A VETEM SURVEY OF A FORMER MUNITIONS FOUNDRY SITE AT THE DENVER FEDERAL CENTER

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ABSTRACT

The present Denver Federal Center in Lakewood, Colorado, was a center for production of small arms and artillery ammunition during World War II and was then known as the Denver Ordnance Plant. When munitions manufacturing ended, some of the buildings were converted to other uses and some were removed. A massive building, thought to be a foundry, just east of Building 20 at the Denver Federal Center, was removed just before the end of the war. Remaining subsurface parts of the building are buried under a clayey loam soil. High-resolution images we recently made using data recorded by the very early time electromagnetic (VETEM) system clearly show some buried parts of the building or objects that were in the building. Many of the subsurface structures produced exceptionally strong signatures that we think were caused by large, relatively shallow buried electrically conductive objects. We find, however, that the correlation between the VETEM images and magnetic data is not high, suggesting that some of the highly conducting objects may not have metal in them. The former foundry site affords an excellent opportunity to evaluate the performance of the VETEM system and other geophysical instruments because of the location and conditions.

INTRODUCTION

During World War II, the present Denver Federal Center (DFC) was established as the Denver Ordnance Plant (DOP), which manufactured munitions ranging from small arms cartridges to artillery shells. Figure 1 is a portion of a larger aerial photograph of the DOP taken about 1945. North is roughly toward the top of the photograph. A large dark building is the dominant feature in Figure 1. Historical data, gathered from individuals who remembered the various activities conducted at the DOP, indicate that the dark building housed a foundry for the manufacture of artillery shells. To the west, left, of the dark building is another building that still exists today as Building 20. The foundry building was removed before the end of World War II, and the site is now the east parking lot of Building 20 at the DFC. The building in the background of Figure 2 is Building 20. Comparison of Figures 1 and 2 makes clear that the parking lot is on the site of the former munitions foundry building of Figure 1. Not all of the old foundry site is paved. Part is a field with sidewalks crossing from the paved parking portion to the street immediately east of Building 20 as shown in Figure 2.

When the DOP foundry shown in Figure 1 was removed, portions of walls and interior objects were buried. We have not investigated the source of the cap material, but it is a reasonable assumption that it came from a nearby location on the DFC site. The electrical conductivity of the clayey loam soil in the unpaved portion of the former foundry area, measured in situ with a Geonix EM31, with DC resistivity, and by laboratory measurements is about 30-50 mS/m. The

high soil conductivity makes the site relatively unfavorable for ground penetrating radar (GPR) imaging (Campbell and others, this volume), but a good candidate for a variety of frequency and time domain electromagnetic systems. A Geophex GEM-2, a GSSI GEM-300, and the Geonix EM31 were used in surveys over this site and the results reported in Eckhart (1998) and Campbell and Eckhart (1999).

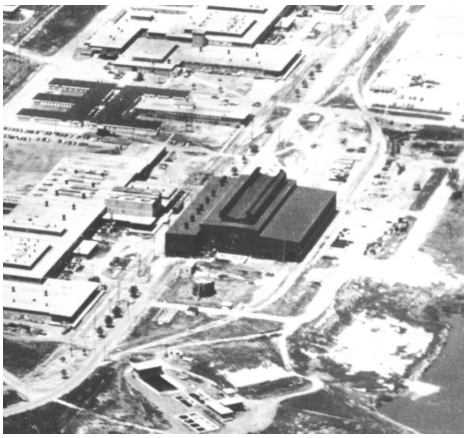

Figure 1. The dark building in the center was a munitions foundry. Photo, circa 1945, supplied by Rene Valero, General Services Administration

Figure 2. Building 20 east parking lot and field on the site of the World War II munitions foundry building. Photo (1998) by Dave Campbell, USGS.

VETEM SURVEY

We decided to survey the same site with the VETEM system (Wright and others, 1999) since its design goals include better penetration than GPR in conductive soils while retaining as much spatial resolution as possible. This survey proved to be a good test of the VETEM system and an excellent opportunity to compare VETEM results directly to those obtained with GPR and with other electromagnetic systems.

