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USE OF REMOTE SENSING TO IDENTIFY
WASTE SOURCES AT ORNL'S SWSA 4[1,2]

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ABSTRACT

Solid waste storage area (SWSA) 4, at Oak Ridge National Laboratory (ORNL), contributes 25% of the ^{90}Sr release from the ORNL complex. Disposal records were destroyed in a fire, thus limiting the ability to locate waste sources contributing to the releases. The use of remote sensing products, including photos and thermal spectra images, provided the needed information to allow field work to progress in an efficient and cost-effective manner. As a result, four major sources were identified. Preliminary estimates suggest that cost avoidance in excess of $5 million will be possible because of the detailed source location knowledge.

Use of Remote Sensing to Identify Waste Sources at ORNL's SWSA 4

Introduction

Waste Area Grouping (WAG) 4, one of 17 WAGs within and associated with Oak Ridge National Laboratory (ORNL), is located along Lagoon Road south of the main plant complex (Figure 1). Solid waste storage area (SWSA) 4 is the largest unit at WAG 4, covering approximately 23 acres. In the 1950s, SWSA 4 received a variety of low- and higher-activity-level wastes, including transuranic wastes, all buried in trenches and auger holes. A fire destroyed most of the records of burial operations.

At present, surface water data indicate that a substantial quantity of ^{90}Sr is being released from the burial trenches in SWSA 4. These trenches have contributed 25% of the ^{90}Sr release observed at White Oak Dam during the period 1987-1994 and about 14% of the total ORNL off-site risk via the drinking water pathway. A site investigation was undertaken in 1995 to locate the sources of ^{90}Sr release, to determine a relative ranking of their importance, and to provide sufficient information to evaluate alternatives for an interim measure to control release and thus reduce the off-site risk.

The investigation strategy involved "back-tracking" along the discharge pathway from White Oak Dam to the western portion of SWSA 4, which contributes about 80% of the WAG 4 ^{90}Sr release. In that area, radiation surveys were conducted to locate discrete discharge points, and seep collection systems were constructed to measure flow and quantify surface releases from individual seeps. Data showing ^{90}Sr concentration along the tributary that drains the area were also used to help rank importance of sources for subsurface flow contributions. This effort narrowed the search for sources within trenches to two specific sites upslope from identified seeps.

At that point, the lack of records showing trenches and disposal operations threatened to limit the definition of sources to general areas. This in turn, implied that only an area-wide remediation, such as capping and collection and treatment of releases would be viable. However, at that point, the use of remote sensing products, including photos and thermal spectra images, provided the needed information to approximately identify trench locations. This information allowed the successful design of intrusive studies to pin-point the locations of sources that were releasing most of the ^{90}Sr to the drainage. The focus of this report is thus on the remote sensing products that were used, and how they were coupled with other parts of the WAG 4 investigation to identify a cost effective remedial option. A site investigation report provides more details (ORNL/ER-329/V1 & V2, 1995).

Remote Sensing Evaluations

Overview

Lack of precise knowledge of trench locations at WAG 4 has been a continuing limitation on efforts to link discharge seeps to specific sources in waste trenches. Information about trench size and location also is needed for evaluating practical options for corrective measures on sources in trenches. A few promising remote-sensing options have been undertaken to help improve knowledge of trench features. A combination of historical and current photographic and thermal images of the site were explored to determine if they could help locate trench boundaries. This resulted in a trench location map, described below, that allowed the investigation to proceed and encouraged use of other remote sensing products. A magnetometer survey using USRADS technology had been conducted in 1993 (Chemrad Tennessee Corporation 1994). Processing of the data offered some promise of identification of trench locations, particularly those trenches containing metal objects. In particular, when used in conjunction with the trench location map, the the combined data strengthened the basis for interpretation. There were still some questions about exact
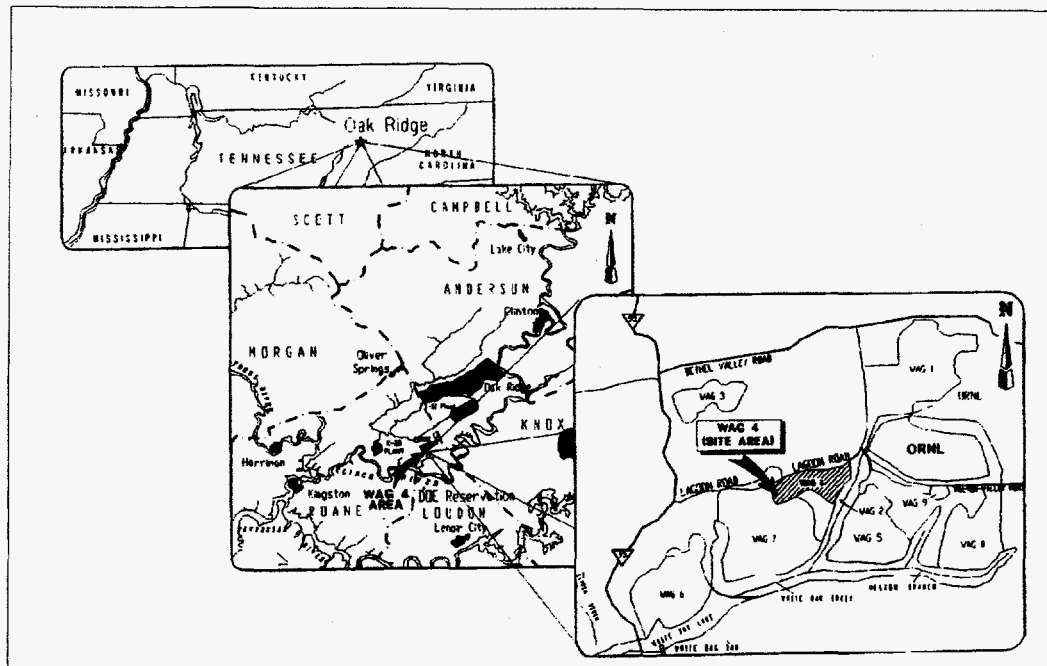
Fig 1. The WAG 4 area in east Tennessee, near Oak Ridge National Laboratory.

