AN AUTOMATED LOCATING AND DATA LOGGING SYSTEM FOR GEOPHYSICAL SURVEYS[1]

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ABSTRACT

Oak Ridge National Laboratory has developed an Ultrasonic Ranging and Data System (USRADS) and interfaced the system with a Geonics EM31 terrain conductivity meter. USRADS keeps track of a surveyor's position by measuring the time-of-flight of ultrasonic pulses from an transducer carried by the surveyor in a backpack to stationary receivers arrayed over the survey area. Also built into the backpack is a radio transmitter that sends the EM31 data to a base station (van or truck) where the surveyor's position and the EM31 quadrature and inphase data are automatically recorded once a second on a portable computer. We surveyed a 13-acre landfill at Idaho National Engineering Laboratory with three people, in three days, collecting over 25,000 EM31 quadrature and inphase readings. At a normal walking pace the average distance between measurement points along the surveyor's path was about 2 ft, with an overall positioning precision of about 0.5 ft for each point. USRADS offers several advantages over conventional EM31 surveys: (1) time and money are saved because it does not require a civil survey to lay a grid before the geophysical survey begins, (2) data are directly recorded by a portable computer and are available for analysis in the field, and (3) refining or expanding the grid about an anomaly does not require civil surveying to add extra grid points. USRADS can also be used with a gamma scintillometer for radiation surveys. Currently, we are working to interface USRADS with a portable X-ray fluorescence spectrometer for detecting heavy metals in soil.

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INTRODUCTION

How often are you faced with the following dilemma? Before a single geophysical measurement can be made, before a single soil sample can be collected, a measurement grid must be established. You have to decide how big an area will be surveyed and how closely the measurements will be spaced, but you know only roughly the area where the drums are buried or the contaminants are migrating. If you design a survey grid that is too large, or with measurement points too closely spaced -- you waste time and money. If you design a survey grid that is too small, or with measurement points too widely spaced -- you risk missing the target entirely, or having to make a second trip to the field. So you compromise, designing a grid with the largest, most complete coverage that your schedule and budget permit, perhaps returning to make additional measurements if an unexpected anomaly is discovered during data processing. What is needed is a flexible grid, a way to monitor the data in the field, to take additional measurements when there are departures from background, and to take measurements outside the original survey area if the anomalous readings continue.

As part of the Department of Energy's Uranium Mill Tailings Remedial Action Project (UMTRAP), ORNL was asked to survey, in three years, 8,000 properties where the presence of uranium mill tailings was suspected. A property survey consists of one or more technicians walking over the area with a gamma scintillometer, the NaI probe crystal swung in an arc a few inches about the ground. Areas with high gamma reading are noted for subsequent soil sampling and analysis. To save time and money ORNL developed an Ultrasonic Ranging and Data System (USRADS) to automatically keep track of the technician's location, and to log the scintillometer readings.

Figure 1 illustrates the operation of the system. The technician's position is calculated using travel times from an ultrasonic crystal carried in a backpack to a number of stationary receivers. Once per second the USRADS backpack pulses the ultrasonic crystal and radios the scintillometer reading to the master receiver. The stationary receivers radio the master receiver whenever they detect an ultrasonic pulse. The ultrasonic travel times are the delays recorded by the master receiver between the backpack signal and the signal from each of the stationary receivers. A portable computer connected to the master receiver records the scintillometer reading and calculates the backpack crystal's location from the travel times. Thus both the position and instrument reading a record automatically.

In the last year we have adapted the system to work with the Geonics EM31 terrain conductivity meter, collecting both the quadrature and inphase data simultaneously (McNeil, 1980a,b; McNeil 1983). Currently we are working to interface USRADS with a portable x-ray fluorescence (XRF) analyzer used to measure the levels of lead, arsenic, and other heavy metals in soil (Raab et al., 1989). In the following sections we describe USRADS in greater detail and present two case studies using USRADS with an EM31, and briefly describe our current work combining USRADS with a XRF analyzer.

USRADS

Hardware

USRADS consists of one surveyor's backpack, fifteen stationary receivers, a master receiver, custom computer interface and counter timer module, a Compaq Portable II personal computer, and a small trailer or a van to transport this equipment (Figure 2). The backpack contains the interface circuitry to receive the signal from the field instrument (EM31, scintillometer, XRF analyzer), an ultrasonic transmitter and radio frequency equipment to establish two-way communications with a computer mounted in the trailer. The ultrasonic transmitter is a lead-zirconate-titanate crystal in the form of a circular cylinder with a hollow core. The crystal dimensions are 2.2 in. in diameter and 1.445 in. in height. This crystalline material and its dimension result in a natural resonance frequency of 19.5 kHz. The crystal is pulsed for 10 msec each second as the data from the portable survey instrument are transmitted to the computer via the radio telemetry link. If the computer detects any problems, either with the data or in determining the surveyor's location, a message is transmitted to the surveyor and displayed on the handheld terminal to alert the surveyor of the malfunction. The backpack can be operated for a normal eight-hour day from a rechargeable gel-cell.

