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SITE CHARACTERIZATION AT THE RABBIT VALLEY GEOPHYSICAL PERFORMANCE EVALUATION RANGE

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ABSTRACT

The United States Department of Energy (U.S. DOE) is developing a Geophysical Performance Evaluation Range (GPER) at Rabbit Valley located 30 miles west of Grand Junction, Colorado. The purpose of the range is to provide a test area for geophysical instruments and survey procedures. Assessment of equipment accuracy and resolution is accomplished through the use of static and dynamic physical models. These models include targets with fixed configurations and targets that can be re-configured to simulate specific specifications. Initial testing (1991) combined with the current tests at the Rabbit Valley GPER will establish baseline data and will provide performance criteria for the development of geophysical technologies and techniques.

The U.S. DOE's Special Technologies Laboratory (STL) staff has conducted a Ground Penetrating Radar (GPR) survey of the site with its stepped FM-CW GPR. Additionally, STL contracted several other geophysical tests. These include an airborne GPR survey incorporating a "chirped" FM-CW GPR system and a magnetic survey with a surfaced-towed magnetometer array unit. Ground-based and aerial video and still frame pictures were also acquired. STL compiled and analyzed all of the geophysical maps and created a site characterization database.

This paper discusses the results of the multi-sensor geophysical studies performed at Rabbit Valley and the future plans for the site.

1. INTRODUCTION

The United States Department of Energy (DOE), Grand Junction Projects Office (GJPO) has established a geophysical test facility in Colorado, known as the Rabbit Valley Geophysical Performance Evaluation Range (GPER). The range is designed to provide a research area for geophysical technologies and techniques. Between 1991 and 1993, tests have been conducted at the GPER and the GJPO will use this baseline information to establish a site characterization database. The U.S. DOE's Special Technologies Laboratory (STL) conducted a Ground Penetrating Radar (GPR) survey of the site with its stepped Frequency Modulated-Continuous Wave (FM-CW) GPR. STL also contracted an airborne GPR survey with a "chirped" FM-CW GPR and a magnetic survey that uses a surface-towed magnetometer array unit.

This paper provides a detailed site description, a brief background of previous surveys and a discussion on the GPR and magnetic surveys. Additionally, the preliminary results of some recent DOE geophysical tests are included and were considered in the analysis. The complete GPR and magnetic data sets form a database for the GPER.

2. SITE DESCRIPTION[1]

The Rabbit Valley GPER is located approximately 30 miles west of Grand Junction, Colorado. The site covers 80 acres described as the eastern half of the northwest quarter of Section 15, Township 10 South, Range 104 West, 6th Prime Meridian, Mesa County, Colorado. See Figure 1 [1]. Access to the area is via Interstate 70, exit south on Rabbit Valley Recreation road. From this point a dirt road must be utilized to gain access to the site.

The area is characterized by mostly high desert terrain with various types of desert vegetation including sagebrush, cottonwood and natural grasses. Sterile wheat is abundant and is used as part of the reseeding program for the area. The majority of the vegetation measures from 7 cm to 40 cm in height. Some taller vegetation exists, but is sparse.

The entire site has been land surveyed with grid points established on 50 meter centers. Three sub-areas were subsequently land surveyed with grid points set on 10 meter centers. A reference point has been established on the northeast corner defined as E1/2 NW1/4, S15, T10S, R104W. A picture of the entire site is shown in Figure 2. The photograph was taken from atop the dome located off the site (west side) in the North-NorthEast direction.

Several cultural artifacts were buried between 1988 and 1992 at depths varying from 0.5 to 2.0 meters. These artifacts were placed in two main areas on the site. Table 1 describes the artifacts with burial location and depth. Figure 3 shows the location of the artifacts relative to the site. During the burial of the targets, the last soil out was used first for backfill. The topsoil was kept separate and spread over the pit to match the surrounding topography. Sterile wheat was then planted.

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[1]The information on the site and target descriptions were obtained from reference [2].

The geologic environment of the area consists of colluvium overlaying the Saltwash member of the Morrison Formation. In general, the surface layer consists of a reddish-brown to buff-tan sandy silty loam (Avalon Loam). This covers a reddish-brown sandy silt that overlays a fine-grained, gray limestone. Several areas have a green-gray clay/mudstone between the silt and limestone layers. The lithology was measured from the pit sidewalls for each target and is shown in Figure 4.

TABLE 1
LIST OF BURIED ARTIFACTS AT THE RABBIT VALLEY GPER

#	TARGET DESCRIPTION	SIZE	LOCATION	DEPTH
1	Plastic container filled with paraffin as a simulated cache.	0.8 m x 0.5 m x 0.5 m (length x width x height)	160W, 30S	0.5 m
2	Non-reinforced concrete cylinder (oriented vertical) with a removable wood lid.	1.2 m dia. x 1.5 m	180W, 80S	0.5 m
3	Corrugated steel culvert, horizontal cylinder, axis oriented north-south.	0.6 m dia. x 1.2 m	285W, 355S	2.0 m
4	Corrugated steel culvert, right horizontal cylinder, axis oriented north-south.	1.8 m dia. x 3.7 m	235W, 395S	2.0 m
5	Reinforced concrete box, long dimension north-south.	2.3 m x 2 m x 1.75 m (length x width x height)	286W, 453S	1.35 m
6	Plastic container, long dimension east-west.	2.5 m x 1.25 m x 1 m	374W, 473S	1 m

3. GEOPHYSICAL BACKGROUND[2]

Small-scale geophysical background measurements were made in area #1 and included magnetics, electromagnetics (EM), resistivity/induced polarization, refraction seismic and pulsed GPR. Results of these tests indicate only minor natural occurring anomalies and a fairly homogeneous geological and geophysical structure. These tests were made prior to the burial of the six artifacts listed in Table 1. The following is a brief summary on the measurement results. Figure 5 is a site plan indicating these minor anomalous sections.

[2]Background geophysical survey data and interpretations were obtained from reference [2].

The total magnetic field over the entire site varies by approximately 15 nanoTeslas and the vertical gradient varies by approximately 2 nanoTeslas. A few anomalies are assumed to be associated with prairie dog activity. Shallow and intermediate depth electromagnetic induction data yielded background conductivity levels from approximately 20 to 40 milli-Siemens/meter (medium range values). The EM measurements can be interpreted as the subsurface being uniform to a depth of 3 to 5 meters. Two small sections in area #1 contained slight anomalies and will not be used for target pits. A highly anomalous area was detected in the resistivity/induced polarization data. Analysis of the data determined that the anomaly was a near surface feature (within 2 meters).

Refraction seismic data indicated that the average soil thickness was approximately 5 meters. The east side of area #1 appears to be a 3-layer condition with bedrock at 1.5 meters. The west side, assumed to be a 2-layer condition with minimal dip has a maximum of 8 meters of soil. Verification of the predicted values by the seismic refraction method were made with several auger holes. Limited video pulsed GPR data were acquired and determined that imaging of shallow targets was possible.

4. SITE CHARACTERIZATION: GENERAL

Two types of geophysical technologies were involved with the site characterization at the Rabbit Valley GPER: ground penetrating radar and magnetic. This entailed three different data collection techniques: airborne, vehicular based and man portable. The purpose of these surveys was two-fold. One goal was to provide an assessment of the equipment's accuracy, resolution and target detectability; the other was to establish a large-scale baseline data set on the undisturbed areas. This will allow before/after comparisons as more artifacts are buried in the future.

The airborne survey was flown by Airborne Environmental Systems (AES), a division of Era Aviation, Inc., with their "chirped" FM-CW GPR. The ground towed magnetic survey was conducted by Geo-Centers, Inc. with their Surface Towed Ordnance Locating System (STOLS™). The ground based survey was carried out by STL with the DOE stepped FM-CW GPR. The site characterization for all three surveys took place during September, 1993. The size of the surveyed area for each method depended upon the practical limitations of the system, time and cost. STL had knowledge of all six target locations since they acted as the principal investigator and could acquire data only over a limited portion of the site. Geo-Centers had no prior knowledge of the target locations. AES was given the location of one target (Table 1, #4) for airborne calibration purposes. After completing a final target detection report, the exact target locations were given to AES who then reprocessed certain images.

The discussion on each survey contains a description of the equipment, test setup and survey method. A site map indicates the areas surveyed along with target hit locations and an analysis of the data. A summary of the test results and several examples are included.

5. SITE CHARACTERIZATION: AIRBORNE GPR SURVEY

5.1. Background

AES has installed a "chirped" FM-CW GPR, known as the EMS-20 radar on a Bell 212 helicopter for airborne mapping of subsurface phenomena [3]. Applications for this system have involved the detection of man-made objects at hazardous waste sites and landfills. The mapping of subsurface plumes of refined hydrocarbons has also been accomplished.

5.2. Airborne GPR: System Description

The EMS-20 system consists of a radar unit, an in-flight processor, a color display and a navigation system which are rack-mounted in the helicopter. The "chirped" FM-CW radar operates at a center frequency of 503 MHz, with a bandwidth of 500 MHz. It is based upon a frequency-modulated, pulse-compression technique. The pulse repetition frequency or PRF is 100 Hz. This yields a system time-bandwidth product of 5×10^6. The continuous power output is 1 watt. The effective resolution is 0.7 meters. It must be emphasized that the performance and success of the airborne GPR is always site dependent. Specifications for the EMS-20 radar are listed in Table 2.

The system incorporates bistatic helical antennas with an oppositely polarized transmit/receive configuration. The radar unit is integrated with a Global Positioning System (GPS) operated in a differential mode. The differentially corrected GPS circular position error is typically less than 5 meters.

The on-board processor digitizes the received "analog radar echoes" and records this raw data on a standard VHS tape. The processor then performs a Fast Fourier Transform (FFT) and displays the radar returns in real time. Color images appear on a graphics monitor. An operator can apply several gain functions to the FFT data and can use an event marker to tag suspected targets. The on-board processed data is recorded on a separate VHS tape. GPS time and position as well as helicopter attitude and speed are also recorded.

Generally, two types of surveys are conducted with the airborne GPR: reconnaissance and close grid. In the reconnaissance mode, parallel flight lines are flown over a site. Flight lines are typically spaced at 30 m for survey altitudes of 60 to 90 m; this yields a 90% coverage. Absolute position and depth can be ambiguous because of the cross axis foot-print. If a set of orthogonal flight lines are flown, i.e. close grid, the data can be combined to minimize the cross axis error. If flight line spacing is reduced to 15 to 24 m a 10% overlap coverage of the site is obtained. A resulting circular error of 5 meters is typical.

A more detailed description of the AES GPR and a discussion of airborne surveys can be found in reference [3]. Figure 6 is a picture of the AES EMS-20 radar on a Bell 212 helicopter in action at the Rabbit Valley GPER.

TABLE 2
EMS-20 RADAR SYSTEM SPECIFICATIONS

Type	FM-CW chirped
Center Frequency	503 MHz
Pass Band	500 MHz (250-750 MHz)
Puls, Length	5 ns
Pulse Repetition Frequency	100 Hz
Continuous Power	1 Watt
Time-Bandwidth Product	5 x 10^6
Effective System Gain	>160 dB
Cross-Axis Foot-Print	150 feet @ 300 feet AGL
Effective Resolution	0.7 m
Antenna Arrangement	Bistatic Polarized Helical
Survey Rate: 90% coverage,reconnaissance 10% overlap, close grid	 100 acres/hour 200 acres/day

5.3. Airborne GPR: Data Format

The raw radar data on VHS tape is transferred to a computer for viewing, processing and analysis. The processing software can display the data with 256 colors, but in general practice 24 or less are used. The color codes represent the intensity of the radar return. The low end of the scale, black to green, represents minimal propagation through the soil. The high end of the scale, red to white, represents radar echoes that are several magnitudes above the average return of the soil. The threshold limits from one color level to another is adjustable. A standard difference is 2 dB.

A portion of the flight line or the entire line can be analyzed. When radar responses from the two sets of orthogonal data are combined, correlated targets are adjusted to correct for cross-track position error. The dielectric constant of the soil, obtained from radar calibration data, is also considered in the processing. The depth of targets can be estimated and the error is directly related to the accuracy of the dielectric constant.

5.4. Airborne GPR: Test Plan

The airborne GPR acquired data over the entire Rabbit Valley GPER. A closed grid survey was flown with approximately 22.8 meter spacing between flight lines. Nineteen flight lines were flown from north-to-south and twenty-four flight lines from west-to-east. The total flying time was 5.3 hours for the actual survey which included a functional test flight for the radar and ferry time for fuel during the survey.

5.5. Airborne GPR: Test Results[3]

The nature of the soil and stratigraphy at the site, especially the clay strata, limits the penetration depth. The estimated penetration depth at the site ranged from 2 meters in Area #2 to a maximum of 4 meters in Area #1. Figure 7 shows a radar record of an undisturbed area in which a clay lens is apparent. Figure 8 is a record taken over the large steel culvert (Table 1, target #4). Note the high intensity (white) echo from the corners of the culvert. Table 3 is a target report summary on the entire site for the airborne GPR. Figure 9 shows all target hits, depth and location. Target #4 was used for the depth calibration. The circular position error is better than 5 meters, generally 2-3 meters.

5.6. Airborne GPR: Conclusions

The major detriment to the performance of the ground penetrating radar is the variation in the extent and depth of the clay strata. It is generally variegated throughout the site, but is more prevalent in Area #2. Coupled with the clay there are also subsurface strata and conglomerates of rocks and rock strata, mostly limestone.

Dielectric constant variations in the soil is believed to range from about 6 on the surface to 12 to 16 for the clay strata. It is the clay strata that limits the penetration depth of the GPR. It is estimated that the average two-way attenuation value in the soil is on the order of 20 dB/meter. The rock, rock strata and outcroppings do not limit the depth of penetration, but they can be confused for a positive detection of buried man-made objects.

6. SITE CHARACTERIZATION: FM-CW GPR SURVEY

6.1. Background

STL has developed a stepped FM-CW GPR for high resolution imaging of subsurface objects [5]. The initial application of this unit was the detection and imaging of unexploded ordnance. In recent years the target types have been expanded to include hazardous waste storage containers [6,8], pipes and utility lines. Additionally, some field tests have been conducted where nonmetallic targets were of interest; these include the detection of dinosaur fossils and the mapping of animal burrows [7].

6.2. Stepped FM-CW GPR: System Description

The stepped FM-CW GPR is a portable, fully self-contained unit. It is comprised of three

[3]The airborne GPR survey test results and conclusions were based on reference [4].

separate pieces: the RF/antenna assembly, the computer assembly and a rechargeable battery box. It acquires, processes and displays data in a real-time mode, approximately 140 msec/sweep. The system operates over the frequency range of 196 - 708 MHz and the RF carrier is quadraphase modulated at 500 kHz. It has the capability to detect targets to depths of 9 meters with a range resolution of 20 centimeters. A 16-bit Analog-to-Digital converter is used to sample I & Q (phase coherent) data, yielding a system dynamic range of 96 dB. These parameters and the overall performance of the GPR are, as always, affected by the soil composition, dielectric constant, E_r, and attenuation factors. Specifications for the stepped FM-CW GPR are listed in Table 4.

The RF/antenna assembly contains the microwave electronics and antennas. A phase locked loop synthesizer generates the frequency output. The antennas are a dielectrically-loaded, cavity-backed design with a planar, 2-arm log spiral element. They operate over the entire frequency band of 196 - 708 MHz and are used bistatically with opposite circular polarization. Modulation circuitry and amplifiers are also contained in this assembly.

The computer assembly uses a 386-based computer to control the entire radar process. It initiates the RF "sweep" and data acquisition, performs a FFT and displays the data. The radar returns are shown on a Liquid Crystal Display (LCD) which can be viewed in direct sunlight. Data can be saved to floppy discs and hardcopies are obtained with a standard printer.

A more detailed description of the STL GPR and a discussion of stepped FM-CW radar can be found in reference [5]. Figure 10 is a picture of the STL GPR in action at the Rabbit Valley GPER.

TABLE 4
STEPPED FM-CW GPR SYSTEM SPECIFICATIONS

Type	Stepped FM-CW
Operating Frequency	196 - 708 MHz
Bandwidth	512 MHz
Number of Sample Points	128
Frequency Step Size	4 MHz
Modulation Frequency	500 kHz
System Dynamic Range	96 dB
Range Resolution (E_r = 4)	20 cm
Unambiguous Resolution (E_r = 4)	9 meters
Antenna Arrangement	Bistatic Log Spiral

Battery Life	6 hours
System Weight	40 kg
Survey Rate	0.5 acre/day

6.3. Stepped FM-CW GPR: Data Format

The GPR acquires data and produces depth profiles on the LCD. A frequency histogram is created as a result of an FFT being performed on the radar return signal.. This frequency information (time-domain pulse response equivalent) is displayed in two areas. A depth profile is displayed on the left portion of the screen and a frequency histogram of the current sample is displayed vertically on the right portion. (An onscreen marker is available to examine the individual records of previous frequency histograms.) The lower frequencies (closer targets, surface return) appear toward the top of the histogram and higher frequencies (deeper targets) toward the bottom. The horizontal axis of the depth profile represents lateral distance on the surface. The horizontal axis of the histogram is signal strength.

The intensity of the depth profile is determined by Gray-scaling the histogram with a variable 9-level Gray scale. This determines the minimum return amplitude required to "turn on" a pixel in the depth profile. The proportional amount of gray scaling is determined by threshold levels. The minimum threshold level of the Gray scale is adjustable. Peaks in the histogram below this level do not show up and larger amplitude returns appear as dark spots. The amount of clutter return displayed can be varied by adjusting this threshold.

Several other display parameter adjustments can be made to the depth profiles. A uniform gain or SCALE is used to raise the general level of the return. An exponential gain or RANGE GAIN is used to compensate for the exponential loss factor of the ground. The deeper information is amplified while the shallower information is attenuated. All parameter modifications are only performed on the displayed data. The stored, raw data remains intact.

The display also has a ruler to approximate the range of targets. Since the propagation velocity is affected by the dielectric constant, E_r, of the soil, the ruler increments or spacing is variable. This spacing is directly proportional to the square root of E_r of the soil. Setting a particular E_r value will determine the proper ruler spacing. The ruler assumes a constant E_r with depth. This ruler is not designed to be 100% accurate, but gives an estimation of depth.

A GPR test pit was constructed in Santa Barbara, California and is diagrammed in Figure 11. The standard test targets consist of seven square metal plates (12 inches x 12 inches) placed in a staircase fashion from one to seven feet deep. They are aligned parallel to the surface. The soil was composed entirely of sand. An example depth profile of the metallic targets is shown in Figure 12. Seven distinct target returns, evenly spaced horizontally and vertically, are clearly identified. Note the large peak in the histogram on the right that corresponds to the metal plate seven feet deep.

The GPR data can be presented in a alternate format. Adjacent depth profiles of a surveyed area are combined to create a reflectivity map. A reflectivity map is an X-ray like picture of a section of ground. All the range (radar reflection) information is integrated to create a plan view image. Reflectivity maps show the lateral location and strength of targets, but no depth information. Producing a reflectivity map requires that relative position information is acquired along with depth profile data. The position information is used to correlate the GPR data. This is useful in analyzing large areas. If an interesting section is found, the individual depth profiles can be examined for more details.

To acquire relative position information, a measuring wheel was mounted to the rear of the GPR. The wheel is attached to an optical encoder that interfaces to the radar control system. The radar control system is programmed to collect data at a specific distance interval. GPR data is then collected in adjacent lines, generally within a square survey area. Since the exact location of each individual radar reflection data point is known, it can be processed to create a reflectivity map.

A reflectivity map was created from data acquired on the test sand pit and is shown in Figure 13a. A standard color intensity mapping is used. The seven targets can be identified. This format was used on the processed Rabbit Valley data and is discussed in section 6.5. The reflectivity map data also can be displayed in a three-dimensional waterfall-type plot, see Figure 13b.

6.4. Stepped FM-CW GPR: Test Plan

The stepped FM-CW GPR survey at the Rabbit Valley GPER was concentrated in Area #1. The area was divided into 20 meter x 20 meter grids. GPR data were acquired in one direction with each grid. The spacing of the collection lines was the width of the GPR unit, 40 cm. Data were acquired every 12.5 cm along these lines. With these spacings and the typical terrain surface at Rabbit Valley, an actual survey rate of 1/3 of an acre per day was achieved. Because of the large amount of area involved, two stepped FM-CW GPRs were deployed.[4] Figure 14 shows the areas surveyed with the stepped FM-CW GPRs.

6.5. Stepped FM-CW GPR: Test Results

Similar to the airborne GPR results, the stepped FM-CW GPR was limited in depth penetration. The high dielectric constant and loss factors of the soil had a negative effect on the performance. The estimated penetration depth was 1 meter in area #2. In area #1 the deepest target was only 0.5 meters so only a rough guess can be made on the maximum penetration depth. This is 2-3 meters which is based upon the soil type and the results of the airborne GPR. Figure 15 is typical GPR depth profile over undisturbed area. Figure 16 is a GPR depth profile over the non-reinforced concrete cylinder (Table 1 target #2). Figure 17 is a GPR reflectivity map of the area around target #2. Figure 18 is a GPR reflectivity map of Area #1 in which target

[4]The DOE unit and the NEODTECHCEN unit. The NEODTECHCEN GPR was built by STL in 1989.