trench locations, and an attempt to refine the data further involved exploring low-frequency ground-penetrating radar (GPR) for nonintrusive location of trench boundaries was explored. Each of these applications is discussed in the following sections, in conjunction with other key findings.

The Strategic Environmental Research and Development Project Map

As a part of the Strategic Environmental Research and Development Project (SERDP), the Oak Ridge ER Remote Sensing Program collaborated with the WAG 4 Site Investigation team to test the applicability of various remote-sensing technologies to waste site characterization. The project involved both data analysis and data fusion, using both classified and unclassified characterization tools. Historical and current photography and thermal imagery were analyzed to derive the SERDP map. Many of the results and data products from this work are classified at secret and higher levels. However, some derived products have been individually reviewed by a classification board and made available at the unclassified level. Figure 2 represents such a product. An unclassified report describing the SERDP project has been issued (King, 1995).

Figure 2 represents a compilation of site information collected from 1952 to the present. Visible trench or cap features were derived from photographs, but location accuracy was limited by a lack of identifiable ground control features. Soil patches, associated with subsidence, represent areas that were filled in to prevent collection of water in trenches. This activity was a common maintenance practice, and such soil patches give reliable clues to the locations of subsiding trenches in many photos. Thermal signatures are the most recently obtained information, and are probably most accurately located. Persistent features were identified, and an interpreter drew a line along the center of the feature. The width of the line on the feature is roughly equal to the width of the thermal signature. Although thermal signatures could not be guaranteed always to represent trenches, the apparent correlation was excellent in the field with trench locations that could be observed. In particular, locations for the original 12 drive-point wells installed in the early part of this investigation corresponded to trench features shown on the SERDP map.

As a result of the excellent correspondence with other available information, the SERDP map was selected as the basis for an expanded investigation to pinpoint locations of sources in individual trenches. The SERDP map information was extracted into a MapInfo (Geographic Information System) format and combined with other site information to produce a base map for much of the drive-point-installation task.

Geomagnetic Walkover Survey

During an earlier characterization of the WAG 4 area, a geomagnetic survey was conducted, using a magnetometer and the USRADS technology for simultaneous recording of instrument readings and precise location (Chemrad Tennessee Corporation 1994). This survey was conducted by the ER Remote Sensing Program's Airborne Geophysical Survey Project. These data were collected in support of ground truthing activities. The data from this survey were analyzed to produce a vertical-magnetic-gradient contour map. This map was combined with thermal and visual spectrum information (discussed in the previous section) to produce the image shown in Fig. 3a,b,c. In most locations, the magnetic patterns appear to match historical drawings of areas and orientation for trench disposal sites in WAG 4. Although the detail is not sufficient to define boundaries of single trenches, the orientation of the magnetic features provides useful information for the interpretation of trench locations. For example, in Fig. 3a, the general orientation of trenches matches the SERDP map orientations fairly well. However, in the portion of the area shown in Fig. 3c, it appears that the thermal signatures do not align with the magnetic signitures from wastes in trenches. Drive point penetration work suggests that the magnetic anomaly data show the correct alignment, and that where there is disagreement between thermal and magnetic data, further exploration is needed.