For this survey we used overlapped and 2-m separation perpendicular antennas because those configurations, ideally, do not respond to the primary field, so that the dynamic range requirement for the receiver is greatly reduced. In both cases the transmitting antenna was a horizontal square loop 30 inches on a side. When overlapped antennas are used, the amount of overlap is carefully adjusted over an area thought to be without buried objects so as to closely null the sum of the primary and earth responses. When the adjustment is completed, the receiver gain may then be set high to maximize system sensitivity to the generally smaller fields caused by induced currents in buried objects or spatial differences in earth conductivity. The surveys were run using a 1-meter line spacing. The VETEM cart was pulled at a speed of approximately 25 cm/s (~50 feet/minute) and the spatial data interval along each line was about 25 cm. Figure 3 shows the current pulse through the transmitting loop antenna in the top panel with the lower panel showing the amplitude spectrum of that pulse. The pulse duration is programmable from 0 to 5000 ns, but the ~2000 ns duration shown here is that used for all the data in this paper.

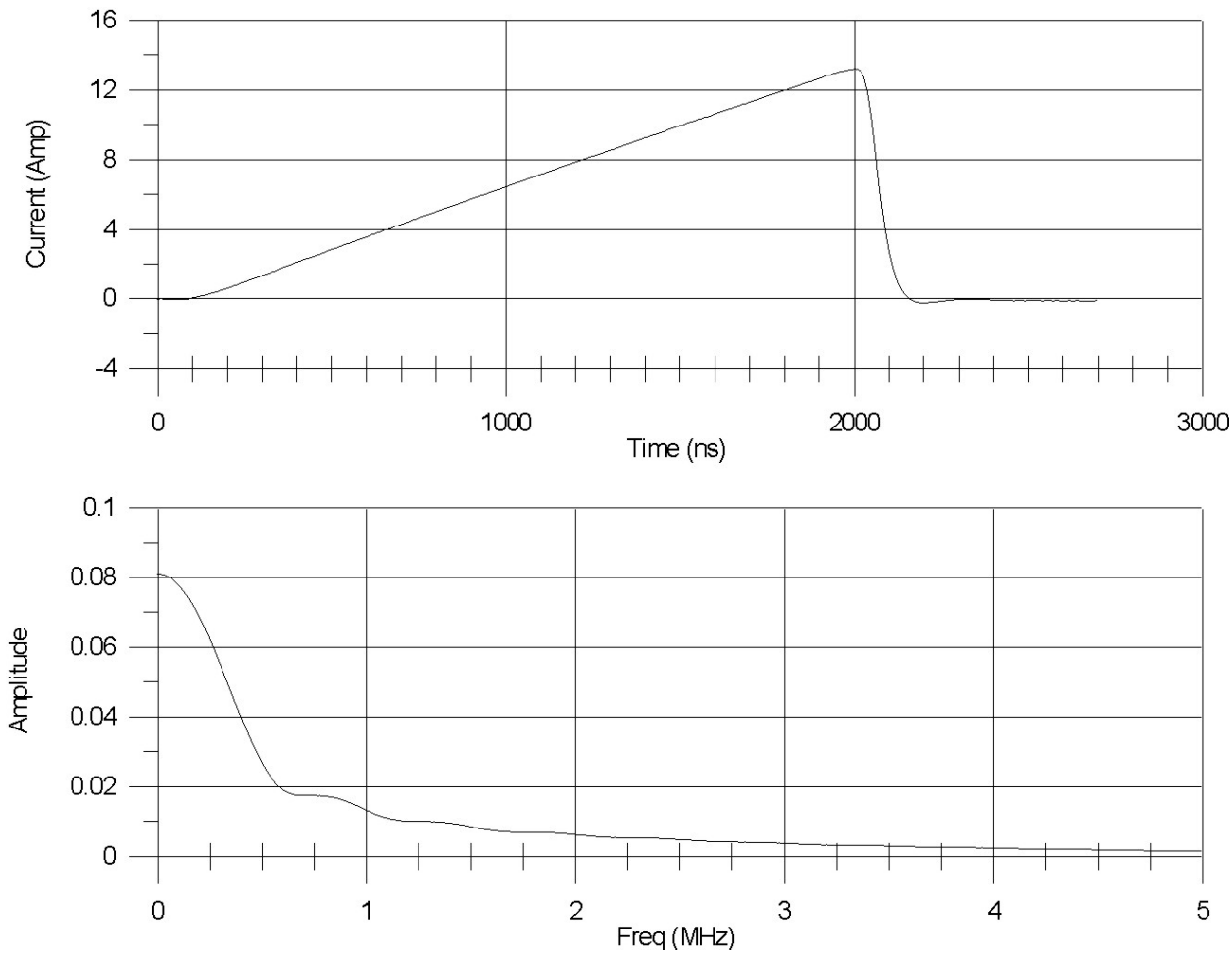

Figure 3. Transmitter loop driving current (top) and the amplitude spectrum (bottom).

