EVALUATION OF GPR AS A TOOL FOR DETERMINATION OF GRANULAR MATERIAL DEPOSIT VOLUMES

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ABSTRACT

University of Missouri Rolla, Department of Geology and Geophysics utilized the ground penetrating radar and Differential Global Positioning System (DGPS) tools to investigate thickness of fine gravel sized milled rock over natural ground throughout a large area of previous mine workings near Joplin, Missouri. Using a 400MHz frequency radar antenna, UMR achieved signal penetration sufficient for this study and data quality was high. Clearly evident in the data is the interface between the milled rock and clay soil. An average radar velocity for all sites was obtained by calibrating the radar signals with one point of available ground truth and the time-to-depth conversion was determined from this. The average depth to the soil layer across all the sites varied from 27cm to 96cm. DGPS was used to map both the areas and GPR survey lines. The GPS data provided the elevation profiles and areas necessary to calculate three-dimensional volumes of the material. The techniques described in this report can be employed for estimating the volume of the granular deposits that is essential for determining available fill material for roadway construction projects.

OBJECTIVES

The objective of this study is to evaluate the utility and cost effectiveness of ground penetrating radar as a tool for determining volumes of aggregate material overlying clay soil or natural ground. A secondary objective is to integrate real time differential GPS (DGPS) to accurately map the materials and provide data essential to calculate volumes.

BACKGROUND

In the Tri-State Mining District of southwestern Missouri, much of the ground is covered by gravel and tailings left behind from the numerous lead and zinc mine mills, where ore laden rock was crushed to extract metals. These materials range in size from fine gravel chat to fine sand sized tailings. Other parts of Missouri have similar but natural granular deposits of gravel and sand. As part of the highway construction process, MoDOT plans to incorporate granular materials that are currently located within highway right-of-way into the roadway fills. MoDOT will be involved with the excavation, transport, and placement of these materials as part of construction. An estimate of the volume of chat material available is necessary for highway designers to determine quantities of fill available. The current method is to backhoe a small portion of each area to determine the chat / soil interface. This interface greatly fluctuates and relying on one dig site may produce an inaccurate approximation of chat volume. Ground penetrating radar has the potential to display this gravel to natural ground transition and provide accurate volumetric estimates. A few GPR profiles would be both more expedient and accurate than digging test pits. A complete GPR profile across a site may show all the depth fluctuations rather than the depth at one location. In the interest of saving time and providing accurate estimates, ground penetrating radar was attempted.

GEOPHYSICAL SURVEY DESIGN

With the ground penetrating radar (GPR) method, a transmitter sends a microwave signal into the subsurface, and the radar waves propagate at velocities that are dependent upon the dielectric constant of the subsurface medium (Cardimona, et al., 1998). Changes in the dielectric constant will be due to changes in the subsurface materials, and these will cause the radar waves to be reflected back to the surface. The time it takes energy to return to the surface relates to the depth at which the energy was reflected. Thus, interpretation of the GPR signal with respect to the travel time of reflected energy yields information on structural variation of the near subsurface.

The GPR survey was successfully completed using 400MHz antennae and electronics designed by Geophysical Survey Systems Inc. UMR deployed the GPR equipment to investigate the thickness of milled rock (chat) over a large area near Joplin, Missouri, where old mine workings and debris cover large portions of the land. The interface between the native soil and the overlying granular material is a high-contrast point where electromagnetic energy will reflect back to the surface to be recorded by the GPR instrumentation. The focus of the survey was to map the depth of the chat-soil interface along survey lines at all 30 field sites. In order to cover the large number of sites, UMR collected data along 1 to 3 survey lines per site. Lines were pre-marked in an “X” pattern on most area sites. The radar survey lines were then DGPS-located by personnel of the Missouri Department of Transportation.

GPS MAPPING AND VOLUME CALCULATIONS

A Trimble Pro XRS unit was used for the GPS part of the study. This unit has an integrated Coast Guard Beacon receiver that acquires differential corrections (DGPS) from the Coast Guard broadcast. Beacons are located along the Missouri and Mississippi Rivers for navigational purposes. MoDOT’s testing of this instrument has found it to be submeter accurate in the horizontal plane and 2 meters accurate in the vertical plane.

