ENHANCEMENTS TO AND CHARACTERIZATION OF THE VERY EARLY TIME ELECTROMAGNETIC (VETEM) PROTOTYPE INSTRUMENT AND APPLICATIONS TO SHALLOW SUBSURFACE IMAGING AT SITES IN THE DOE COMPLEX

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NEEDS

Shallow non-invasive subsurface imaging is of great importance to the DOE and other communities for a variety of reasons. Electromagnetic (EM) techniques of various types are attractive methods because they can be fast and provide relatively high resolution images of the shallow subsurface. Ground-penetrating radar (GPR) has been used for such imaging, but GPR typically fails to achieve the required depth of penetration in conductive soils. For example, waste pits are often covered with clay caps to prevent moisture infiltration, but mineralogical clays are electrically conductive. GPR usually fails to map the contents of waste pits because of the high electromagnetic attenuation and dispersion (frequency-dependent velocity) which result from the high conductivity of the clay caps.

Another class of EM instrument operates either in the time or frequency domain at much lower frequencies, such that the depth of penetration can be higher than for GPR. This class of instrument typically operates in the induction regime where the electromagnetic fields are described by a diffusion equation, rather than the wave propagation equation that generally applies for GPR. A disadvantage of this class of instrument has been relatively poor resolution, especially in the vertical dimension.

VETEM is aimed at filling the gap between GPR and EM induction instruments.