#2 and several other anomalies can be identified. Table 5 is a target report summary for the stepped FM-CW GPR. The position error is better than 0.2 meters.

6.6. Stepped FM-CW GPR: Conclusions

The conclusions for the stepped FM-CW GPR survey are basically identical to those of the airborne survey. Naturally occurring strata will limit the effectiveness of GPR especially in area #2. Area #1 is more desirable because of the thicker layer of sandy, silty soil.

7. SITE CHARACTERIZATION: MAGNETIC SURVEY

7.1. Background

Geo-Centers, Inc. has integrated a sensor array of magnetometers with an all-terrain vehicle for collection of total field magnetic anomaly data [9]. The "Surface Towed Ordnance Locating System" or STOLS™ was originally developed for the Department of Defense for ordnance detection and has since been redesigned as part of the Technology Transfer commercialization effort. Location of hazardous waste containers along with other environmental characterization applications for this system are currently being explored.

7.2. Magnetometer Array: System Description

STOLS™ is comprised of three main components: the sensor controller, the data logger computer and the navigation system. The data logger and navigation system are housed in an off-road single passenger vehicle. The sensor controller and sensors are mounted on a towed platform. The vehicle and tow platform are chiefly constructed out of non-magnetic materials including high strength aluminum, bronze and titanium. The engine block is magnesium. This is required in order to minimize the magnetic self-signature. The system can collect very high density data (over 100,000 points per acre) at speeds up to 5 miles per hour (8 km per hour). Specifications for STOLS™ are listed in Table 6.

The sensor platform is equipped with an array of seven Geometrics 822 Cesium vapor optically pumped total field magnetometers. They are mounted at 0.5 meter intervals and can be adjusted from 15 to 45 cm off the ground. A sensor control computer acquires data from the magnetometer array at a 20 Hz rate. It also monitors power levels, sensor current levels and platform orientation. Orientation of the sensor platform is measured with a compass and pitch and roll inclinometer.

A ruggedized PC computer is used for data acquisition and operator interface. It receives "data packets" from the sensor controller computer and monitors the validity of all data. This data is recorded on removable hard disks. It also receives position information from a differential GPS receiver. The GPS is used for navigation and to synchronize the data acquisition cycle. This allows for rapid data collection with sub-meter accuracy in determining anomaly positions.

A more detailed description of the STOLS™ and a discussion on magnetic theory can be found in reference [10]. Figure 19 is a picture of the Geo-Centers, Inc. STOLS™ at the Rabbit Valley GPER.

TABLE 6
MAGNETOMETER ARRAY (STOLS™) SPECIFICATIONS

Type	Cesium vapor (7 each)
Survey Rate	3.5 - 5 miles per hour (5.6 - 8 km per hour)
Coverage	25 - 35 acres/day
Data Density	100,000 points/acre @ 3.5 MPH
Position Accuracy	< 0.5 meters
Power Supply	120 Volt, 1000 Watt unit

7.3. Magnetic Survey: Data Processing and Format

Image processing of the magnetic and GPS data is done on a Unix workstation to produce high resolution magnetic maps. These images are created through a four stage process: data positioning, signature isolation, interpolation and display. The data positioning process correlates the GPS and compass data with the magnetic field data and assigns a latitude, longitude and elevation to each magnetometer data point. A linear interpolation is used since the GPS updates the position at a 1 Hz rate while the magnetic data is recorded at 20 Hz.

The signature isolation process removes the effects of the Earth's magnetic field from the data. Total field magnetometers can not differentiate between the primary or secondary magnetic fields or their directions. The output is a vector sum of all magnetic sources. Whenever STOLS™ performs a magnetic survey a reference magnetometer records the variations of the Earth's ambient magnetic field outside the survey area. This is then subtracted from the sensor platform data to yield the magnetic field contributions of ferromagnetic objects.

The interpolation stage takes the magnetic anomaly data and interpolates it onto a grid. The grid is defined with 10 cm spacings and uses a nearest neighbor algorithm. This allows a standard format for display and additional image processing.

The display stage maps the magnetic anomaly levels in either gray scale or pseudo-color. Several image processing techniques can be applied to the data that include image enhancement filters, edge detection and intensity-based region segmentation. Point dipole modeling can be applied when isolated, non-overlapping anomalies are present. In general, a semi-automated target analysis algorithm is performed and a target map and report listing are issued for a given survey area.

7.4. Magnetic Survey: Test Plan

The STOLS™ acquired data over 24 acres of the site. Complete coverage of Areas #1 & #2 were made with parallel east-west runs. The grid spacing of these runs was 4 meters. The survey was accomplished in two days. Figure 20 shows the area covered by the towed magnetic survey.

7.5. Magnetic Survey: Test Results[5]

The towed magnetometer array system detected the three metallic buried objects. Other magnetic anomalies at the site were very minimal with some being caused by surface clutter. Figure 21 is a magnetic data map of Area #2 showing three anomalies that correspond to known buried artifacts. Figure 22 is a close up magnetic data map of the large steel culvert (Table 1, target #4). Table 7 is a target report summary for the magnetic survey. The position error is better than 0.5 meters.

7.6. Magnetic Survey: Conclusions

The performance of the STOLS™ unit at the Rabbit Valley GPER was excellent. Since the site has a low magnetic background, the placement and detection of new artifacts should be easily accomplished. The data acquired in areas #1 and #2 will serve as baseline information and assist in determining locations for the future artifacts.

8. SITE CHARACTERIZATION: PHOTOGRAPHIC INFORMATION

Various photographs were taken of the geophysical test equipment at the site. Each 20 m x 20 m area that was surveyed with the stepped FM-CW GPR was photographed for documentation purposes. A plan-view video recording of the entire site was made during the airborne GPR survey. This is referred to as "optical data" by AES and is on standard VHS tape.

9. OTHER DOE GEOPHYSICAL SURVEYS

Currently, several other extensive geophysical studies are being conducted at the GPER for the DOE. These include an airborne EM survey, a time-domain EM survey, a VLF EM mapping survey, a resistivity survey and a proton magnetic survey. Preliminary results of these surveys have been used in the conclusions for this paper. The final analysis and results of these additional surveys will be published soon and will be included in the Rabbit Valley GPER database.

[5]The magnetic survey test results and conclusions were based on reference [10].

10. FUTURE PLANS/CONCLUSIONS

Upon conclusion of the other DOE geophysical studies, more artifacts will be buried at the Rabbit Valley GPER. During fiscal year 1994, several geophysical surveys are planned to be repeated. The main purpose of these tests will be to conduct A/B comparison experiments. Public disclosure of the results and access to the geophysical database for the Rabbit Valley GPER should begin in late 1994. Use of the site should also commence during this time period.

The format of the magnetic and GPR data is ideal for a database. By combining this data with USGS maps and other geophysical tomography data a geophysical GIS database for general site characterization can be created. This is a natural extension of the data fusion idea that has arisen in recent years. The addition of results from other geophysical techniques makes this database a more powerful tool. The applications are obvious for environmental restoration and hazardous waste management. Such fields such as paleontology and archeology may also benefit from this type of database.

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12. REFERENCES

1. ----, Topographical map: "Ruby Canyon Quadrangle, Ruby Canyon, Colorado-Mesa County," United States Department of the Interior Geological Survey (USGS), 1968.

2. ----, "Rabbit Valley Geophysical Test Area geophysical background characterization of sub-area #1 and subsequent target emplacement," Chem-Nuclear Geotech (Geophysical Projects Group) for the U.S. Department of Energy, Grand Junction Projects Office, July 1991.

3. Cameron, R.M., "Development and application of airborne Ground Penetrating Radar for environmental disciplines," Ninth Thematic Conference on Geologic Remote Sensing, Pasadena, California, USA, February 8-11, 1993.

4. -----, Airborne Environmental Systems (AES), a division of Era Aviation, Inc., "Airborne Ground Penetrating Radar Survey at the Rabbit Valley Geophysical Performance Range," for Special Technologies Laboratory, November 22, 1993.

5. Koppenjan, S.K., and Bashforth, M.B., "The Department of Energy's Ground Penetrating Radar (GPR), an FM-CW system," Underground and Obscured Object Imaging and Detection, SPIE Proceedings, vol. 1942, April 15-16, 1993.

6. Bashforth, M.B., and Koppenjan, S.K., "Ground Penetrating Radar applications for hazardous waste detection," Underground and Obscured Object Imaging and Detection, SPIE Proceedings, vol. 1942, April 15-16, 1993.

7. Koppenjan, S.K., and Bashforth, M.B., "Ground Penetrating Radar applications: Department of Energy case studies," Underground and Obscured Object Imaging and Detection, SPIE Proceedings, vol. 1942, April 15-16, 1993.

8. Koppenjan, S.K., and Bashforth, M.B., "GPR applications for hazardous waste detection," Ninth Thematic Conference on Geologic Remote Sensing, Pasadena, California, USA, February 8-11, 1993.

9. Foley, J.E., "Environmental Characterization with Magnetics and STOLS," unpublished, submitted to IEEE Transactions on Geoscience and Remote Sensing, November 12, 1993.

10. Foley, J.E., Geo-Centers, Inc., "STOLS survey at Rabbit Valley," for Special Technologies Laboratory, November 26, 1993.

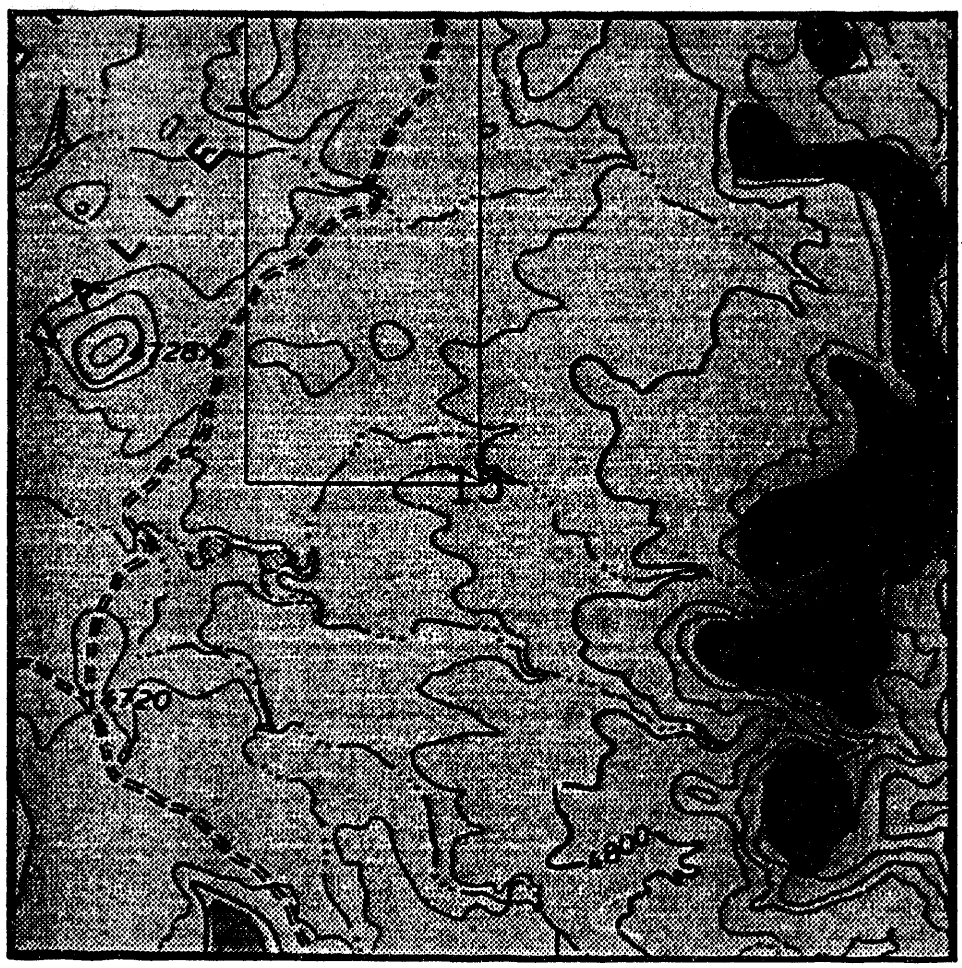


FIGURE 1. Rabbit Valley site from USGS map.

FIGURE 2. The Rabbit Valley Geophysical Performance Evaluation Range

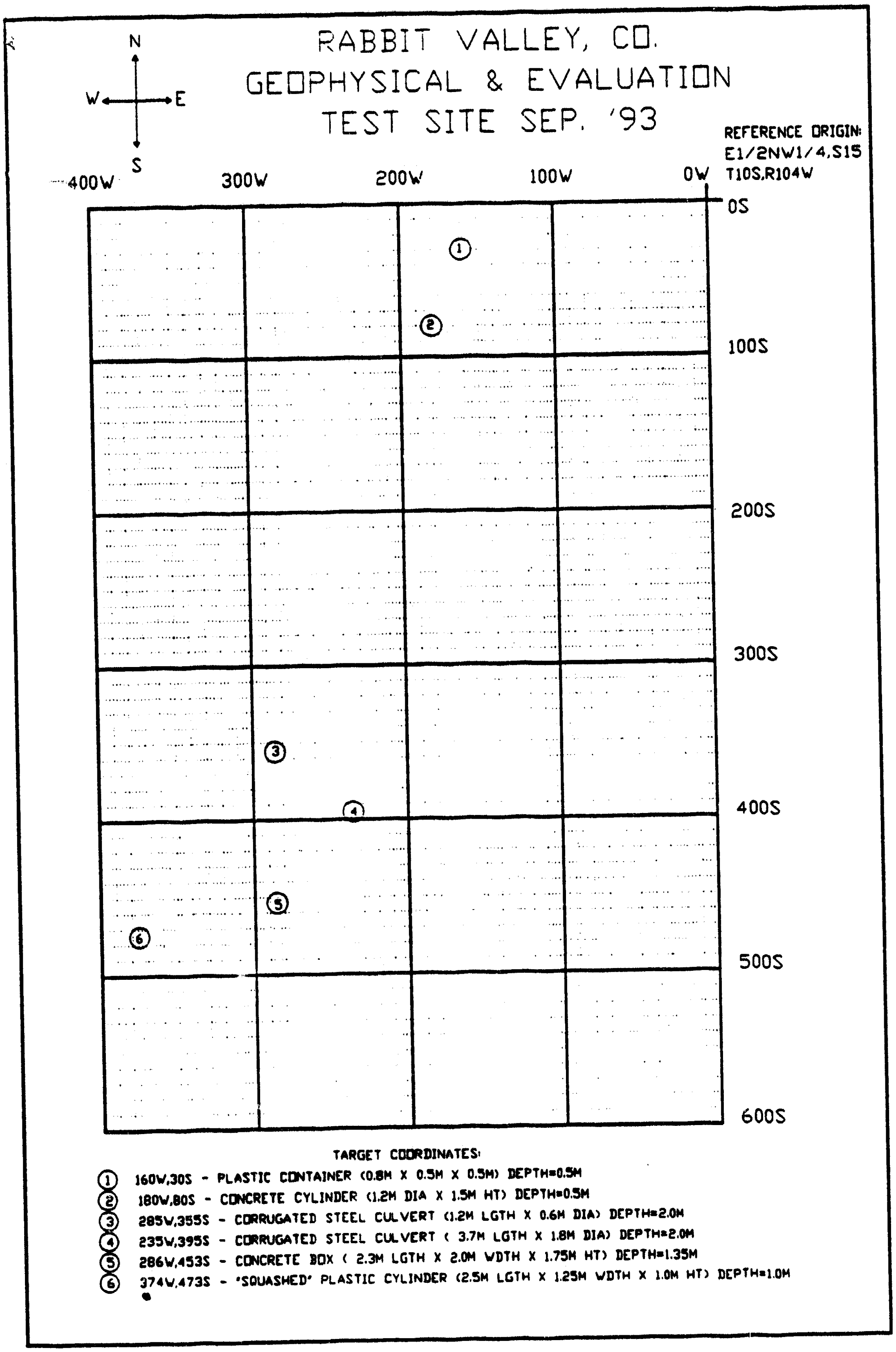


FIGURE 3. Rabbit Valley GPER, site plan with buried artifact locations.

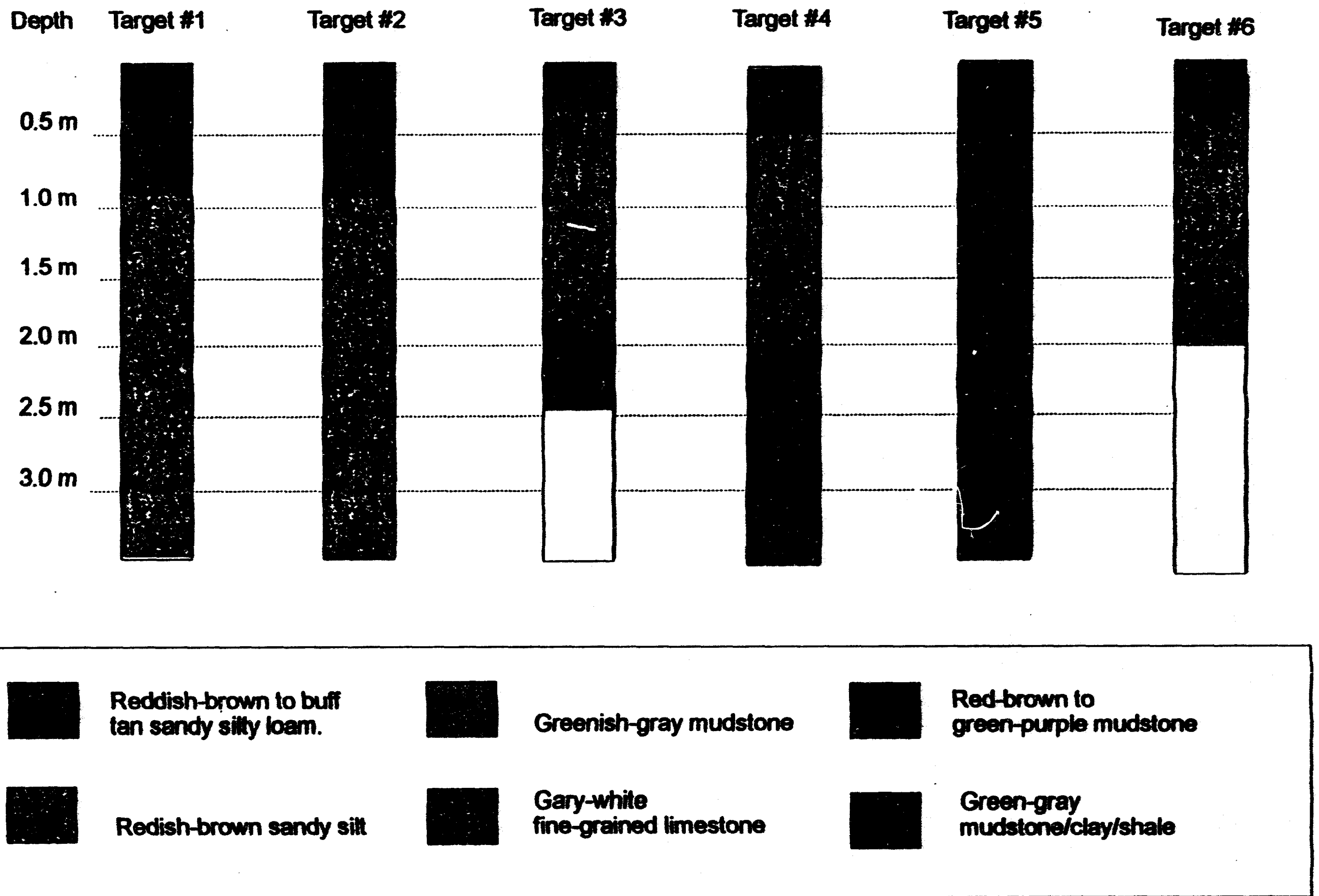


FIGURE 4. Soil lithology from target pits.

FIGURE 6. AES system, EMS-20 radar on a Bell 212 helicopter.

