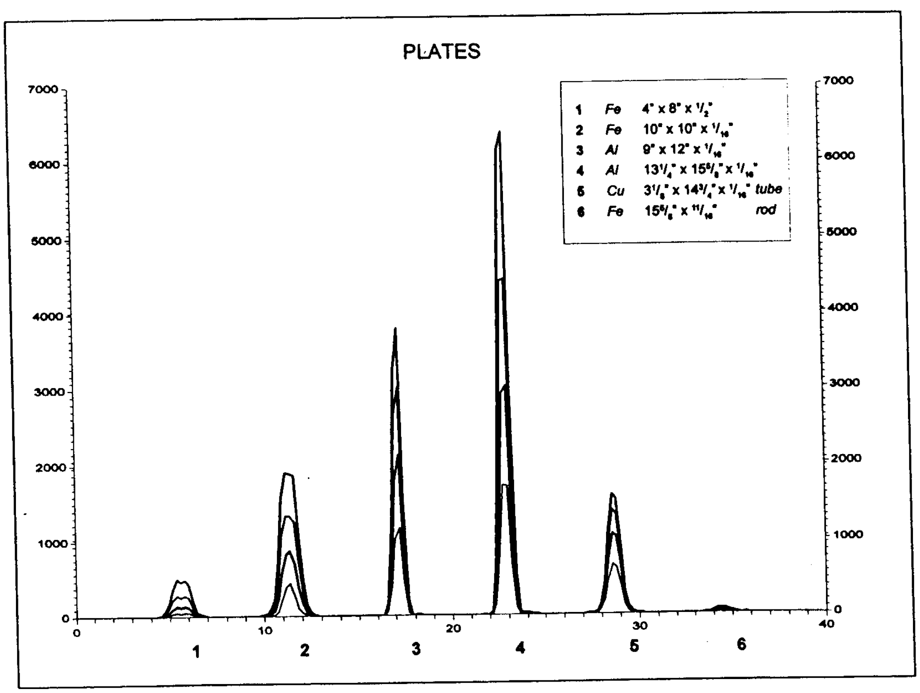

Figure 8

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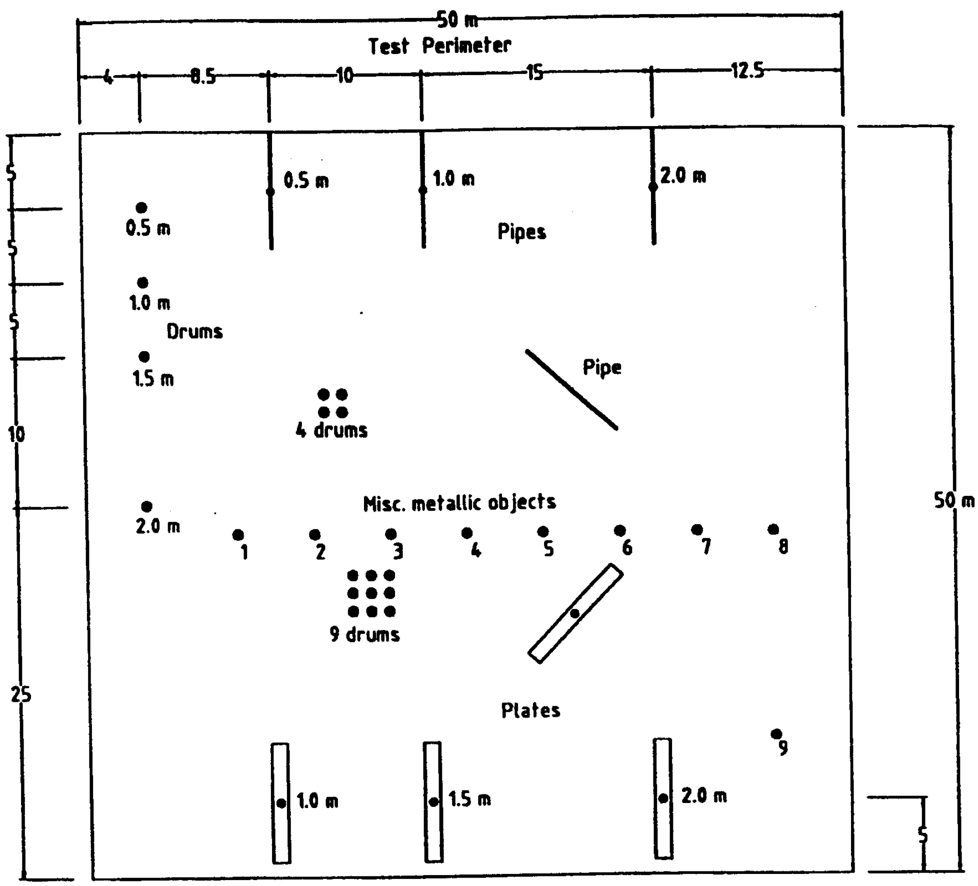