Fig. 2. Strategic Environmental Research and Development Project Map of WAG 4

Fig 3.   The SERDP map that was produced from remotely sensed information. The quality of the original figure is significantly better than this reproduction, which has been exported from a GIS file and converted to WordPerfect format.
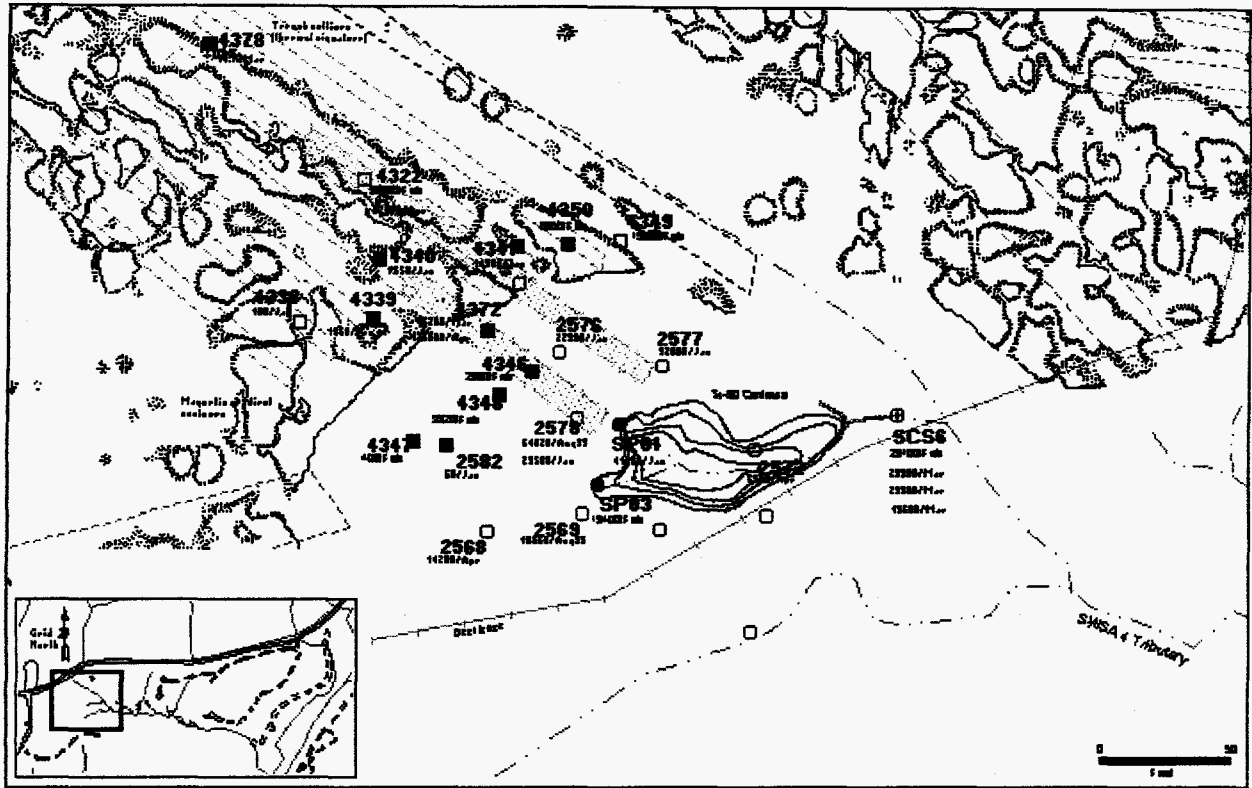
Fig. 3a. Combined vertical magnetic gradient and thermal signiture data - West WAG 4