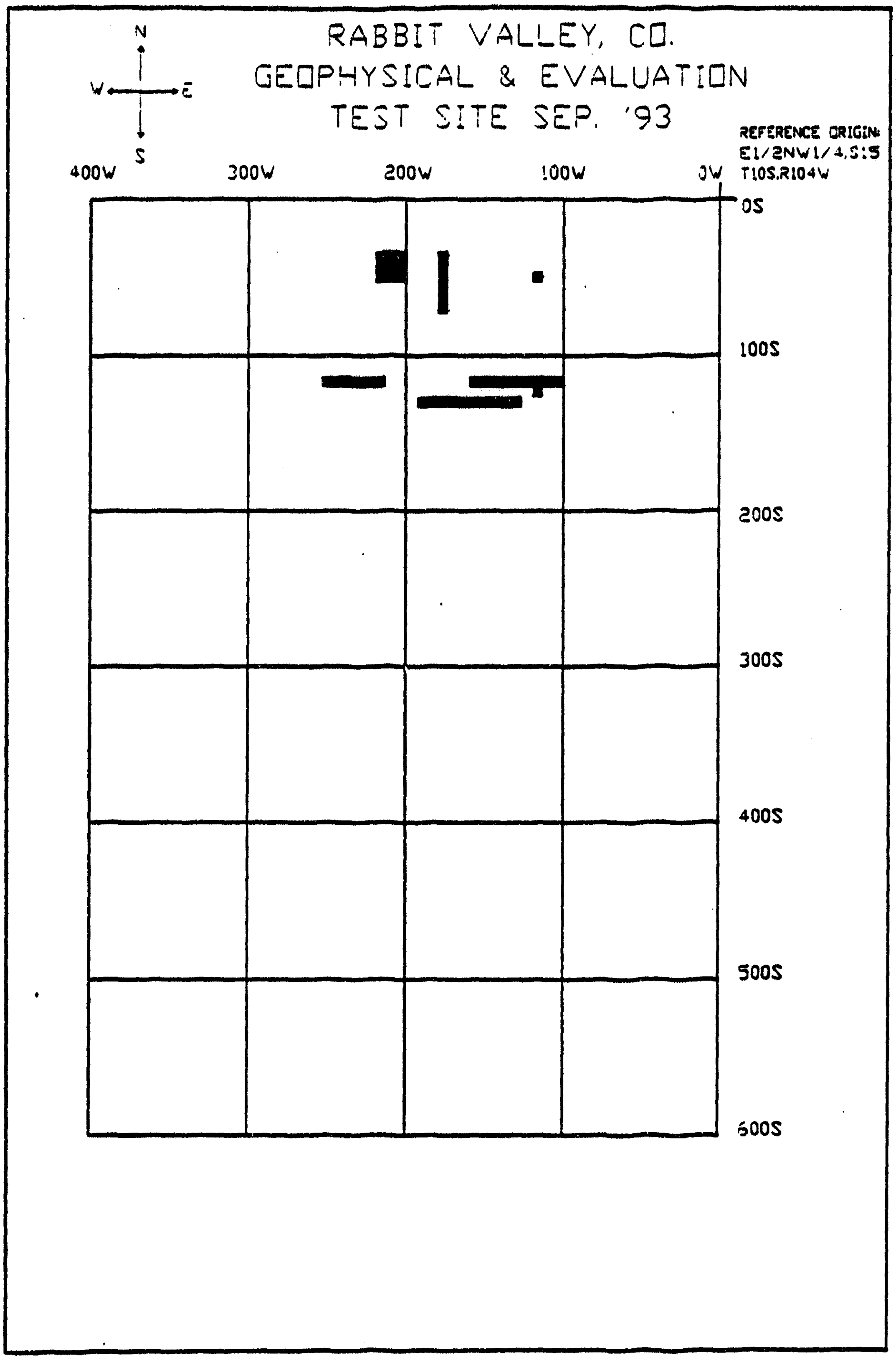
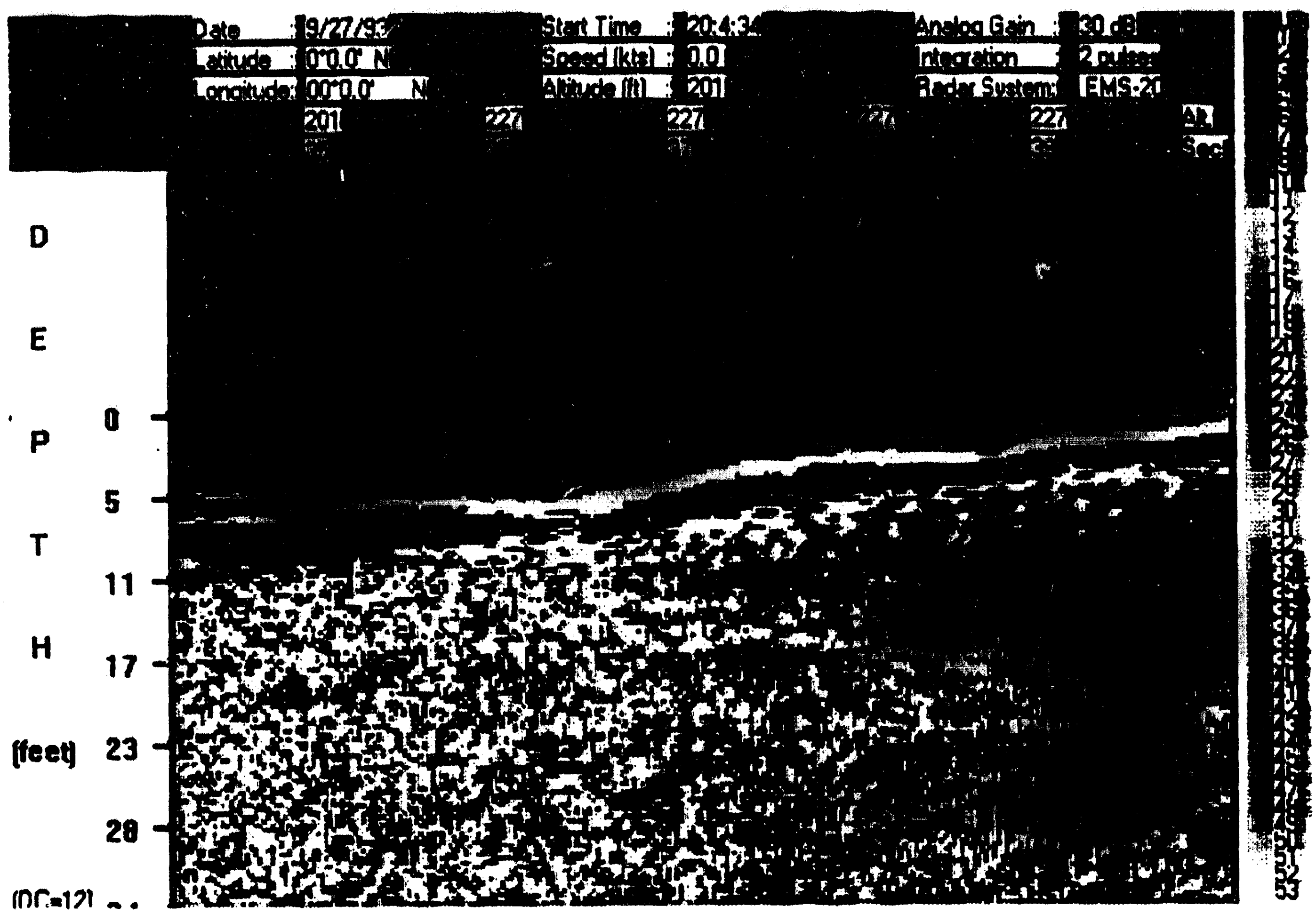


FIGURE 5. **Site plan with anomalous areas from background measurements.**



LINE: N ⇒ S 1 FRAME: 1

SPEED:	**23.22 FT/SEC**	**7.08 METERS/SEC**
RANGE:	**118.46 FT**	**36.11 METERS**
RANGE SCALE:	**18.22 FT/INCH**	**2.19 METERS/CM**

DIFFERENTIAL GPS POSITION

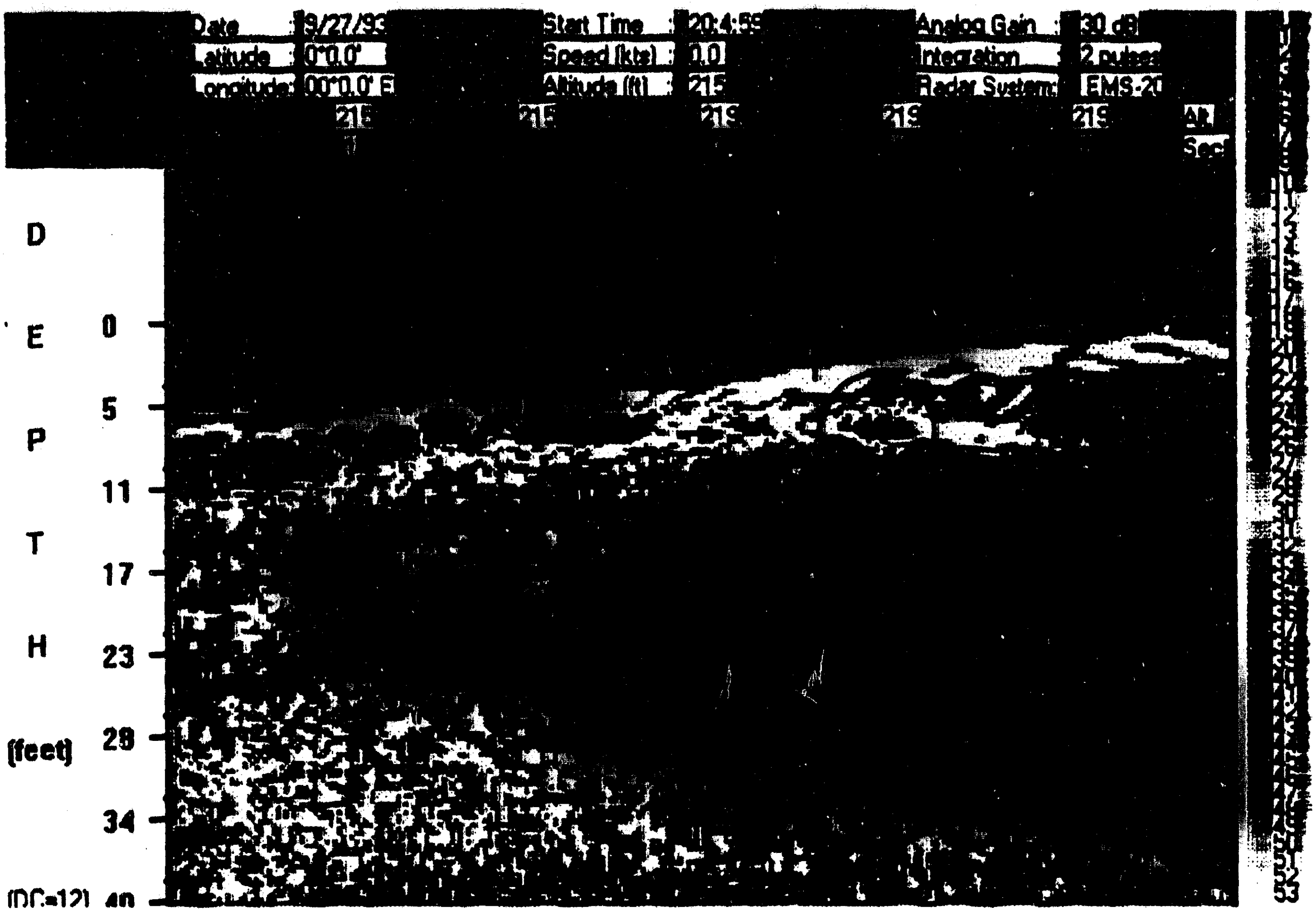
TIME: **LATITUDE:** **LONGITUDE:**

RANGE (METERS) AND BEARING TO TARGET FROM NE BENCHMARK

RANGE: ____________ **BEARING (TRUE):** ________

COMMENTS:

FIGURE 7. Typical airborne GPR data profile over undisturbed area.



LINE: N ⇒ S 1 FRAME: 6

SPEED:	**23.22 FT/SEC**	**7.08 METERS/SEC**
RANGE:	**118.46 FT**	**36.11 METERS**
RANGE SCALE:	**18.22 FT/INCH**	**2.19 METERS/CM**

DIFFERENTIAL GPS POSITION

TIME: 20:05:03.69 LATITUDE: 39⁰ 11' 40.92" LONGITUDE: 108⁰ 59' 08.64"

RANGE (METERS) AND BEARING TO TARGET FROM NE BENCHMARK

RANGE: ____________ BEARING (TRUE): ________

COMMENTS:

FIGURE 8. Airborne GPR data profile over Target #4, steel culvert 2m deep.

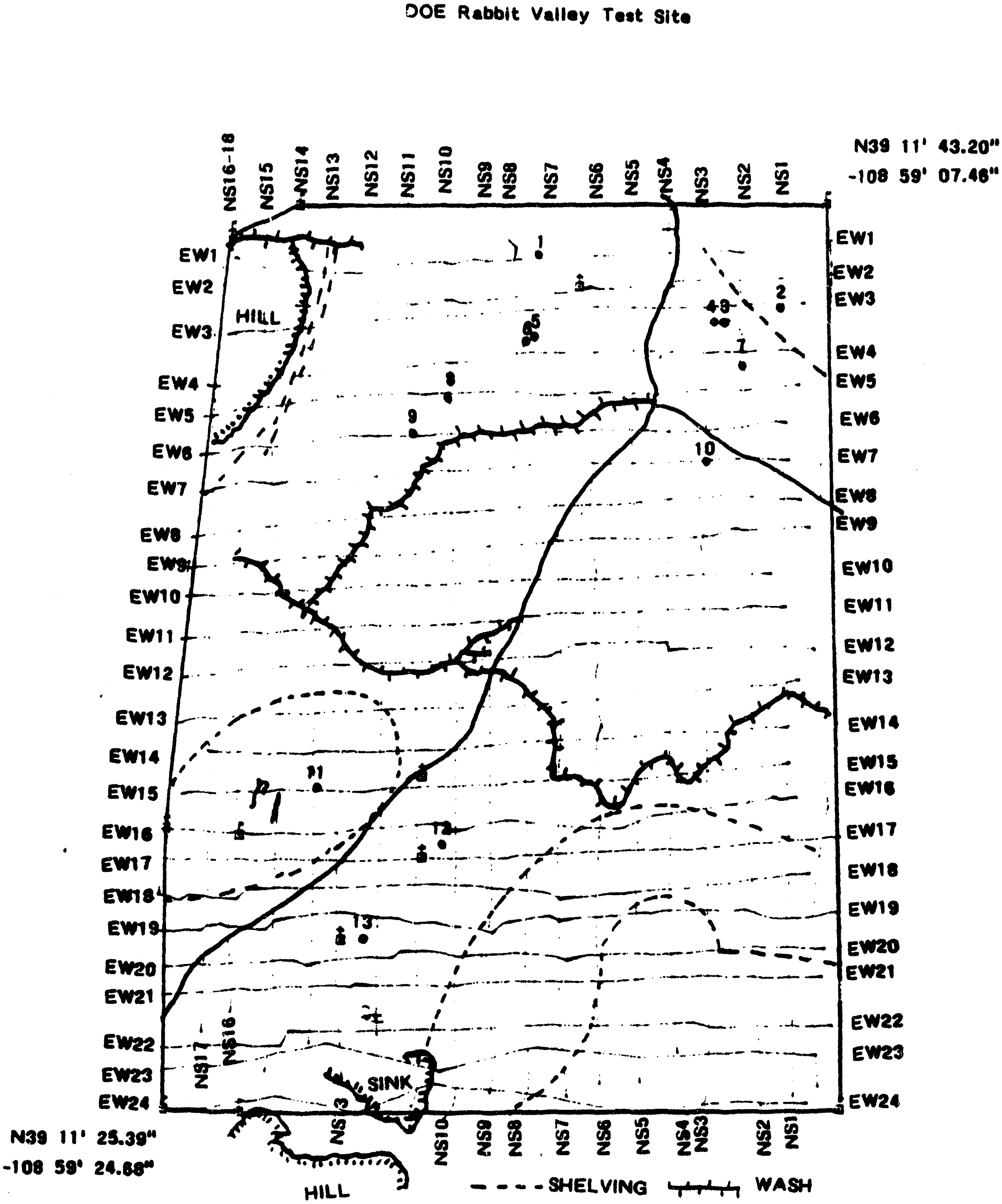


FIGURE 9. Target hits and location for airborne GPR.

TABLE 3 Target Report for the Airborne GPR Survey.

TARGET NUMBER	N ⇒ S FRAME	W ⇒ E FRAME	RANGE[1] (METERS)	BEARING[2] (TRUE)	N ⇒ S[3] RANGE	E ⇒ W[4] RANGE	COMMENTS
1	7 - 6/7	1 - 11	178.1	259.7	36.2	173.5	
2	1 - 6/7		84.3	199.4			
3 & 4	2 - 4 3 - 15		(3): 95.1 (4): 100.9	(3): 220.0 (4): 224.8	(3): 74.3 (4): 73.3	(3): 57.9 (4): 67.9	
5 & 6	7 - 7/8 8 - 7	3 - 10 4 - 10	198.6	246.6	82.57 84.4	179.7 181.7	
7	2 - 8	4 - 14 5 - 12/13	112.0	207.7	97.2	51.6	
8	10 - 5 11 - 5/6/7	5 - 11 6 - 9	265.4	244.6	120.5	236.5	
9	11 - 10	6 - 13	290.0	242.0	143.8	250.8	
10	3 - 7	7 - 15	178.3	205.1	176.6	74.5	
11	13 - 18	13 - 8	442.3	221.8	356.5	282.4	52.3 m, 260°.4 from benchmark north-east of target
12	10 - 14 11 - 11/12	16 - 10/11 17 - 8/9	456.2	211.0	400.3	214.4	Steel culvert pipe buried 2 meters from top of pipe.
13	12 - 19/20	19 - 11 20 - 10/11	532.4	212.8	454.1	275.4	14.1 m, 92°.7 from benchmark due west of target

[1]. From Northeast Bench Mark unless otherwise noted

[2]. In Decimal Degrees from True North

[3]. Measured South along eastern survey boundary line

[4]. Measured West from North-South Boundary line on East Side.

FIGURE 10. The DOE stepped FM-CW GPR.

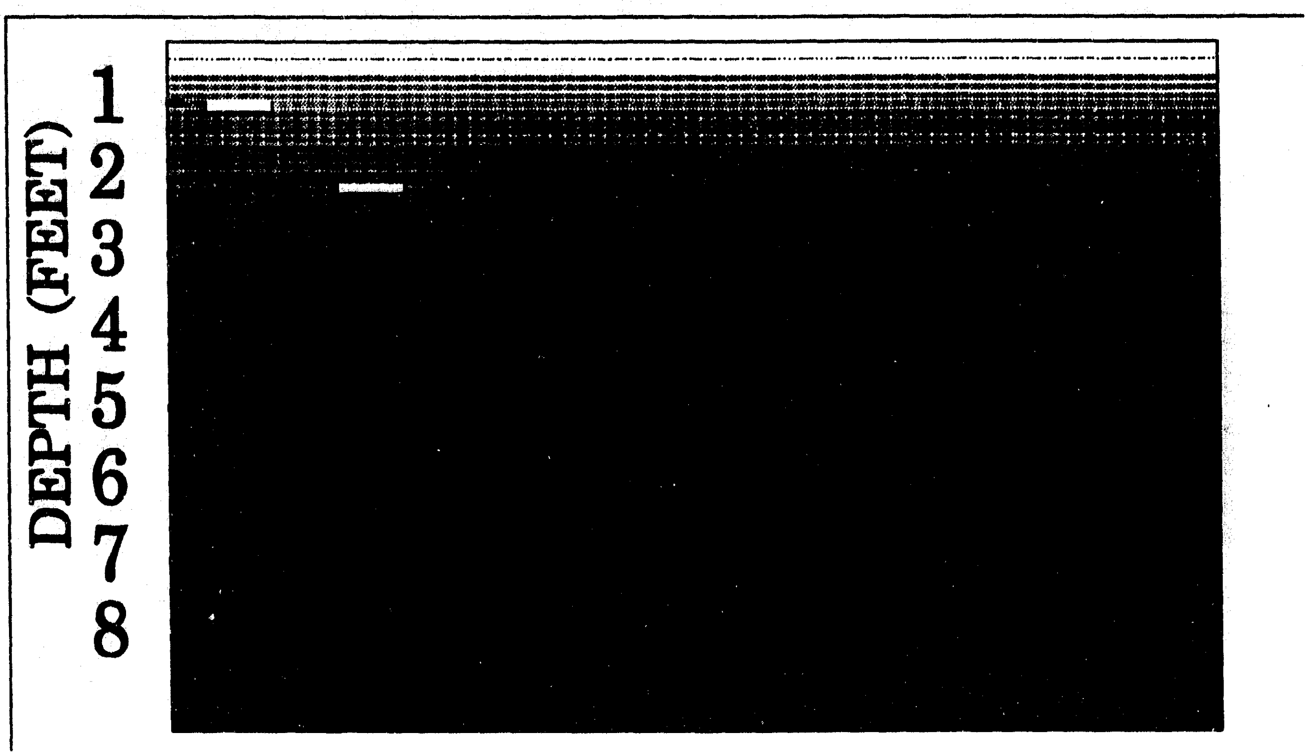


FIGURE 11. STL test sand pit, Santa Barbara, California.

