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High Performance Ground Penetrating Radar Survey of TA-49/Area 2 Final Report

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HIGH PERFORMANCE GROUND PENETRATING RADAR SURVEY OF TA-49/AREA 2 FINAL REPORT

by

Robert F. Hoeberling and Manuel J. Rangel, III

ABSTRACT

The results of high performance ground penetrating radar study of Area 2 at Technical Area 49 are presented. The survey was commissioned as part of Los Alamos National Laboratory's continuing Environmental Remediation program and was completed and analyzed before borehole studies in AREA 2 were started. Based upon the ground penetrating radar results, the location of one of the planned boreholes was moved to assure the drilling area was as safe as possible. While earlier attempts to use commercial radar devices at this facility had not been successful, the radar and digital processing system developed at Los Alamos were able to significantly improve the buried physical detail of the site.

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1. INTRODUCTION

The use of ground-penetrating radar (GPR) for geological purposes has been considered for the last two decades. Increased technology for the radar equipment and the on-site computation makes new applications feasible. This article describes the present status of the GPR technology and indicates the exciting possibilities for near-term prototypes now being constructed. The Environmental Remediation (ER) program recognized the need for a versatile GPR that could identify buried objects and underground voids. Unfortunately, the available GPR units have proved unsatisfactory for many field applications. Minimal depth of soil penetration at present burial sites, insufficient resolution to identify buried objects, and minimal image reconstruction capability contribute to unsuccessful surveys.

The Department of Energy's (DOE) ER program has identified ground-penetrating radar as a high-value technology to support the cleanup effort. ER needs a non-intrusive system for locating and characterizing buried, hazardous waste. The system must not only register the presence of wastes, but must, within the physical limits of the technology employed, identify the buried container or waste and give indication of its physical condition, i.e. is it leaking or crushed?.

Most ER activities require imaging relatively small objects buried at shallow depths. Several geophysical techniques, including GPR, will sense the presence of metallic objects. Geophysical techniques include magnetic and controlled-source electromagnetic techniques using a towed array or a borehole protocol. Natural electromagnetic source techniques operate at too low a frequency to resolve such shallow objects and gravity techniques are not viable because of the small mass of

the targets. Standard seismic techniques will not work because they are designed for much lower frequencies, that can only sense very large objects. Therefore, GPR is the preferred technique that can achieve high resolution object identification because of the high-frequency, broad-band transmitted signal.

AOT-9 specifically designed a High-Performance Ground-Penetrating Radar (HIPERGPR) system for ER applications. HIPERGPR can have a significant, beneficial impact on several critical ER areas, such as wide-area field surveys and non invasive subsurface characterization. The goal of the AOT-9 development program is to ensure satisfactory HIPERGPR performance not only in benign environments, but also in the more difficult ER environments daily encountered in field applications. Using the HIPERGPR for non-intrusive ER, requires that the system be optimized for the best transmitted wave form. The system requires digitally filterable, return-signal processing to improve buried target imaging and must provide user friendly display readout. These improvements will provide the ER program with, a compact system that is significantly more useful than currently available equipment. A DOE Cooperative Research and Development Agreement with Analysis Programming Processing Instrumentation (APPI) Company provides the means for perfecting the HIPERGPR.

2. DESCRIPTION OF THE HIPERGPR SYSTEM

The nuclear weapons effects program has long supported the development of very high-powered, fast rise-time pulsers and the expensive diagnostic suites to demonstrate electronic damage to military weapons systems. These newly developed technologies suggest a solution to the subsurface mapping problem that combines the benefits of both broad-band sensor operating frequencies with significantly higher peak power. The HIPERGPR has the ability to operate simultaneously over frequencies from 100 MHz to 2 GHz at a level of 2 MW peak power. HIPERGPR's higher peak power increases the penetration depth. The high frequency spectral content ensures accurate identification of small objects deeper than previously accessible with commercial hardware. HIPERGPR provides better spatial resolution of buried-object detail. Identifying small buried objects requires the extended high-frequency spectral content of HIPERGPR. The higher the frequency content of the transmitted pulse, the better the spatial resolution. Simultaneously achieving both high-spatial resolution and more penetration depth requires a significant increase in the peak transmitted power; HIPERGPR has been specifically designed and built to provide the required peak transmitted power. Figure 1 shows the main components for the present system. Separate transmit and receive antennas allow for better resolution of deeply buried objects. The return-signal processing was designed to be flexible enough to allow future image-processing improvements.

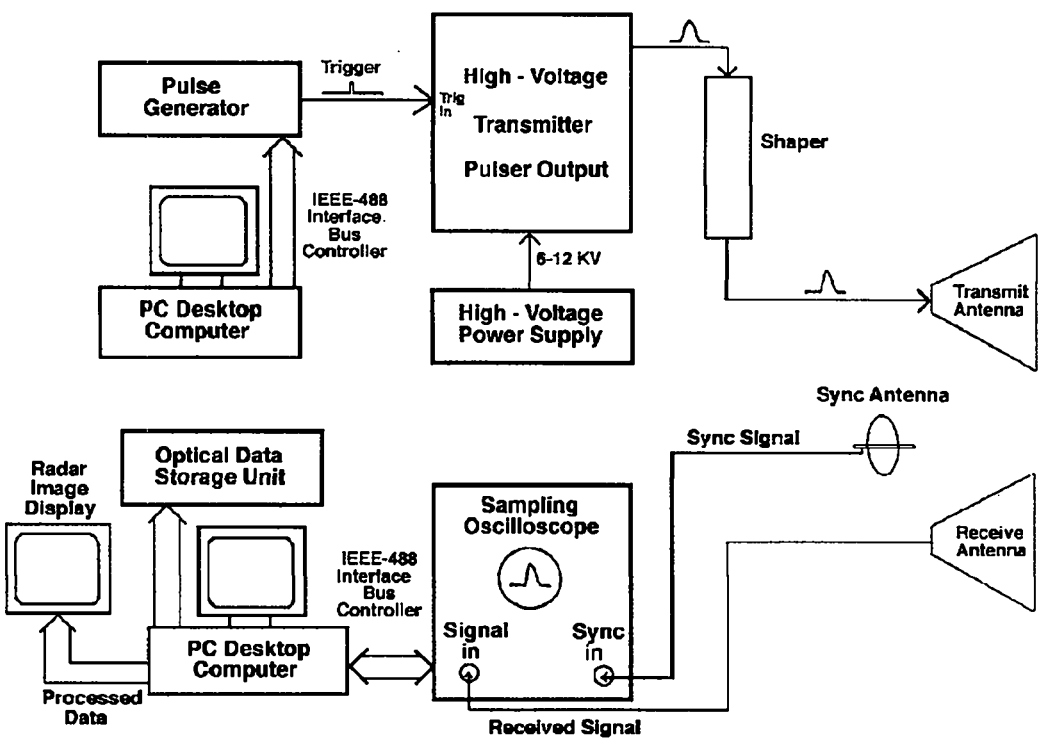

Fig. 1. HIPERGPR system.

Table 1 contains the typical media attenuation factors and penetration depths for the currently available commercial technology and for the completed HIPERGPR. AOT-9's major remaining task is to finish the data-processing algorithms to assist a non-technical operator in establishing critical subsurface returns.

The useful penetration depth, as compared with conventional GPR, can be increased by up to a factor of twelve. In field tests, HIPERGPR has improved the survey depth by a factor of six compared to commercial units and will significantly improve Los Alamos National Laboratory's (LANL) ongoing remediation efforts at Technical Area (TA)-49.

Table 1 - Media Attenuation and Comparative Penetration Depths

	Attenuation	Penetration Depths	
Media	**dB/m**	**L(m)present**	**L(m)HIPERGPR**
Fresh Water	0.18	20.0	240.0
Dry Soil	0.44	14.0	105.0
Wet Soil	1.93	6.0	27.0
Wet Clay	12.6	1.4	4.6
Salt Water	100.0	0.3	0.7

An instrumentation van houses the prototype HIPERGPR system. The HIPERGPR equipment is shown in Fig. 2. The final HIPERGPR system will be packaged into a compact unit where the versatility of a mobile instrumentation data-processing laboratory is not required. Presently, the $0.2m^3$ high-voltage pulser and power supply are rack mounted.