The stationary receivers contain an ultrasonic receiver and a radio transmitter. The dimensions of the metal box that houses the ultrasonic receiver card, transmitter card, and rechargeable gel-cell battery pack are 10x10x15 cm. Each stationary receiver has a unique radio frequency so that the master receiver can identify which stationary receivers heard an ultrasonic signal. The master receiver therefore contains 15 radio receivers, one for each stationary receiver, and a receiver and transmitter for communication with the backpack. Both the master receiver and the computer are powered by a gasoline-operated generator also carried in the trailer.

Software

If available, a digitized schematic drawing of the property can be stored in the computer prior to the survey using AutoCAD. The survey data are added to this information. The property schematic is displayed on the computer's monitor. As the surveyor traverses the property, his past and present position are displayed to denote the completeness of coverage by the surveyor. During the survey, the software checks incoming information and alerts the surveyor (via the backpack terminal) if errors are detected either in the survey data or position data. All data are stored on the hard disk every 30 seconds.

Analysis of the data in the field is a major advantage of USRADS over conventional geophysical surveys. Any commercial PC software package can be used in the field for data analysis. Or the operator can use a number of routines that are part of USRADS to ensure sufficient data is obtained to characterize the property before leaving the site. The graphics routines included in USRADS are Replay, Block Statistics, Contour, and 3-D plots of the data. The Replay program will generate the same display that the surveyor viewed when the survey of the property was completed. The data are replayed in the same order as the data were taken. The Block Statistics routine enables the operator to select a grid block size and have the data analyzed for each block. If the mean of the data for a particular grid block is greater than the operator-entered threshold, then that block is highlighted on the CRT, and the statistical information for that grid block are stored in the summary report. By indicating preset thresholds, anomalous areas can be identified and vital statistics can be calculated (area, number of measurements, measurement range, average and standard deviation). Graphical representations are made in two- and three-dimensional display. The Contour routine generates a summary report and outlines the areas that exceeded the user input threshold.

Setup

The system setup takes about half an hour for a one-acre site. Up to 15 stationary ultrasonic receivers are positioned such that the surveyor is in range (about 200 ft) of at least three of the stationary receivers from any location on the property. The operator then places an ultrasonic transmitter (the "top hat") on one of the stationary receivers and the travel time to each of the other stationary receivers is recorded by the system. The top hat moved to the next stationary receiver and the process repeated until a matrix of travel times between all the receivers is complete. Only one distance measurement between any two of the stationary receivers is required to calculate the local speed of sound (which depend on temperature and elevation) and calculate the relative positions of the remaining stationary receivers. Note that the travel time matrix contains redundant information. For example, the system records the travel time from receiver 6 to receiver 9 as well as the travel time from receiver 9 to receiver 6. This redundancy is used to check that all the receivers are functioning properly.

Operation

A minimum of two people are required to operate USRADS. One walks the property with the geophysical instrument (Figure 3) while his position and instrument's readings are automatically recorded by USRADS; the other operates a portable computer that analyzes the data as it is coming in and tells the EM31 operator where additional coverage is needed. The EM31 operator generally walks a free-form rectangular grid over the area, perhaps pausing to collect extra data if suggested by the EM31 readings.

CASE HISTORY: CHECKING STATION

Background

The Tennessee Wildlife Resources Department operates a checking station near the Oak Ridge Reservation where hunters who hunt on the reservation bring deer to be tested for radionuclide contamination. The checking station is little more than a farm house with gravel road leading to and from a nearby highway. We chose this site for our initial tests of the USRADS/EM31 combination because it is close to the laboratory, and devoid of power lines, steel fences, and other objects that might interfere with the EM31.

Procedure

Figure 4 is a screen dump of the what the computer operator saw during the survey (with annotations added) and illustrates a number of points. First, once the setup is complete, USRADS software plots the receiver locations and a set of axes scaled to encompass the receiver spread. But the position and instrument readings are still recorded if the technician walks outside the spread as long as he remains within 200 ft of three of the receivers. Second, with the EM31 disconnected, USRADS can be used as a simple tracking device to map features of interest (e.g. the gravel road) instead of relying solely on hand sketched field drawings. Third, as the EM31 operator walks his position is plotted once per second on the computer screen: as a dot if the EM31 reading is below a preset threshold, and as a block if it exceeds the threshold. During the survey at the checking station, for example, we saw an anomaly parallel to one leg of the gravel road, probably a buried water or sewage line, so the block highlighting proved useful. Finally, notice the how closely spaced the measurements are along a given traverse (about 2 ft at a normal walking pace).

Results and Discussion

With the final track map superimposed on the contoured data (Figure 5) it is clear that an anomaly is associated with both loops of the road, but is much stronger for the southern loop (about 50 ft on the y-axis). A 3D plot of the data (Figure 6) shows that the road is less conductive than the surrounding soil, plotting as a valley on the 3D plot, but that this negative anomaly is superimposed on a strong positive anomaly created by the buried utility (presumably) next to the southern loop (These plots were created using Surfer by Golden Graphics.)