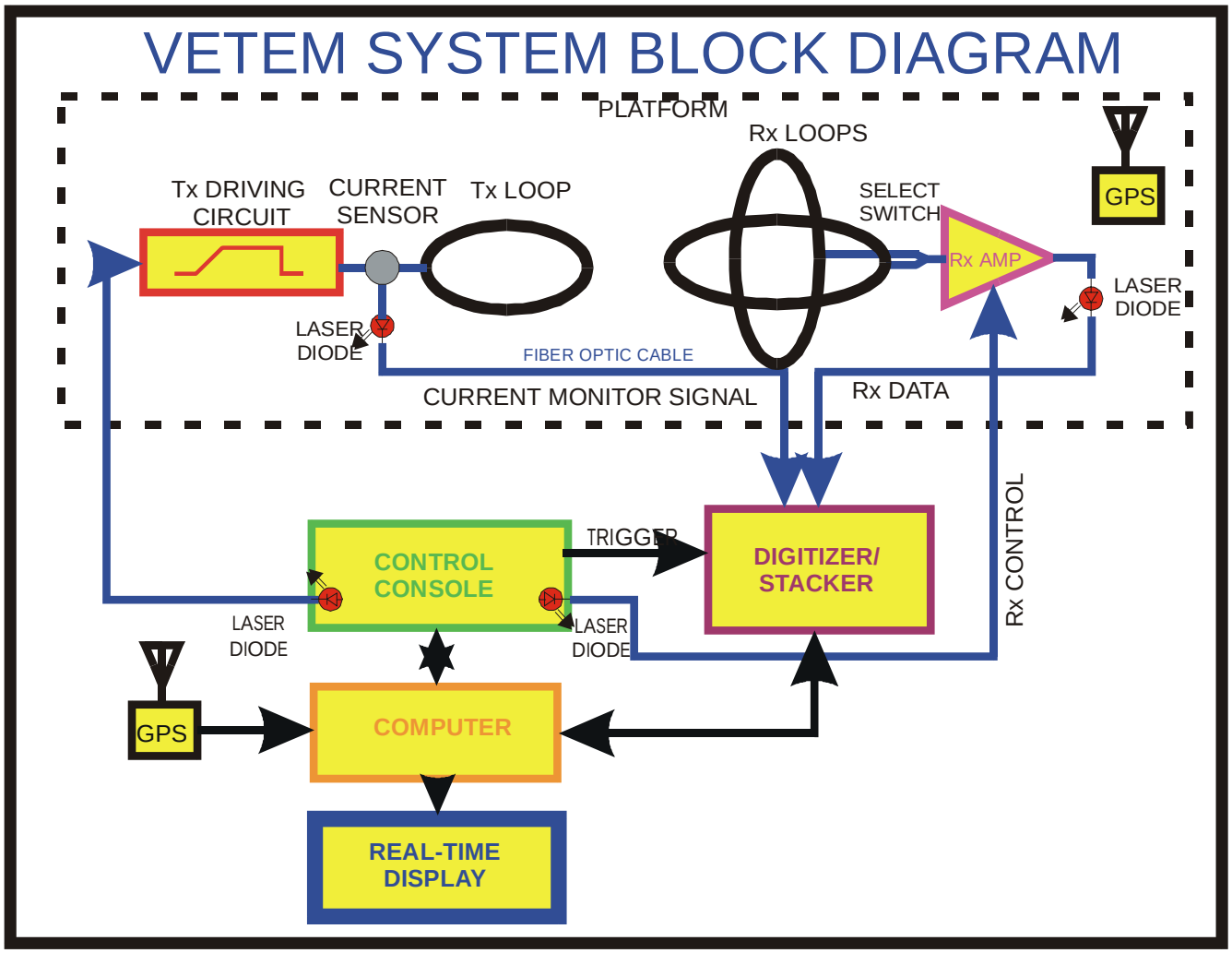
OBJECTIVES

- Enhance the state of the art of shallow (0 to ~ 5 m) electromagnetic (EM) subsurface imaging in conductive earth.
- Achieve better penetration than GPR in conductive earth.
- Achieve better resolution than conventional time-domain EM systems in the first 5 m of depth.
- Develop forward and inverse numerical models appropriate to the VETEM system.
- Determine the effectiveness of the VETEM system by field applications at DOE sites.