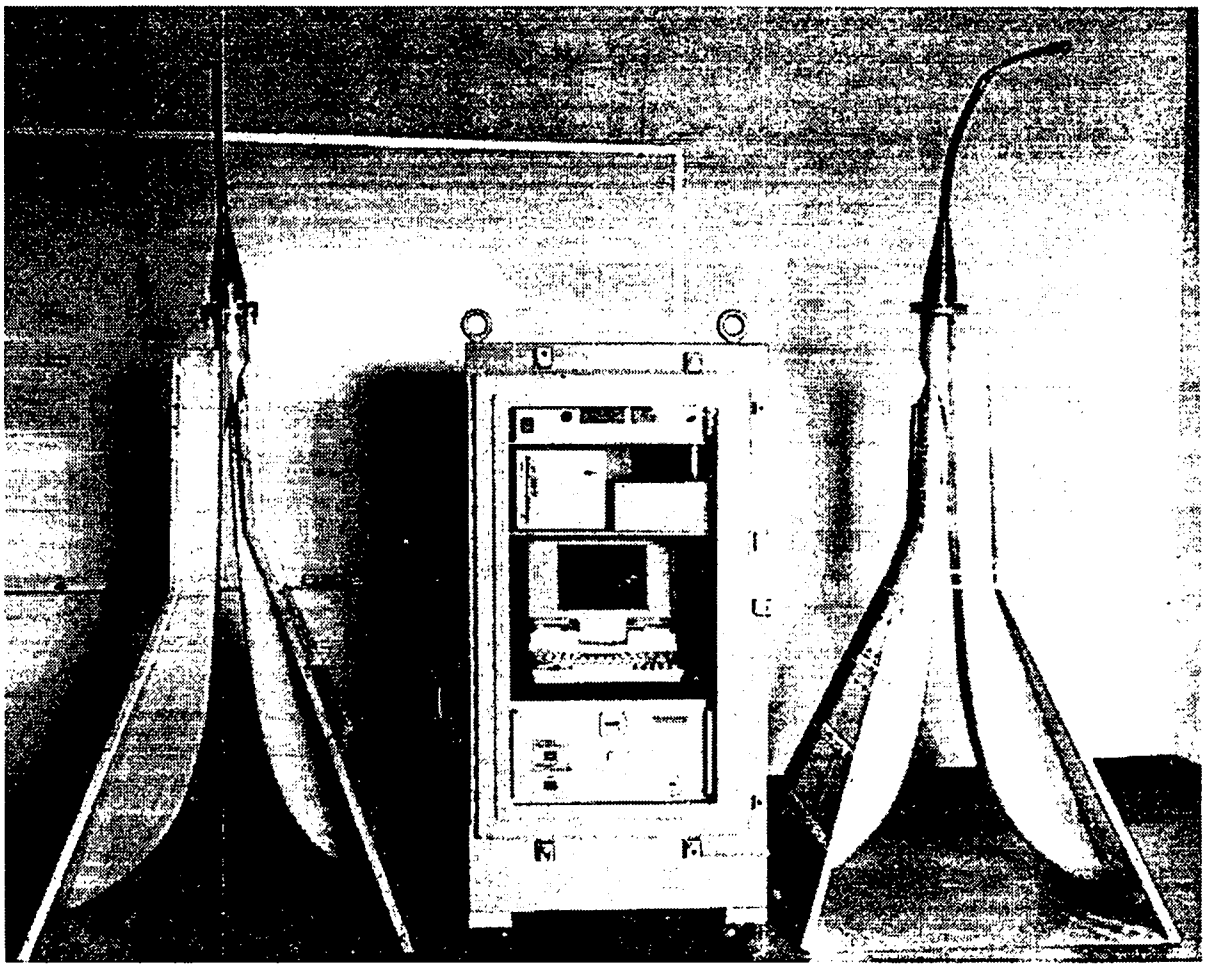

Fig. 2. The HIPERGPR unit.

AOT-9 evaluated several commercial GPR systems for application to the ER problem. Several GPR systems are available, and all were used during the survey to characterize the area. Some units are well designed and have potential for satisfying many of the ER requirements for shallow applications; however, the units require additional development. The commercial units can be used in several configurations that provide a low-power pulse at a fixed set of center frequencies.

The HIPERGPR and commercially available systems use the same principles for transmission. However, one significant difference is that the HIPERGPR transmits a pulse of 6,000 times higher power and punches through the opacity problem. The HIPERGPR also uses significantly improved image-processing algorithms to aid the field operator.

3. SCOPE OF WORK

The Solid Waste Management Unit, identified as Area 2 is located within the interior fenced area of TA-49. AOT-9 conducted a subsurface survey to search for underground features that would interfere with drilling six boreholes to monitor the areas.

The GPR survey needed to verify that the six planned borehole locations were clear of subsurface structures that might indicate undocumented, contaminated areas. The survey also needed to map the area without disturbing the buried, contaminated materials and to verify the subsurface features of the large diameter, back filled boreholes discussed in the next section. The site contains several 6 ft. diameter boreholes that were used from 1959-1961 for hydronuclear testing and later for burying contaminated materials. The original test area was then covered with 4 ft. of clay and one foot of protective asphalt. The disturbed soils placed over the test area complicated the problem of pattern recognition from the ground-penetrating radar returns. The asphalt covering was designed to form a protective cap for the area and removed all of the surface features associated with the large boreholes. The survey site area was approximately 15,000 sq. ft. The GPR surveyors referenced area plots to existing landmarks - the major one being a logging hole, identified as core hole #2, approximately in the center of the asphalt pad.

4. DESCRIPTION OF AREA 2 AT TA-49

The survey site is located north of State Route 4 on the southern boundary of Water Canyon. Areas 2 and 2A are at the top right corner of the photograph. Figure 3 is 1965 aerial view that shows the TA-49 main work areas. A significant series of hydronuclear tests had been done from 1959 to 1961. By 1965, the experimental program was finished and Area 2 had been cleared and covered with a rectangular asphalt pad. The work area had comprised a large series of shafts that were bored 50 - 120 ft deep and represented the remains of an experimental area where subsurface hydronuclear experiments took place. Hazardous and radioactive materials, including multikilogram quantities of beryllium, lead, plutonium, and uranium remain in the TA-49 shafts. Trace quantities of fission products, heavy metals, tritium, high explosives, and organics were also buried. The experimental effort used totals of ~40 kg of plutonium, 93 kg of enriched uranium, and at least 82 kg of depleted uranium.

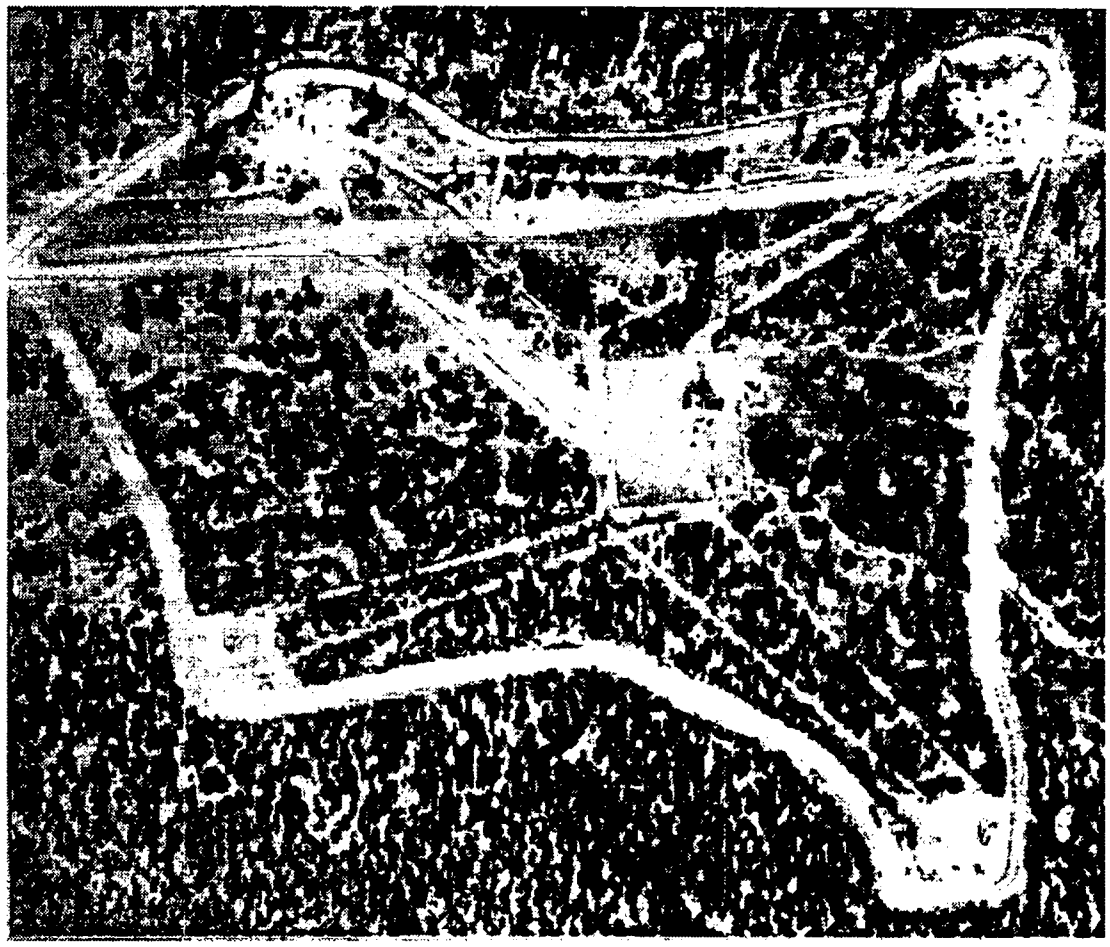

Fig. 3. Aerial view of TA-49, including Areas 2 and 2A.

The TA-49 shafts are now being monitored for local geological changes. The six new boreholes are needed to monitor the area. Four are planned to be 10 ft and the other two are planned to be 150 ft deep (Fig. 4). A 700 ft deep borehole drilling nearby Area 2 is completed and the additional borehole drillings began in February 1994.