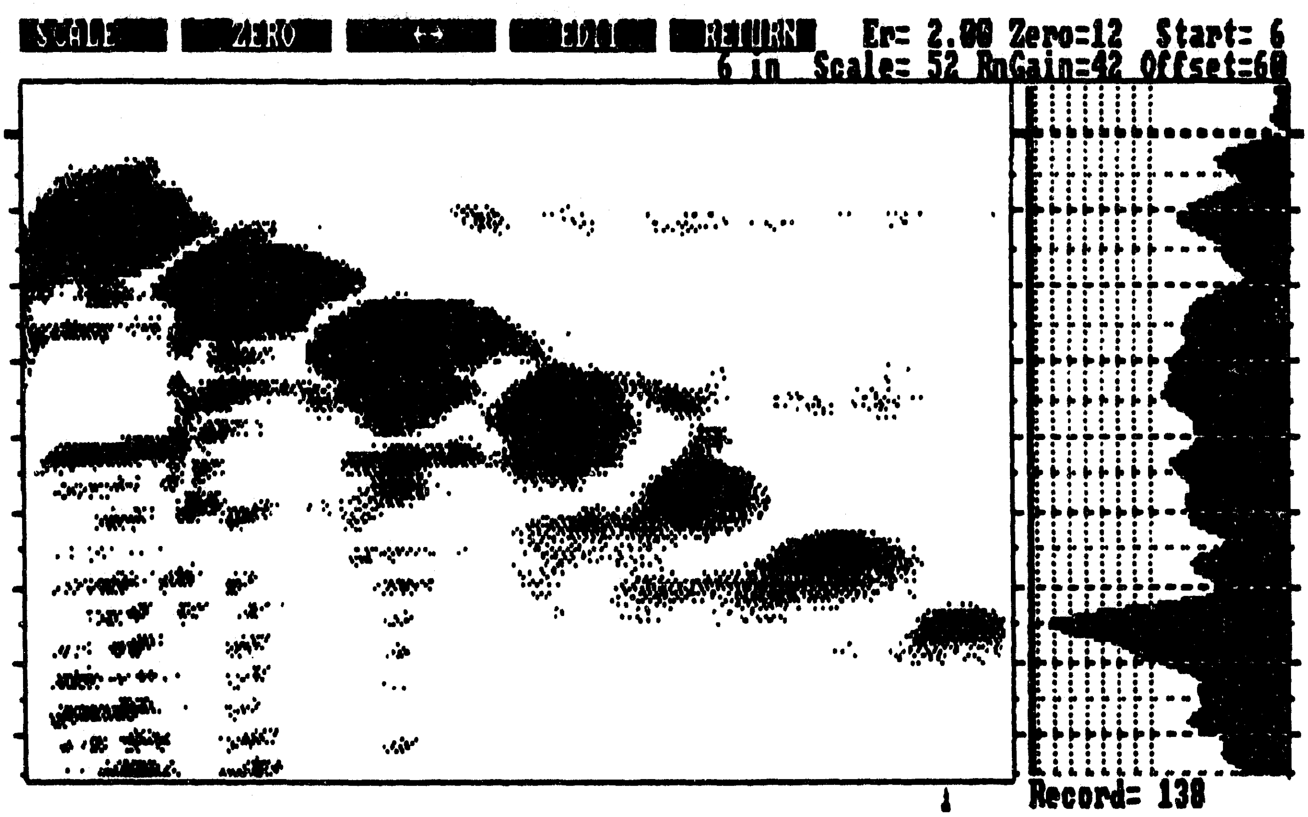


FIGURE 12. Stepped FM-CW GPR depth profile over test sand pit.

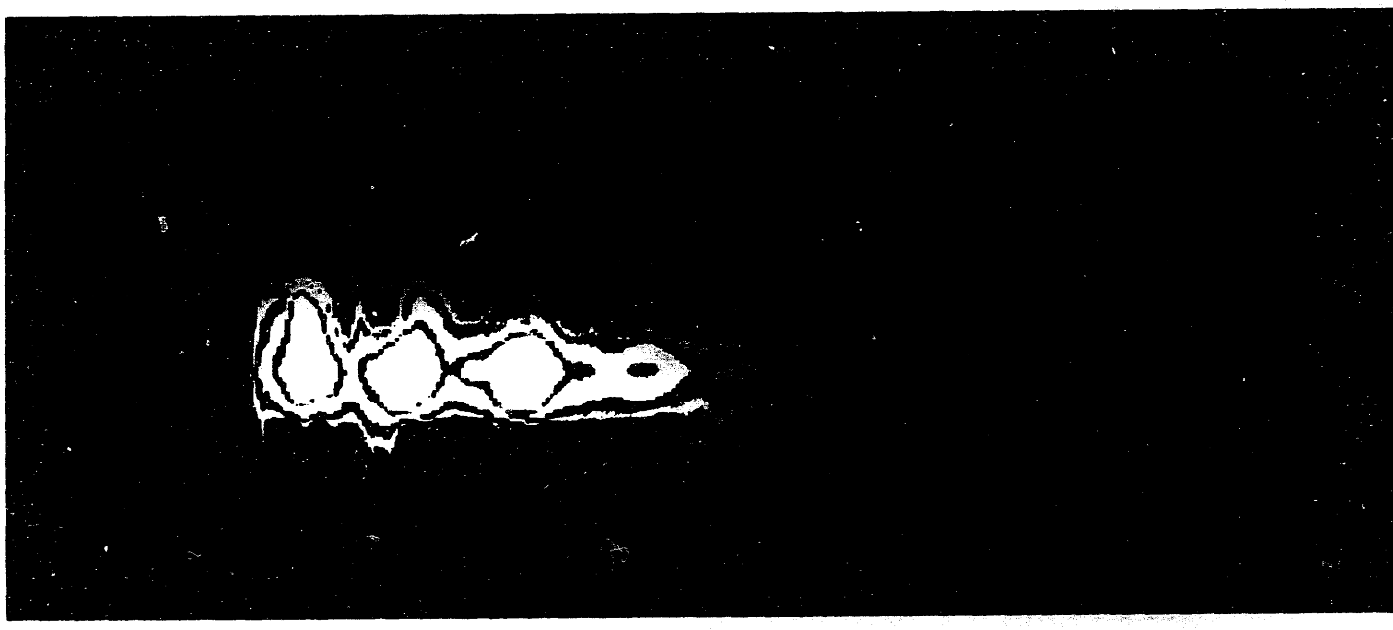


FIGURE 13a. Stepped FM-CW GPR reflectivity map of test pit.

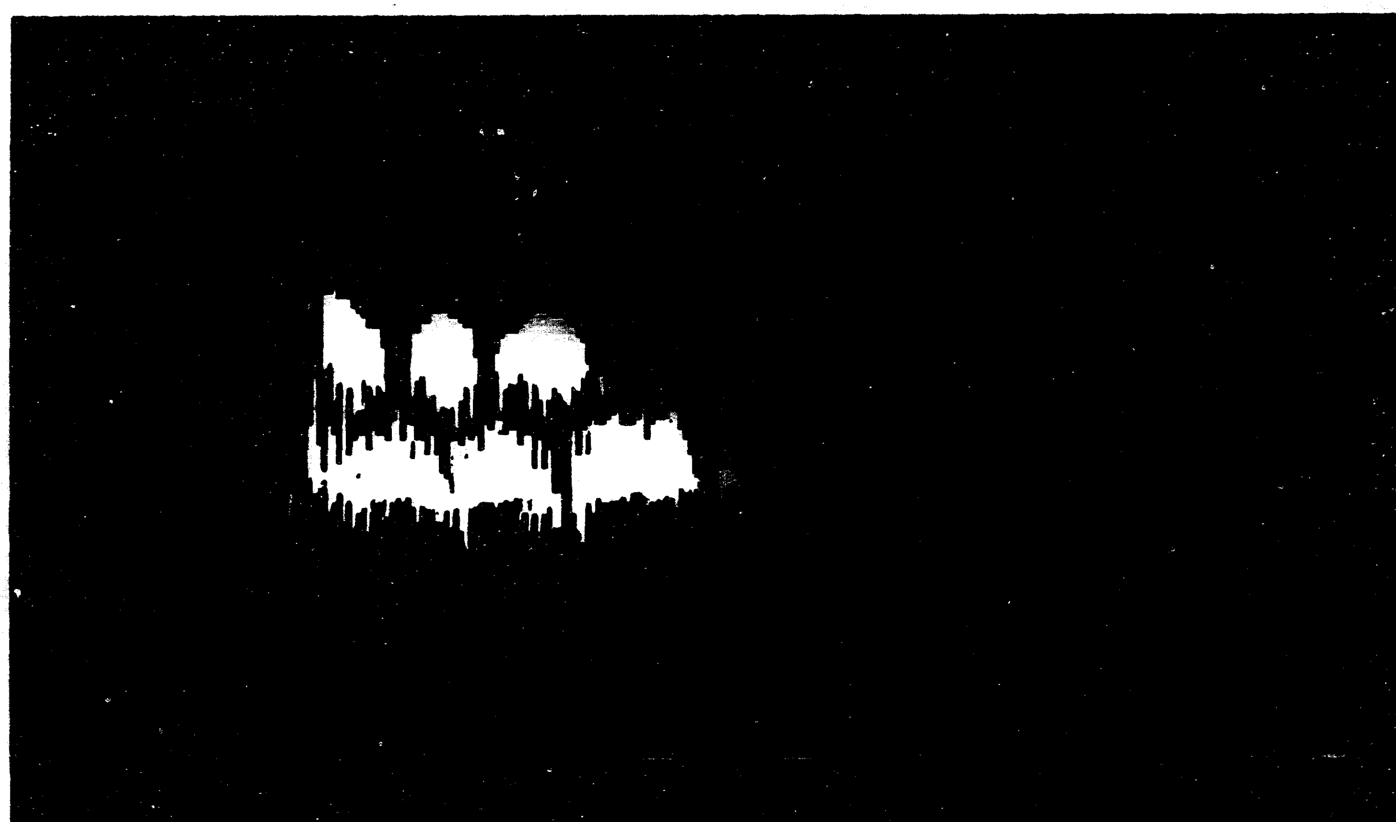


FIGURE 13b. Stepped FM-CW GPR waterfall-type reflectivity map of test pit.

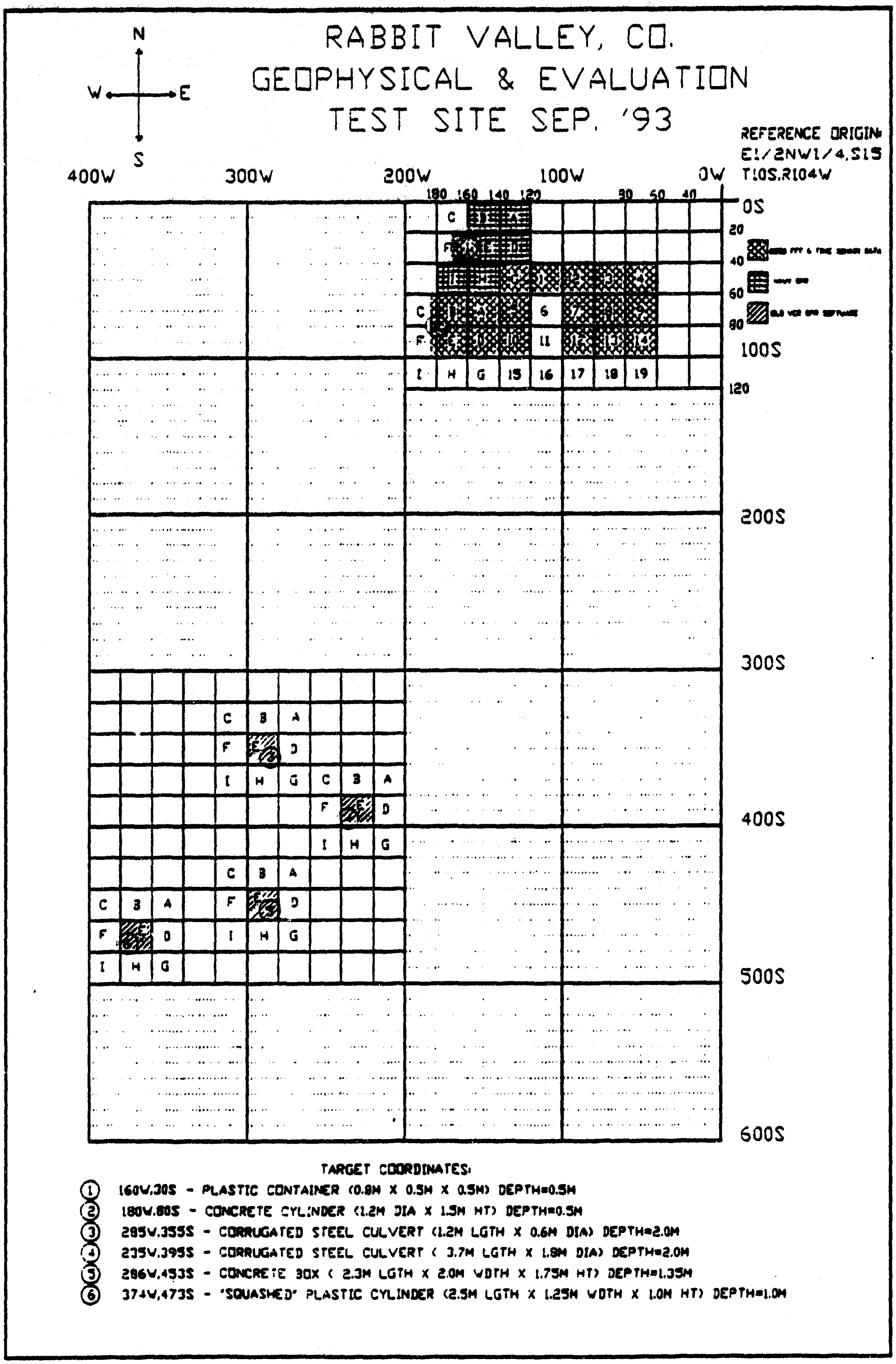


FIGURE 14. Areas surveyed with the stepped FM-CW GPR.

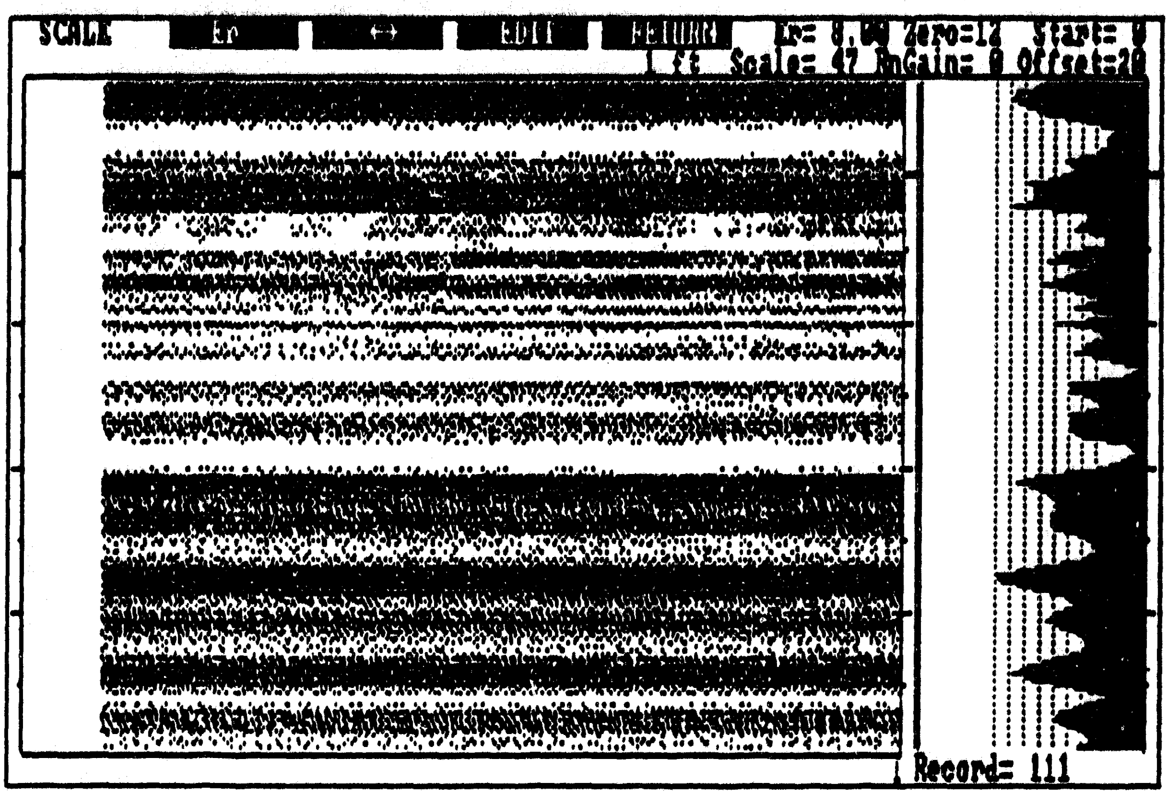


FIGURE 15. Typical stepped FM-CW GPR depth profile over undisturbed area.

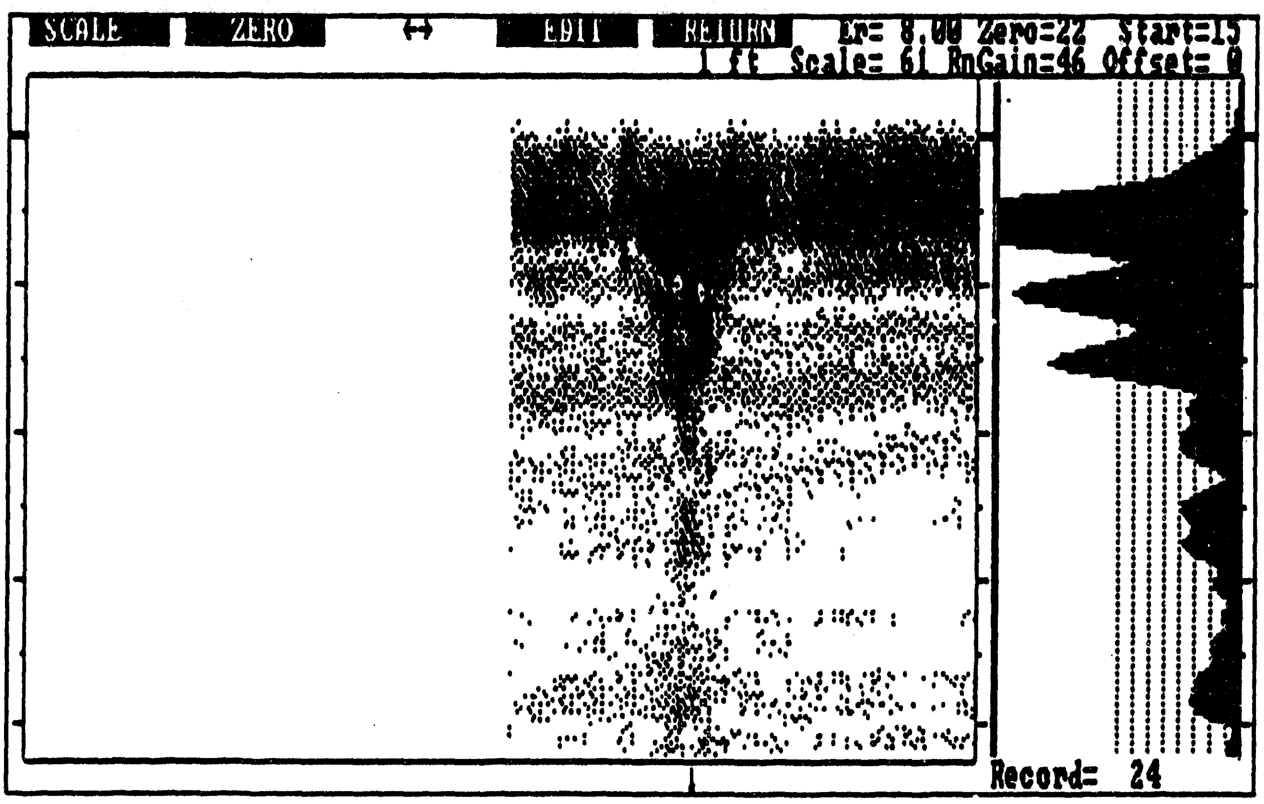


FIGURE 16. Stepped FM-CW GPR depth profilr from target #2,
non-reinforced concrete cylinder, 0.5m deep.