Figure 4 shows five receiver data scans taken along line 17 S of Figure 5 for the perpendicular antenna configuration. Figure 5 is a shaded relief spatial map of the signal amplitude at 1400 ns, when the transmitting antenna current is still ramping up. Figure 6 shows the corresponding receiver data scans using overlapped antennas along line 17 S. Figure 7 is a 1400 ns time-slice map of the residual (average waveform subtracted) data for the overlapped antennas. The locations for the data shown in Figure 6 are marked with corresponding symbols in Figure 7. The variation of the received signal over the site was unusually large. Our interpretation is that there are shallow, large conductivity contrasts due to buried objects or structures. Of the five data scans shown in Figures 4 and 6, four are relatively closely spaced and one, marked with the triangle symbol, is quite different. If the corresponding locations are noted in Figures 5 and 7, we see that the latter scan is over a relatively flat portion of the map, whereas the others lie on top of features that may be walls, tanks or tank foundations, or other structures. Another distinctive feature is the inflection points in the data prior to transmitter turn-off, for example at about sample number 325 (650 ns) in Figure 6. The post turn-off behavior is also quite different for the five scans along the line. The shapes of the responses suggest that the four similar scans were taken above relatively highly conducting structures.

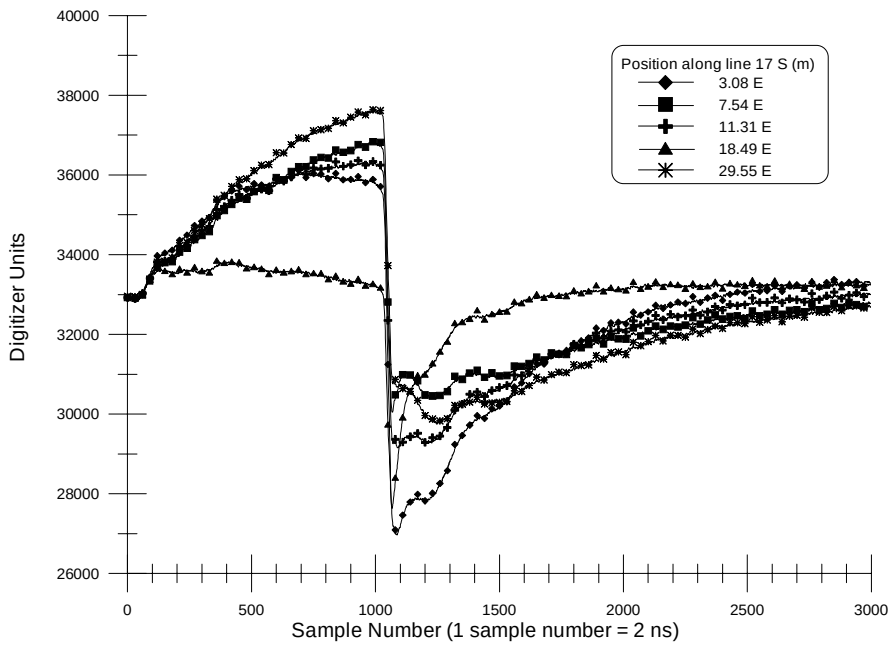

Figure 4. Five receiver scans along Line 17 S of Figure 5 using the perpendicular antenna configuration. The positions along the line are given in the legend.