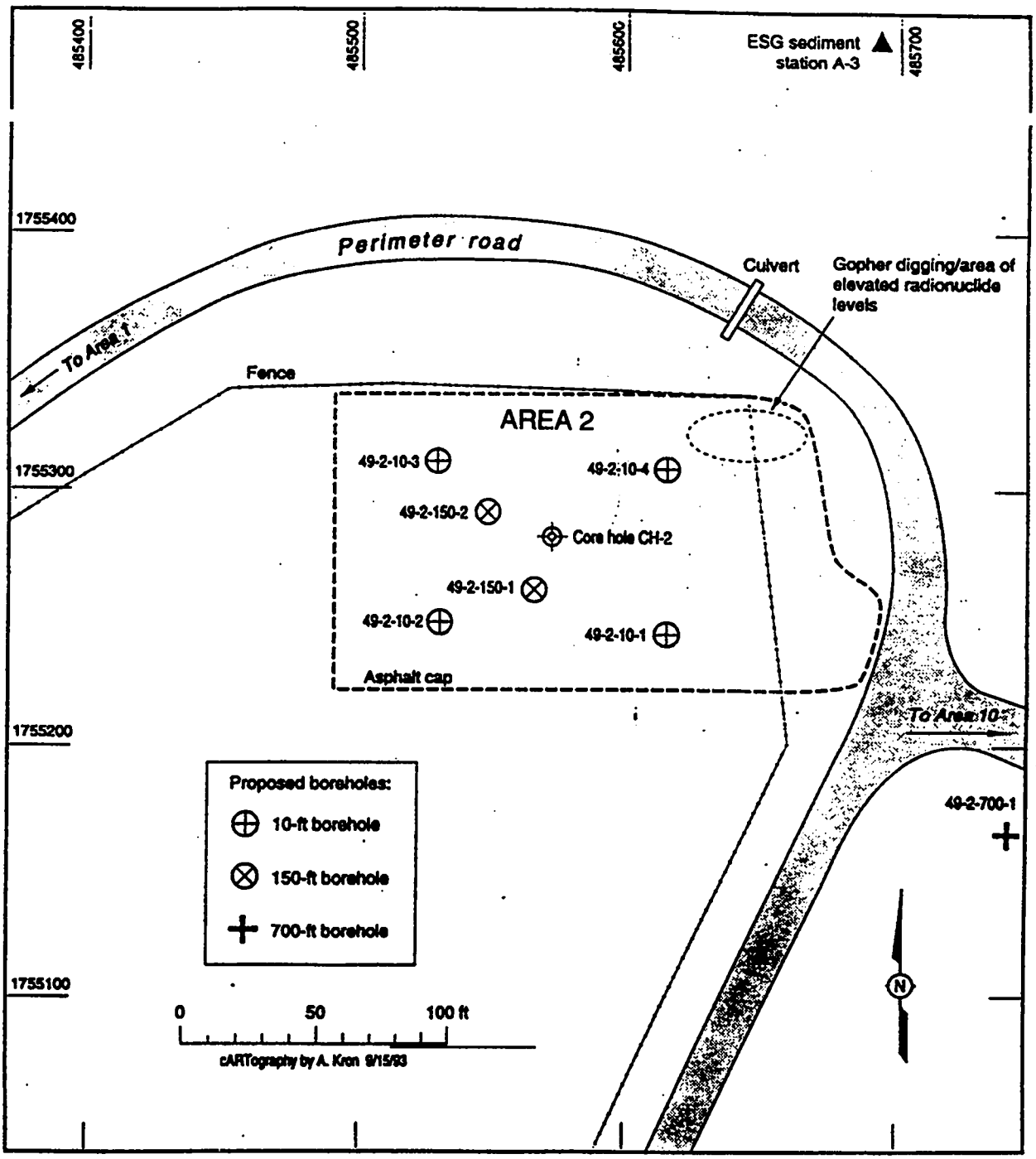

Fig. 4. Location of planned bore holes for Area 2.

TA-49 is currently used for high-power microwave research and for the Laboratory's Hazardous Devices Team demolition area activities that do not involve radioactive materials.

In addition to the previous underground experiments, the area contained support facilities including shafts, radiochemical facilities, sumps, and landfills. However, since the experiments ceased in 1961, no significant additional contamination has occurred at the site.

LANL environmental monitoring data for ground and surface water and soil samples indicate that TA-49 contaminants have not moved beyond the Laboratory boundaries. Ground water contamination is highly unlikely because the main aquifer is about 1200 ft below the site. Additionally, access restrictions, a drilling ban, and stabilization procedures have enhanced safety at TA-49. The Laboratory has developed a work plan to determine the amounts and areas of contamination at TA-49. Site characterization studies are scheduled to continue from 1992 through 1995.

Within TA-49 twenty potential SWMU's have been identified at TA-49 and aggregated as the TA-49 Operable Unit. Known or suspected contamination at the remaining TA-49 SWMUs involves trace soil contamination by heavy metals, radionuclides, high explosives, organics, and other chemicals associated with facilities supporting the underground experiments. The area has been the subject of extensive radiological surveys to locate surface contamination. The results of these surveys, Purtymun and Stoker, are shown in Fig. 5-10. Figures 5 and 6 are Uranium activity sample survey results for the soil of Areas 2 and 2A. The area was checked for gamma-decay radiation, which corresponds to the telltale energies of uranium decay. Figures 7 and 8 are the results of Plutonium-238 sample surveys for the area. Figures 9 and 10 are Plutonium-239 sample survey results for the area.

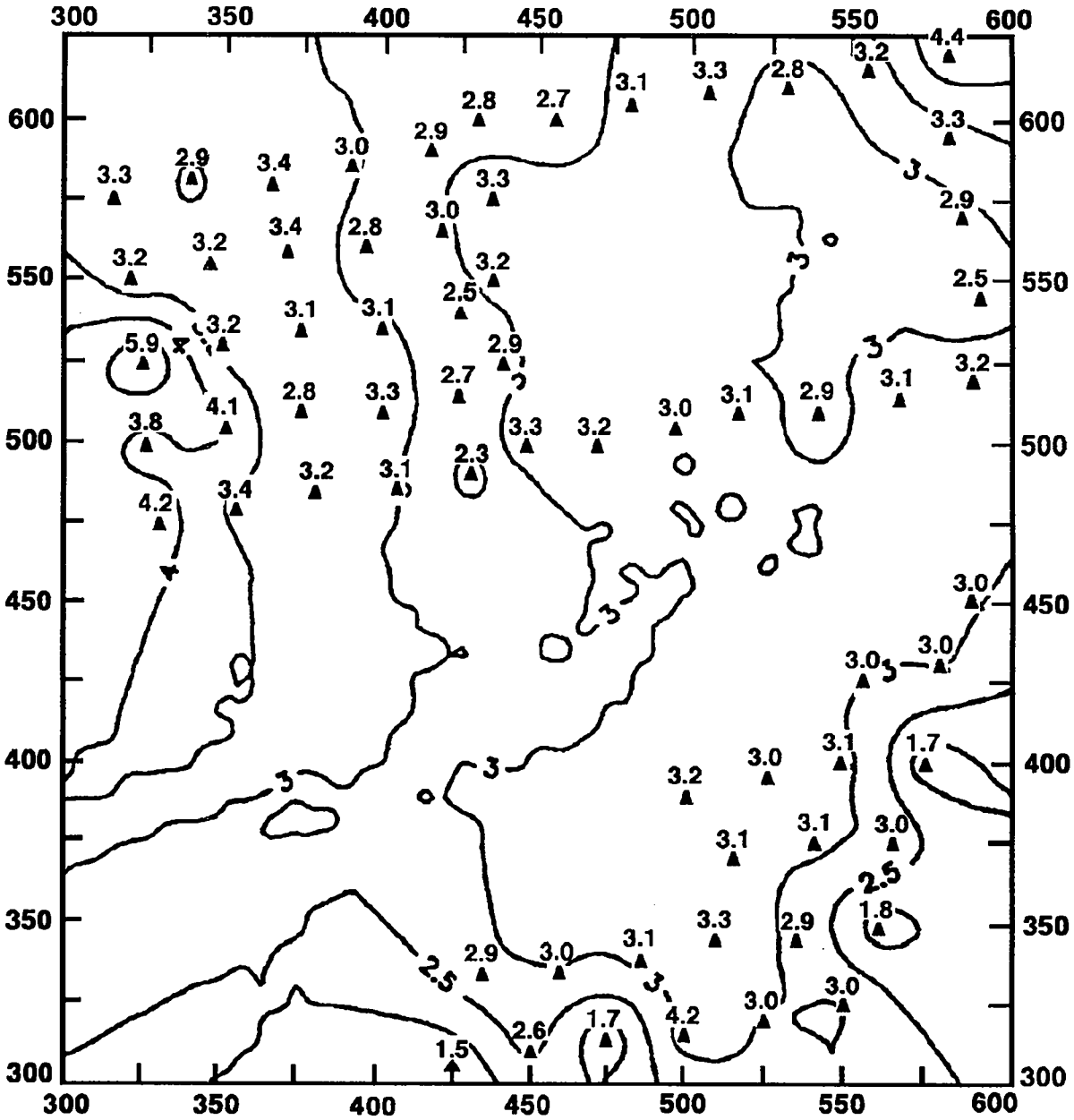

Fig. 5. Contour plot of Area 2 soil for uranium activity.

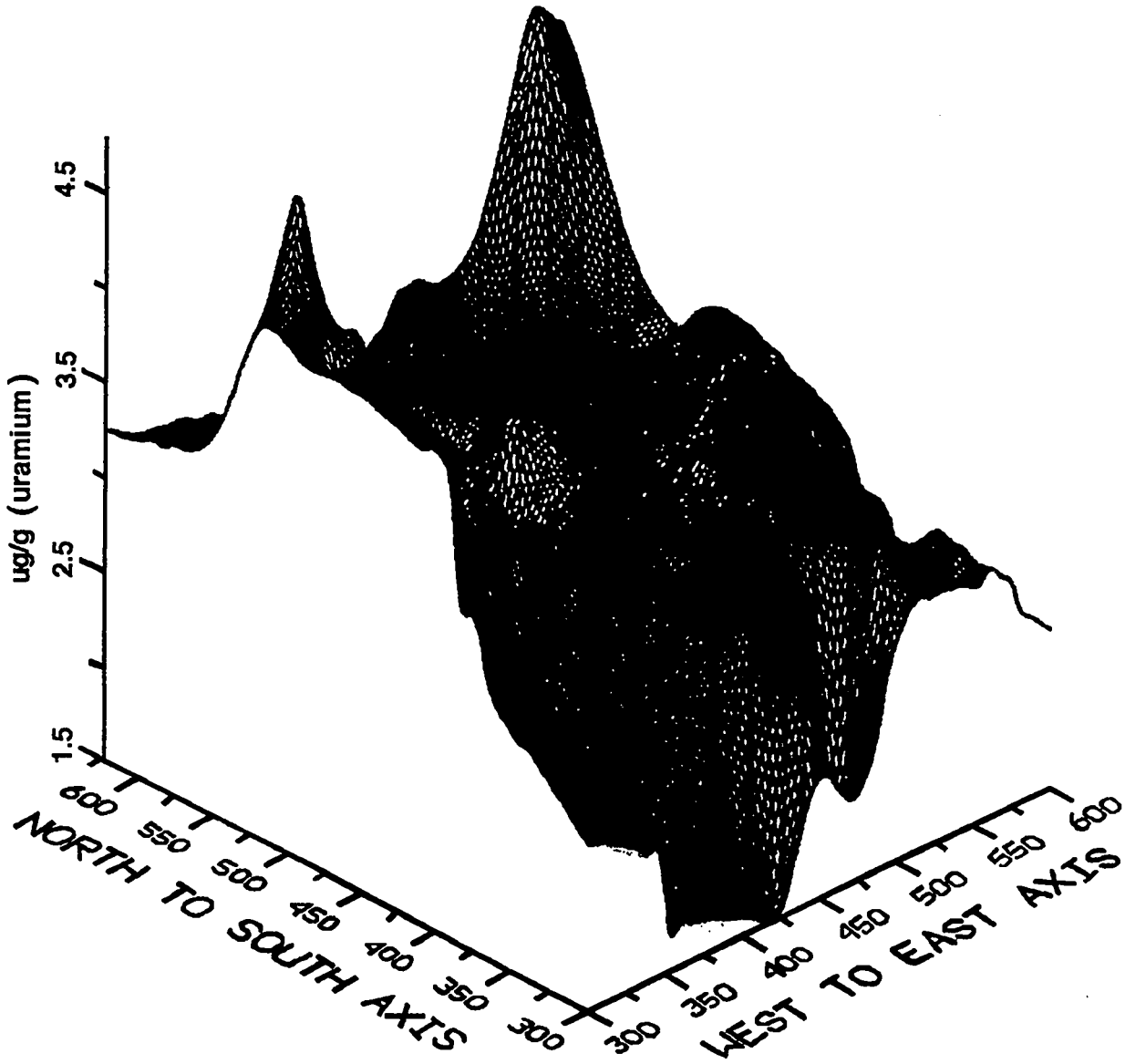

Fig. 6. Three dimensional plot of Area 2 soil for uranium activity.