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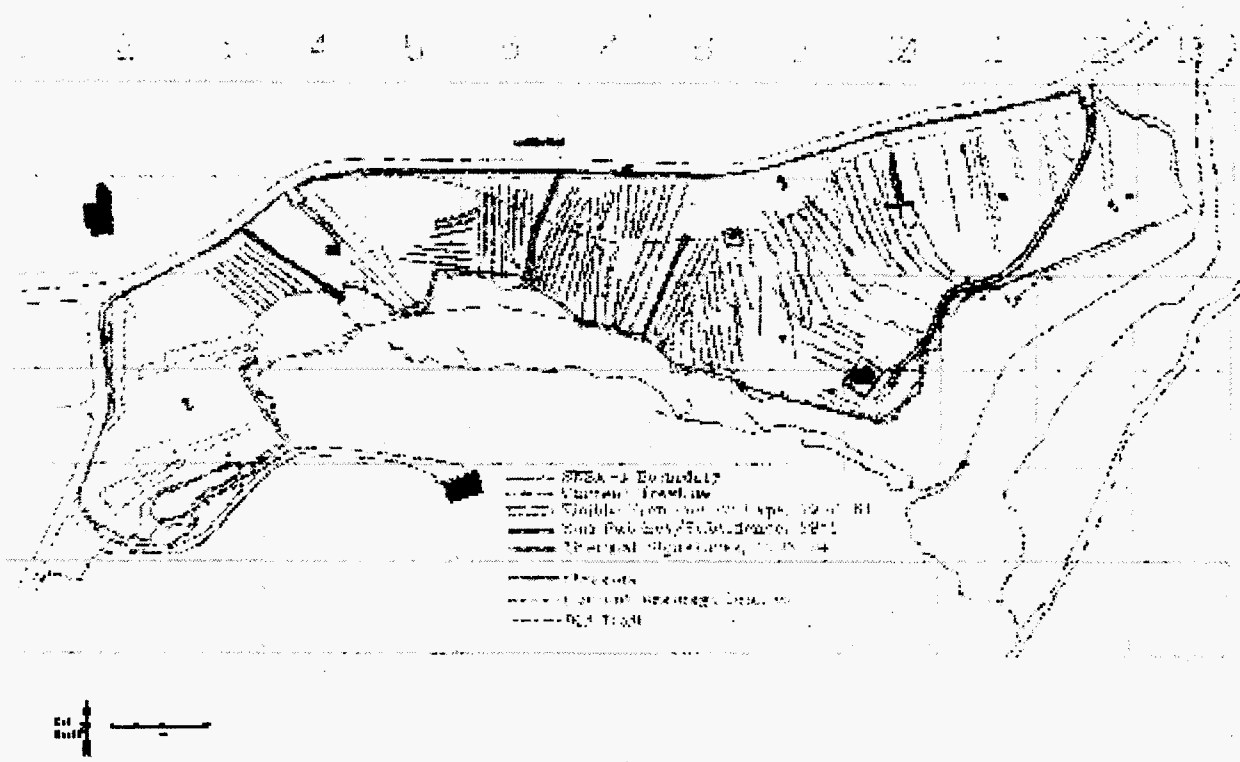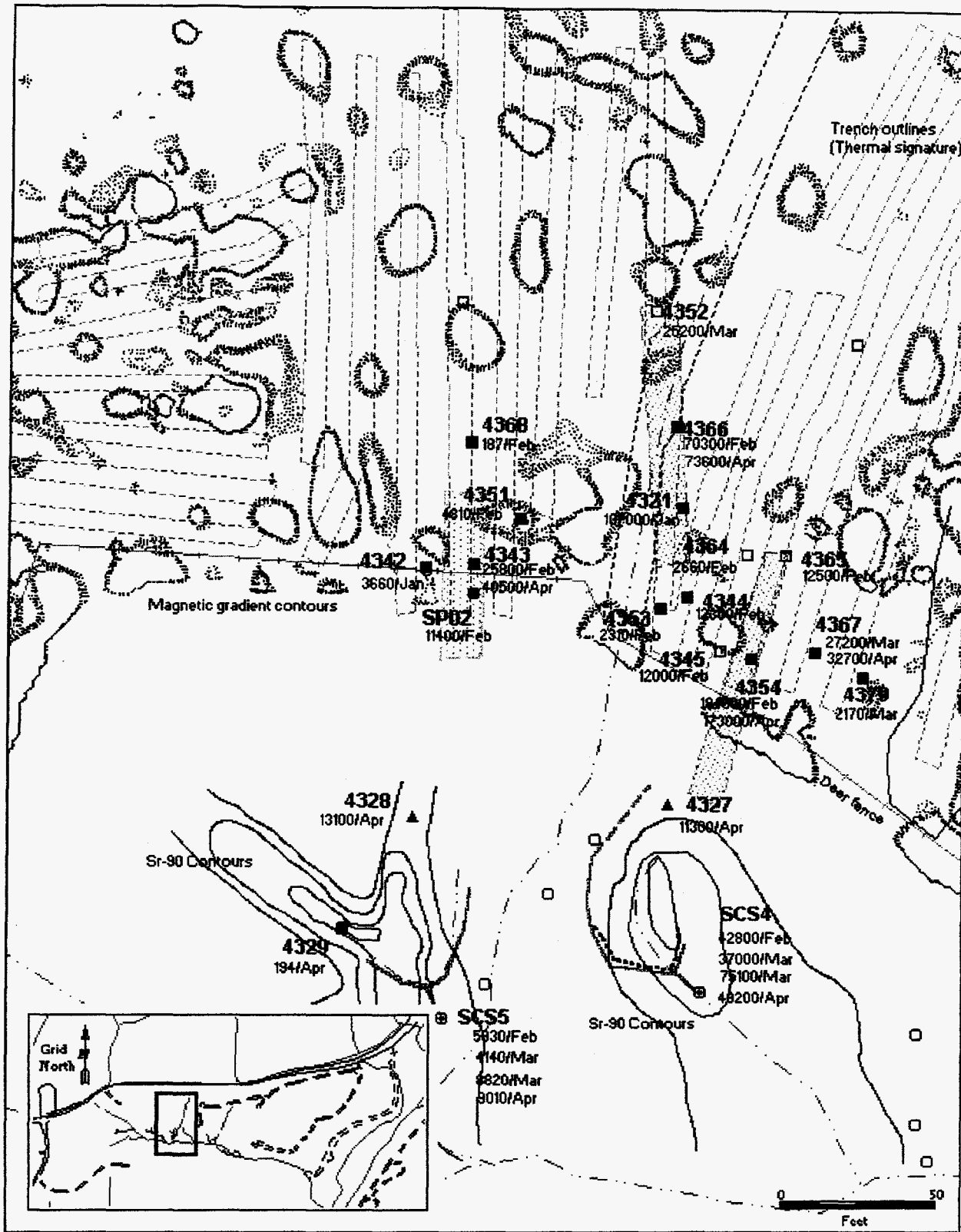
Fig. 3b. Combined vertical magnetic gradient and thermal signature data - Central WAG 4