As part of this test we deliberately walked beyond the range of the receivers, and at about -100 ft (Figure 5) the track starts to break up, but USRADS successfully locks back onto the backpack when the EM31 operator comes back into range. During this early test we also noticed that occasionally USRADS drops out or incorrectly locates a point. We have since improved the system and this occurs less often, plus we have added a simple data filter that strips out points where the EM31 operator has apparently teleported.

CASE HISTORY: IDAHO NATIONAL ENGINEERING LABORATORY

Background

In June, 1989, a crew from Oak Ridge National Laboratory (ORNL) performed a terrain conductivity survey of the Central Facilities Area II (CFA II) landfill at Idaho National Engineering Laboratory (INEL). The purpose of the survey was twofold: First, we wanted to provide INEL staff with a detailed map of the spatial variation of apparent electrical conductivity of the landfill. This map can be used to determine the landfill boundaries and identify any large metal objects within the landfill. Second, we wanted to demonstrate the advantages of the USRADS technology at a Hazardous Waste Remedial Action Program (HAZWRAP) site.

The CFA II landfill was the primary landfill for INEL from 1972 to 1982. The landfill is located on poorly sorted sand and gravel alluvium deposited by the Big Lost River. Lithologic logs from boreholes in the landfill show alluvium ranging from 25 to 30 ft thick (Wood et al., 1989). A series of basalt flows and interbedded sediments at least 2000 ft thick underlie the alluvium. The landfill is an old gravel pit progressively filled by bulldozers pushing lumber, construction debris, asphalt, asbestos, cafeteria waste, and virtually all other non-radioactive waste produced at INEL during these years into the pit, and covering the waste with roughly 3 to 4 feet of dirt and seeded with grass to prevent waste from blowing away. The waste pit is up to 30 feet deep in some areas, the trash resting directly on the fractured basalt bedrock. In other areas there is a layer of native soil between waste and bedrock.

Procedure

The rule of thumb is to place the receivers where the surveyor will always be within 200 ft of at least two of them. With USRADS up to 15 receivers can be deployed, so a single setup can provide coverage over several acres. We encountered strong winds, however, and had to decrease the setup size to one acre. For one-acre blocks we were able to track the surveyor reliably, even in winds that were occasionally blowing over the heavy wooden tripods used to support the stationary receivers (gusts over 50 mph).

The choice of a one-acre units also made it easy to tie our setups to metal signposts at CFA II which were spaced at 100 ft interval over much of the site. The INEL grid coordinates for these signposts have not yet been determined, so to tie our setup to the INEL grid we place receivers, when possible, over the steel pins that mark the grid reference points for the monitoring wells at the site. A total of 13 one-acre setups were required to cover CFA II, and we collected a total of over 25,000 data pairs (quadrature and inphase measurements) in three days.

A track map (Figure 7) shows the locations of these data and shows the coverage. The surveyor's path meanders slightly; a consequence of walking a rectangular grid in the absence of survey markers. The coverage is so dense, however, that there are no large data gaps. The coverage does not extend to the northern border of the pit as shown in Figure 7 because this encompasses the edge of the backfilled area and part of the unfilled pit, whereas we stopped our traverses at the top edge of the fill.

Results and Discussion

The data was gridded and contoured using the program Surfer (Golden Software) on a 5 ft grid spacing using a kriging algorithm to perform the interpolation, and assuming a linear variogram. Usually the choice of interpolation algorithm has a strong affect on the results, but with USRADS the data coverage is so tight, and the interpolation distances so small (generally 5 ft or less), that kriging, inverse distance squared, and linear interpolation, all yield similar contours.

The quadrature data (Figure 8) shows a wide distribution of anomaly sizes and shapes -- not surprising for a landfill (the rectangular "holes" in the plots are areas where there was no data within 15 ft, th search radius using in the interpolation). There is probably a slight difference between the electrical conductivity of the landfill soil and the surrounding undisturbed soil, but undoubtedly all of the anomalies greater than a few mmhos/m were created by buried metal objects. The 15 mmho/m contour on the quadrature data (background was steady 11 mmhos/m) was selected as the landfill boundary.

CONCLUSIONS

USRADS offers geophysicists a number of advantages. For the geophysicist in the field, chief among these is the ability to monitor data as it is being collected and to refine or expand the survey coverage as he or she feels is required. For the interpreter is it generally a case of the more data the better, and USRADS delivers data -- 3600 measurements an hour -- available on computer, and easily linked with data files containing the locations of roads, fences, storm drains, or other objects that might affect the interpretation.