COLUMBIA GOLF COURSE TEST SITE

- vertical barrel .6 by .9 m
- pipeline .10 by 8 m
- sheet metal 1 by 8 m
- target markers with depth

Survey direction

Figure 9

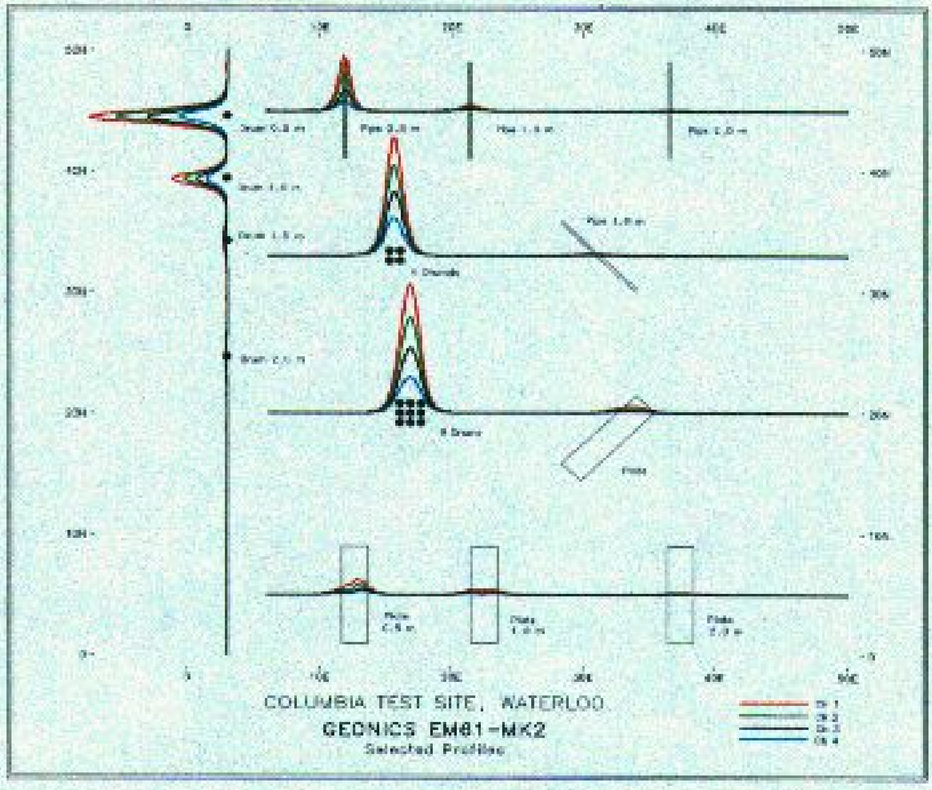