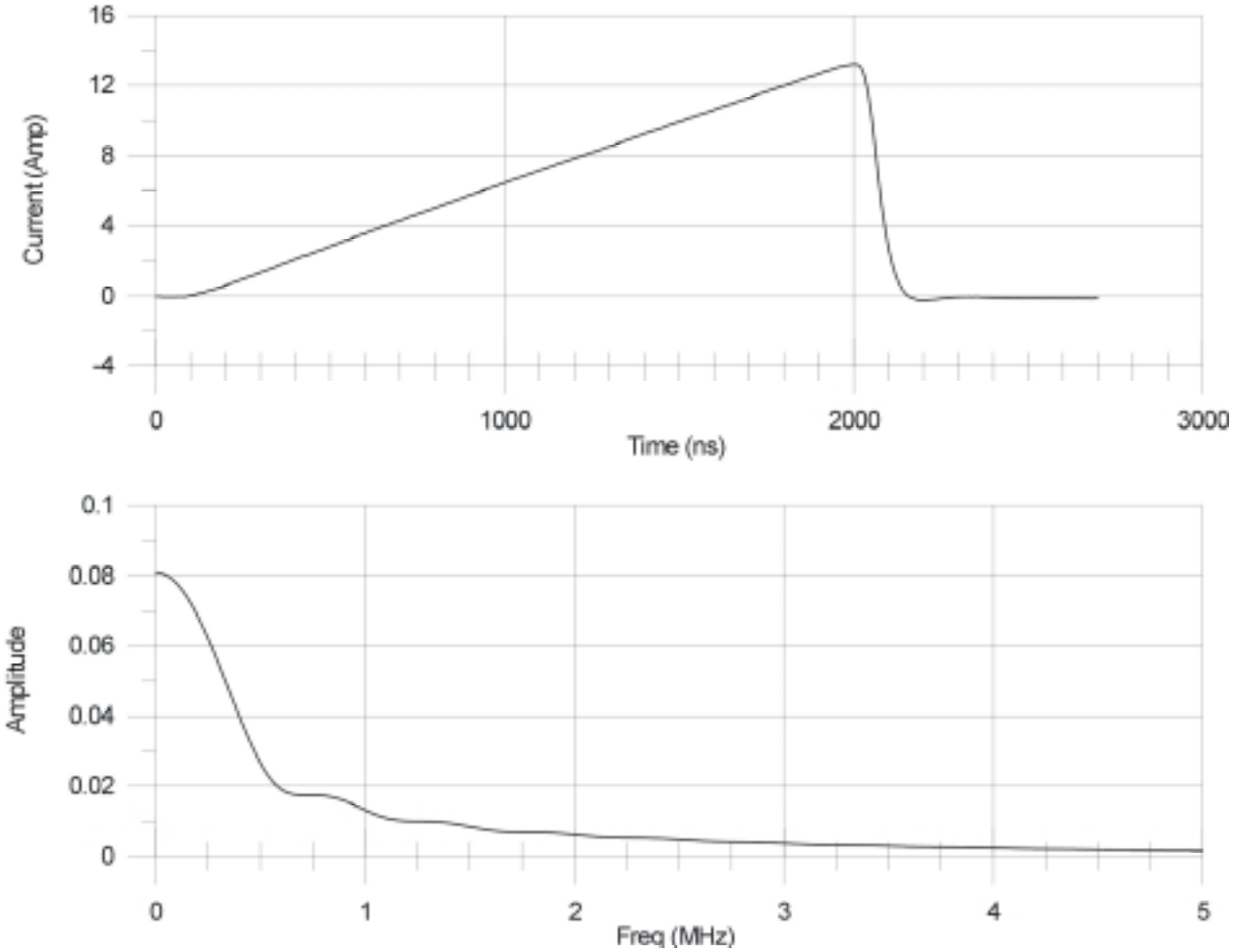
VETEM SYSTEM DESCRIPTION

The VETEM system is a highly flexible time-domain system. The system block diagram looks much like that of a typical time-domain GPR. However, we use real-time full waveform digitization and waveform averaging to achieve much faster rates of signal-to-noise ratio improvement. Some of the features of the VETEM system are:

- Non-stop profiling at speeds of 5 to 25 cm/s (~ 10 to 50 ft/min) with a typical spatial data density of about 20 cm.
- Can use either electric field dipole antennas or magnetic field loop antennas.
- Can operate over a bandwidth of ~ 10 kHz to 100 MHz by changing antennas.
- Can record the transmitter waveform to allow full waveform deconvolution.
- Can tow cart with truck-mounted winch, or behind an All-Terrain Vehicle.
- Can record multiple field polarizations.
- Uses fiber-optic cables to minimize unwanted electromagnetic coupling.
- Real-time kinematic Global Positioning System navigation is under development.
- Horizontal and vertical gradiometer configurations are under development.



VETEM system block diagram



A typical transmitter current waveform (top) using the large loops and the corresponding FFT (bottom) The pulse length is programmable and the transmitter current waveform is deconvolved from the receiver waveform for inversions.

VETEM data acquisition with the perpendicular loop antennas.

VETEM SYSTEM APPLICATIONS

The VETEM system has been demonstrated at the Cold Test Pit at the Idaho National Engineering and Environmental Laboratory (INEEL) and used in an application to Pit 9, which is an actual radioactive waste burial pit at INEEL. In addition, we found that a field just to the east of our office building at the Denver Federal Center covers the site of a World War II munitions foundry.

DENVER FEDERAL CENTER FOUNDRY SITE

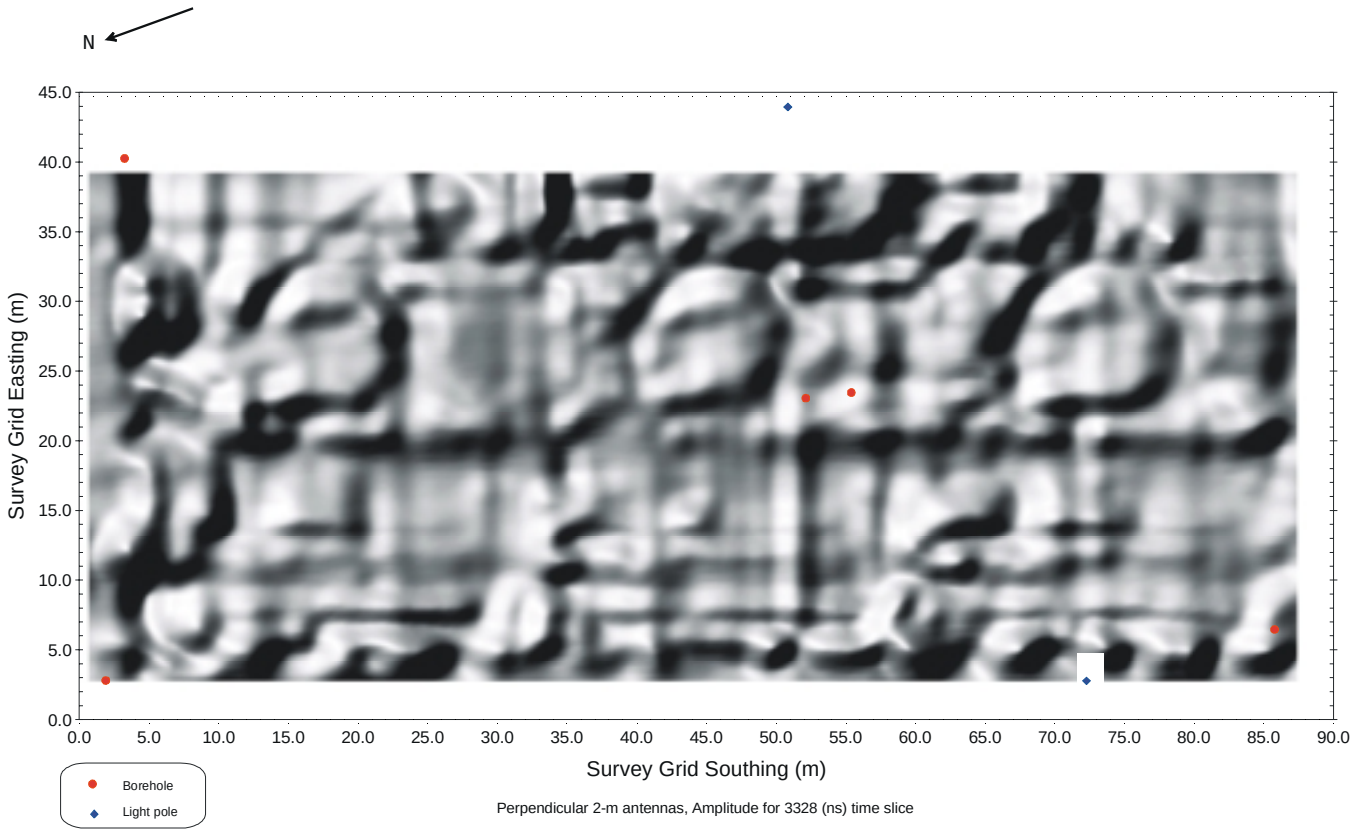
The VETEM system was run over the former foundry site and produced very high resolution images of subsurface structures. GPR has proved disappointing at that site because the soil conductivity is high (Campbell and others, 2000) EM systems evaluated at the site produced relatively low resolution images (Campbell and Eckhart, 1999)The VETEM data produced high resolution images that are now the baseline against which all other geophysical imaging is compared.