Fig 3b. Vertical magnetic gradient data and remotely sensed information are compatible in this portion of the burial ground, although magnetic signatures are somewhat sparse.
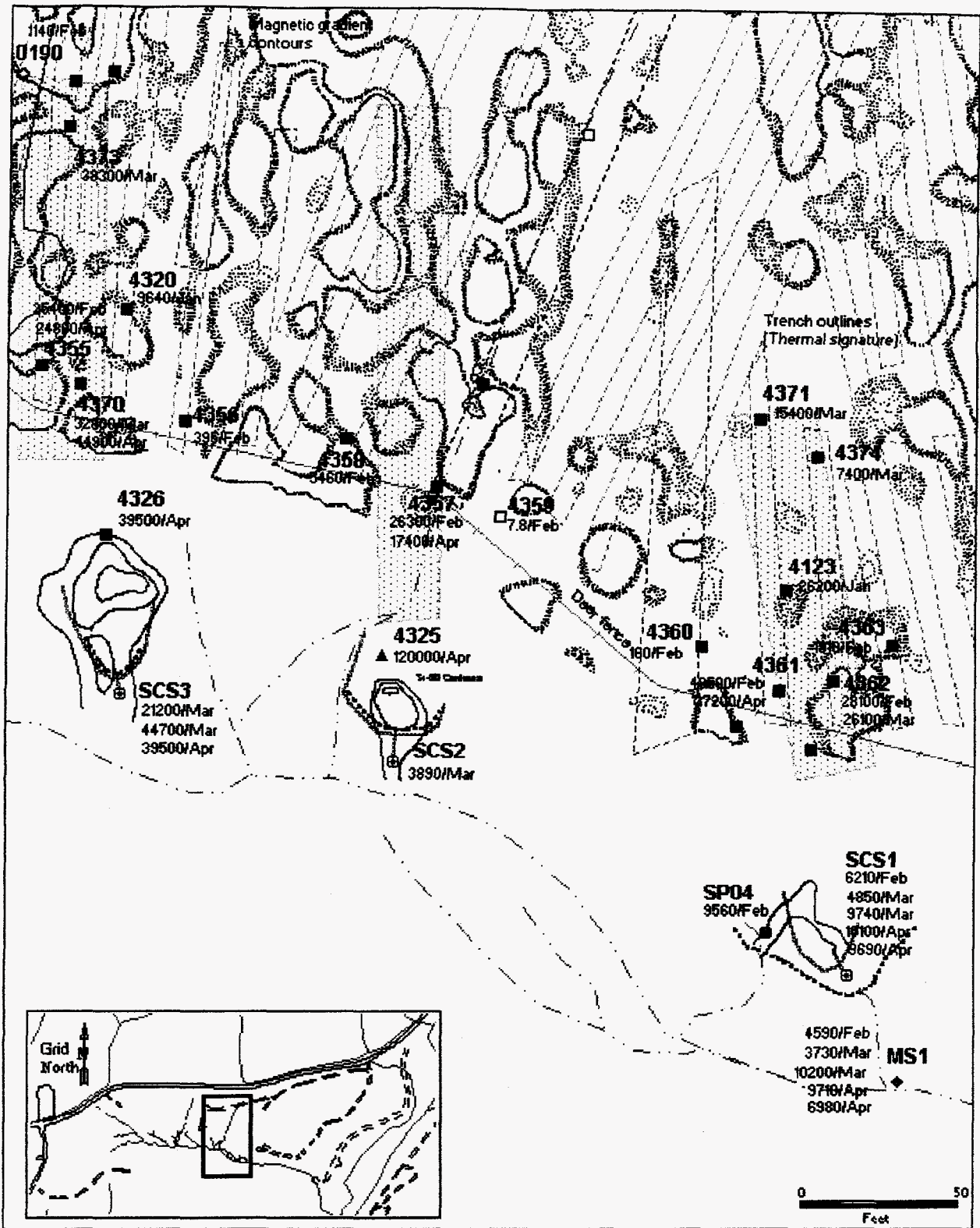
Fig. 3c. Combined vertical magnetic gradient and thermal signature data - East WAG 4

Fig 3c. This shows some areas where thermal imagery and vertical magnetic gradient information don't match. The magnetic data appear more reliable, based on direct field observation.

Low-Frequency Ground-Penetrating Radar

Summary of Field Study. GPR surveys provide high-resolution imaging of the near surface by transmitting a short radar pulse from an antenna placed on the ground surface, and measuring the reflected pulses at a nearby receiving antenna. Three different antennae were tested at WAG 4—25 MHZ, 50 MHZ, and 100 MHZ.

In August 1994, six GPR lines were run across portions of WAG 4. These lines were laid out in two groups: one group near the bathtubbing trenches near the western portion of the site, and one group near drive point 4, near the center of the site. The Sensors and Software PulseEkko IV, using 25-MHZ and 50-MHZ antennae, was operated on 1-ft spacing to collect data. In general, the 50-MHZ antennae seem to have a penetration depth of about 10 ft, and the 25-MHZ antennae seem to penetrate about 15 ft. Data were collected along one line (C03) in the central group using 100-MHZ antennae, but these had at best a penetration of 6 ft to 7 ft, and were not used after that test.

Each radar line location was selected to cross one or more trenches in a direction approximately perpendicular to its axis. This was determined from magnetic maps and photography available before field operations began. Locations of the endpoints of the GPR lines were surveyed after acquisition to allow direct comparison of the GPR data with other data sets. The GPR method provides cross-sectional images of the subsurface by reflecting radar pulses from natural or man-made objects that have dielectric properties differing from those of overlying or surrounding materials. The cross-sectional images derived from data taken at one foot spacing appear to include reflections from materials within the trenches and weathered bedrock between and beneath the trenches. There is no simple way to distinguish between the man-made and natural objects; therefore, interpretation of the images relies heavily on previously acquired experience and site information. These results are described in detail in ORNL/ER-329/V1&V2, and are not discussed further here because they do not contribute to final results.

Presentation of Results. GPR survey lines for the study areas are shown superimposed on approximate trench locations derived from the SERDP map (Fig. 2) in Fig. 4a,b. Figure 5 is a cross-sectional image developed from a 25-MHZ survey showing distance on the horizontal axis and time (depth) on the vertical axis from line C03 (Fig. 4b). Traces are plotted at 0.5-ft increments, with CDP 200 being the west end of the line. Because the first trace plotted is at station 203, it is 1.5 ft from the west end of the line. Depth is determined by calculating travel times based on an estimated velocity. In the analysis, a velocity of 0.2 ft/ns is assumed. This is probably accurate to about 20%.

The image shown in Fig. 5 was derived by common-midpoint enhancement of data acquired at several antenna separations. These data were acquired only along line C03. Signals occurring at depths of less than 5 or 6 ft in Fig. 5 should be discounted, because they do not represent reflected signals. Comparison of the data with drive point data and photographic imagery suggests that GPR is able to detect the bottoms of trenches, and is not responding as much to the material in the trenches as to the trenches themselves.