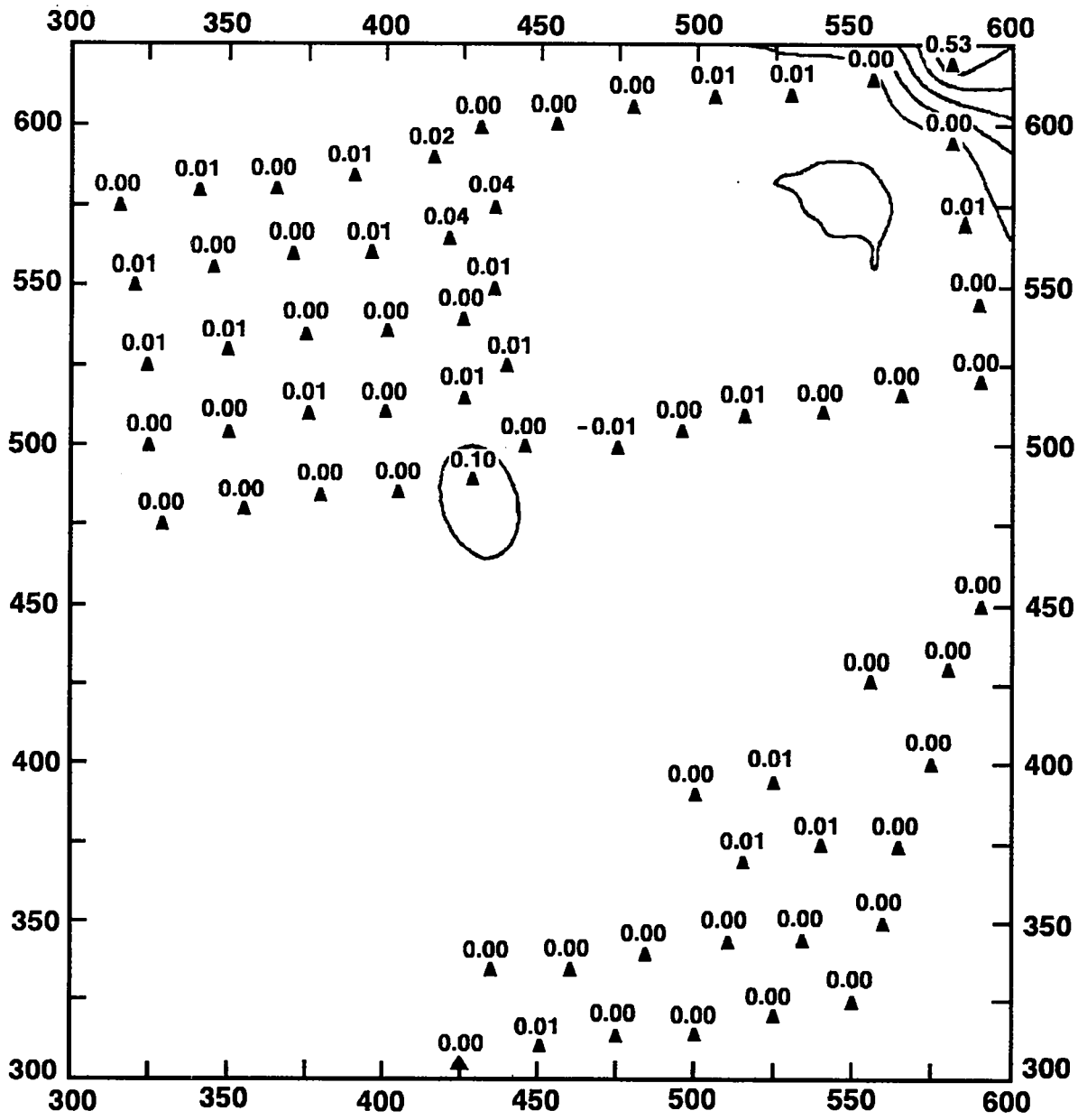

Fig. 7. Contour plot of Area 2 soil for Plutonium-238 activity.

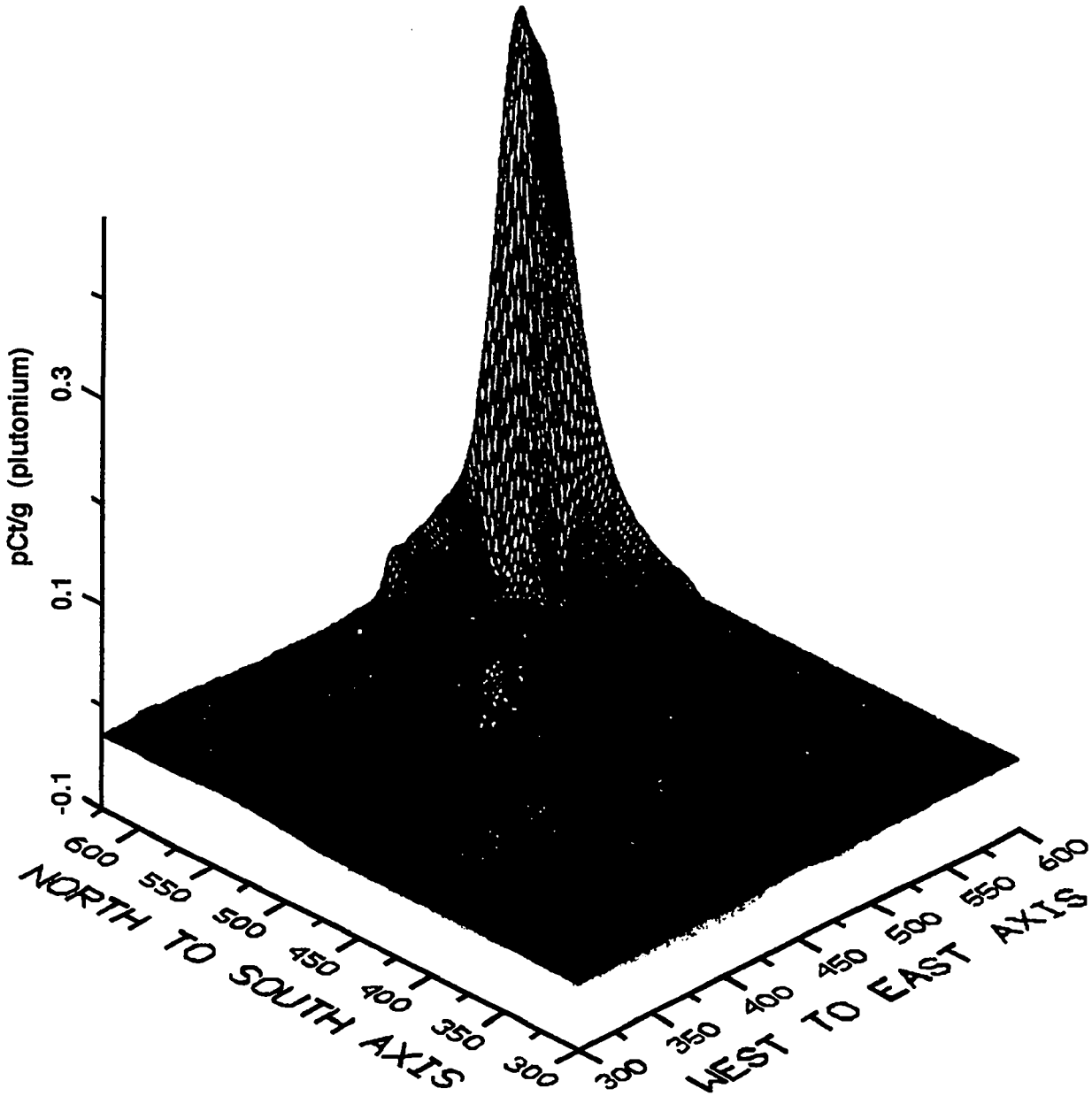

Fig. 8. Three dimensional plot of Area 2 soil for Plutonium-238 activity.