The Denver Federal Center is situated west of the city of Denver on the Front Range.

The large munitions foundry (black building in photograph) was dismantled after WWII. The foundation and underground utilities were buried under clay-rich conductive fill dirt.

Underground structures were uncovered during excavation for a sewer line.

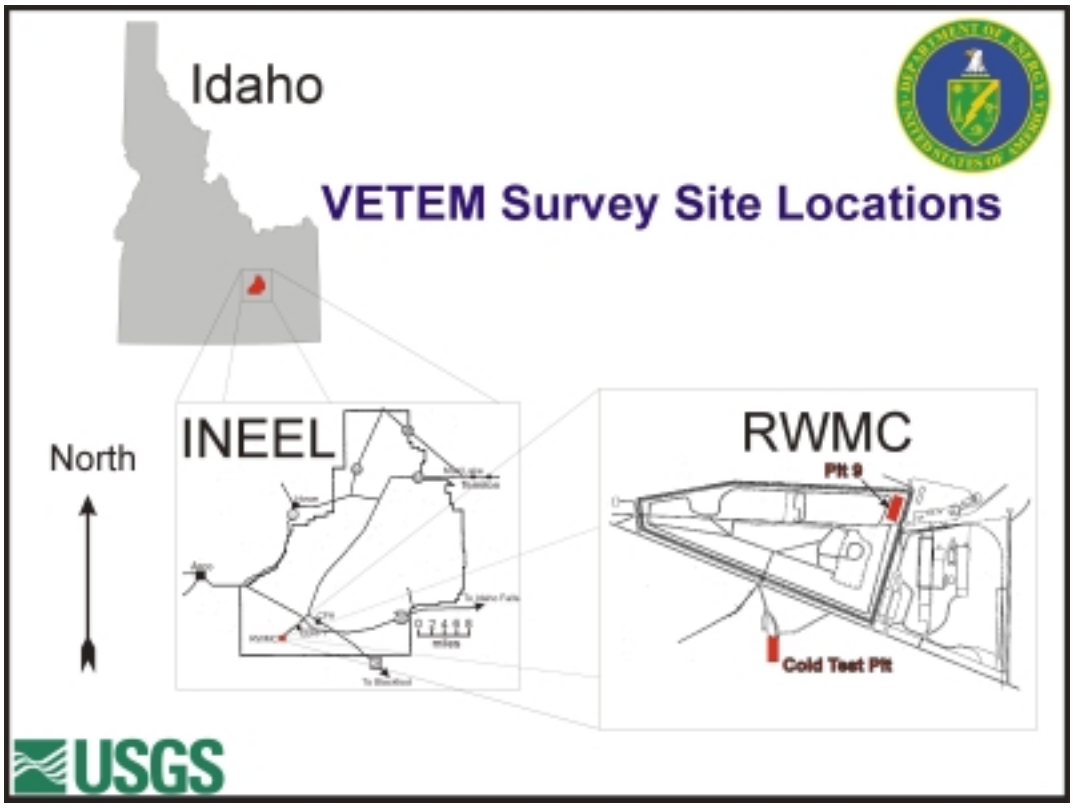
A parking lot and lawn covers the former foundry site. The survey was conducted over the unpaved area.