Conclusions. Several conclusions can be drawn from the GPR data. First, antenna frequencies above 25 MHZ do not provide sufficient depth penetration to be useful for defining trenches at WAG 4. Second, data collected for common-midpoint enhancement processing appear more useful than data collected using a single antenna separation method. Finally, the data interpretation is very difficult, if not impossible, without supplementary site-specific information such as approximate trench locations and depths. However, where such information is available, radar data can be valuable for refining trench boundaries, and the method appears promising enough to merit further use for localized studies.
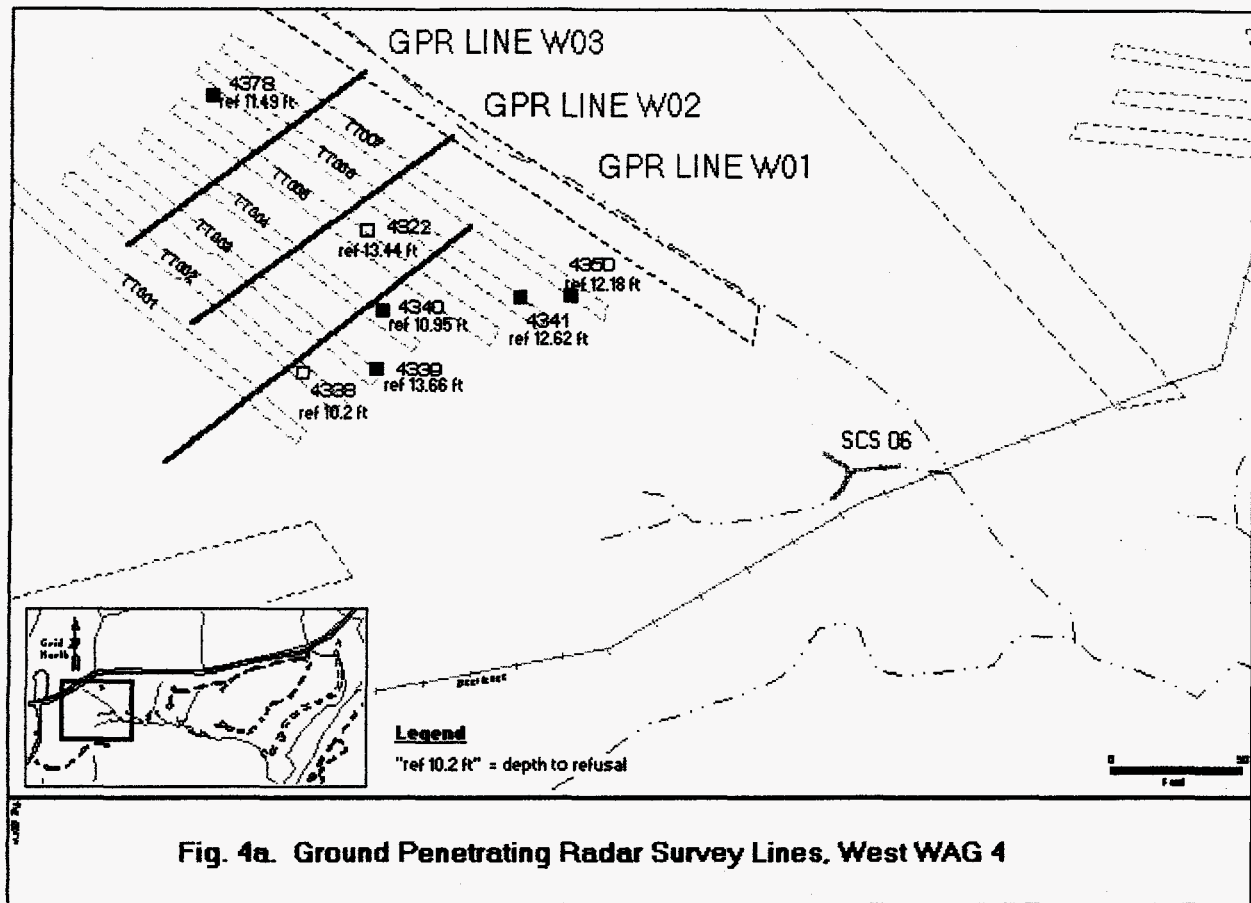
Fig. 4a. Ground Penetrating Radar Survey Lines, West WAG 4

Fig 4a. The GPR lines, which run across estimated trench outlines in the upper left portion of the figure, note the locations for ground penetrating radar surveys. These lines were single-observation collections, and generally were not as useful as common-depth profiling.