CURRENT EFFORTS AND FUTURE WORK

All field measurements involve positioning and data logging, so USRADS has many potential field applications. Currently we are completing work for the Environmental Protection Agency to link USRADS with a portable XRF analyzer. Several papers on the applications of portable XRF surveying are included in this volume. USRADS offers the advantage not just of positioning data, but also allowing the entire XRF spectrum to be stored for each measurement, and not just the metal assays. With the whole spectrum it will be possible to reanalyze the data using different models for soil moisture, mineral content, etc. Anticipating future applications, we have made the hardware and software changes to the system as general as possible. Linking USRADS with a portable magnetometer, or very low frequency (VLF) detector are two application we are currently considering.

ACKNOWLEDGEMENTS

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LOCATING THE USRADS SURVEYOR BY TRIANGULATION

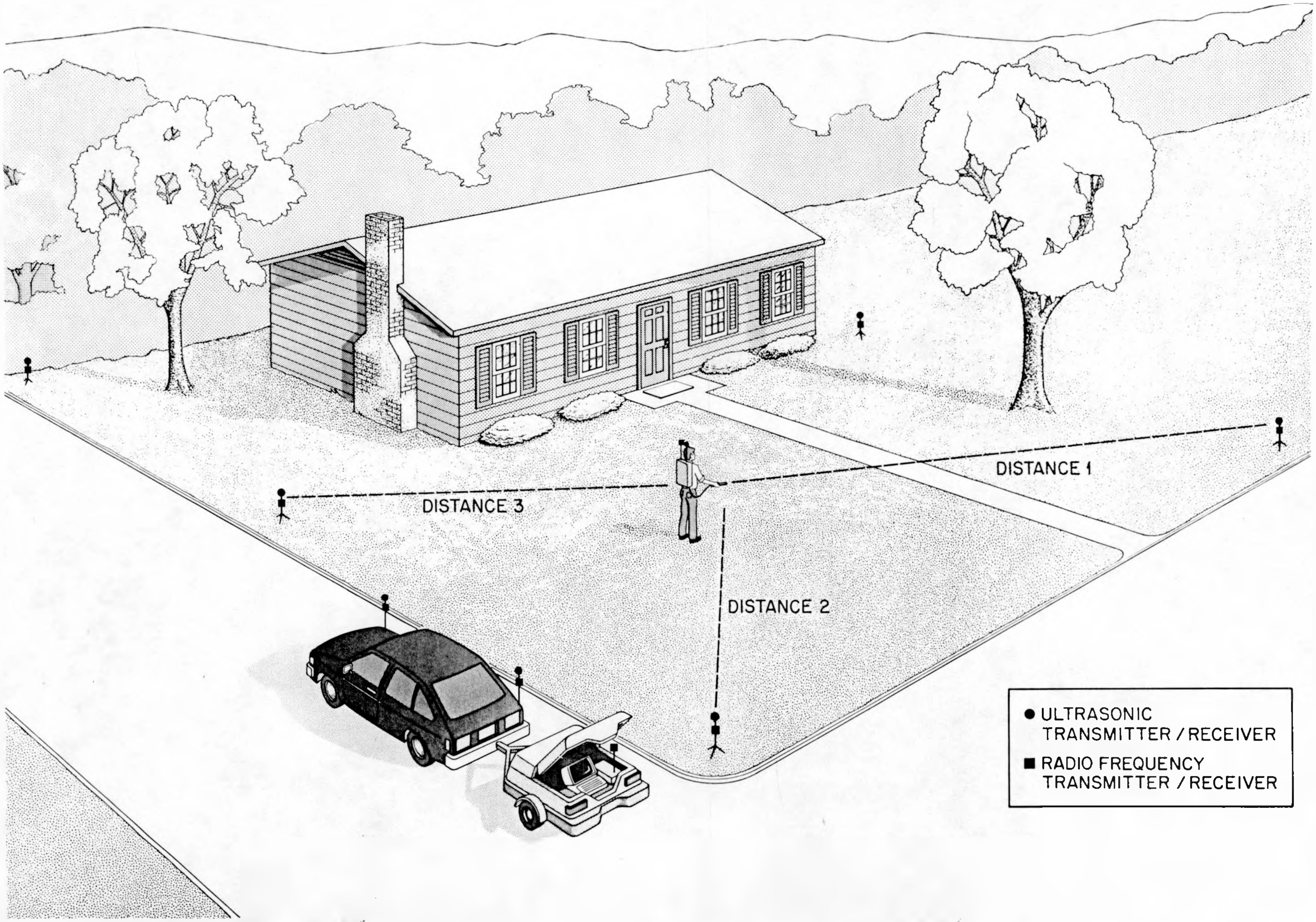

Figure 1. USRADS locates the surveyor using ultrasonics.

Figure 2. USRADS/EM31: Compaq Portable II computer, master receiver, stationary receivers (on truck tailgate); backpack and handheld terminal (being adjusted); EM31 terrain conductivity meter (on ground).