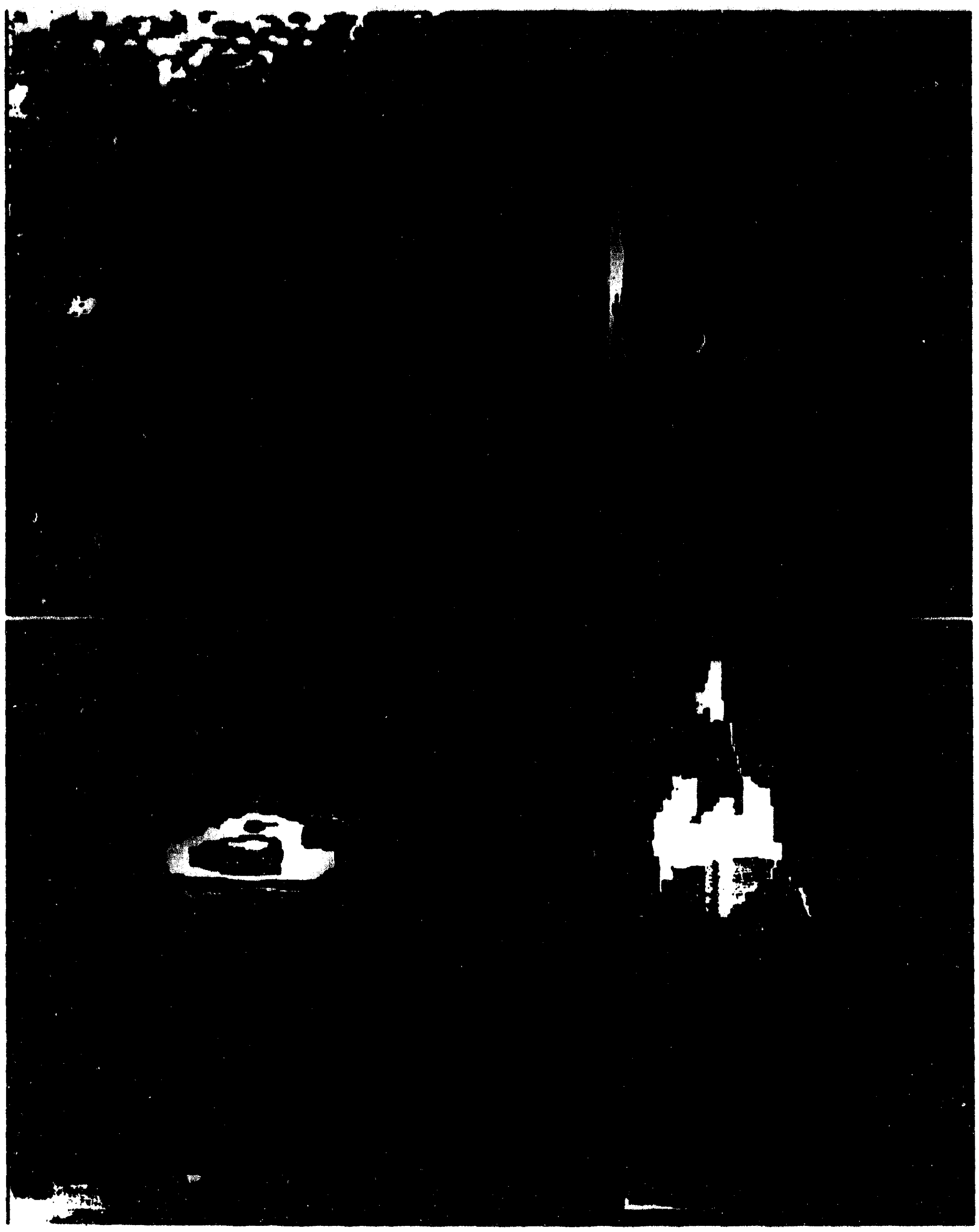


FIGURE 17 (bottom). Stepped FM-CW GPR reflectivity map of target #2.
FIGURE 18 (top). Stepped FM-CW GPR reflectivity map of area #1.

TABLE 5
TARGET REPORT FOR THE STEPPED FM-CW GPR

#	COMMENTS	DIELECTRIC CONSTANT	ESTIMATED DEPTH	ACTUAL DEPTH
1	Barely detectable.	8	0.5 m	0.5 m
2	Exact position determined.	8	0.5 m	0.5 m
3	Not found.	>10	-	2.0 m
4	Not found.	>10	-	2.0 m
5	Not found.	>10	-	1.35 m
6	Not found.	>10	-	1 m

FIGURE 19. Geo-Centers, Inc., Surface Towed Ordnance Locating System (STOLS™)

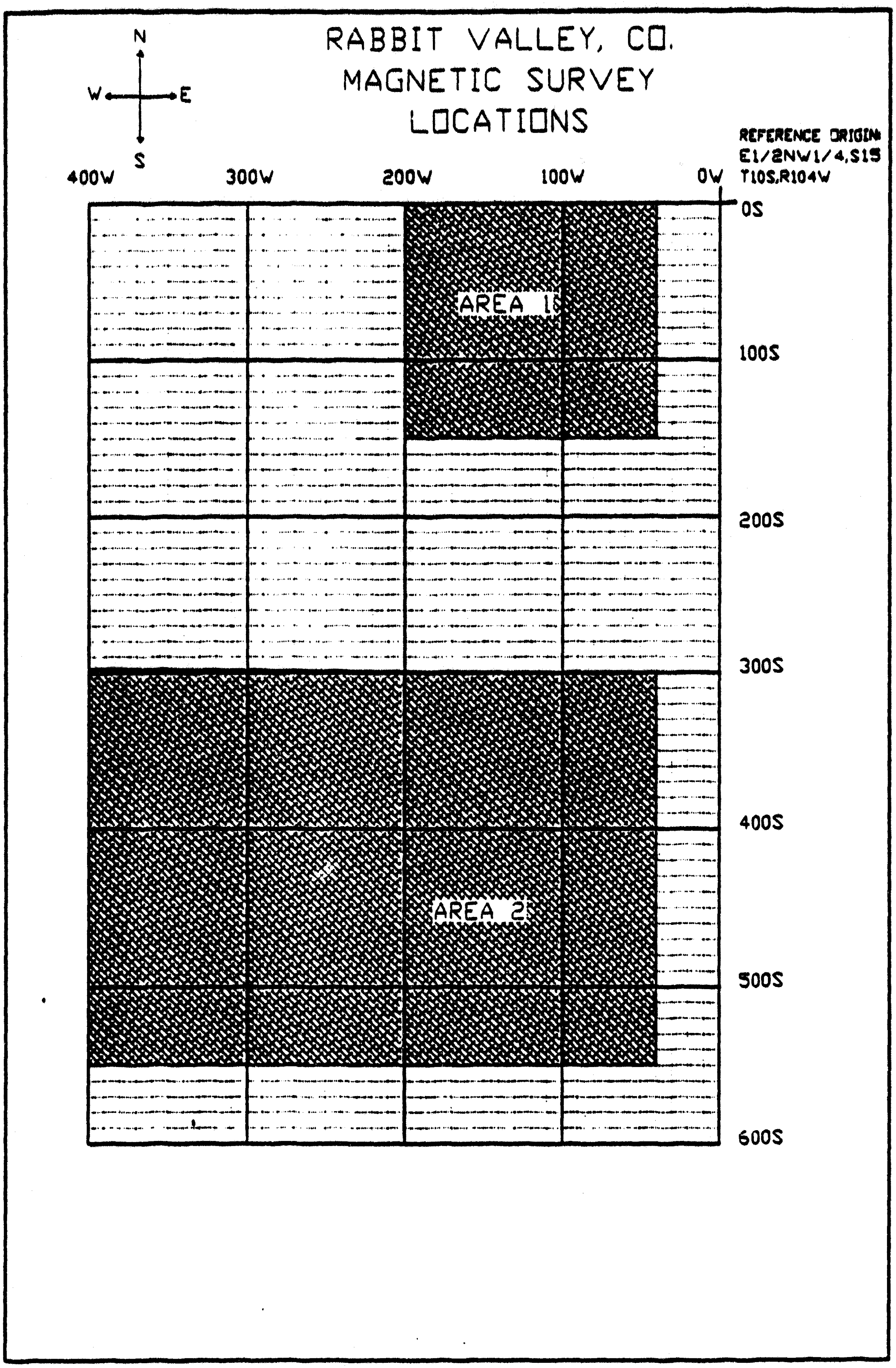


FIGURE 20. Area surveyed with the magnetometer array system

Grand Junction -- Rabbit Valley Site Two
Magnetic Survey With STOLS 9/22/93

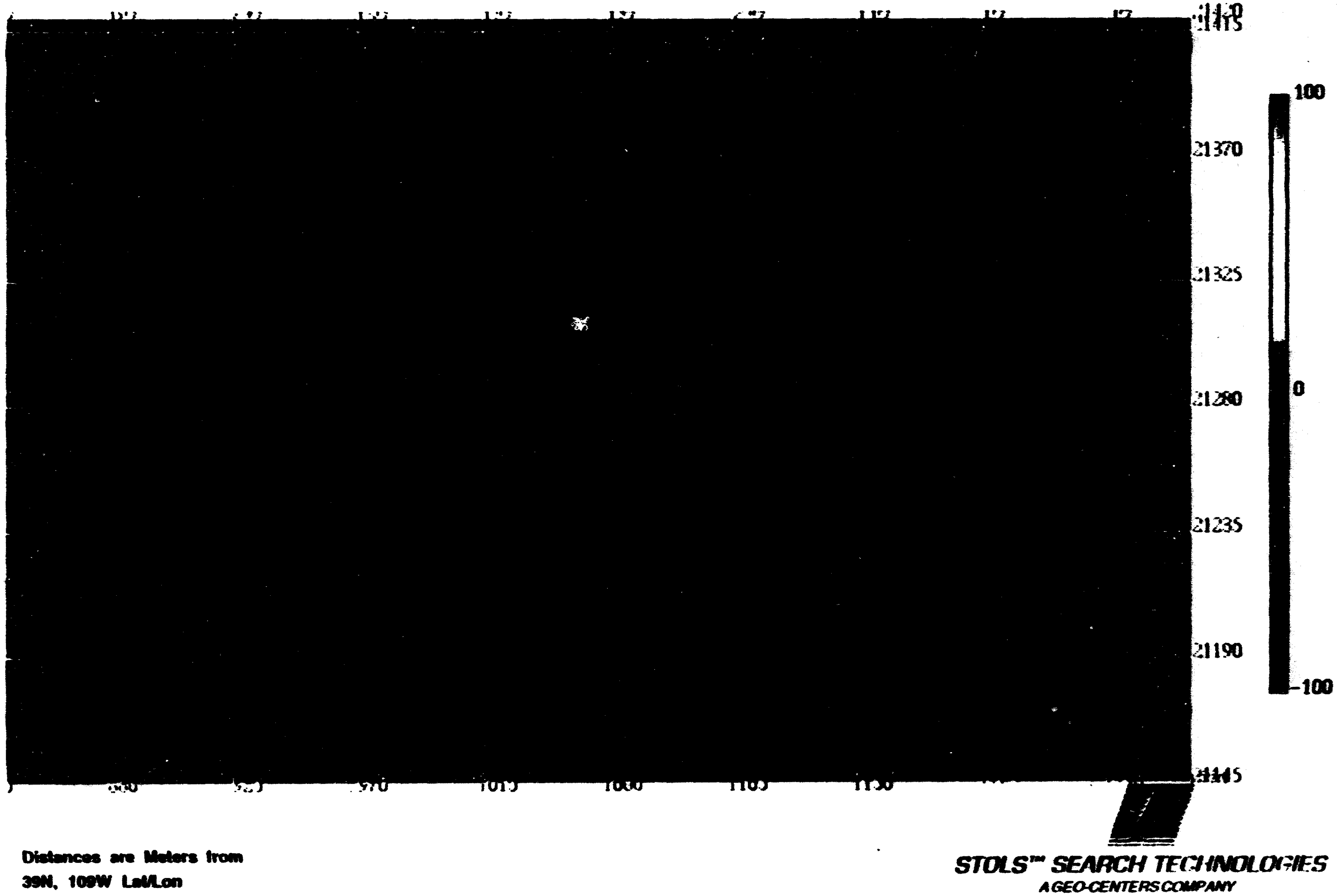


FIGURE 21. Magnetic data of area #2.

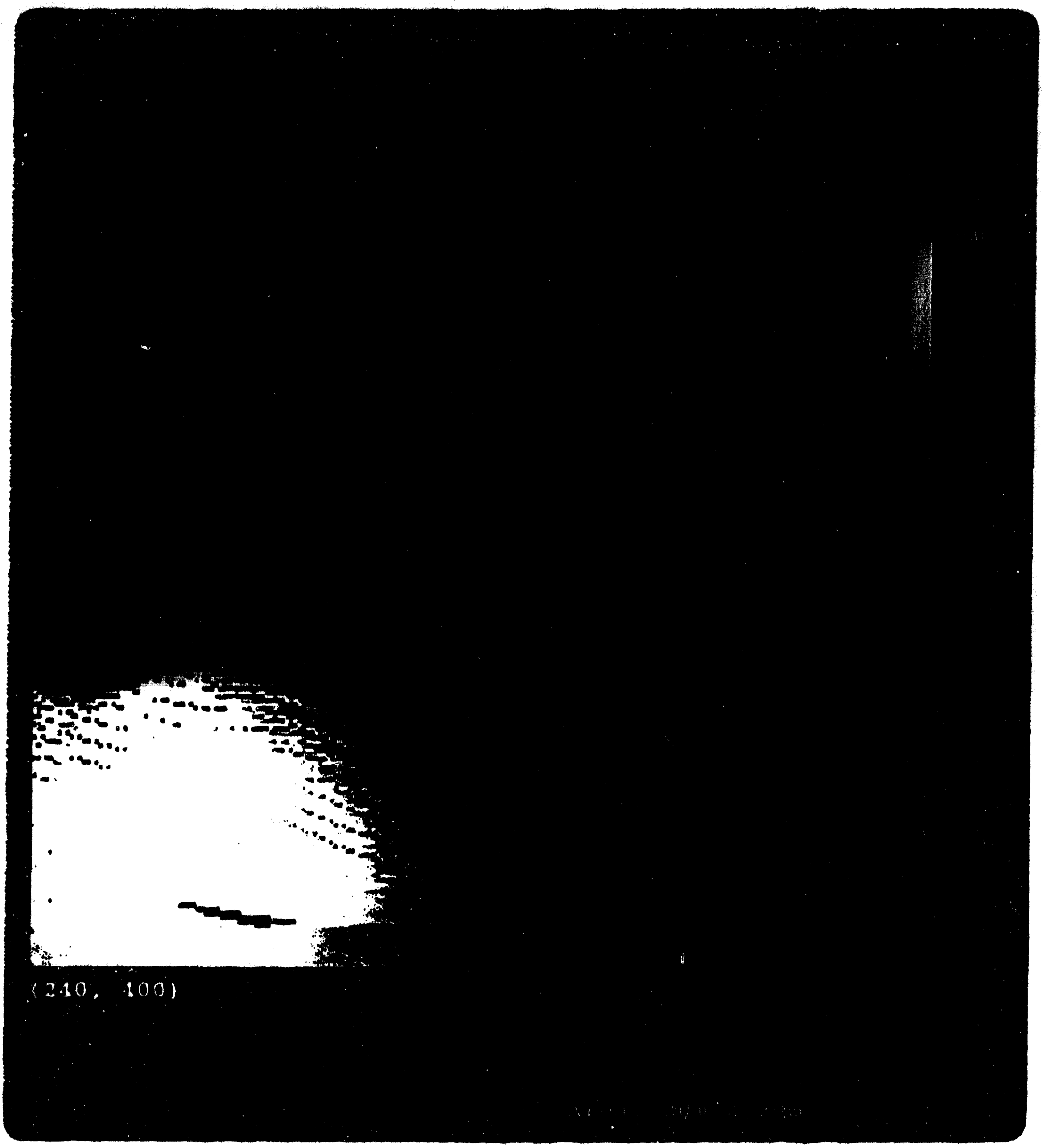


FIGURE 22. Magnetic data of target #4, steel culvert 2m deep.

TABLE 7 Target Report for the Magnetic Survey.

Positions in meters west (x) and south (y) of reference station

Category code : s=small, m=medium, l=large, p=no size given, pinpoint only

Total number of targets: 56

#	Quad	x(m)	y(m)	z(m)	Category/Notes
1	B5	374.4	377.6	0.3	s
2	C4	326.9	417.9	0.2	s
3	E5	234.9	371.0	0.4	s
4	A2	403.0	486.8	—	p (fencepost)
5	A2	400.0	499.1	0.3	s
6	A3	399.5	449.4	0.0	s
7	A5	399.7	355.8	0.2	s
8	B5	350.7	349.8	—	p (large/deep)
9	B4	343.2	420.5	0.3	s
10	B2	366.9	497.8	0.3	s
11	B2	349.7	499.5	0.0	s
12	C3	312.0	474.4	0.3	s
13	C3	334.2	447.8	0.0	s
14	C3	299.5	450.1	0.0	s
15	C3	316.9	473.9	—	p (several small clustered objects)
16	C6	307.7	313.0	—	p (faint)
17	D5	285.5	350.9	0.2	s
18	D5	284.5	355.0	2.9	l (obvious large target)
19	D4	274.9	391.5	0.0	s
20	D4	280.4	422.6	—	p (faint)
21	D3	264.5	439.9	0.1	s
22	D3	269.9	449.8	0.4	s
23	D3	282.0	457.9	0.2	s
24	D3	290.0	450.3	0.2	s (adjacent to major target)
25	D3	286.9	452.0	2.4	l (obviously large target)
26	D2	280.4	495.3	0.1	s
27	E2	250.2	500.6	0.2	s
28	E2	209.6	482.0	0.0	s
29	E3	249.7	449.8	0.2	s
30	E3	250.0	437.0	0.1	s
31	E4	250.0	409.4	0.1	s
32	E4	242.0	387.5	0.0	s (adjacent to large target)
33	E4	235.6	394.4	3.2	l (large target)
34	E4	210.6	395.3	0.0	s
35	E5	241.0	362.1	2.4	l
36	F5	198.1	359.3	—	p (faint)
37	F3	194.0	445.9	1.0	s
38	F2	189.5	485.1	3.5	l (mostly negative lobe)
40	F2	169.6	485.5	1.6	s
41	F1	181.6	541.3	0.2	s
42	F5	195.4	384.3	3.2	m
43	G4	137.9	407.8	0.1	s
44	G2	141.8	486.5	1.5	s
45	H2	80.0	482.3	1.6	m
46	H2	111.0	504.5	0.2	s
47	H2	109.5	506.0	0.3	s
48	H2	109.6	506.4	0.7	s (three objects close together)
49	H5	89.8	377.9	0.0	s
50	I4	70.5	389.5	0.7	s
51	H3	92.9	447.9	0.5	s
52	I1	38.9	532.1	1.7	s (faint)
53	J3	1.1	445.3	0.8	s
54	F2	175.8	520.1	—	p (large/deep)
55	F6	166.8	316.6	0.1	s
56	G6	149.9	320.3	—	p (large/deep)

SITE CHARACTERIZATION AT THE RABBIT VALLEY GEOPHYSICAL PERFORMANCE EVALUATION RANGE

Steven K. Koppenjan

Michael G. Martinez

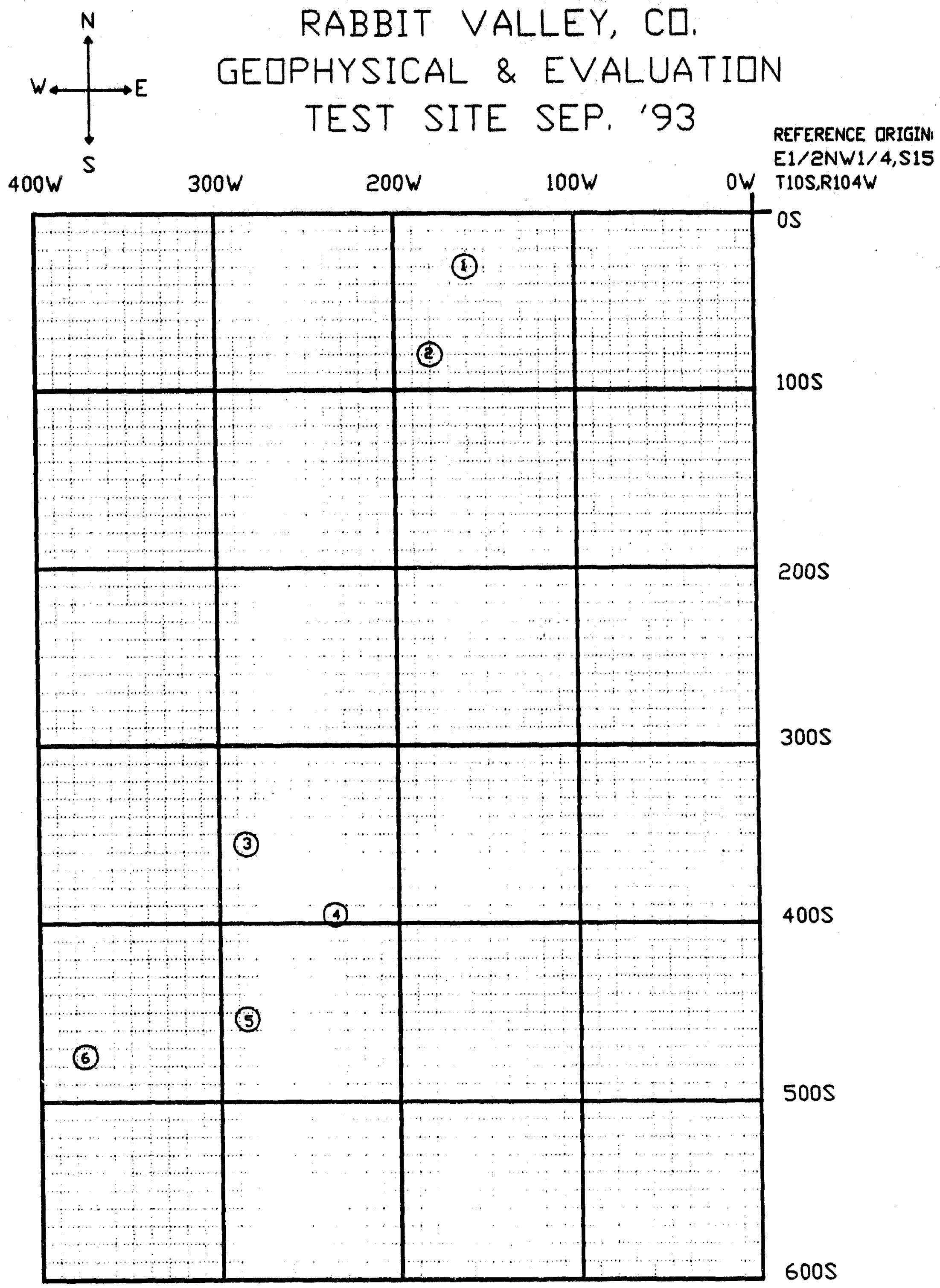
Special Technologies Laboratory

U.S. DEPARTMENT OF ENERGY
OFFICE OF INTELLIGENCE
SPECIAL TECHNOLOGIES LABORATORY
(STL)

Special Technologies Laboratory

Rabbit Valley site from USGS map.