Fig. 4b. Ground Penetrating Radar Survey Lines, Central WAG 4

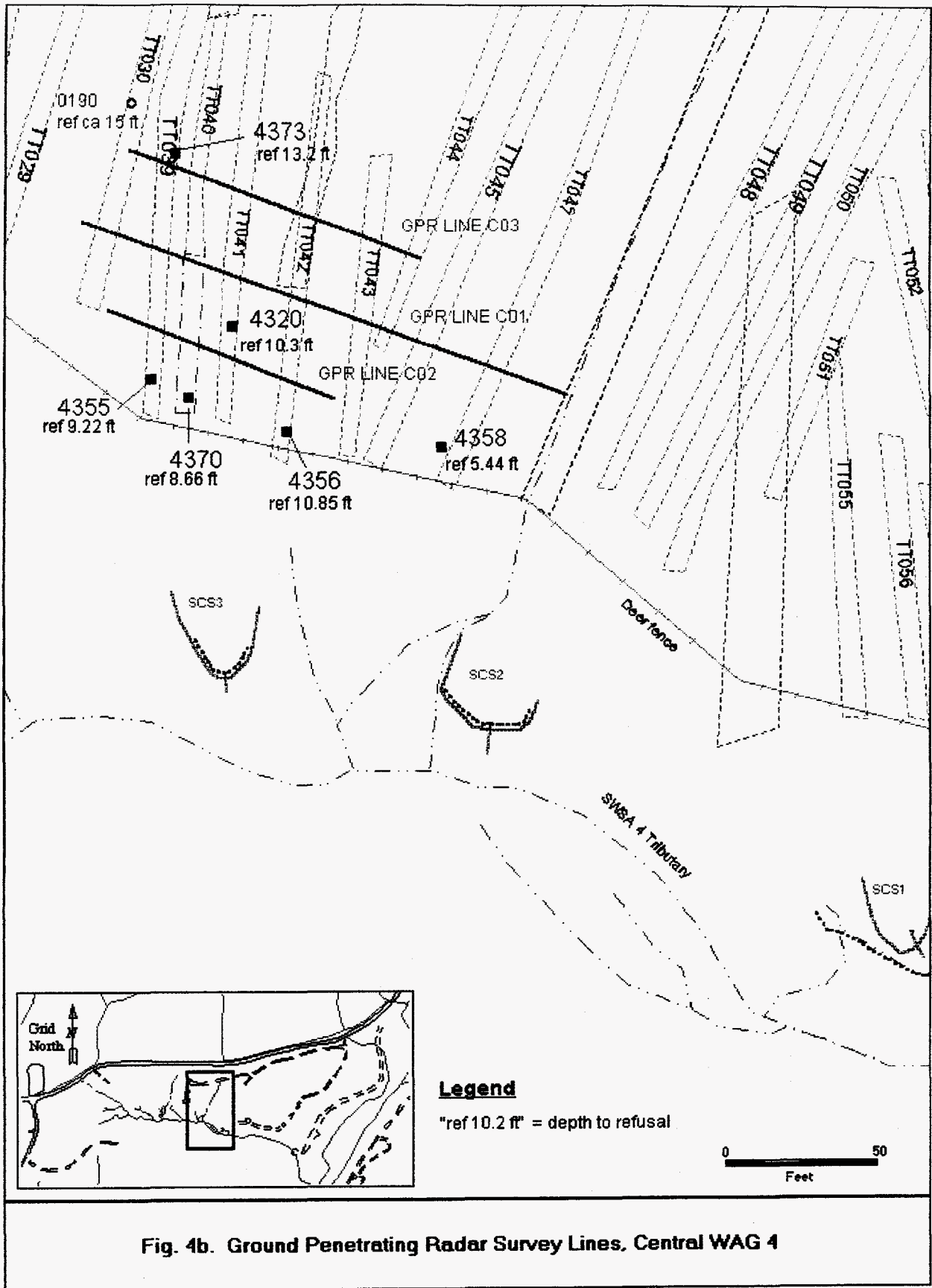Fig 4b. Ground-penetrating radar (GPR) line C03, near the top left of the figure, yielded in the most useful information. This line was collected using a common-depth profiling method, and the results are presented in Fig 5.
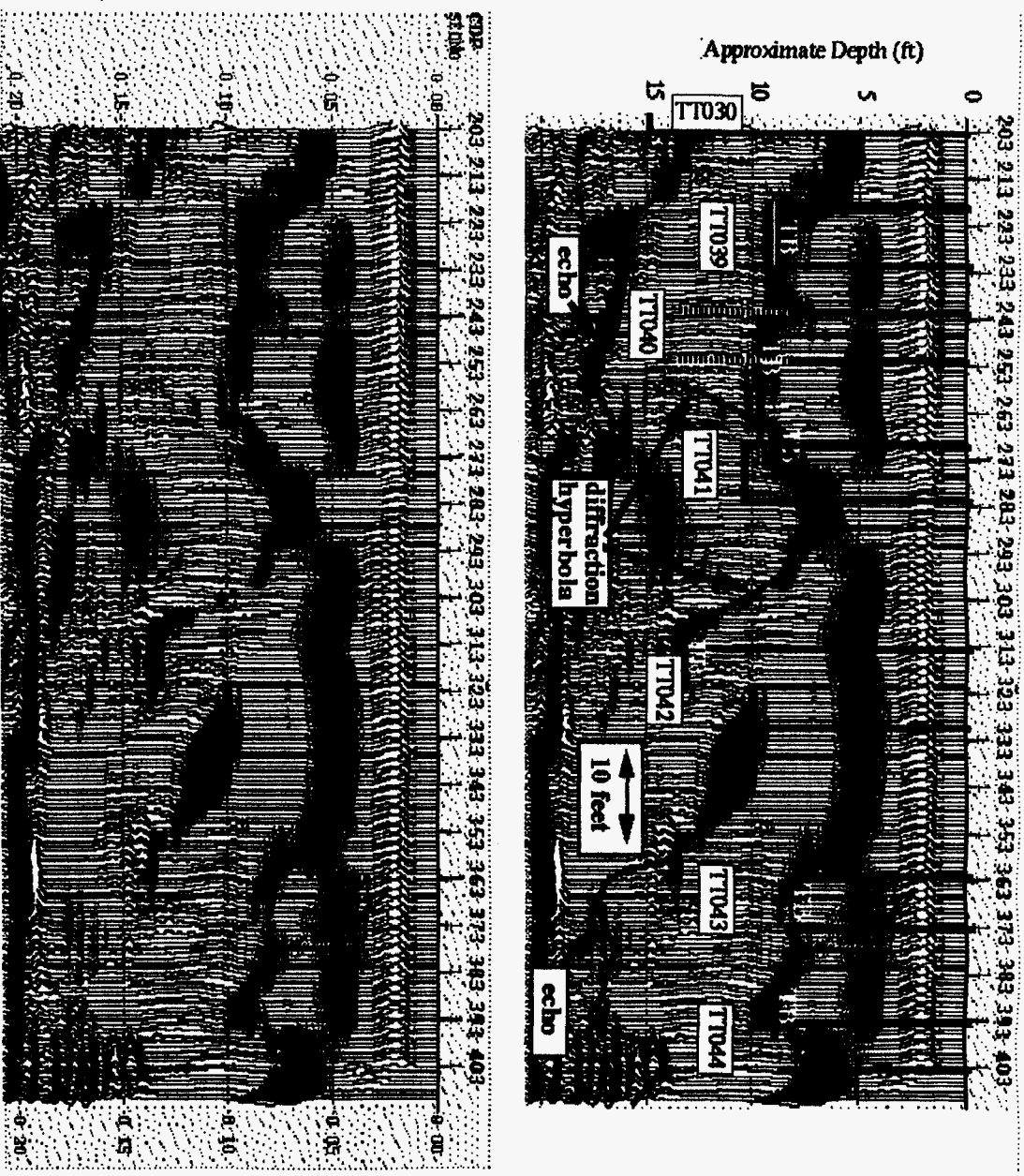
Fig 5. Approximate trench locations and depths superimposed on a common-depth point GPR profile. (TB= interpreted trench bottom). The lower panel is an uninterpreted radar section for comparative purposes.