Figure 10

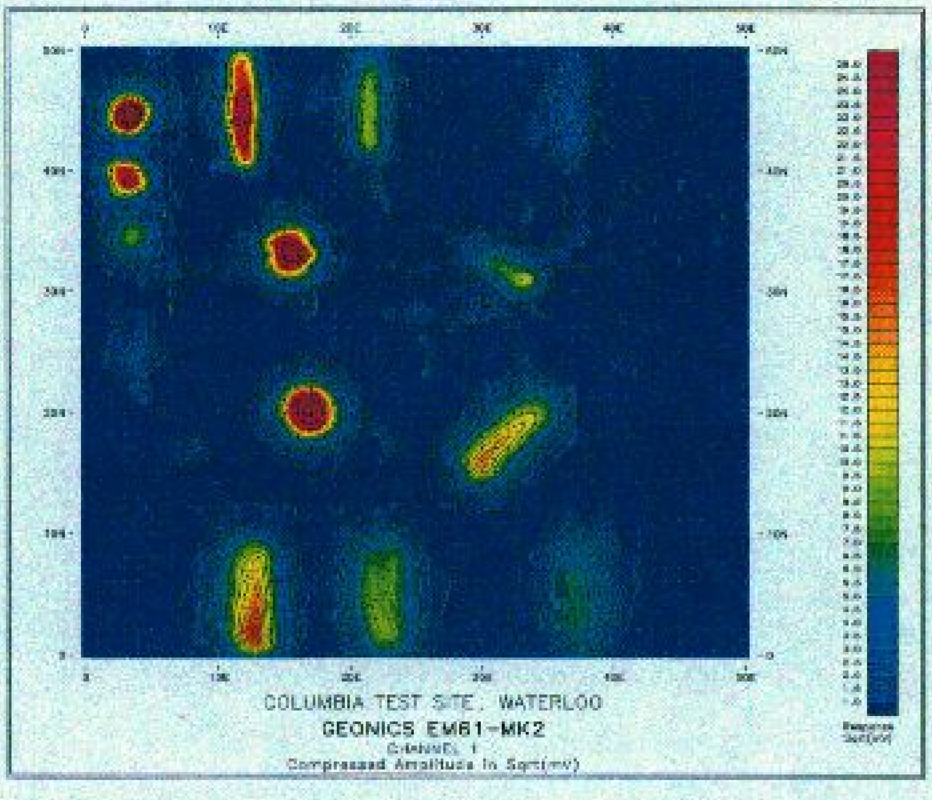

Figure 11

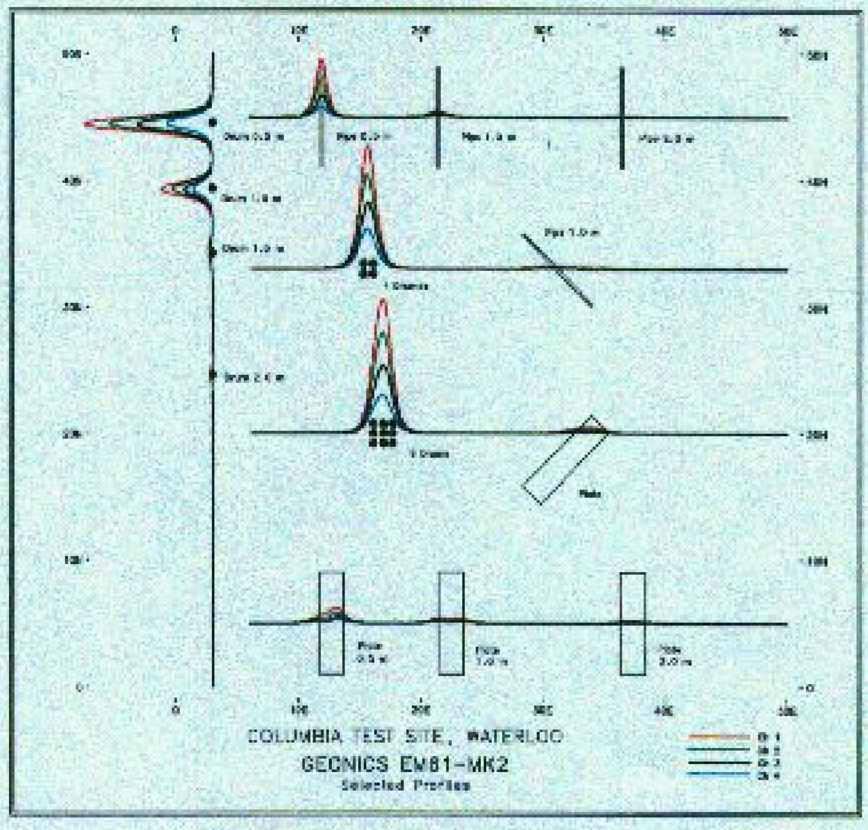

Figure 12

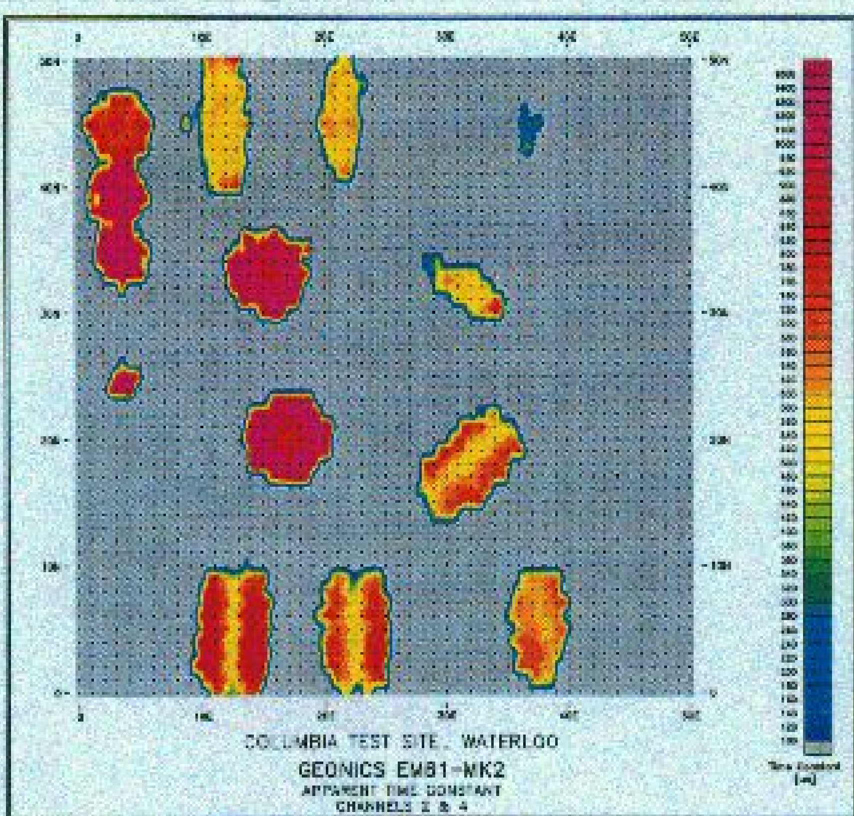

Figure 13