The Rabbit Valley Geophysical Performance Evaluation Range



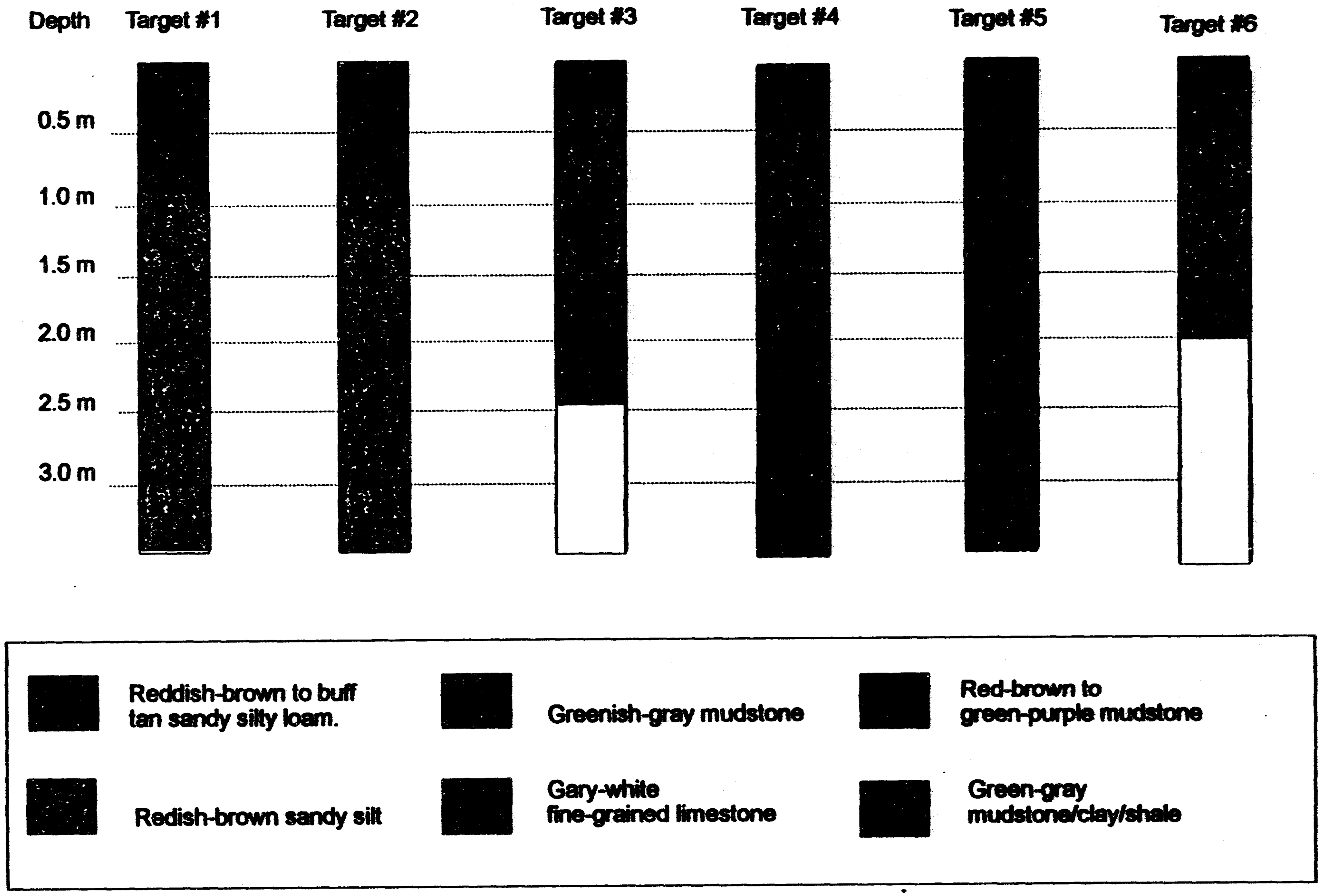
TARGET COORDINATES:

1. 160W,30S - PLASTIC CONTAINER (0.8M X 0.5M X 0.5M) DEPTH=0.5M
2. 180W,80S - CONCRETE CYLINDER (1.2M DIA X 1.5M HT) DEPTH=0.5M
3. 285W,355S - CORRUGATED STEEL CULVERT (1.2M LGTH X 0.6M DIA) DEPTH=2.0M
4. 235W,395S - CORRUGATED STEEL CULVERT (3.7M LGTH X 1.8M DIA) DEPTH=2.0M
5. 286W,453S - CONCRETE BOX (2.3M LGTH X 2.0M WDTH X 1.75M HT) DEPTH=1.35M
6. 374W,473S - 'SQUASHED' PLASTIC CYLINDER (2.5M LGTH X 1.25M WDTH X 1.0M HT) DEPTH=1.0M

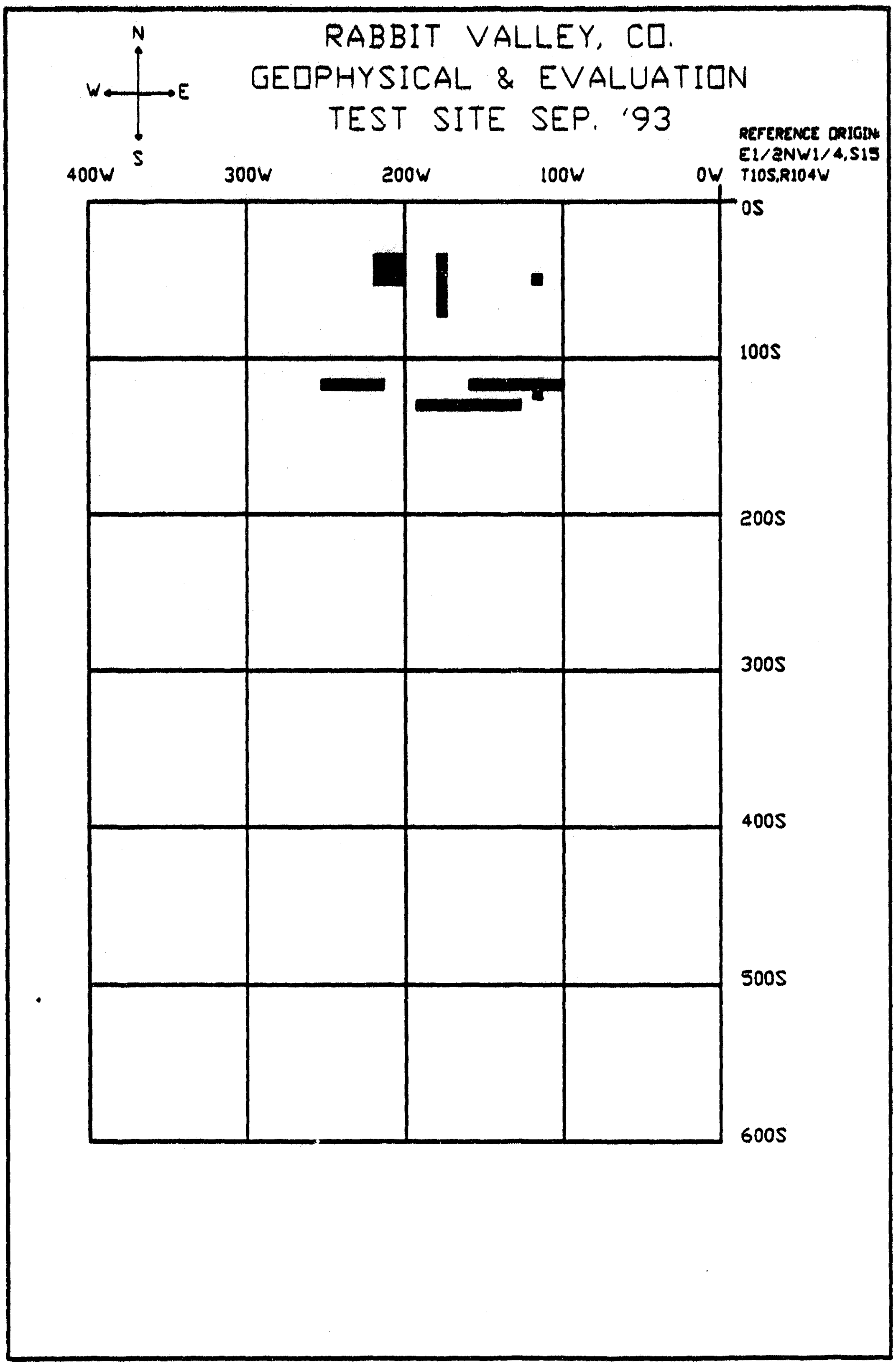
Rabbit Valley GPER, site plan with buried artifact locations.

LIST OF BURIED ARTIFACTS AT THE RABBIT VALLEY GPER

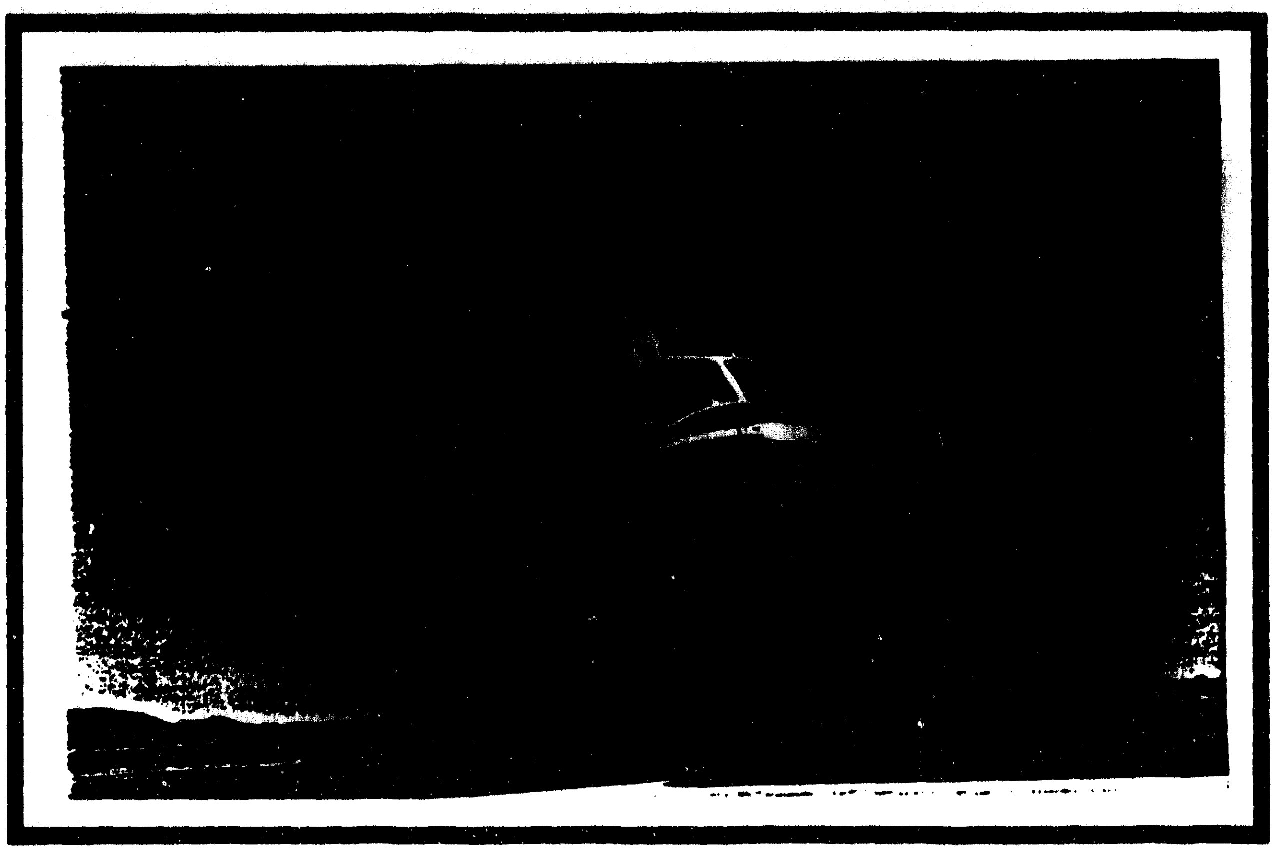
#	TARGET DESCRIPTION	SIZE	LOCATION	DEPTH
1	Plastic container filled with paraffin as a simulated cache.	0.8 m x 0.5 m x 0.5 m (length x width x height)	160W, 30S	0.5 m
2	Non-reinforced concrete cylinder (oriented vertical) with a removable wood lid.	1.2 m dia. x 1.5 m	180W, 80S	0.5 m
3	Corrugated steel culvert, horizontal cylinder, axis oriented north-south.	0.6 m dia. x 1.2 m	285W, 355S	2.0 m
4	Corrugated steel culvert, right horizontal cylinder, axis oriented north-south.	1.8 m dia. x 3.7 m	235W, 395S	2.0 m
5	Reinforced concrete box, long dimension north-south.	2.3 m x 2 m x 1.75 m (length x width x height)	286W, 453S	1.35 m
6	Plastic container, long dimension east-west.	2.5 m x 1.25 m x 1 m	374W, 473S	1 m



Soil lithology from target pits.



Site plan with anomalous areas from background measurements.



AES system, EMS-20 radar on a Bell 212 helicopter.

EMS-20 RADAR SYSTEM SPECIFICATIONS

Type	FM-CW chirped
Center Frequency	503 MHz
Pass Band	500 MHz (250-750 MHz)
Pulse Length	5 ns
Pulse Repetition Frequency	100 Hz
Continuous Power	1 Watt
Time-Bandwidth Product	5×10^6
Effective System Gain	>160 dB
Cross-Axis Foot-Print	150 feet @ 300 feet AGL
Effective Resolution (?)	0.7 m
Antenna Arrangement	Bistatic Polarized Helical
Survey Rate: 90% coverage,reconnaissance 10% overlap, close grid	 100 acres/hour 200 acres/day

Target Report for the Airborne GPR Survey.

TARGET NUMBER	N ⇒ S FRAME	W ⇒ E FRAME	RANGE[1] (METERS)	BEARING[2] (TRUE)	N ⇒ S[3] RANGE	E ⇒ W[4] RANGE	COMMENTS
1	7 - 6/7	1 - 11	178.1	259.7	36.2	173.5	
2	1 - 6/7		84.3	199.4			
3 & 4	2 - 4 3 - 15		(3): 95.1 (4): 100.9	(3): 220.0 (4): 224.8	(3): 74.3 (4): 73.3	(3): 57.9 (4): 67.9	
5 & 6	7 - 7/8 8 - 7	3 - 10 4 - 10	198.6	246.6	82.57 84.4	179.7 181.7	
7	2 - 8	4 - 14 5 - 12/13	112.0	207.7	97.2	51.6	
8	10 - 5 11 - 5/6/7	5 - 11 6 - 9	265.4	244.6	120.5	236.5	
9	11 - 10	6 - 13	290.0	242.0	143.8	250.8	
10	3 - 7	7 - 15	178.3	205.1	176.6	74.5	
11	13 - 18	13 - 8	442.3	221.8	356.5	282.4	52.3 m, 260°.4 from benchmark north-east of target
12	10 - 14 11 - 11/12	16 - 10/11 17 - 8/9	456.2	211.0	400.3	214.4	Steel culvert pipe buried 2 meters from top of pipe.
13	12 - 19/20	19 - 11 20 - 10/11	532.4	212.8	454.1	275.4	14.1 m, 92°.7 from benchmark due west of target

[1]. From Northeast Beach Mark unless otherwise noted

[2]. In Decimal Degrees from True North

[3]. Measured South along eastern survey boundary line

[4]. Measured West from North-South Boundary line on East Side.

LINE: N ⇒ S 1 FRAME: 1

SPEED:	**23.22 FT/SEC**	**7.08 METERS/SEC**
RANGE:	**118.46 FT**	**36.11 METERS**
RANGE SCALE:	**18.22 FT/INCH**	**2.19 METERS/CM**

DIFFERENTIAL GPS POSITION

TIME: **LATITUDE:** **LONGITUDE:**

RANGE (METERS) AND BEARING TO TARGET FROM NE BENCHMARK

RANGE: ____________ **BEARING (TRUE):** ________

COMMENTS:

Typical airborne GPR data profile over undisturbed area.

LINE: N ⇒ S 1 FRAME: 6

SPEED:	**23.22 FT/SEC**	**7.08 METERS/SEC**
RANGE:	**118.46 FT**	**36.11 METERS**
RANGE SCALE:	**18.22 FT/INCH**	**2.19 METERS/CM**

DIFFERENTIAL GPS POSITION

TIME: 20:05:03.69 LATITUDE: 39° 11' 40.92" LONGITUDE: 108° 59' 08.64"

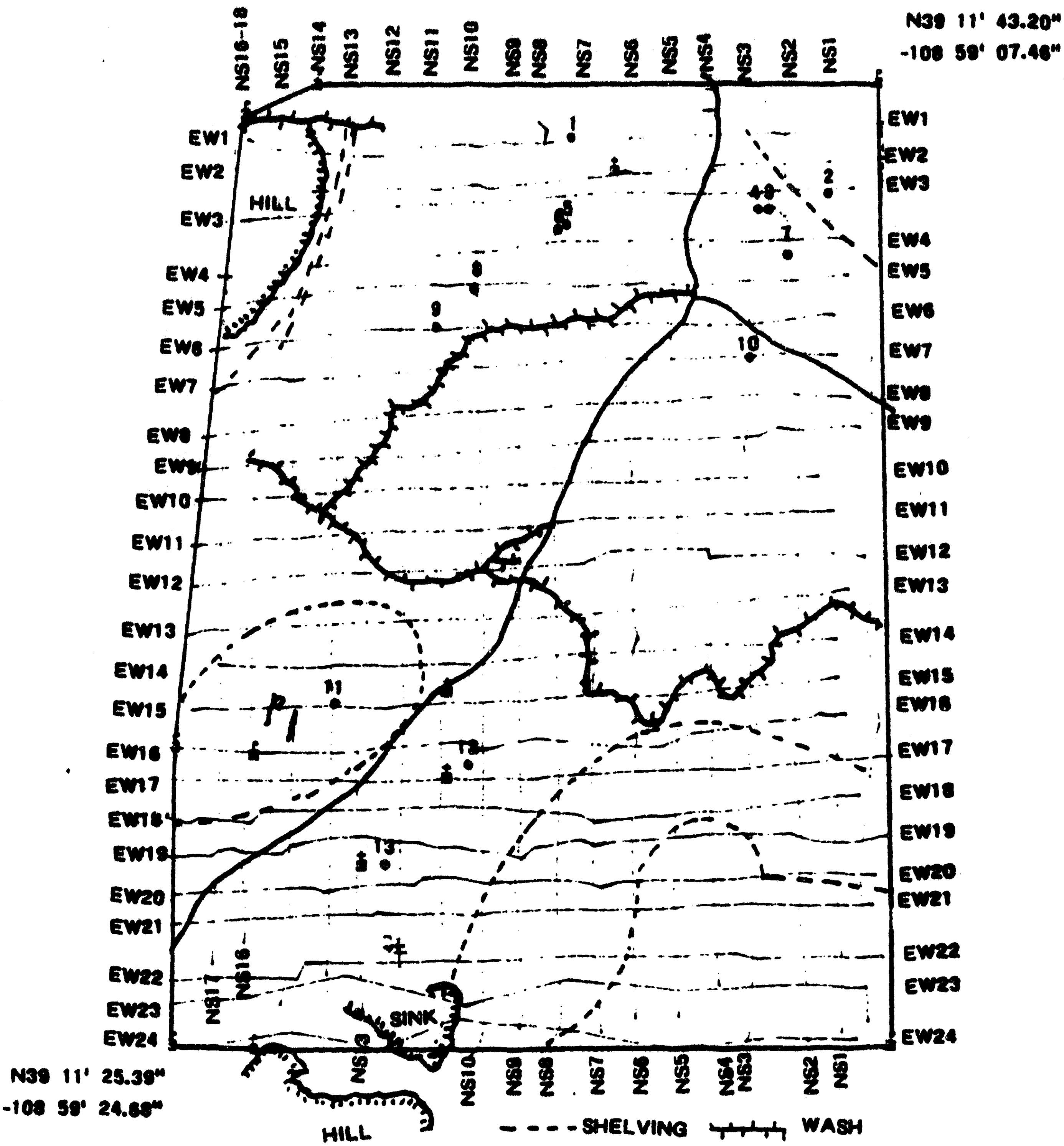
RANGE (METERS) AND BEARING TO TARGET FROM NE BENCHMARK

RANGE: ____________ **BEARING (TRUE):** ________

COMMENTS:

Airborne GPR data profile over Target #4, steel culvert 2m deep.