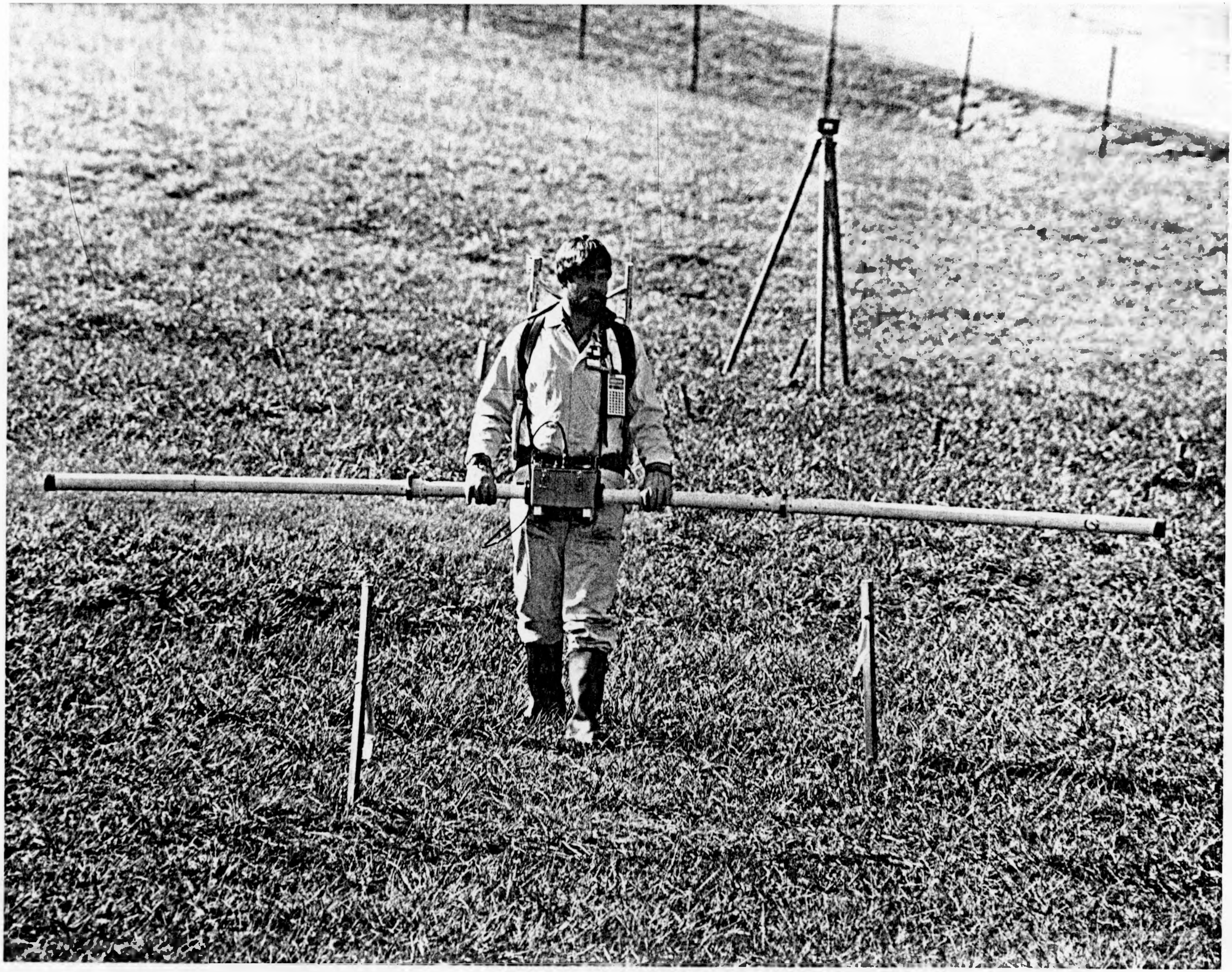

Figure 3. USRADS/EM31 survey in progress. Stationary receiver mounted on tripod in background.