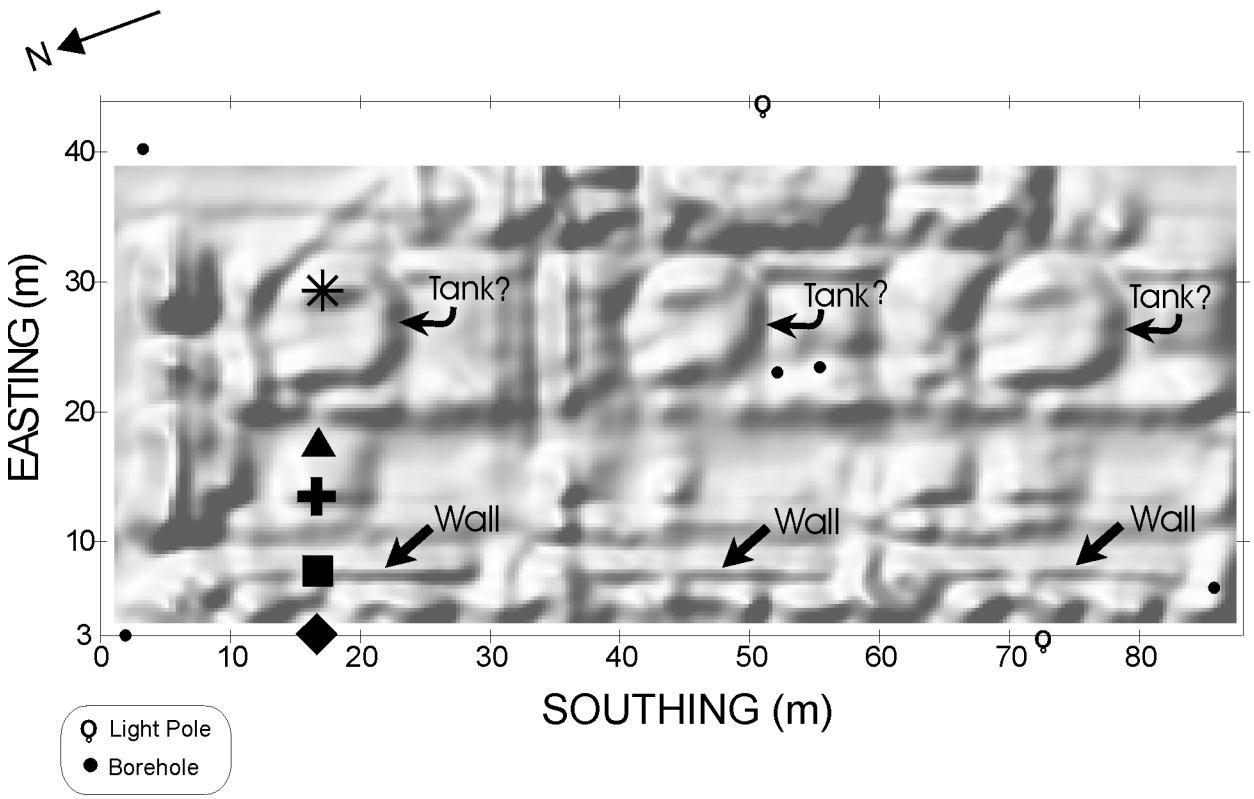

Figure 5. A shaded relief map of signal amplitude at 1400 ns using 2-m spaced perpendicular antennas. Buried structures, thought to be storage tanks or tank foundations and wall segments, are indicated. The symbols along Line 17 S correspond to the data scans shown in Figure 4. Data at the map edges are missing because a 2 x 2 matrix smoother was applied to the data.

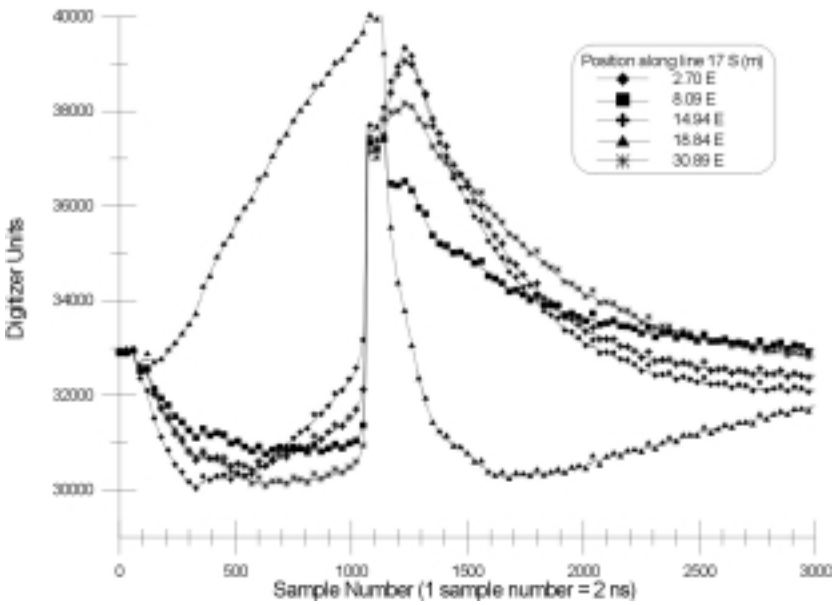

Figure 6. Five receiver scans along Line 17 S of Figure 7 using the overlapped antenna configuration. The positions along the line are given in the legend.