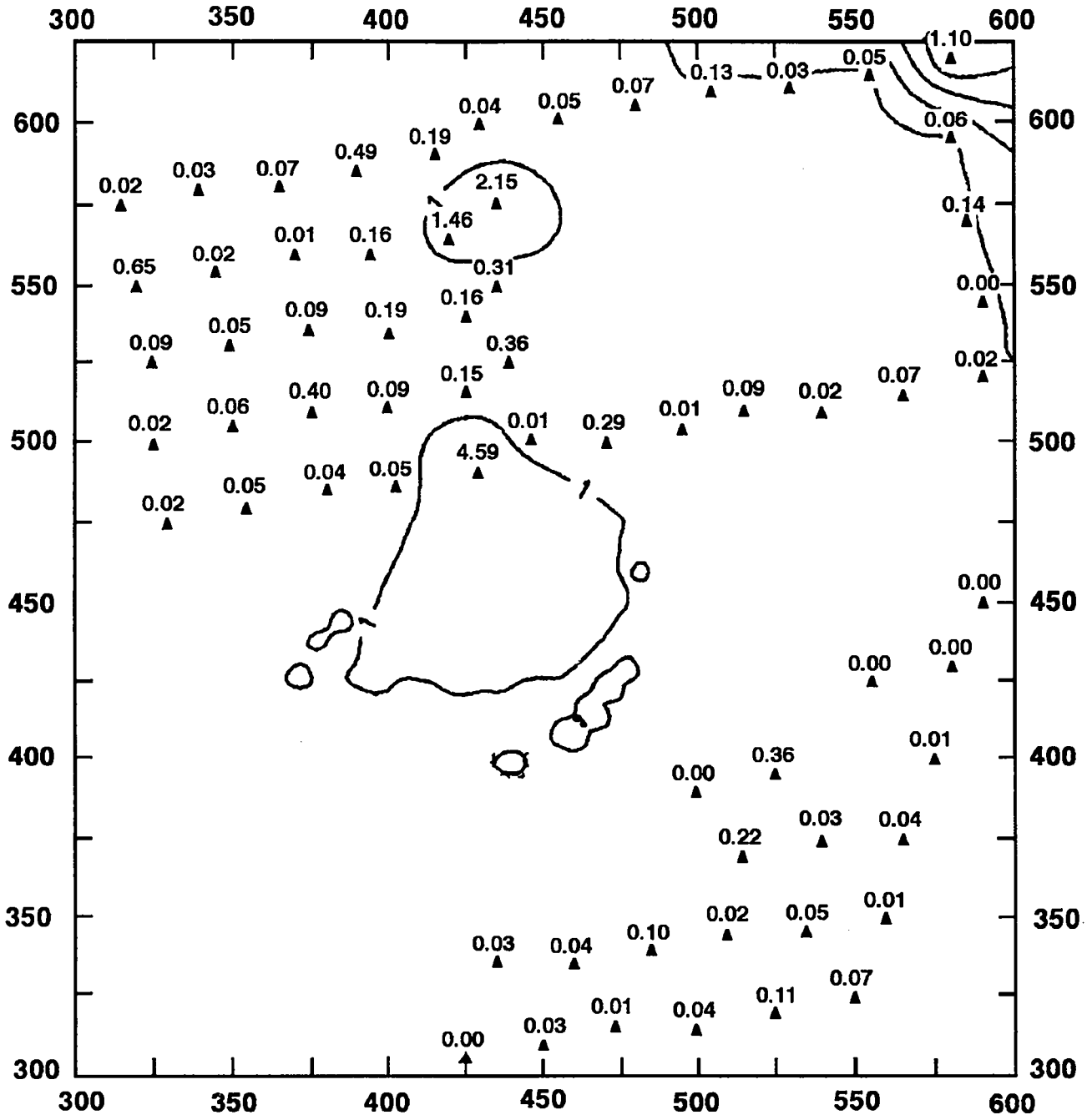

Fig. 9. Contour plot of Area 2 soil for Plutonium-239 activity.

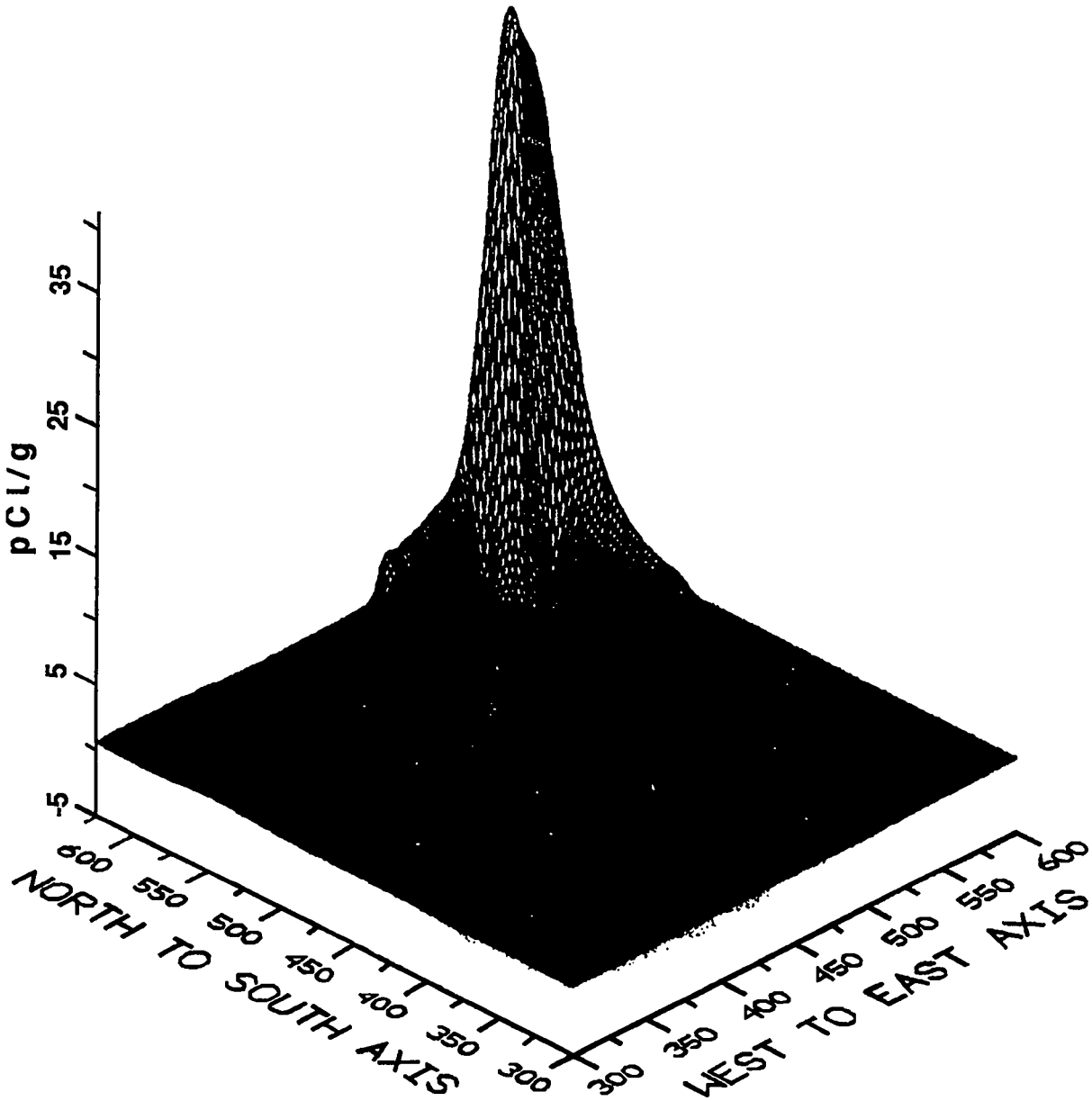

Fig. 10. Three dimensional plot of Area 2 soil for Plutonium-239 activity.

Since 1960 frequent groundwater, surface water, and soil sample monitoring have shown no evidence of any contaminant migration beyond Laboratory boundaries.

Asphalt, concrete, and natural vegetation covers stabilize surface contamination at TA-49. The largest, known accidental contamination involved small levels of fissionable materials released during a 1960 drilling operation at one test shaft. Contaminated materials were returned to the shaft and the area over and around the shaft was capped with clean, clay-bearing soil and an asphalt cover. Concrete plugs and natural vegetative covers now seal other shafts. After the 1961 experiments, some surface equipment and structures were removed or decontaminated. A second clean-up campaign was completed in 1971. The La Mesa forest fire in 1977 destroyed most remaining wooden structures and additional uncontaminated building debris was cleaned up in 1984. Workers disposed of all non-hazardous debris in a landfill at the northwest section of TA-49.

Future plans are to assess the extent of contamination and select possible remedial actions. The alternatives range from long-term monitoring and institutional controls to excavation and disposal of contaminated soils and restoration. The Hazardous and Solid Waste Amendment module of the Laboratory's Resource Conservation Recovery Act operating permit guides remediation, specifying the sequence of events identifying, characterizing, and remediating contaminated areas.

Government and industry must cooperate to ensure the safe management of past, present, and future waste. The Laboratory is committed to informing the public about investigative actions and the entire cleanup process.

5. GROUND-PENETRATING RADAR SURVEY RESULTS

High voltage pulser technology limits the penetration depth of present GPR systems. AOT-9 constructed pulsers with much higher amplitude than commercial systems. AOT-9 also created image-processing techniques and hardware for this research.

Area 2 was surveyed with two complete sets of AOT-9 GPRs. The surveyed asphalt area was 100 ft, east to west, by 100 ft, south to north. The logging hole approximately centered in the asphalt cover was the primary reference and was chosen as the 0,0 location for the survey. Survey results are shown in Figs. 11-13. The results are presented in three different ways. Figure 11 presents a top-down, contour plot of the measured return profiles. The color designates the depth of first radar return. Existing historic records provided the position of the 6-ft diameter boreholes. The replication of the independent GPR survey of the historic record is important to assuring the planned drilling effort.