SCREEN DUMP

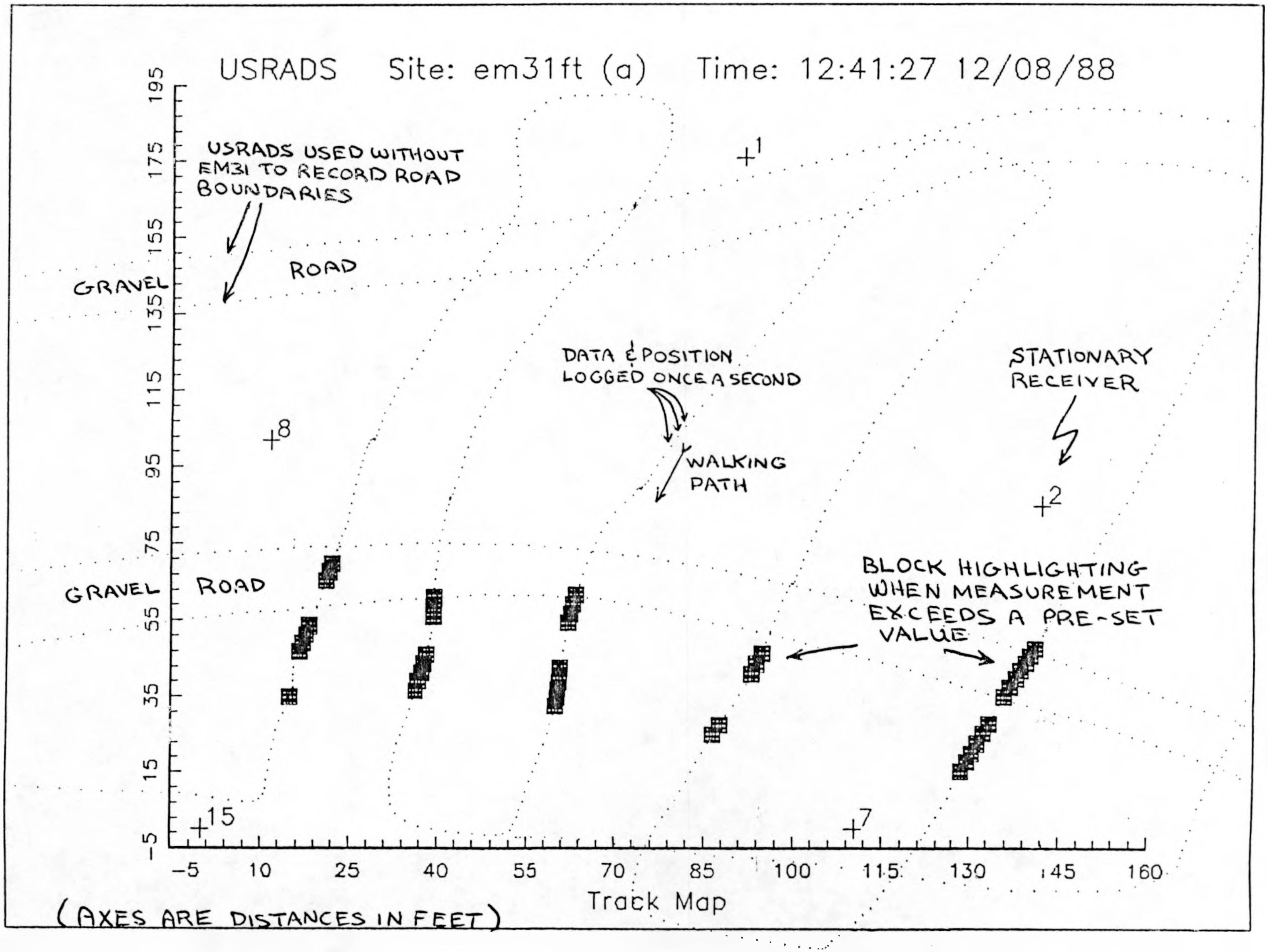

Figure 4.

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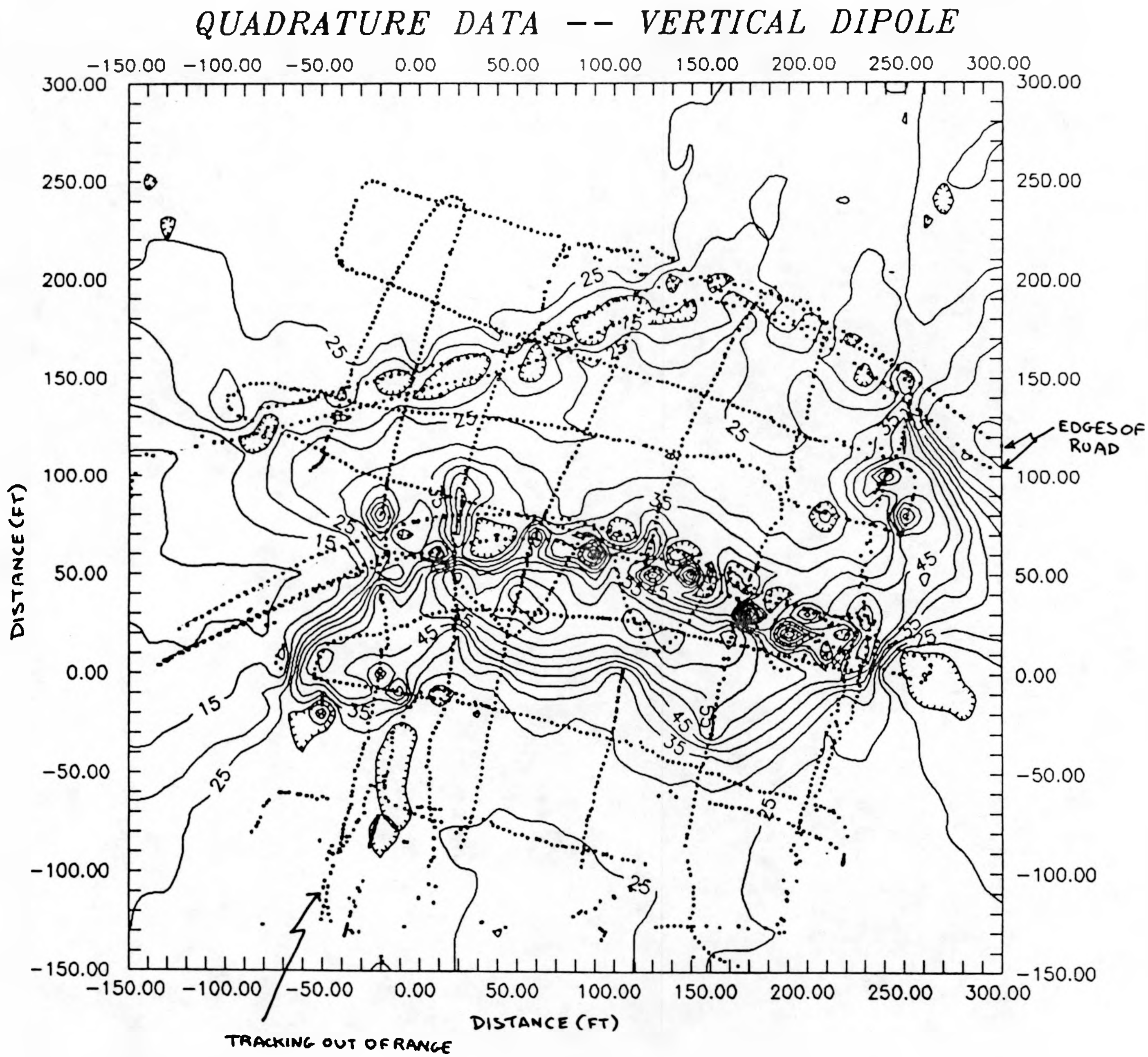