It appears that common-midpoint acquisition and processing are needed to image trenches. Data acquisition for the image shown in Fig. 5 required about 3 hours in the field and about 3 days of processing afterward. The GPR antennae that were used have a maximum penetration depth of about 15 ft at this site, and therefore will be ineffective where thick fill was deposited over the trenches. Lower-frequency antennae are not a reasonable option, although penetration might be improved slightly by using a more powerful transmitter.

Summary of Remote Sensing Methods Evaluation

Overall, the SERDP map (Fig. 2) appears to be the most generally useful remote sensing product available for this study. It appears to provide more detailed information than the vertical-magnetic-gradient map; however, the combined information from both sources is probably more robust than either one in isolation. For example, where the general orientation of features is the same in both data sets, the magnetic data may help in allowing fine-scale interpretation of the SERDP map, especially when used in concert with other information such as drive point construction data or visual observations in the field. The low-frequency GPR analysis discussed in the preceding section shows promising results, when combined with information from the SERDP map and the vertical-magnetic-gradient data. Because it represents a non-intrusive method, it merits consideration as a tool for detailed trench delineation in conjunction with interim actions on specific trenches. The key to successful application is beginning from a known target and extending to new areas. It should be particularly useful in areas where burial trenches do not contain many metal objects.

Conclusions

Although beyond the scope of this report, it is important to put the remote sensing component of the study into context. Of the six individual seep areas identified, measured releases via the surface pathway at two were responsible for more than 50% of the ^{90}Sr releases during the evaluated periods, even though they contributed only about 10% of the flow volume during the same period. Subsurface pathways apparently contributed the remainder of ^{90}Sr released, and ^{90}Sr concentrations in the stream draining the site suggest the same two seeps are the primary contributors. Upslope from each seep area, one or two apparent source regions were identified. It was possible to isolate four apparent major sources in trenches directly upslope from the two most important contributing seeps. In each case, the ^{90}Sr concentration at the seep was approximately from 35% to 50% of the highest value observed in the upslope trench most likely to be the source. It is believed that control of these few sources is the key to a cost-effective interim action to reduce ^{90}Sr releases and off-site risk. Without the remote sensing results, the ability to quickly and effectively pinpoint the locations of the individual sources would have been lost. The most likely alternative for controlling releases under that scenario has been estimated to cost in excess of $5 million more that an alternative to directly control the sources. Thus it is important to recognize the contribution made through analysis of remotely sensed data. It is not the total answer, but it can be a very important contributor to overall success.

Throughout the project, data were synthesized using a geographic information system, allowing spatial display and interpretation. This was an important element in expediting the investigation and rapid documentation of the results. In particular, it is very important to efficient operations to assure that all data, including that collected by remote sensing, can be organized into a common geographic base and combined for display and interpretation. The WAG 4 investigation is a good example of the use of such an approach.

Citations:

ORNL/ER-329/V1 & V2. "Site Investigation Report for Waste Area Grouping 4 at Oak Ridge National Laboratory." August 1995.

King, A.L., J. L. Smyre, T. K. Evers. "Strategic Environmental Research and Development Project FY 1994: Assessing National Remote Sensing Technologies for use in U.S. Department of Energy Environmental Restoration Activities. Oak Ridge Solid Waste Storage Area Case Study." ORNL/TM-12926, February 1995.