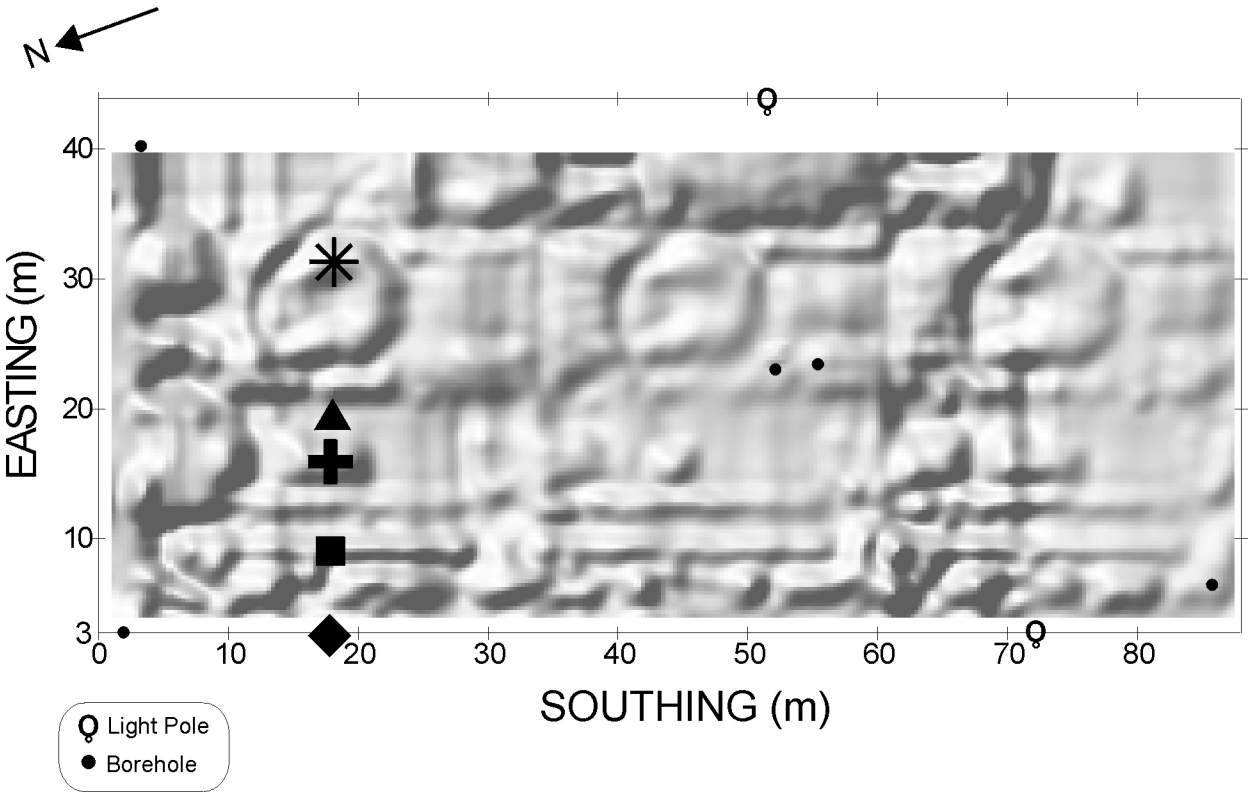

Figure 7. A shaded relief map of residual data at 1400 ns taken using the overlapped antenna configuration. In these data the average waveform for each line has been removed to produce the residual data. The major features shown in Figure 5 are also seen here. The symbols along Line 17 S correspond to those in the legend in Figure 6.

In all of the maps the gridding was done on a 30-cm square grid using a minimum curvature fit and a 2 x 2 matrix smoother.

During installation of a utility line, in about 1994, a portion of the surveyed site was exposed (Figure 8). We estimate that the left foreground of Figure 8 is at approximately 20 m east and 9 m south on the grid of Figures 5 and 7. The left side shows a pad, basement, wall, or foundation, now buried. A probe hit a hard surface at 62-cm depth at 21 m east and 9 m south on our grid.

Figure 8. Some of the remaining structure of the former foundry building exposed in 1994 during the laying of a new utility line. The view is approximately to the south. Photo by Harley King, USGS.

Depth is not proportional to time, as for GPR, but at various times different features may appear, disappear, or change, and the raw (i.e. average waveforms not removed) and residual data can have different appearances. This may be a time domain analog to a frequency domain result that a buried wall produced quadrature-phase maxima, minima, or nulls depending on frequency (Campbell and Eckhart, 1999). Figure 9 shows the raw overlapped antenna data at the 1400 ns time slice. Comparing Figure 9 to Figure 7 we see that highs appear lows and vice versa. Because of the shaded relief presentation, Figure 9 viewed upside down resembles Figure 7 viewed right side up. Lines 27 S and 28 S were corrupted because of antenna movement, and the data to the south of Line 73 S are of reduced amplitude because of low receiver battery voltage. Figure 10 is a 2300 ns time-slice map, showing receiver response just after transmitter turn-off.