DOE Rabbit Valley Test Site

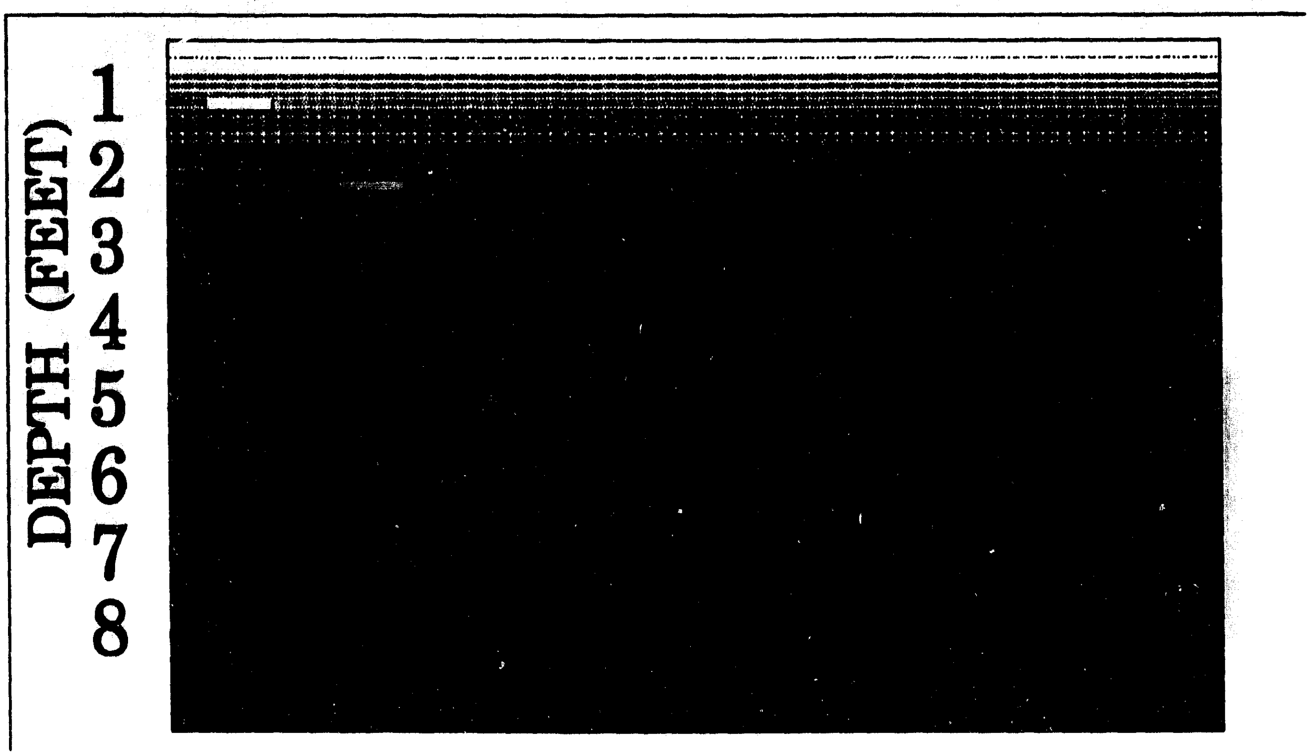


Target hits and location for airborne GPR.

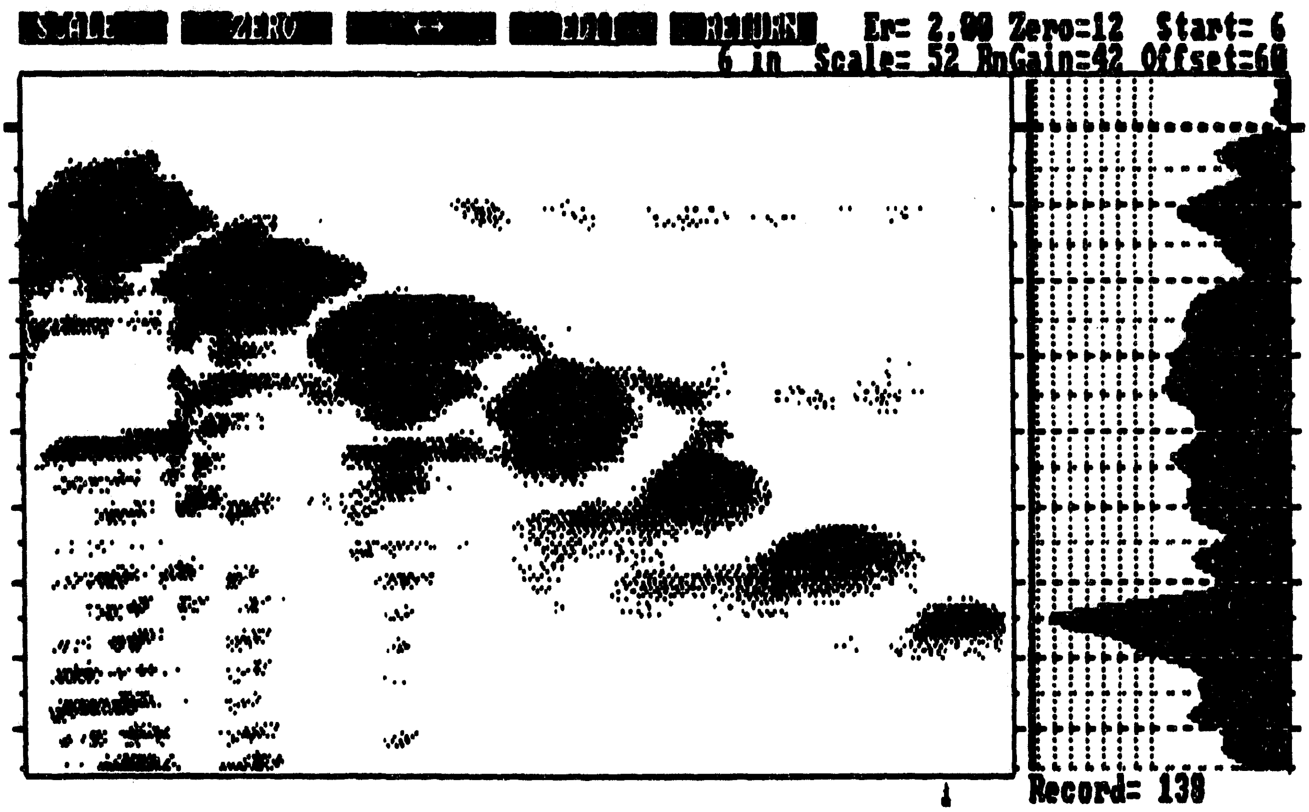
The DOE stepped FM-CW GPR.

STEPPED FM-CW GPR SYSTEM SPECIFICATIONS

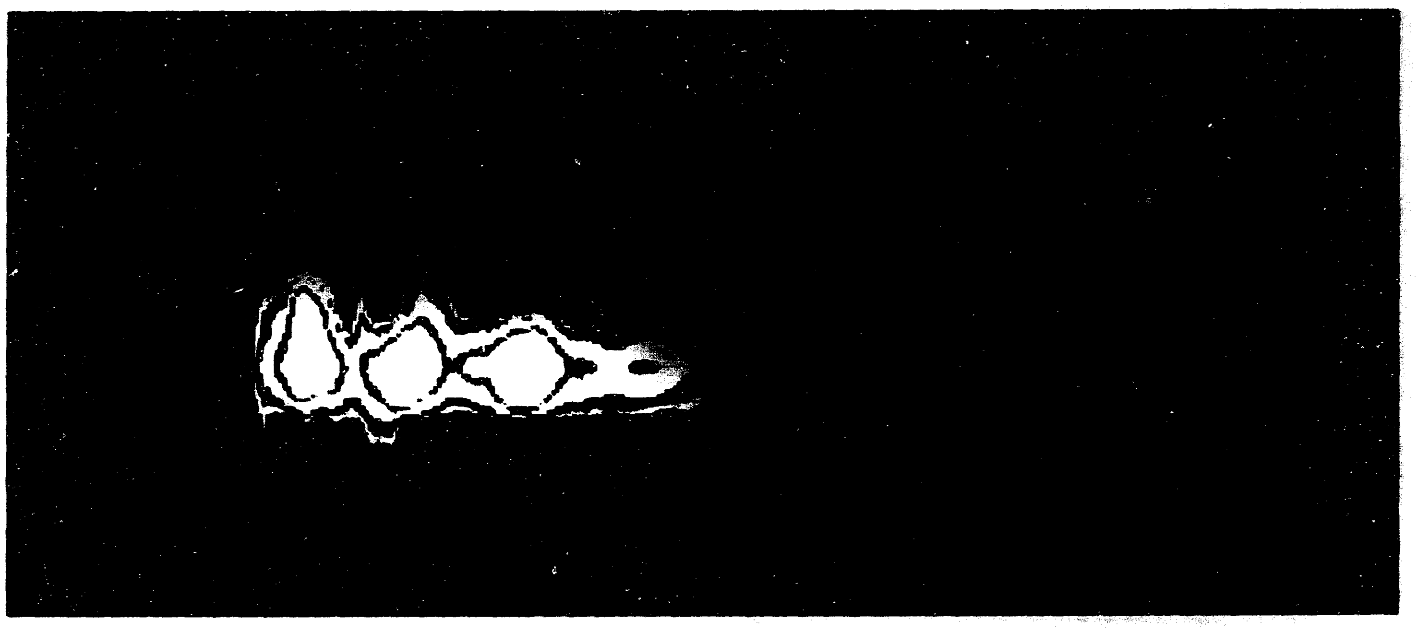
Type	Stepped FM-CW
Operating Frequency	196 - 708 MHz
Bandwidth	512 MHz
Number of Sample Points	128
Frequency Step Size	4 MHz
Modulation Frequency	500 kHz
System Dynamic Range	96 dB
Range Resolution ($E_r = 4$)	20 cm
Unambiguous Resolution ($E_r = 4$)	9 meters
Antenna Arrangement	Bistatic Log Spiral
Battery Life	6 hours
System Weight	40 kg
Survey Rate	0.5 acre/day



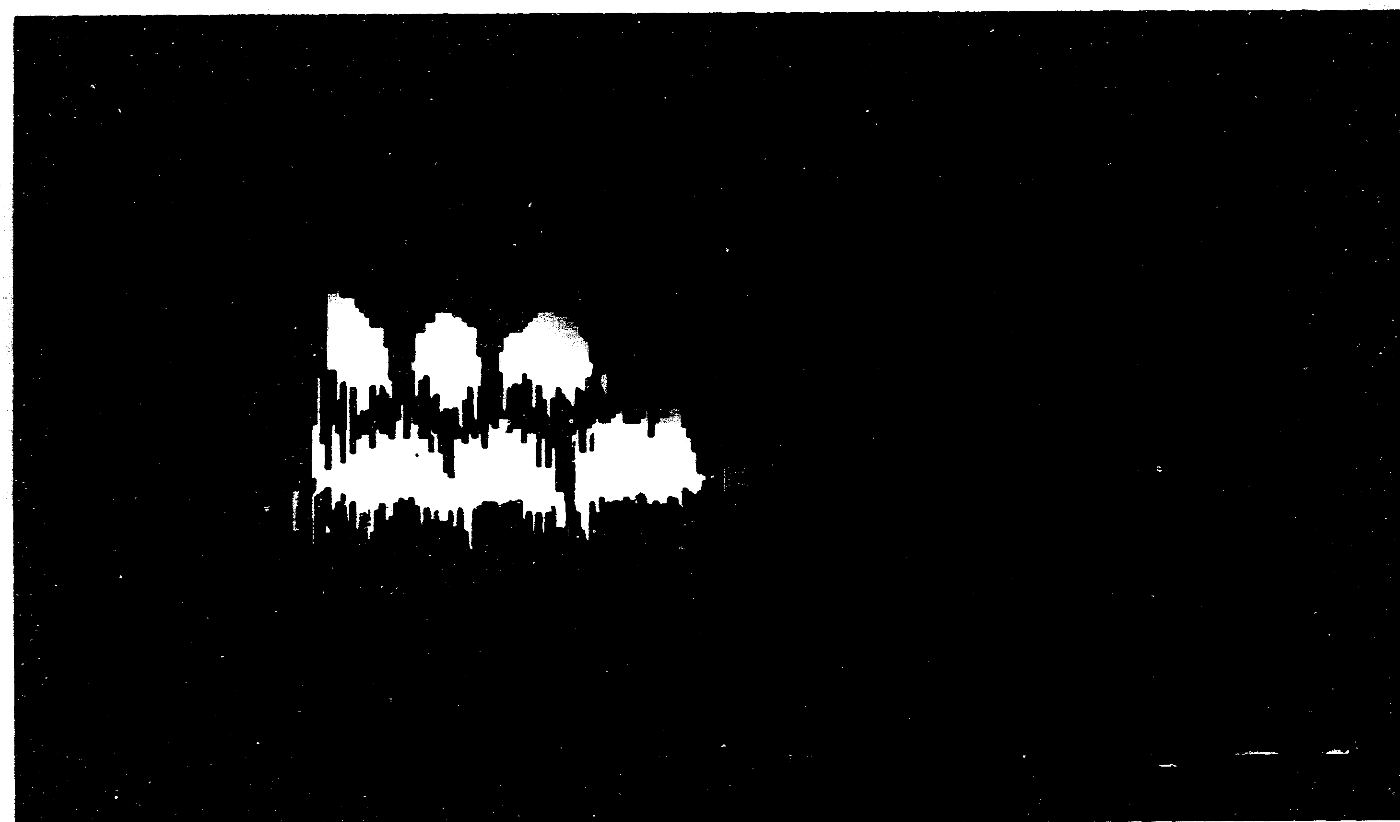
STL test sand pit, Santa Barbara, California.



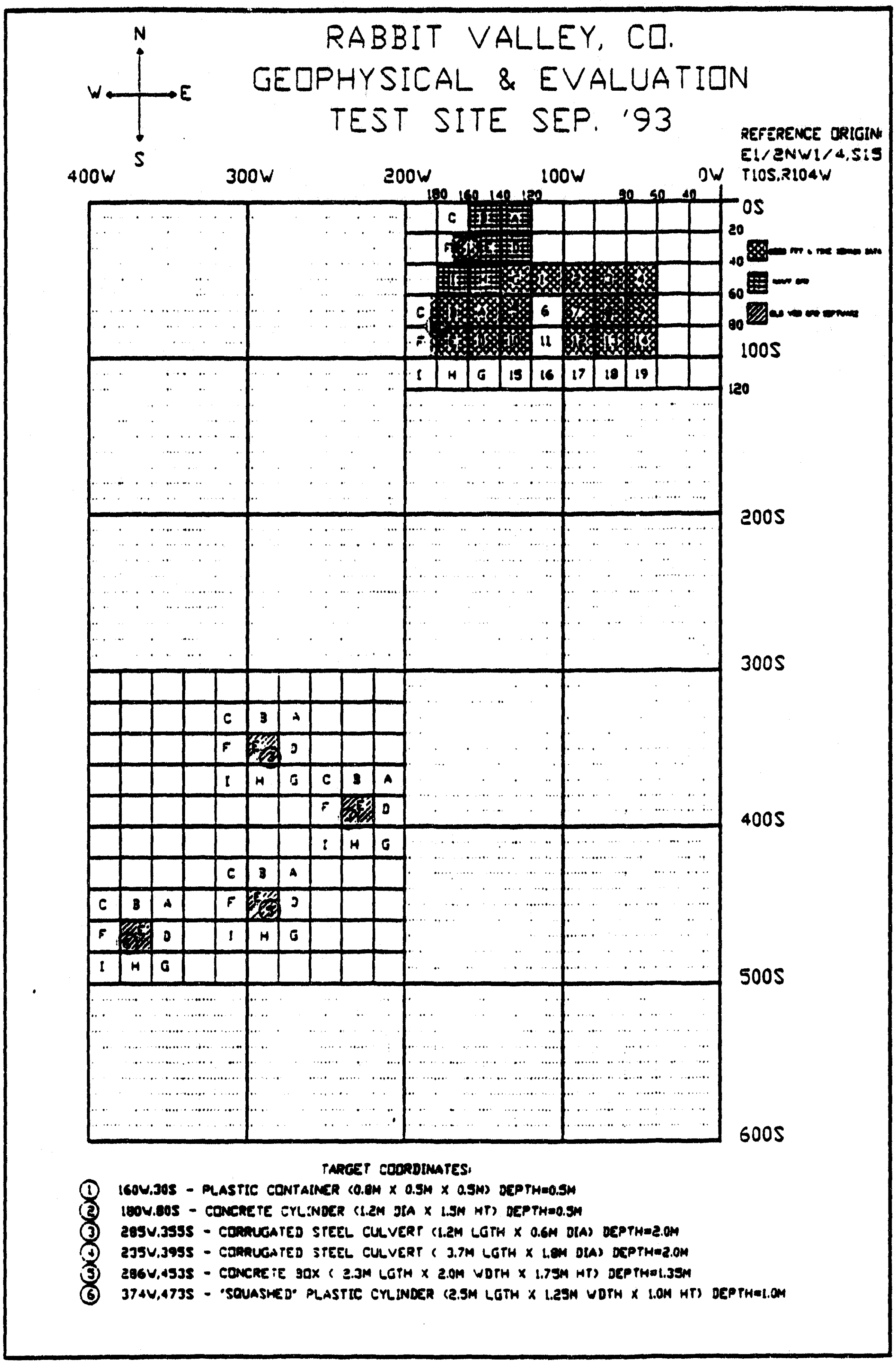
Stepped FM-CW GPR depth profile over test sand pit.



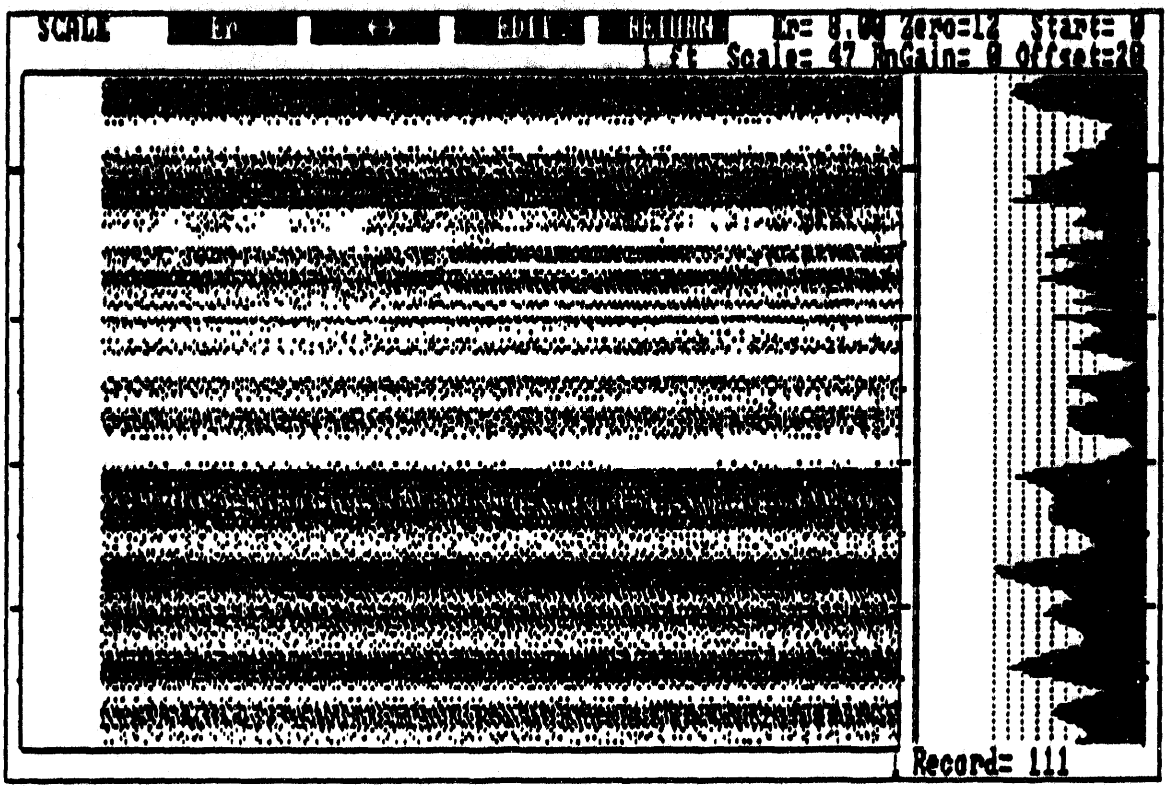
Stepped FM-CW GPR reflectivity map of test pit.