This VETEM image of the subsurface at the site of the former foundry reveals three similar ring-like structures and associated walls, suggestive of an industrial blueprint.

Pit 9

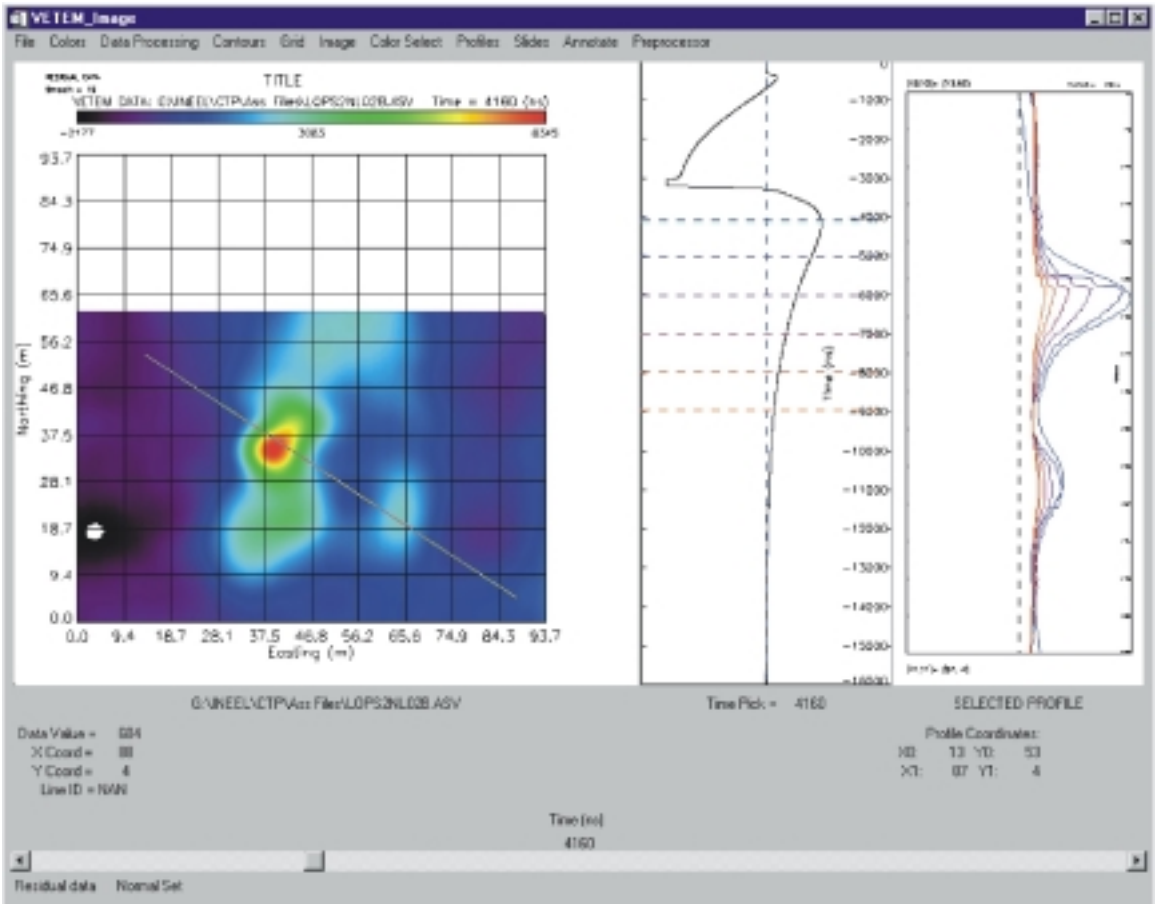
At Pit 9 VETEM and other electromagnetic and magnetometer instruments were used to map the locations of conductive subsurface objects. In addition, the VETEM data were processed using the University of Illinois 1D Distorted Born Iterative Method (DBIM) inversion to get depth estimates. We took data with two antenna configurations, overlapped and 2 m spaced perpendicular . These configurations were chosen because they null the primary field from the transmitter which allows the receiver to be adjusted to higher gains to make it more sensitive to the smaller signals of interest from buried objects. We show conductivity with depth below, from which estimates of depth to the top of buried metal objects can be made. The latest inversion information can be found at http://empc22.ece.uiuc.edu