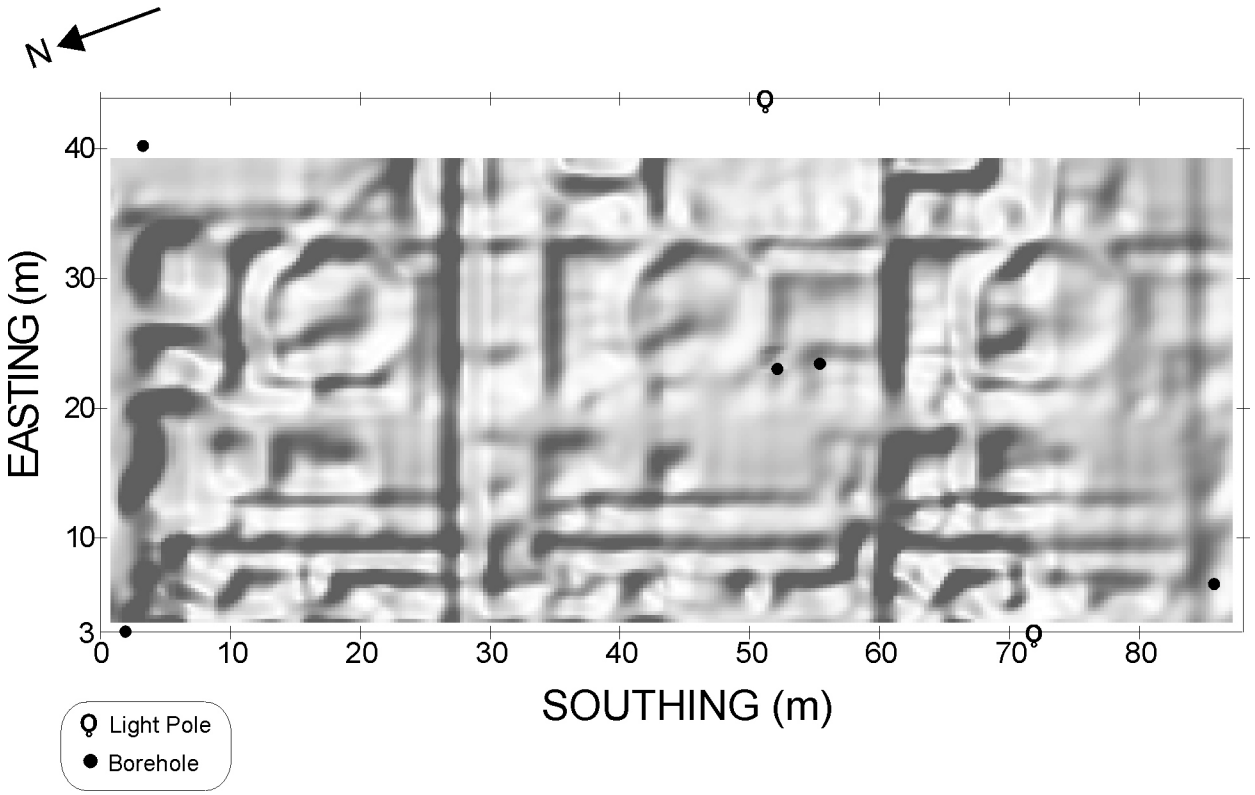

Figure 9. The raw data time slice at 1400 ns taken with overlapped antennas. The data along lines 27 S and 28 S are defective (see text).