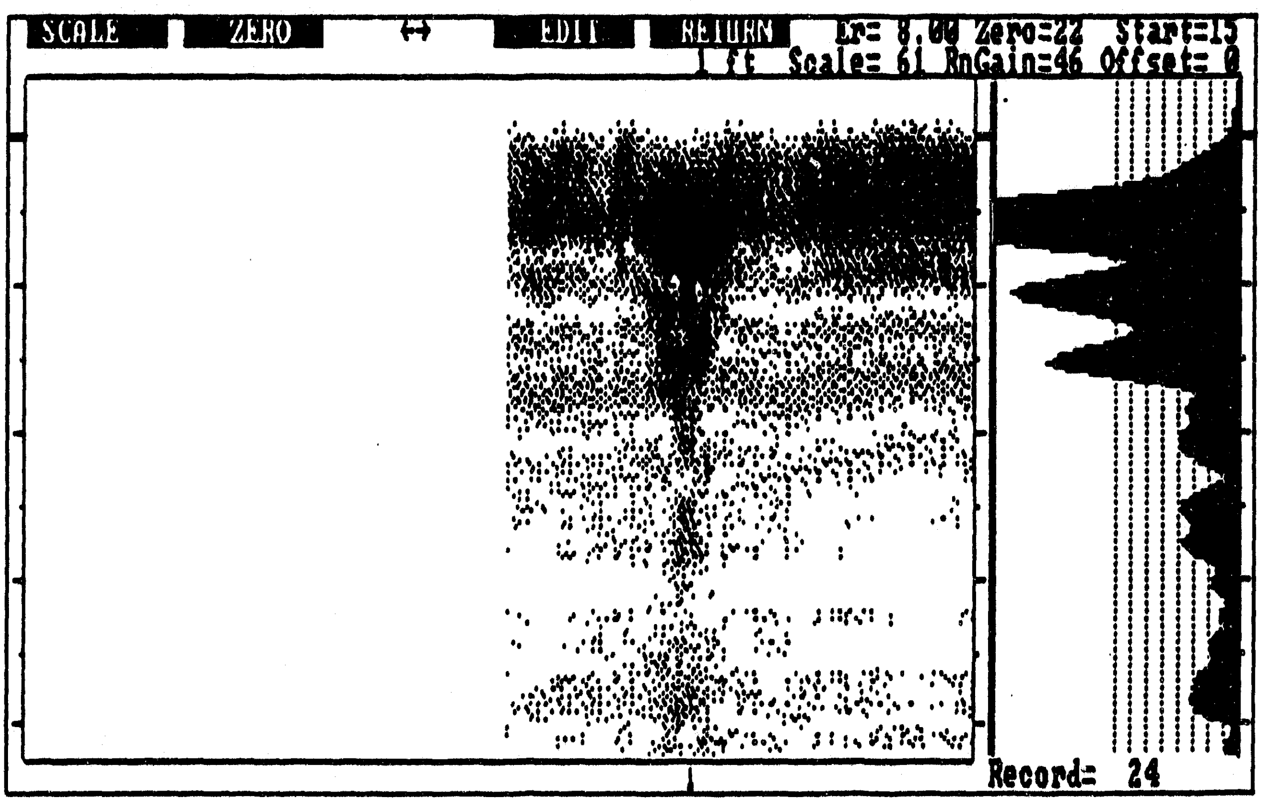
Stepped FM-CW GPR waterfall-type reflectivity map of test pit.



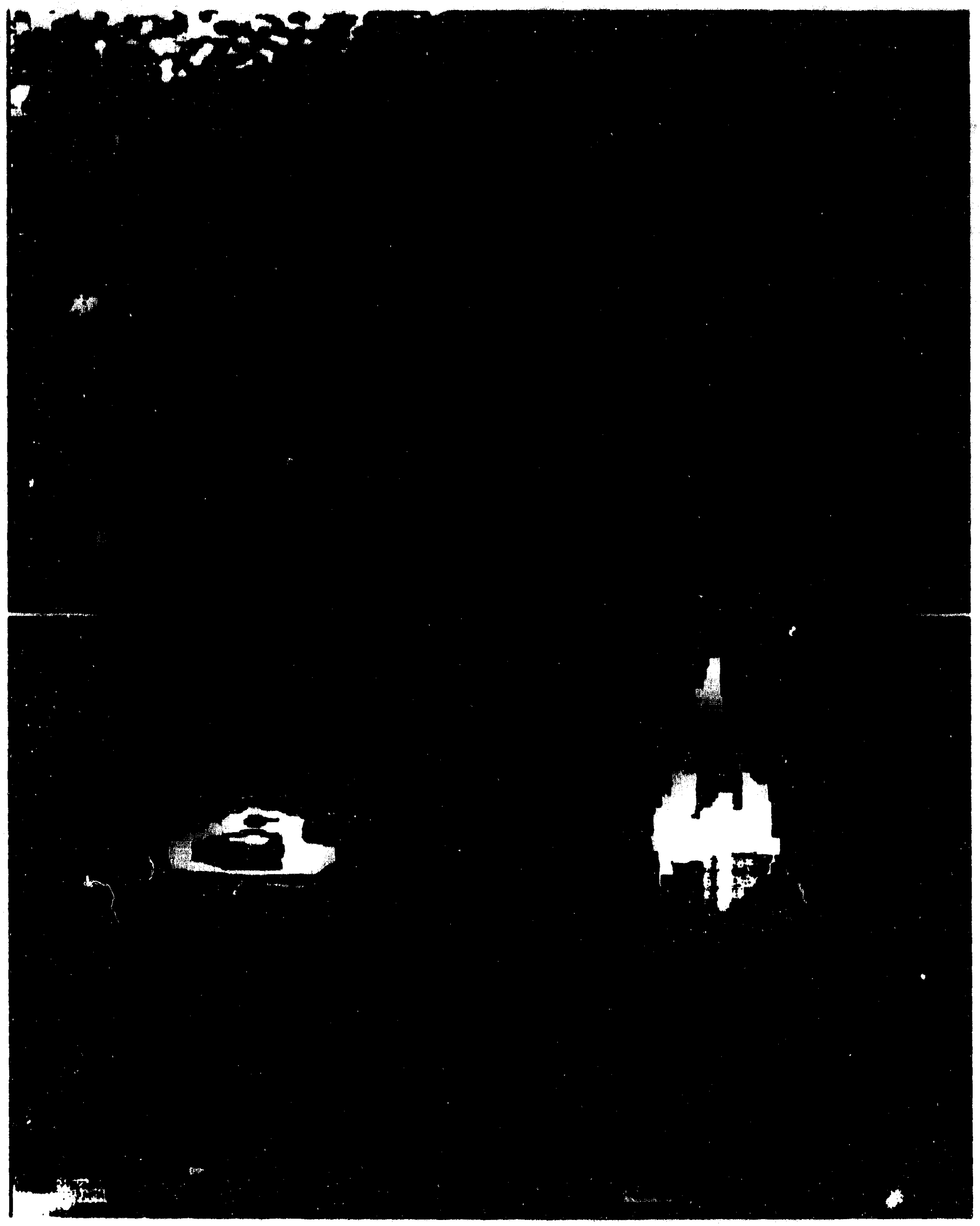
Areas surveyed with the stepped FM-CW GPR.



Typical stepped FM-CW GPR depth profile over undisturbed area.



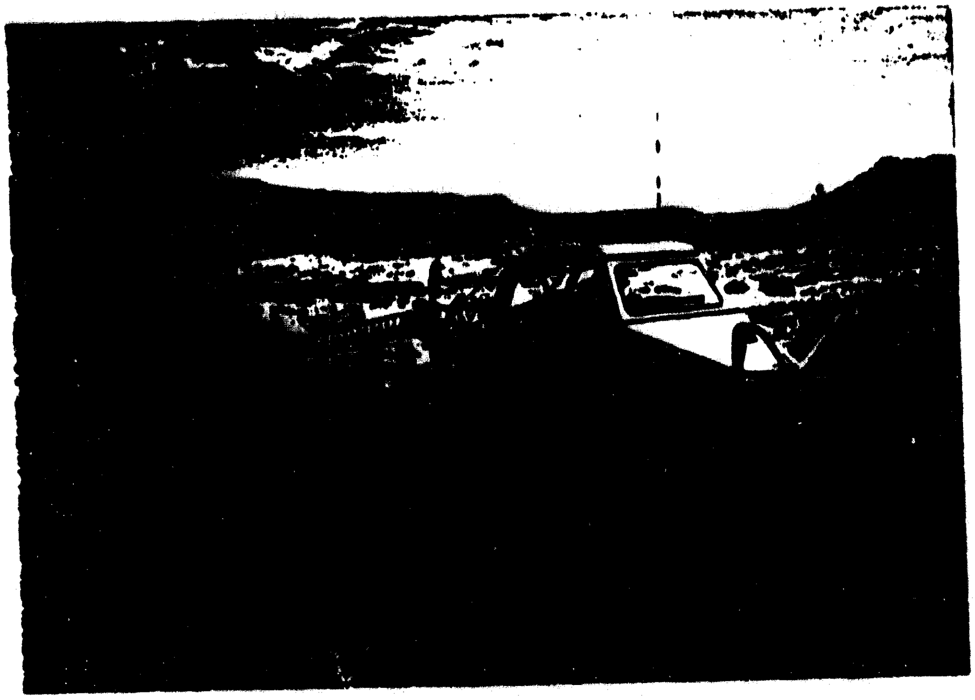
Stepped FM-CW GPR depth profilr from target #2, non-reinforced concrete cylinder, 0.5m deep.



Stepped FM-CW GPR reflectivity map of target #2 (bottom).
Stepped FM-CW GPR reflectivity map of area #1 (top).

TARGET REPORT FOR THE STEPPED FM-CW GPR SURVEY.

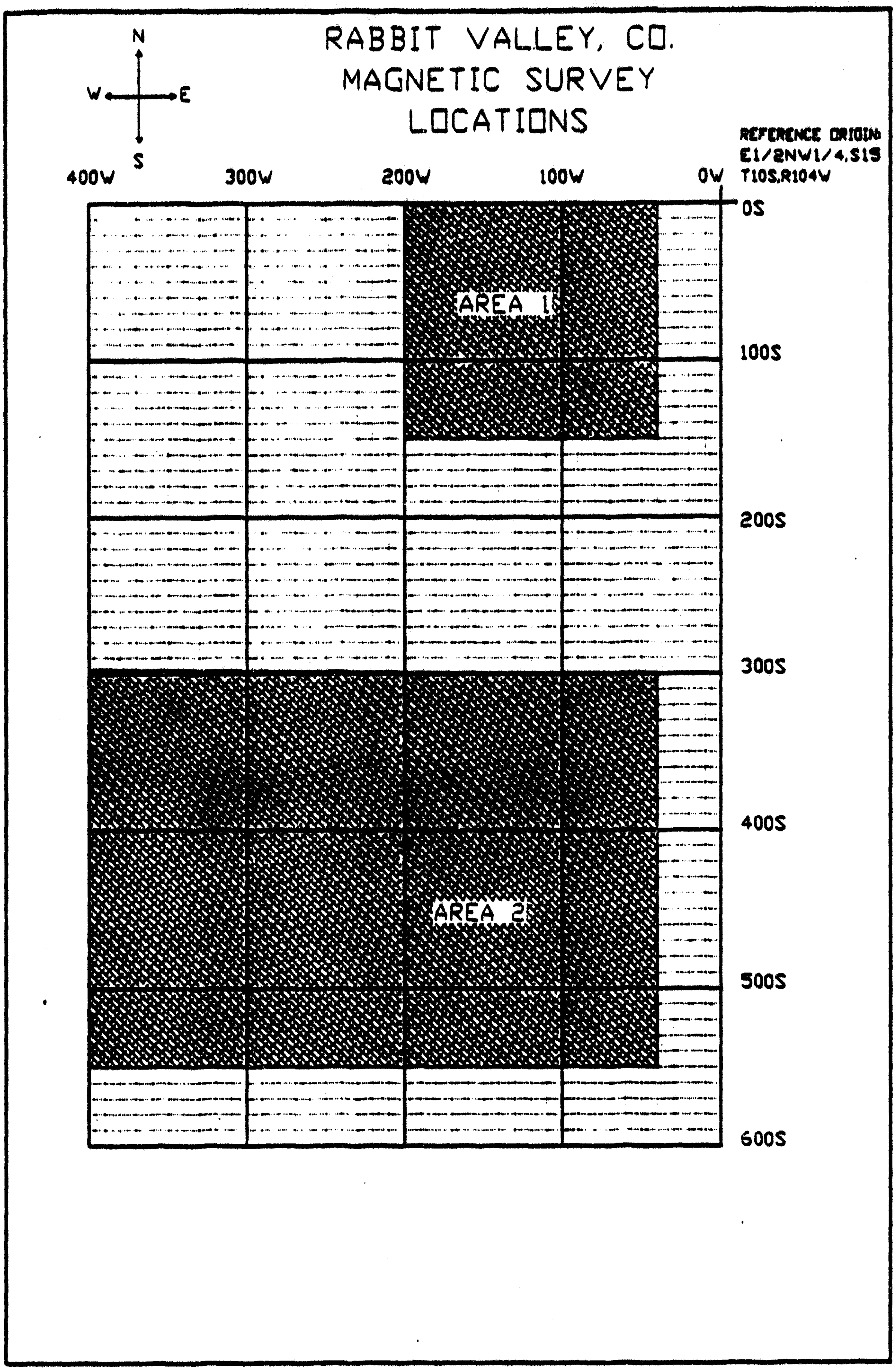
#	COMMENTS	DIELECTRIC CONSTANT	ESTIMATED DEPTH	ACTUAL DEPTH
1	Barely detectable.	8	0.5 m	0.5 m
2	Exact position determined.	8	0.5 m	0.5 m
3	Not found.	>10	-	2.0 m
4	Not found.	>10	-	2.0 m
5	Not found.	>10	-	1.35 m
6	Not found.	>10	-	1 m



Geo-Centers, Inc., Surface Towed Ordnance Locating System (STOLS™)

MAGNETOMETER ARRAY ($STOLS^{TM}$) SPECIFICATIONS

Type	Cesium vapor (7 each)
Survey Rate	3.5 - 5 miles per hour (5.6 - 8 km per hour)
Coverage	25 - 35 acres/day
Data Density	100,000 points/acre @ 3.5 MPH
Position Accuracy	< 0.5 meters
Power Supply	120 Volt, 1000 Watt unit



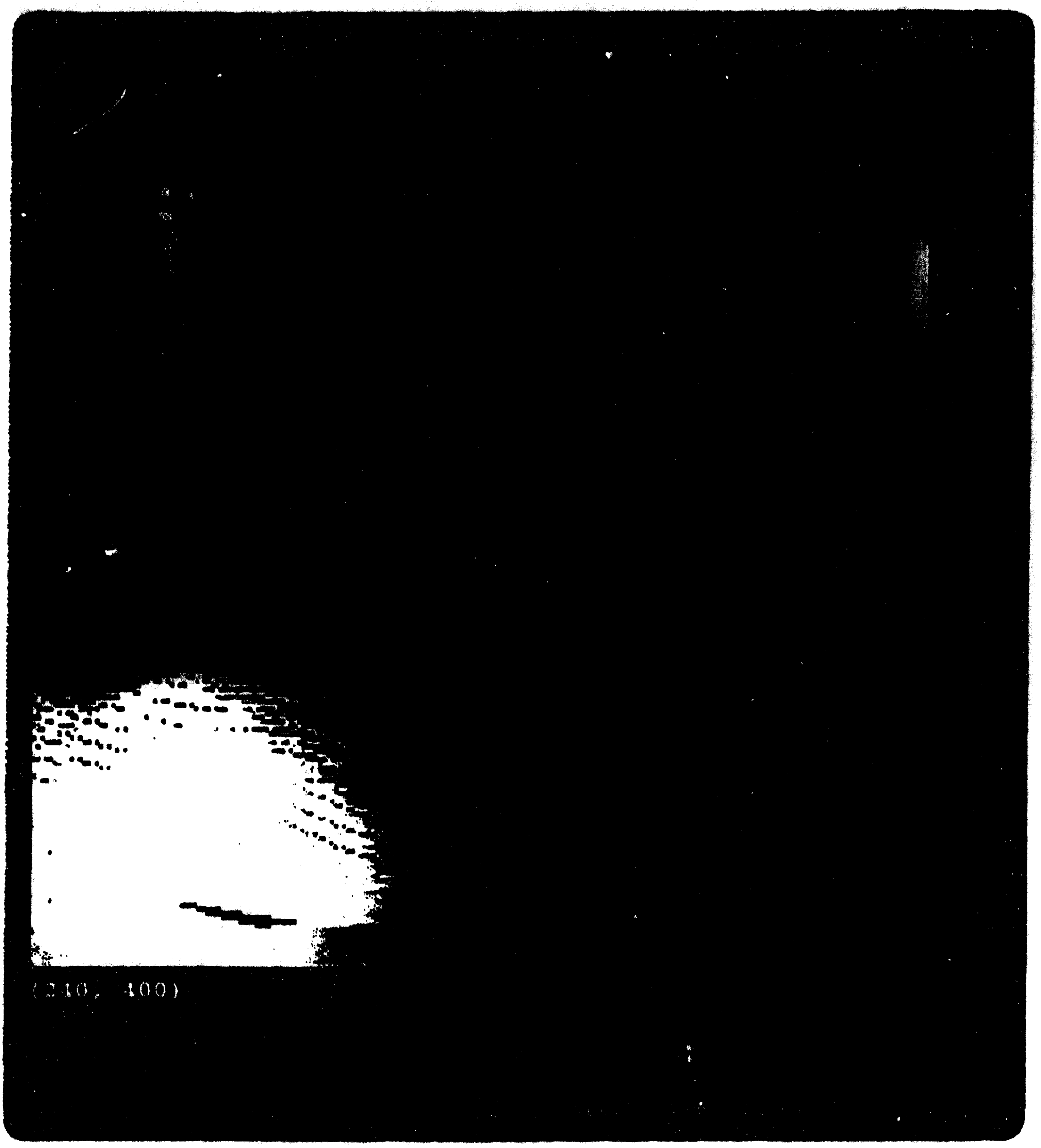
Area surveyed with the magnetometer array system

Grand Junction -- Rabbit Valley Site Two
Magnetic Survey With STOLS 9/22/93

Distances are Meters from
30N, 108W Lat/Lon

STOLS™ SEARCH TECHNOLOGIES
A GEO-CENTERS COMPANY

Magnetic data of area #2.



Magnetic data of target #4, steel culvert 2m deep.

Target Report for the Magnetic Survey.

Positions in meters west (x) and south (y) of reference station

Category code : s=small, m=medium, l=large, p=no size given, pinpoint only

Total number of targets: 56

#	Quad	x(m)	y(m)	z(m)	Category/Notes
1	B5	374.4	377.6	0.3	s
2	C4	326.9	417.9	0.2	s
3	E5	234.9	371.0	0.4	s
4	A2	403.0	486.8	—	p (fencepost)
5	A2	400.0	499.1	0.3	s
6	A3	399.5	449.4	0.0	s
7	A5	399.7	355.8	0.2	s
8	B5	350.7	349.8	—	p (large/deep)
9	B4	343.2	420.5	0.3	s
10	B2	366.9	497.8	0.3	s
11	B2	349.7	499.5	0.0	s
12	C3	312.0	474.4	0.3	s
13	C3	334.2	447.8	0.0	s
14	C3	299.5	450.1	0.0	s
15	C3	316.9	473.9	—	p (several small clustered objects)
16	C6	307.7	313.0	—	p (faint)
17	D5	285.5	350.9	0.2	s
18	D5	284.5	355.0	2.9	l (obvious large target)
19	D4	274.9	391.5	0.0	s
20	D4	280.4	422.6	—	p (faint)
21	D3	264.5	439.9	0.1	s
22	D3	269.9	449.8	0.4	s
23	D3	282.0	457.9	0.2	s
24	D3	290.0	450.3	0.2	s (adjacent to major target)
25	D3	286.9	452.0	2.4	l (obviously large target)
26	D2	280.4	495.3	0.1	s
27	E2	250.2	500.6	0.2	s
28	E2	209.6	482.0	0.0	s
29	E3	249.7	449.8	0.2	s
30	E3	250.0	437.0	0.1	s
31	E4	250.0	409.4	0.1	s
32	E4	242.0	387.5	0.0	s (adjacent to large target)
33	E4	235.6	394.4	3.2	l (large target)
34	E4	210.6	395.3	0.0	s
35	E5	241.0	362.1	2.4	l
36	F5	198.1	359.3	—	p (faint)
37	F3	194.0	445.9	1.0	s
38	F2	189.5	485.1	3.5	l (mostly negative lobe)
40	F2	169.6	485.5	1.6	s
41	F1	181.6	541.3	0.2	s
42	F5	195.4	384.3	3.2	m
43	G4	137.9	407.8	0.1	s
44	G2	141.8	486.5	1.5	s
45	H2	80.0	482.3	1.6	m
46	H2	111.0	504.5	0.2	s
47	H2	109.5	506.0	0.3	s
48	H2	109.6	506.4	0.7	s (three objects close together)
49	H5	89.8	377.9	0.0	s
50	I4	70.5	389.5	0.7	s
51	H3	92.9	447.9	0.5	s
52	I1	38.9	532.1	1.7	s (faint)
53	J3	1.1	445.3	0.8	s
54	F2	175.8	520.1	—	p (large/deep)
55	F6	166.8	316.6	0.1	s
56	G6	149.9	320.3	—	p (large/deep)

DATE FILMED

7/15/94

END