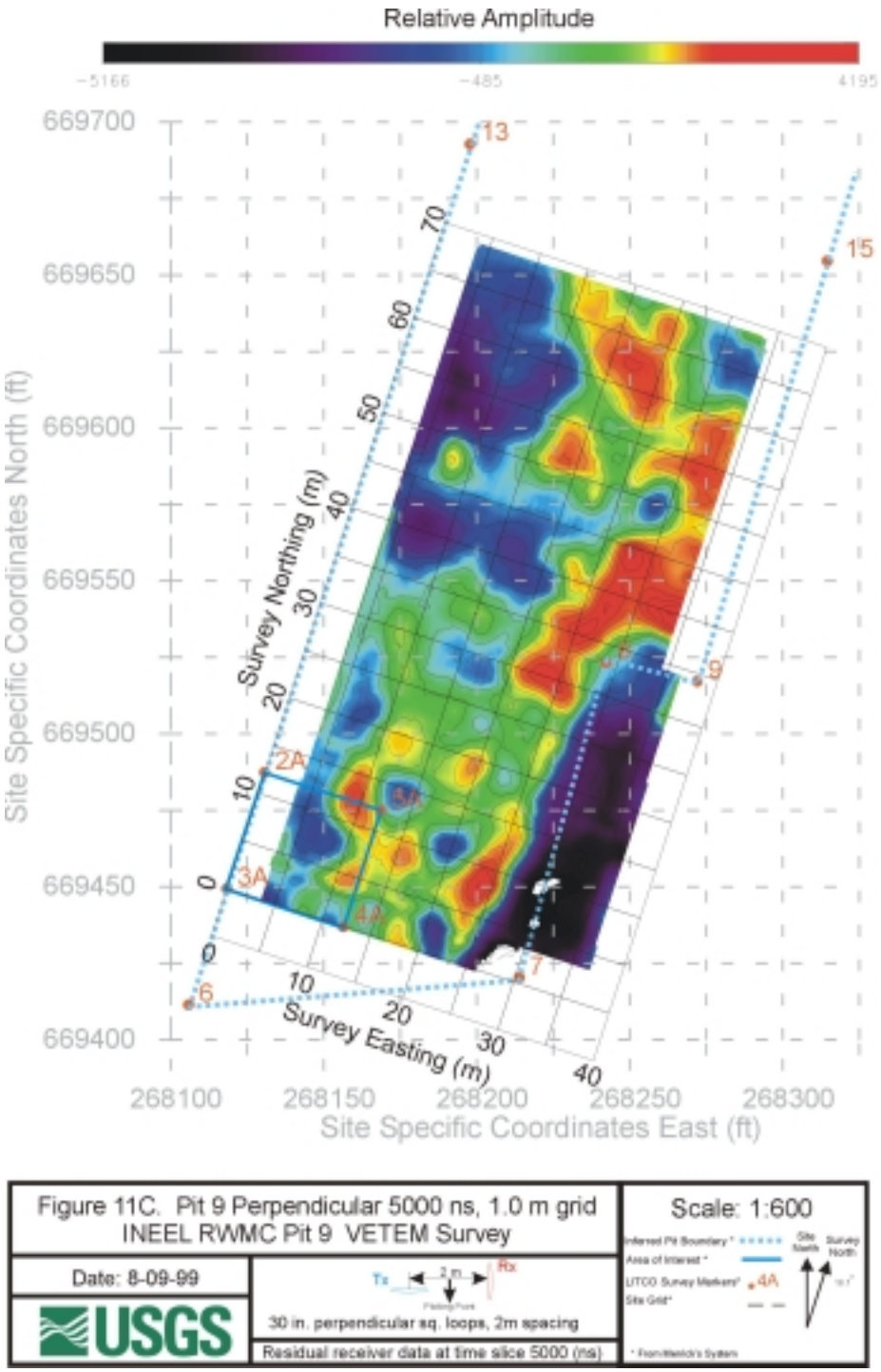
The site is located west of Idaho Falls, Idaho on the Snake River basalt flood plain.