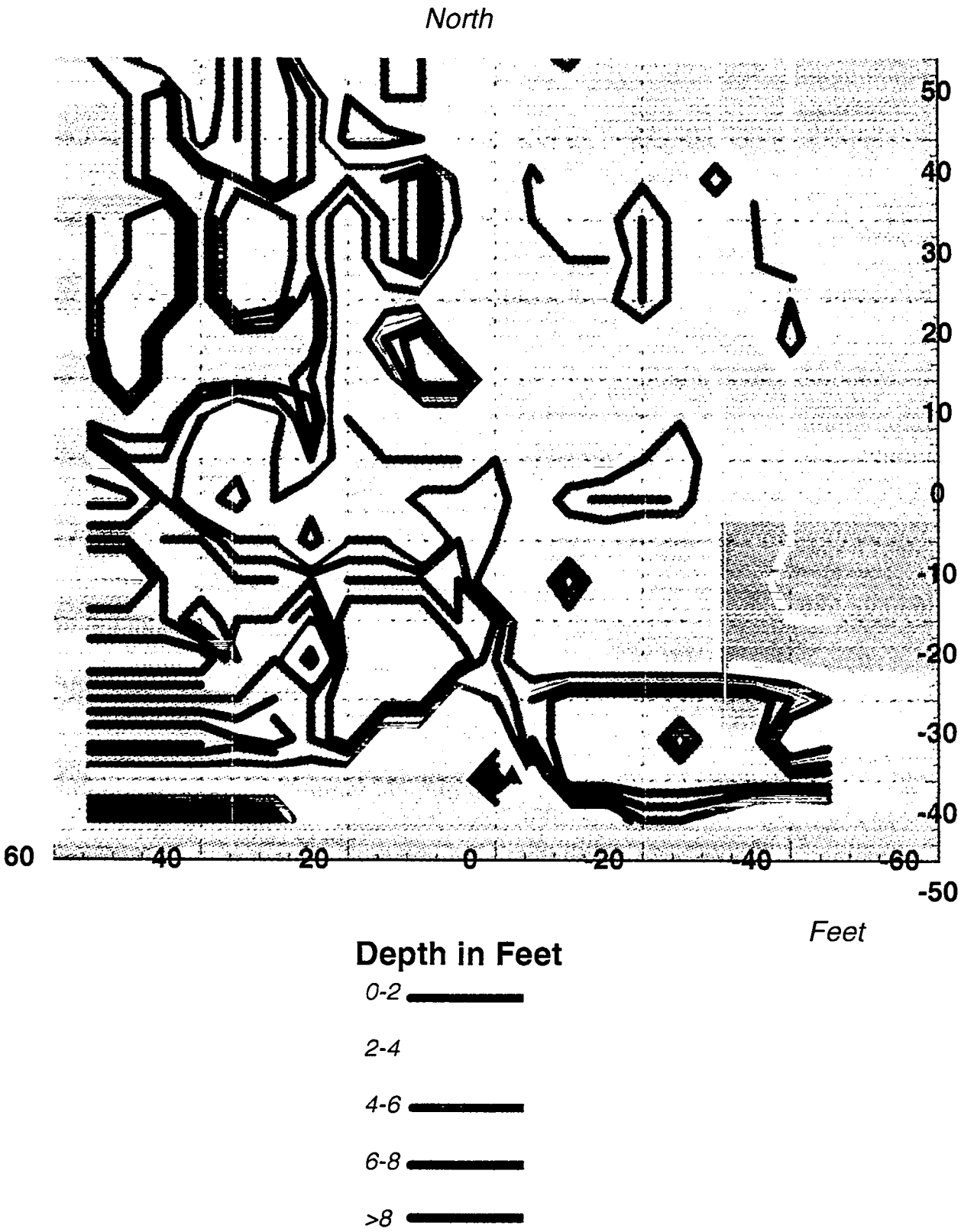

Fig. 11. Contour plot of GPR survey of Area 2

Figure 12 also displays the results of the survey from a top down perspective. Different colors are used to depict the depths of first ground penetrating return reflection of the transmitted pulse. The cooler colors (green, blue, and black) correspond to deeper depths of undisturbed soil. Colors towards the hotter end of the spectrum, (yellow to red) indicate that returns are closer to the surface. The shallower areas are regions of prior activity that teams need to avoid during drilling operations. Black indicates the deepest areas of undisturbed media while red depicts shallow, disturbed area. The blue circles show the planned drilling locations. The numbers inside the blue circles indicate the planned drilling depth. Several planned drilling locations positioned are over areas showing in the black (clean) areas. The clean areas for drilling include the shallow, 10 feet deep boreholes in the NW, SW and SE quadrants and both 150 feet boreholes. In Fig. 13, the survey indicates clearance for drilling corresponding to boreholes 49-2-10-1,2,3 and 49-2-150-1,2.

The transparent overlay shows the location of the old boreholes previously discussed in the description section. Comparing the pattern of the GPR survey with the over lay shows a correspondence of shallow depth disturbance with the location of some of the old boreholes. The old boreholes have evidently undergone settling that influences the top soil over each of the borehole or a disturbance of drainage pattern. This allows a completely indispudant cross check of the old borehole locations, even after all of the surface features of the old boreholes have been erased. Two of the old boreholes show no disturbance in the radar returns. These may correspond to boreholes where no settling occurred because the plugging process used at the time was completely successful and no settling occurred. The boreholes in the area were refilled in a number of ways. Typically, the plugging process consisted of refilling the borehole with locally available fill to within ten or twenty feet of the surface, adding a layer of weak concrete plug material and then filling to grade with available fill. In some cases, metal debris from the area was also disposed by placing it in the borehole. Several boreholes had a metal plate at 20 feet. Some fraction of the radar return may be due to the debris added to fill the old boreholes.

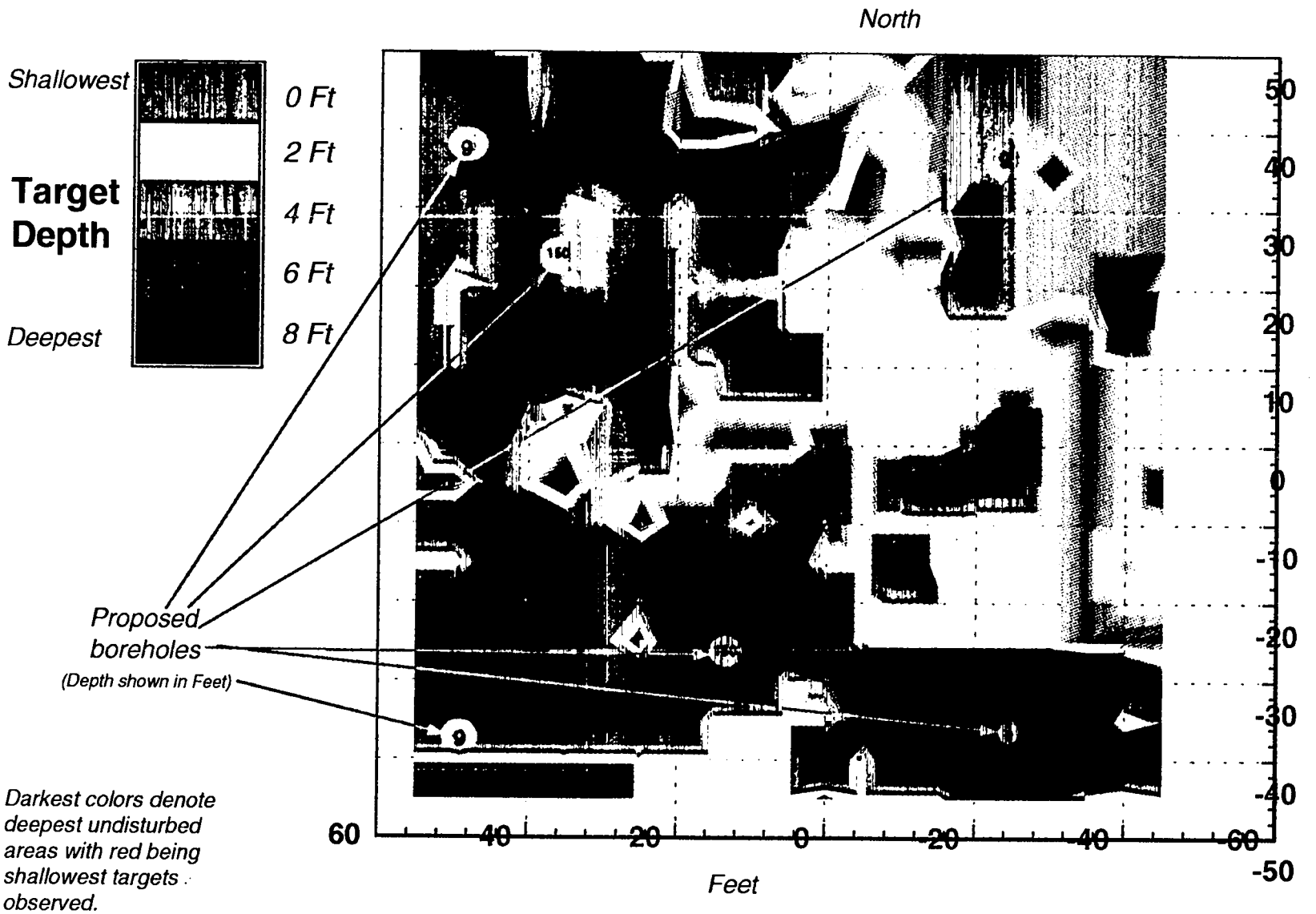

Fig. 12. Pseudocolor Contour Plot of Areas 2

Figure 13 is a three-dimensional pseudo-color display of the same survey measurement data presented from another perspective. The valleys correspond to regions that have no radar-signal returns close to the surface.

The subsurface survey grid defined magnetic north as the reference. To locate the boreholes, the original survey grid used another reference with a seven degree offset. Surveyors digitally modified the results of the subsurface survey to perform an overlay of the scans and allow direct comparison of the two data sets.

The survey results show large areas of soil that are homogeneous and clear of any buried object returns, corresponding to the black areas in the figures. Of the planned borehole locations, only the one in the northeast corner show near-surface signal returns. This may be due to shallow buried debris or high moisture content in the near-surface soil.

The initial GPR survey indicated some areas of disturbed soil that might interfere with the planned bore holes. Upon review of the GPR results with the ER office of primary responsibility in December of 1993, the overall site remediation plan for Area 2 was placed into a reevaluation phase to consider the potential risks of drilling into an area that showed disturbed radar returns. While the most probable explanation for the disturbed returns was water laden clay that has very high conductivity, the radar returns could also be due to buried metal debris of unknown radioactivity.

In particular, the planned drill hole in the northeast quadrant of the asphalt pad, identified as 49-2-10-4 in Fig. 4, was of concern because of the near surface radar echo that indicated an area of geophysical disturbance. The presence of a disturbing echo had not been anticipated because the documentation for the area showed that a homogeneous top layer of clay had been placed to assure that surface moisture could not permeate through the top layer and cause erosion of the area. Discussions during December resulted in a change of the contractual effort to complete the ER planned drill holes.

In early February of 1994, an extensive resurvey of the planned northeast drill hole location was initiated. A new, undisturbed place in the same quadrant was needed to complete the drilling operation. The redirection involved repositioning of the drill hole away from where the GPR indicated an area of return disturbance. The previous GPR survey had been done on a coarse survey grid and only indicated regions not satisfactory for deep drilling operations.

The final survey only include the area requiring additional attention. The survey grid spacing encompassed only a 10 ft by 10 ft area around the area required for the last drill hole and was done on a survey line spacing of two feet. The results of the survey are shown in Figures 14 and 15. The first figure is the two dimensional view from the top and the color legend shows the depth to the first return from inside the ground. The second is the same data plotted in a three dimensional display. The area from the first survey that was not recommended for drilling again showed a near

surface radar return disturbance that made it unsatisfactory for drilling. The resolution of the GPR effort was not sufficient to conclusively identify the nature of the buried material, eg., scattered metal debris or a wet clay layer, but the GPR survey did indicate that the initially intended drilling area did not provide an ideal drilling position. The high resolution survey did find a relatively clear area was identified that was three feet west and eight feet south of the initially proposed location.