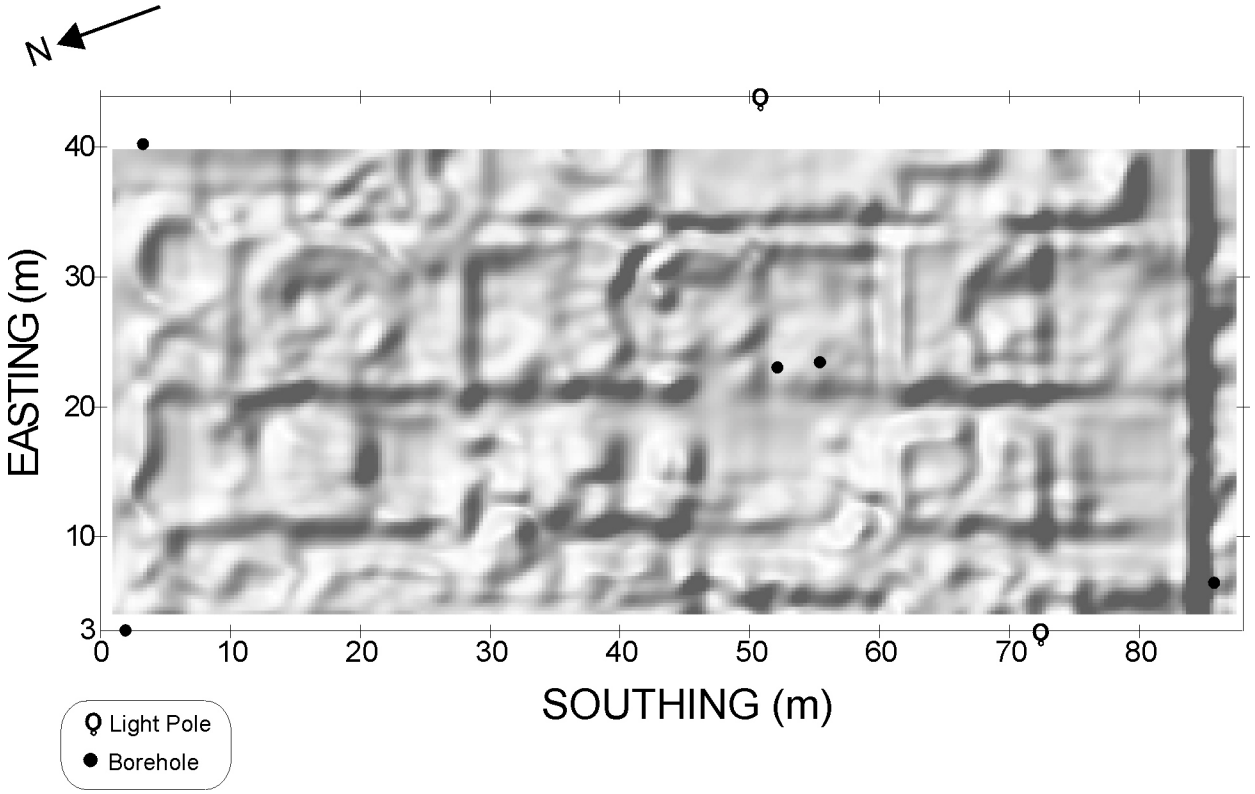

Figure 10. The raw data at time slice 2300 ns taken with overlapped antennas.

The differences between Figures 10 and 9 are apparent. An image formed from the raw data using perpendicular antennas at the 3300 ns time slice looks almost identical to Figure 5. For late times, however, the appearance changes again. At a time of 10000 ns (Figure 11), well after transmitter turn-off, most of the regular, clearly man-made, features seen in the previous figures appear distorted. For VETEM in its current configuration, 10000 ns is a late time. By 10000 ns signals have decayed to small amplitudes. Not all features decay at the same rate, however. For example, the wall at 8 E can still easily be identified with the corresponding feature seen in Figures 5 and 7. At a very early time slice (not shown) we see a faint image of the central sidewalks, though not so clearly as with the GPR (Campbell and others, this volume). We are beginning to examine the use of relative decay times as a diagnostic tool (Smith and others, this volume).