Figure 5.

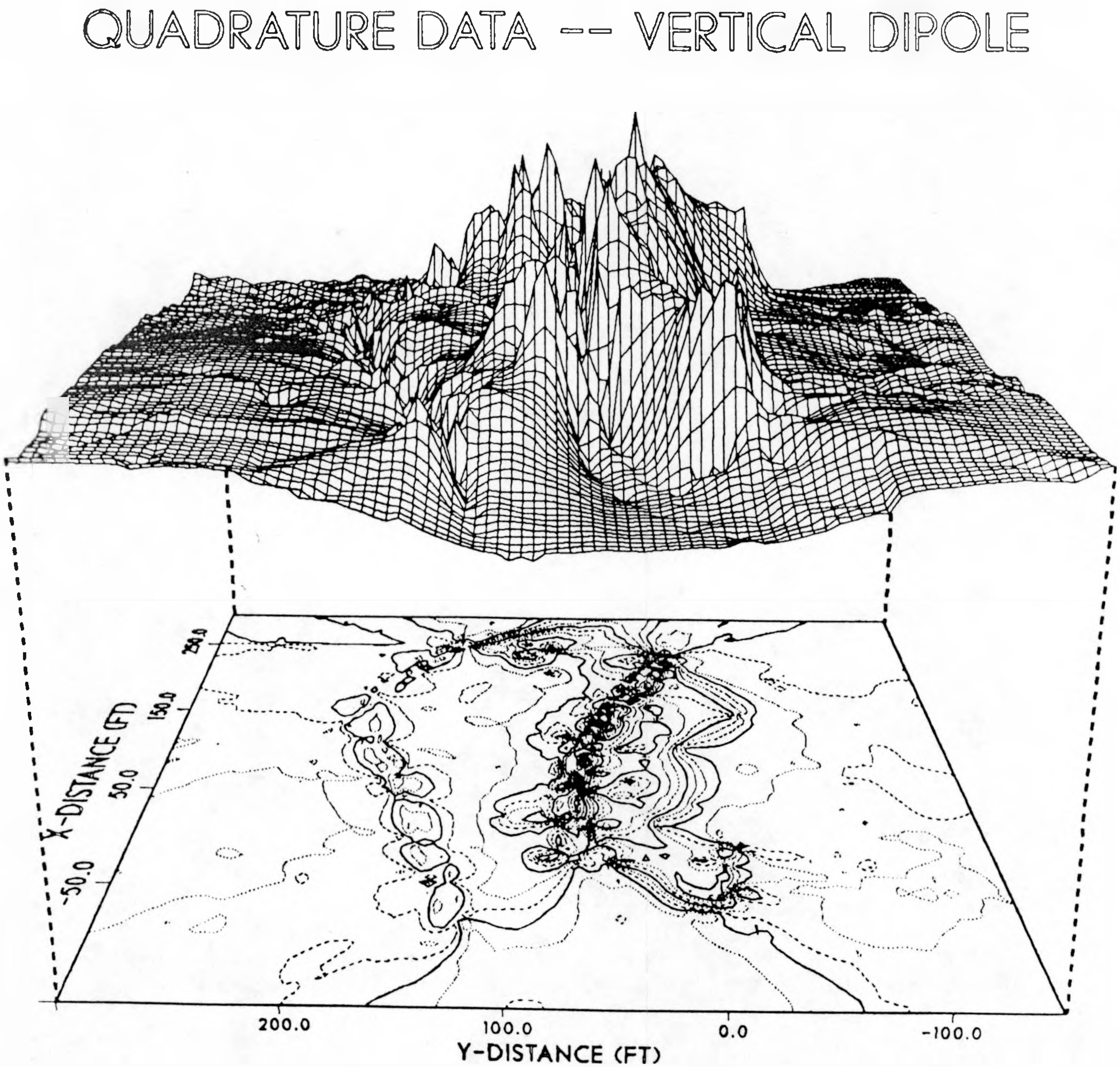
QUADRATURE DATA -- VERTICAL DIPOLE
X-DISTANCE (FT)
250.0
150.0
50.0
-50.0
200.0
100.0
0.0
-100.0
Y-DISTANCE (FT)