The image developed from the subsurface returns indicated a broad shelf that may have been caused by a previous trenching effort that was perhaps for drainage control. The search of the documentation for the site is continuing to find a record of trenching activities. In any event, the location for the drilling position for the northeast quadrant hole was moved, based upon the GPR survey results.

The subsequent drilling operations commenced in late February and did clarify the prior GPR survey results. Evidently, the effort to minimize surface water penetration into the test area had motivated earlier custodians to use a clay based material to cap the area. This hypothesis is supported both by the written record of the site and the results of the subsequent six drill hole program.

The usage of clay did make the GPR effort more difficult. As shown in Table 1, the presence of water laden clay poses a challenging situation for the GPR effective range. The overall penetration through the water laden clay is a testament to the performance of the GPR in an adverse location.

The drilling program was slowed because of the wet clay fouling the bit and the effuse collection device. However, the whole process was completed without incident. The moisture content as a function of the drill depth is shown in Figure 16. The cause of the disturbed returns shown in the previous figures was due to the water laden clay. The high conductivity of the clay/water mixture causes an almost metallically strong radar return. Although the GPR was not able to directly discriminate between scattered metal debris and clay/water mixture, the drilling program was able to use the GPR survey results to develop a modified drilling plan that completely satisfied the ER mission and avoided the issue of potentially drilling through contaminated material.

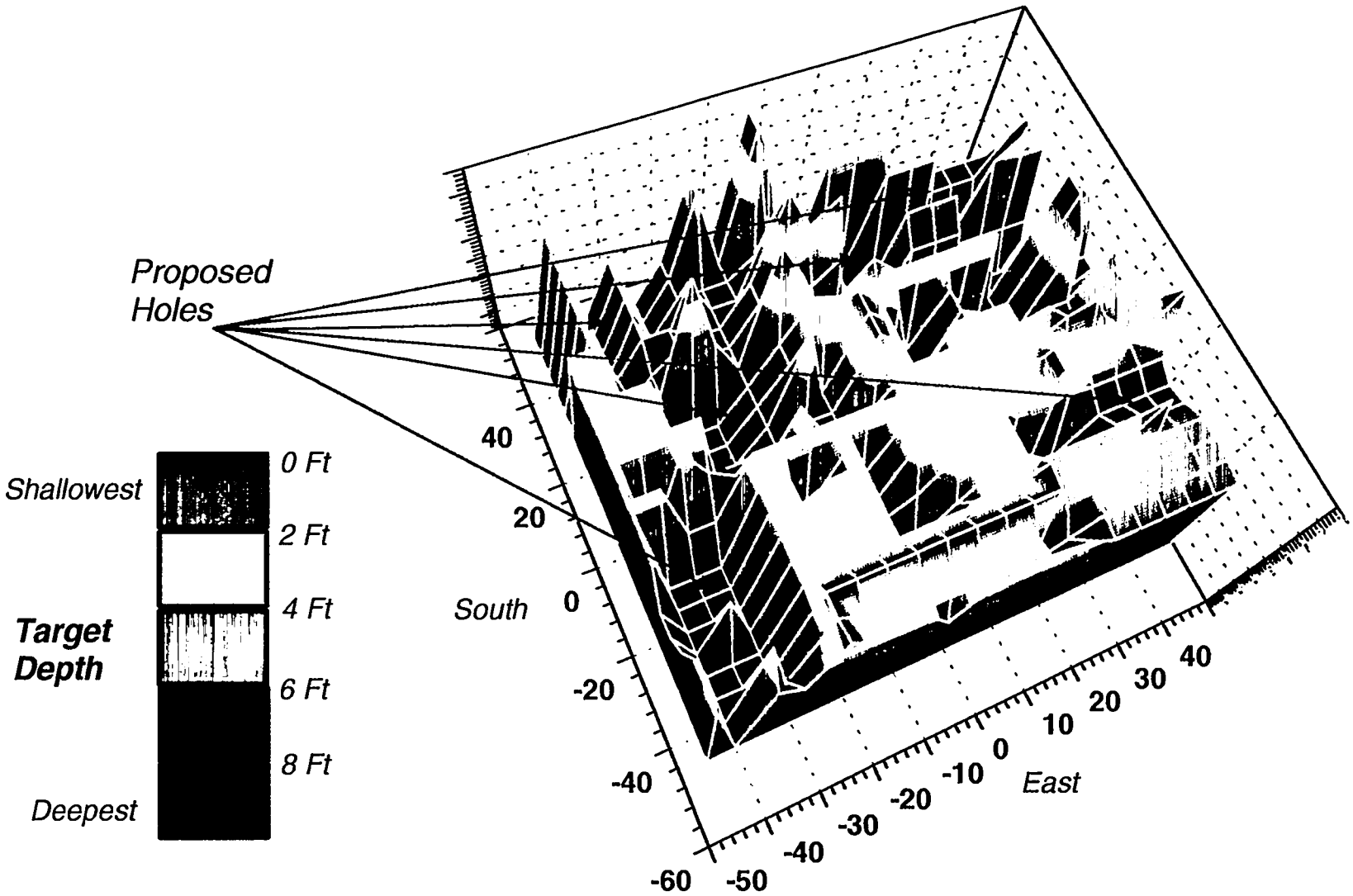

Fig. 13. Three Dimensional Plot of Area 2

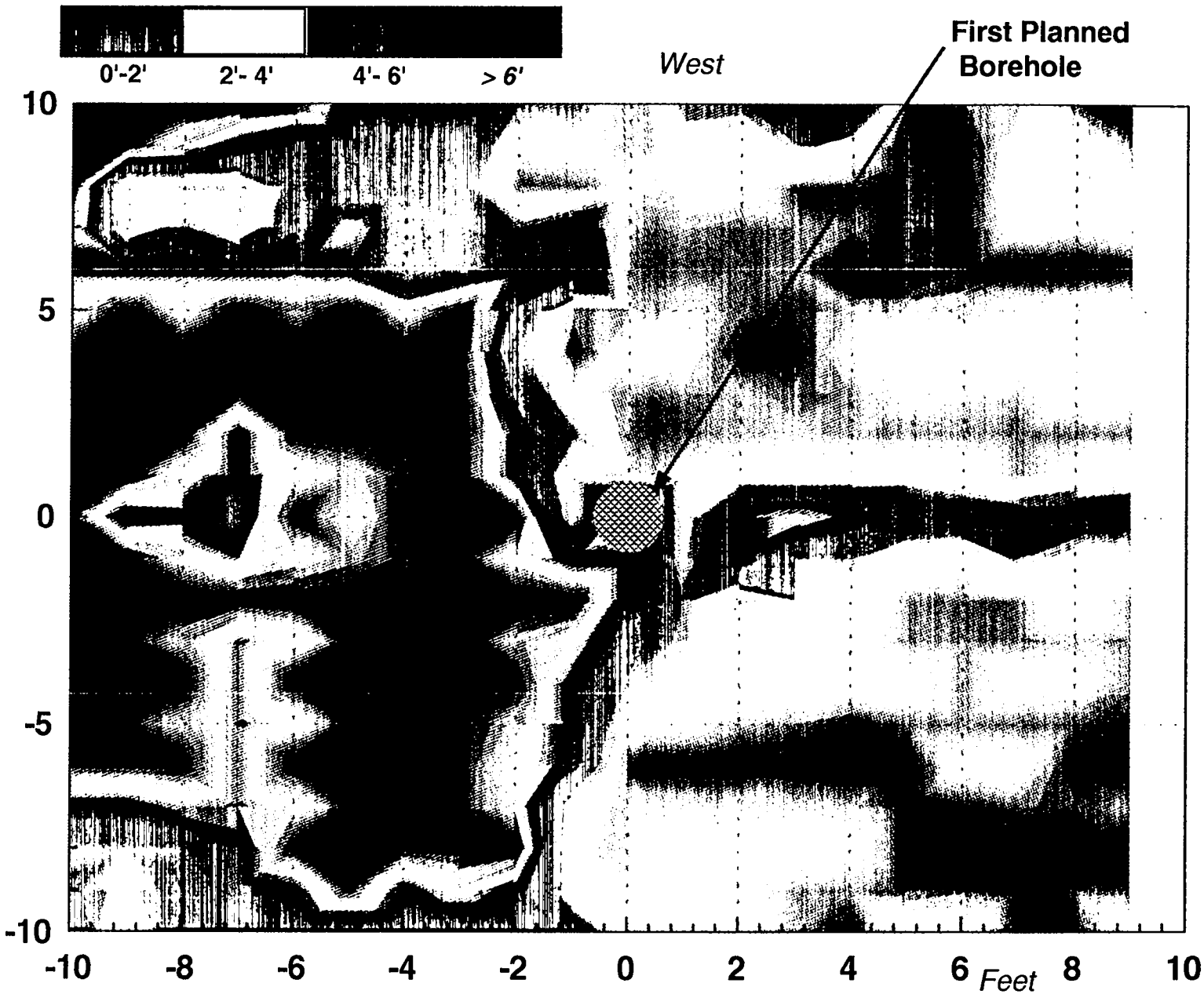

Fig. 14. Two dimensional high resolution survey results.