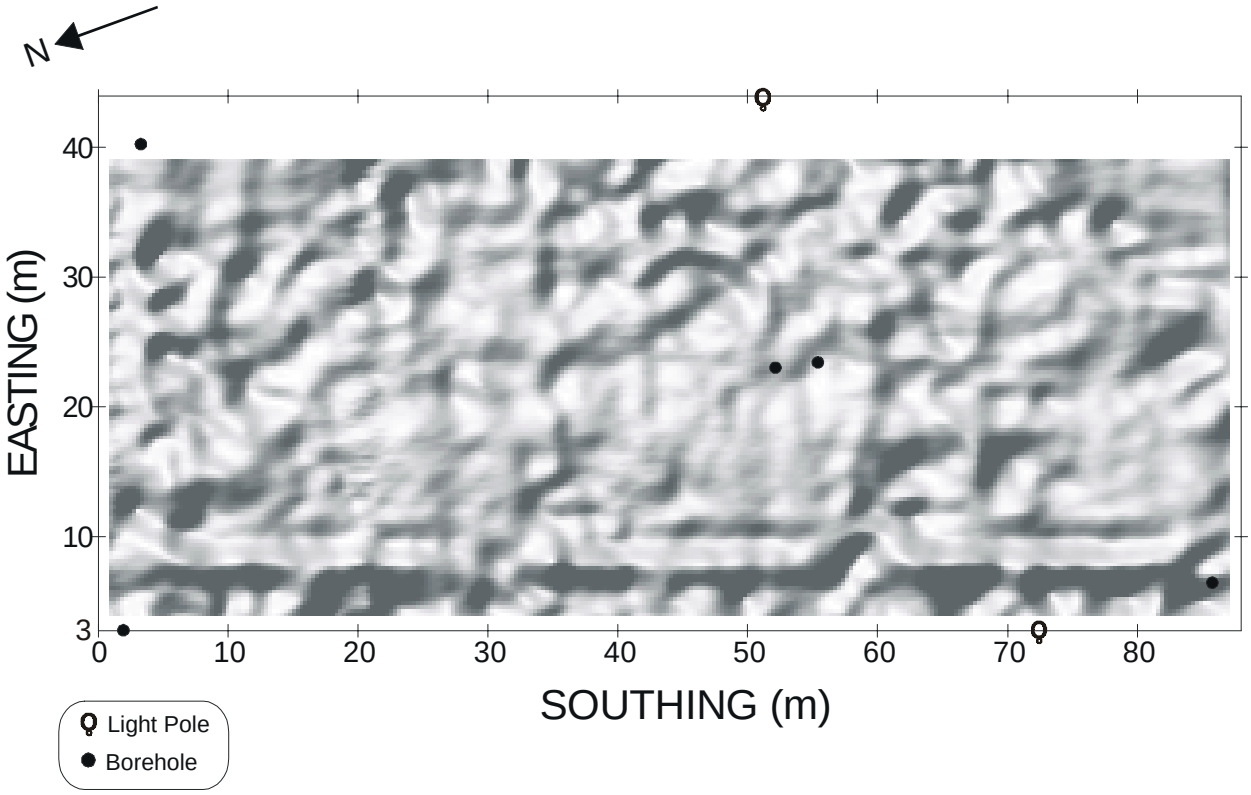

Figure 11. A shaded relief map of residual data using 2-m spaced perpendicular antennas at a time slice of 10000 ns. At this relatively late time, signal amplitudes are low and many of the regular features that were clear at earlier times are now completely or partly unrecognizable. The feature that we identified as a wall in Figure 5, at about 8 E, is still clear, however.

FUTURE PLANS AND A PUZZLE

The University of Illinois is developing fast 1D and 3D inverse algorithms to allow us to estimate depths (Cui and Chew, 1998, 1999). We have electric field antennas under test to enable VETEM operation as a low-frequency GPR. We plan to re-survey the DOP foundry site using the electric field antennas, stabilized overlapped loops, gradiometer antenna configurations, and a new receiver.

There is a puzzle in our data. The VETEM data suggest strongly conducting objects, such as walls, that we initially thought to contain metal. However, the magnetic data (Campbell and others, this volume) do not correlate well with the VETEM data and some features we interpret as conductive produce no magnetic signature. J.D. McNeill (oral communication) noted that he had found some concrete with high moisture content to be very conductive. Perhaps that is true in the case of the foundry site. Laboratory measurements might answer that question, but no material samples are presently available for testing. If the buried building materials are less conductive than the soil, however, it may be that we are observing 2D or 3D geometric effects.

CONCLUSIONS

From this study we conclude several things. First, the VETEM instrument is capable of producing high-resolution images of shallow underground structures when those structures present good conductivity contrasts. Second, the high spatial data density that was used here is needed for high-resolution shallow imaging. Third, the use of wideband pulses containing energy from a few kHz into the few MHz has merit for applications similar to this one. The penetration in the conductive soil was better than with high frequency GPR (Campbell and others, this volume) and our images compare favorably to those obtained with frequency domain instruments (Campbell and Eckhart, 1999). We plan to re-survey portions of the site with commercial electromagnetic systems, using lower sensor heights than recommended for normal operation by the manufacturers, and making certain that the spatial data density is at least as high as was used with VETEM. From these data we will produce shaded relief images as was done for the VETEM data. This re-survey should confirm or refute our conclusion that spatial data density, height above ground, and image processing differences, either alone or in combination, do not account for the higher spatial resolution of the VETEM images. Fourth, the overlapped antennas produced somewhat sharper images than the 2-m spaced perpendicular antennas, but optimal adjustment and mechanical stability requirements for overlapped antennas are demanding and require further development. A one-millimeter change of antenna overlap produces an appreciable change in the response. Fifth, the images can change considerably depending on the time slice chosen. Finally, inflection points we see in these data are intriguing and we are looking at our data to see whether inflection points can be used in interpretation.

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Disclaimer

The use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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