A historical photograph documents radioactive waste burial activity at INEEL.

The VETEM platform traversed Pit 9 along E-W lines.



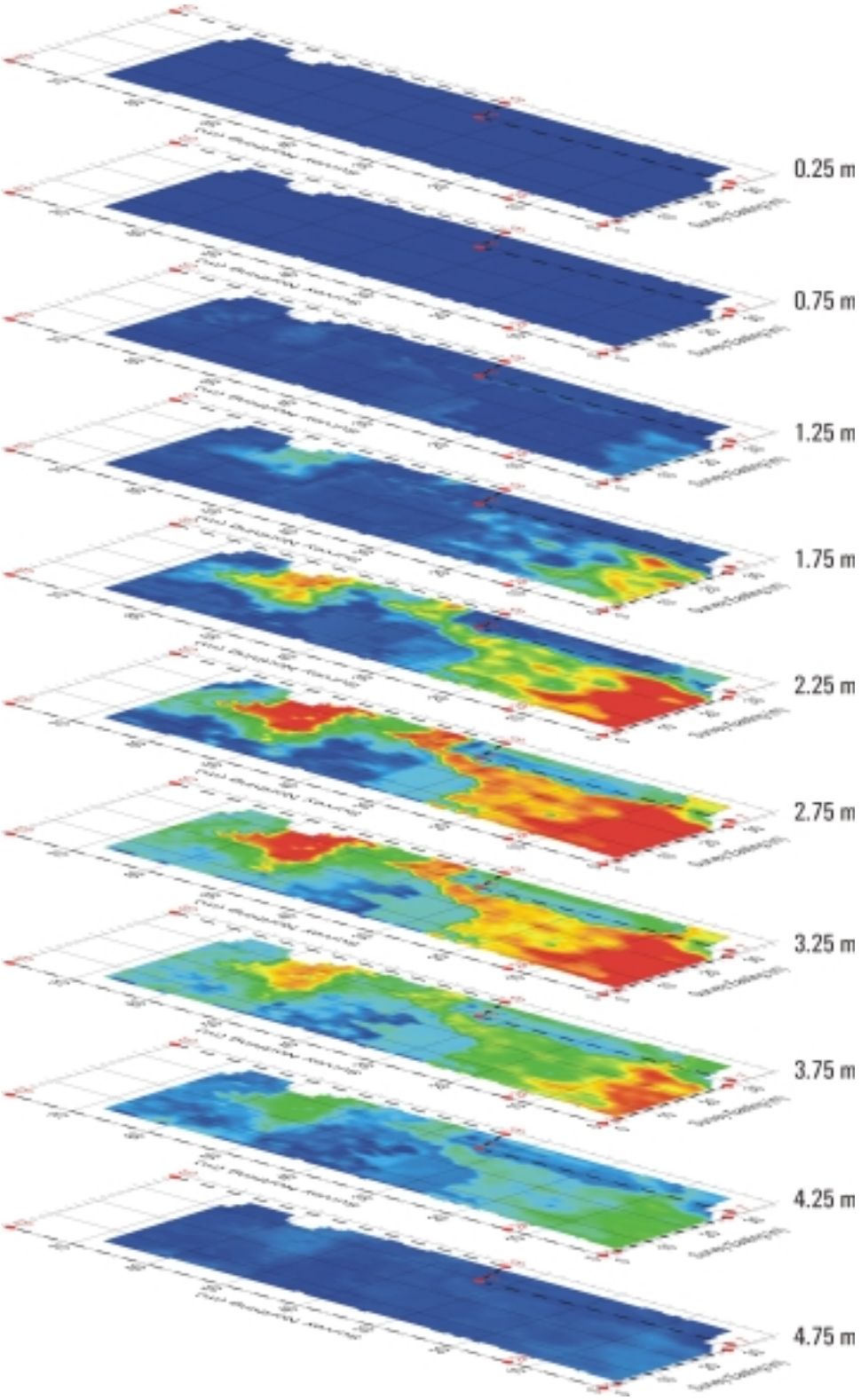
VETEM data are processed with a fully featured data analysis and display software package.