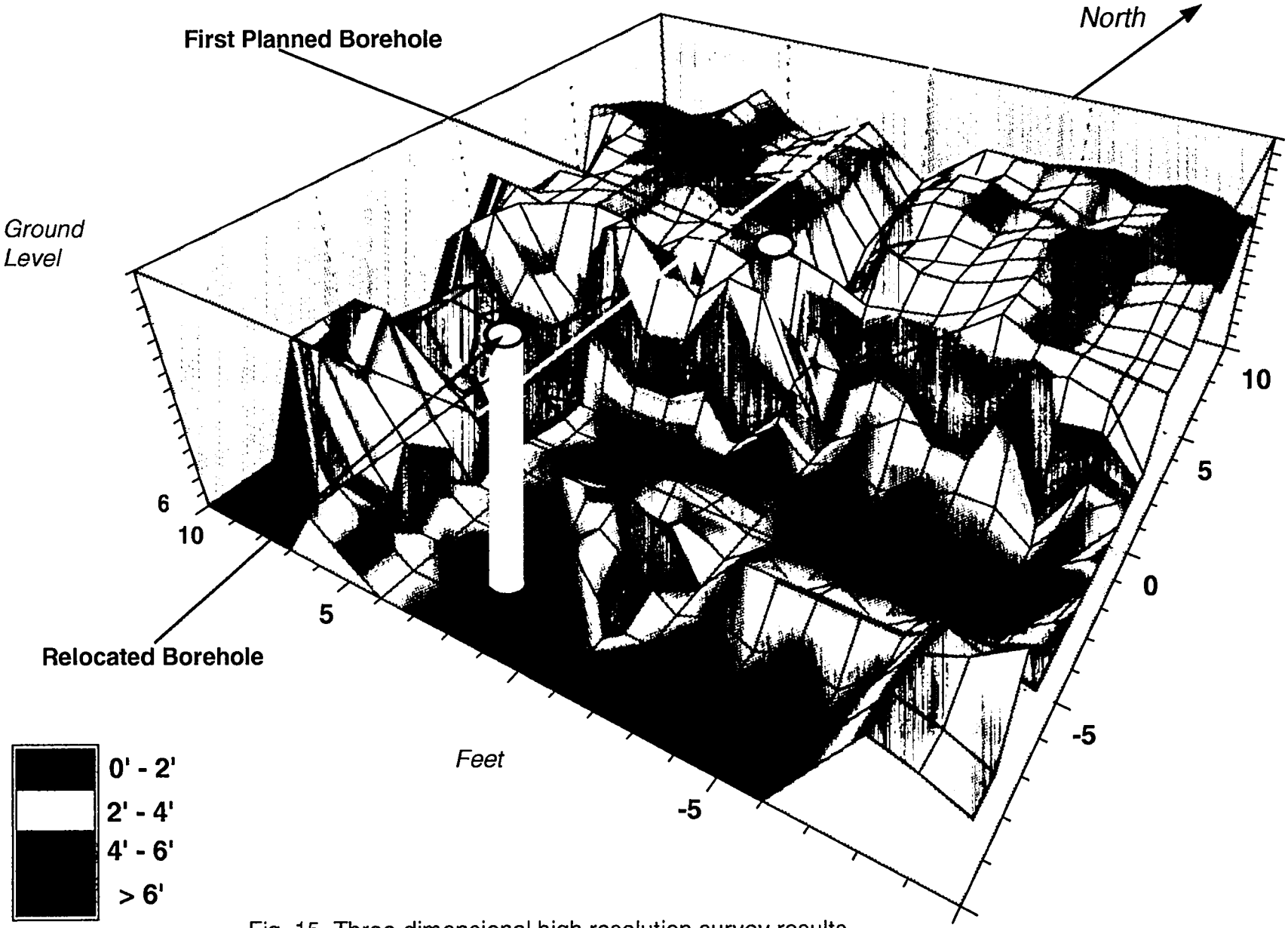

Fig. 15. Three dimensional high resolution survey results

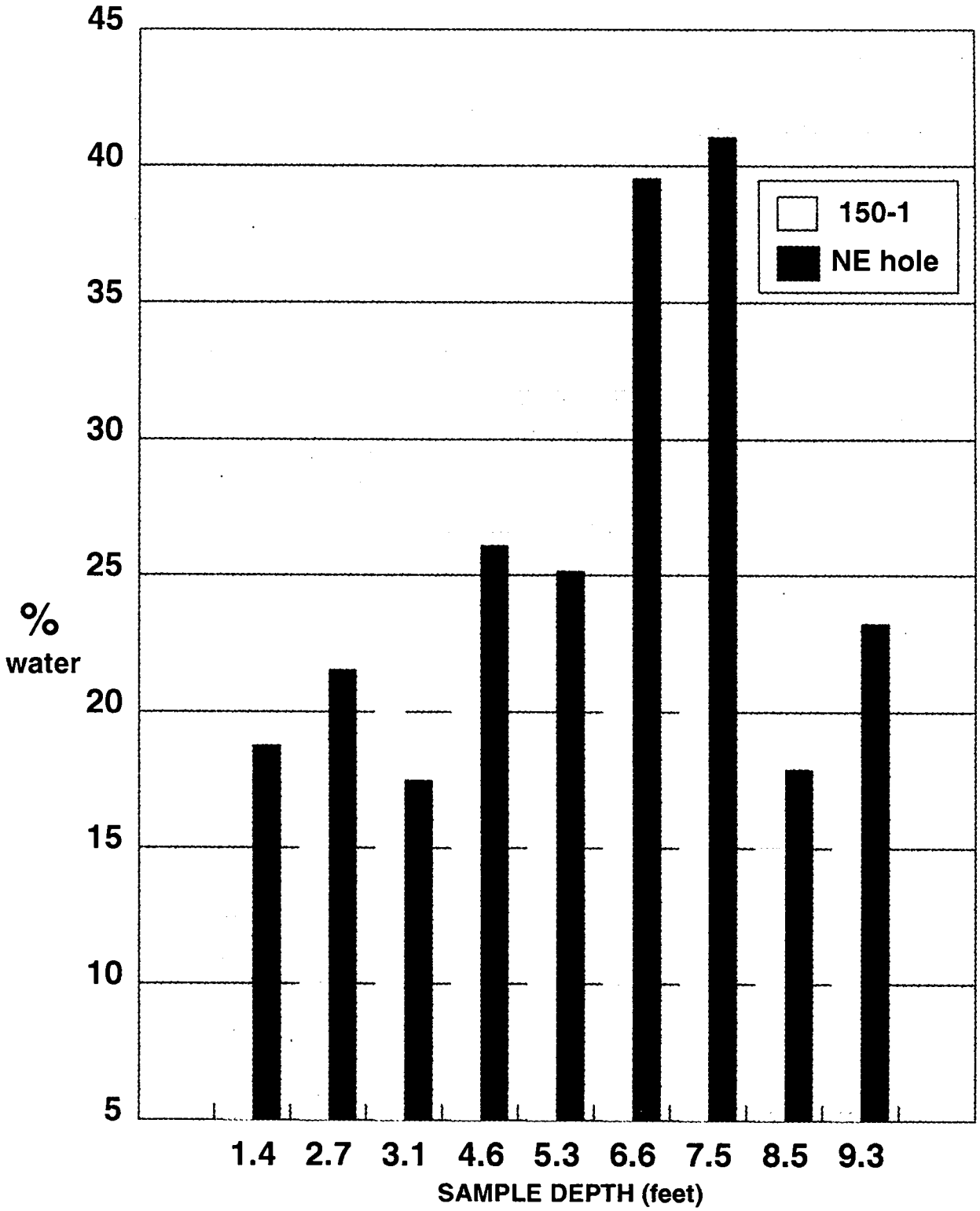

Fig. 16. Results of core sampling for moisture content

6. CONCLUSIONS AND RECOMMENDATIONS

The purpose of the ground penetrating radar survey reported here was to independently verify the location of the previously. Excavated six foot diameter shafts that had been covered over with no remaining surface features. The survey was necessary to ensure that all precautions were used to avoid an inadvertent breaching of a contaminated subterranean test cell or near surface contaminated debris, if present. The survey was successful and no radioactive material was encountered during the drilling process. Based upon the first survey, the planned locations for the two 150-ft-deep boreholes appeared to be pin clean, homogeneous soil areas. After AOT-9 personnel obtain sample drilling core information, they will correlate return signals to the moisture content in the soil. Personnel will also measure additional information about the complex dielectric content.

The planned shallow boreholes in the southeast, southwest and northwest quadrants also were clean, homogenous soil areas. The planned, shallow borehole in the northeast quadrant was in a region showing returns from shallow depths. Therefore, the drilling needed to be relocated to a nearby, undisturbed area.

The characterization of AREA 2 has provided both GPR return strengths and soil moisture content from the six boreholes. This can be used to develop a moisture content subterranean map of the high water content areas. Such a moisture map could help interpret where the water is entering under the asphalt cap and also document changes with seasons and time.

The survey needs to be expanded to include area 2A, which is adjacent to area 2 and has six similar boreholes that were not covered with asphalt or clay. Comparison of the two sets of radar returns will provide a measure of which post test treatment provides better stabilization against water intrusion to the borehole. The lack of a return corresponding to disturbance at two places known to be locations of old boreholes at the -23(E),+37(N) and +26(E),-15(N) positions shown in the overlay of Figure 12 may be due to the holes having been capped with clean concrete ,i.e. not filled with debris or dissimilar type soil. A search of prior test documentation may help clarify the history of each of the shaft holes.

We recommend that the HIPERGPR survey inside the fence area be continued. A finer grid survey with more depth resolution is now feasible. Also, the discovery of buried pipe type returns near the asphalt pads indicates additional previous activity that has now been buried. An additional HIPERGPR survey can map the locations and generate a permanent digital record. Such a record will be an important record of the soil moisture content that can be used for later comparisons.

The next step in understanding AREA 2 is to survey to a depth of twenty-five feet. While the survey reported here were designed primarily to quickly identify potential hazards at the six planned borehole locations, HIPERGPR is capable of locating the metal covers emplaced at a depth of twenty feet for some of the test holes. The final survey will locate the metal spheres at the

bottom of the shaft. This is necessary to identify the condition of the residual test materials. The end of the Cold War and the declassification of some nuclear effects research activities made many hardware and software resources available for other uses. Dual-use technology is now a recognized tool for helping both commercial and national laboratories move forward in a more environmentally conscious way.

More than 4,400 identified sites need to be characterized during the ER program. Several known hazardous sites will require non invasive techniques. GPR is recognized as a potentially valuable ER tool for determining the depth and lateral extent of dangerous subsurface objects. GPR theoretical resolution is superior to any other method for the delineation of buried objects and pit and trench wall boundaries.

The success of this ground penetrating radar survey that used new technology developed by Los Alamos to help end the Cold War can now be applied to successfully complete the post Cold War ER effort. The speed and depth of penetration demonstrated during the course of this survey effort means that the ER work can now be done more rapidly and safely. While the previous attempt to use a commercial GPR unit at this site was unsuccessful because of lack of depth penetration, the Los Alamos GPR effort was successful and will now be applied to other ER efforts.

7. ACKNOWLEDGMENTS

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