Figure 6.

Figure 7. Survey walking path recorded by USRADS; each dot represents a measurement point.

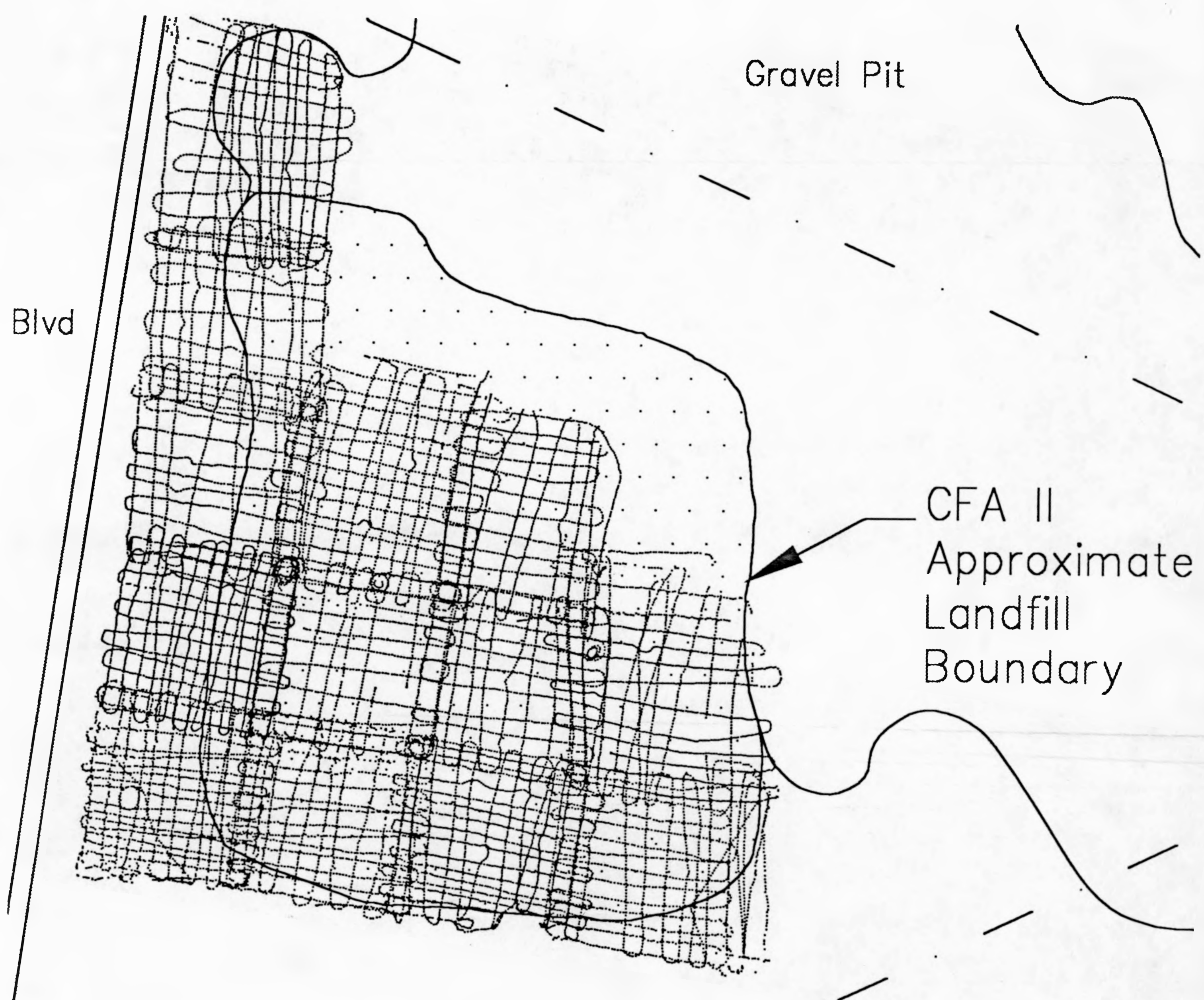

FIGURE 8. CFA II EM31/USRADS
QUADRATURE DATA (MMHOS/M)