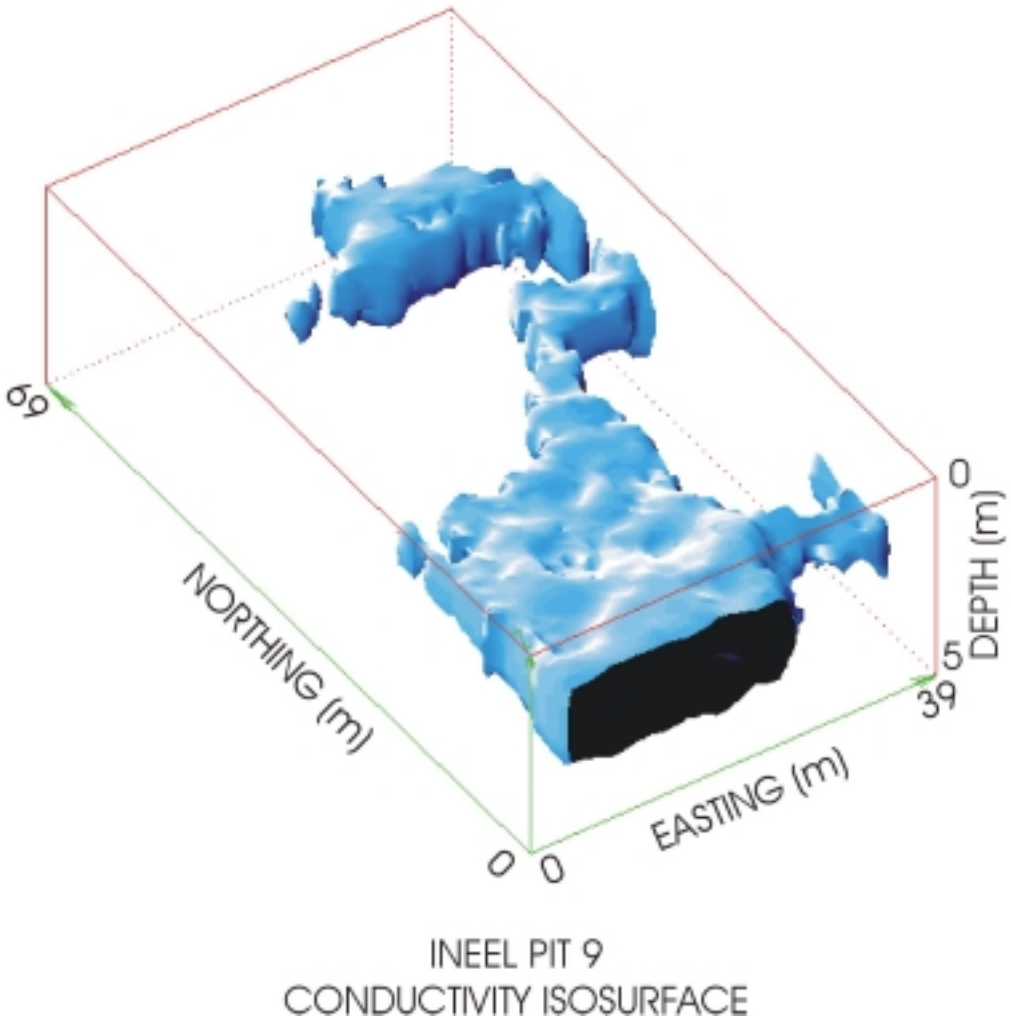
This image of INEEL Pit 9 shows the spatial distribution of signal strength 5000 nanoseconds into the received waveform.

UNIVERSITY OF ILLINOIS INVERSE MODELING

The University of Illinois has developed a fast 1D Distorted Born Iterative Method algorithm. The Pit 9 VETEM data were inverted using this algorithm and yielded the calculated conductivities with depth shown below. From these calculations it is possible to estimate depths to the tops of buried electrically conductive objects.



The University of Illinois model yielded computed conductivities with depth as shown in this stack of images.



Modeled conductivity variations in 3-D. High calculated conductivities are enclosed by the blue surface.

CONCLUSIONS

The VETEM system:

- achieves better depth of investigation than GPR in conductive earth.
- produces high resolution images of subsurface conductivity contrasts.
- performs favorably compared to conventional EM systems.

Inversion of the data to calculate depth to the top of highly conducting waste is possible using the 1D DBIM inversion developed by the University of Illinois.

REFERENCES

Further information may be found in the following papers and the references contained in these papers.

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