Areas were mapped quickly by walking their perimeters with the DGPS unit while acquiring position data every 5 seconds, resulting in a point every 3 meters. This allowed the designated areas to be overlain on highway plans and provided area calculations. When choosing a data-logging interval, area size and mapping speed must be taken into consideration. A 5 second interval at walking pace provides a position about every 3 meters, which is adequate for the large areas which ranged from 5,000 to 120,000 square meters. Too much data and detail would be burdensome. The chat piles were much smaller and thus a 1 or 2 second interval was used to provide adequate detail. A position was also acquired at the top of the pile to estimate height for volume calculations. Piles were calculated as 1/3 x area x height while areas were simply calculated as area x average depth.

Without DGPS, areas would be either be scaled from aerial photos at a much lower accuracy or surveyed by traditional methods. Survey crews would be kept busy for weeks mapping the large areas at an accuracy not required for volume estimates. DGPS provided elevation profiles and positions of the radar lines as well. The integration of GPR and GPS proved beneficial, as the resulting time and cost savings were substantial as compared to traditional surveying.

WHAT IS GPS?

The NAVSTAR Global Position System consists of 24 satellites in very high, stable orbits at 20,000 km (12,600 miles) elevation that are controlled by ground-based monitoring stations. The satellite orbits are in 6 planes with a 55-degree rotation, with each plane having 4 or 5 satellites. The system was developed and is currently maintained by US Department of Defense. A satellite revolution is completed in about 12 hours. NAVSTAR GPS provides all weather, “worldwide”, accurate three-dimensional positioning 24 hours a day. Like AM-FM radio, the satellite signals support an unlimited number of users. The advantage of using satellites over ground based methods is that they eliminate the traditional “line of sight” survey requirement. Instead of “leap frogging” around ground clutter, receivers are placed where there is a clear view of the sky, allowing longer baselines. Another advantage is that GPS is a “dynamic”

positioning system, allowing a person to map while moving. It is reliable due to its resistance to intentional jamming or interference and is capable of highly accurate geodetic surveying.

Differential GPS (DGPS) is a technique that significantly improves both the accuracy and the integrity of the Global Positioning System. DGPS involves the use of two receivers - one at a fixed location, the “base station”, and one that the user maps with, called the “roving” or “rover” receiver. DGPS requires high quality GPS base station receivers at accurately surveyed locations. GPS data is collected and each position and its corresponding “errors” are tagged with GPS time at both the base and roving unit. The base station compares the satellite measurements with the known x,y,z position and then estimates the error components. The difference between the GPS calculated position and the known position is the error. These errors are occurring everywhere within same vicinity, at the same time. The base station quickly forms a correction for each satellite in view. An x, y, z correction is generated and will adjust the rover position accordingly to bring it from the false position to “truth”. This correction either is archived into a computer for later use, called “post processing” or broadcast immediately by radio for “real time corrections”.

The Coast Guard has implemented a series of local area differential stations to cover harbors, inland waterways, and coastal waterways of the United States. This correction service is free and requires a special radio to receive the signals. Some private services use a frequency modulation (FM) subcarrier to transmit corrections to small areas. The disadvantage of ground based broadcasts is that radio is “line of sight” and the receiver may lose signal in ground clutter such as trees, structures, and valleys. Electromagnetic interference can be another problem, usually caused by car engines or thunderstorms. Another private industry segment uses geostationary satellites as the communications link to broadcast corrections. These systems consist of several reference stations located around the country, networked through a centralized satellite uplink facility. The satellite broadcast eliminates much of the loss of radio signal caused by topography. Both FM and Satellite correction services require a subscription and the users must purchase a radio receiver and pay an annual fee, around $800 per year per unit as of January 2000.

GPR DATA

Radar equipment was carried in a pickup truck, and the antennae were pulled along the pre-marked survey lines. Acquisition was difficult in the rough terrain, but data quality was quite high (Figures 1-4). The average depth to the soil layer across all the sites varied from 27cm to 96cm, using an average electromagnetic dielectric constant of 27.9.

Ground truth on one survey line allowed us to determine the general stratigraphy that consisted of dry chat, wet chat, soil mixed with chat, and soil. A 1 meter deep pit was dug by hand and shovel to expose the profile and measure the depth of the soil contact. The strongest reflection in the GPR data came from areas where water was perched above the clay-rich soil (Figures 1 and 2). The target zone, the chat-to-soil interface, was clearly distinguishable in the data (Figures 3 and 4), especially when viewed on the computer screen with judicious application of amplitude enhancement color transforms that clearly highlight the change in soil stratigraphy.

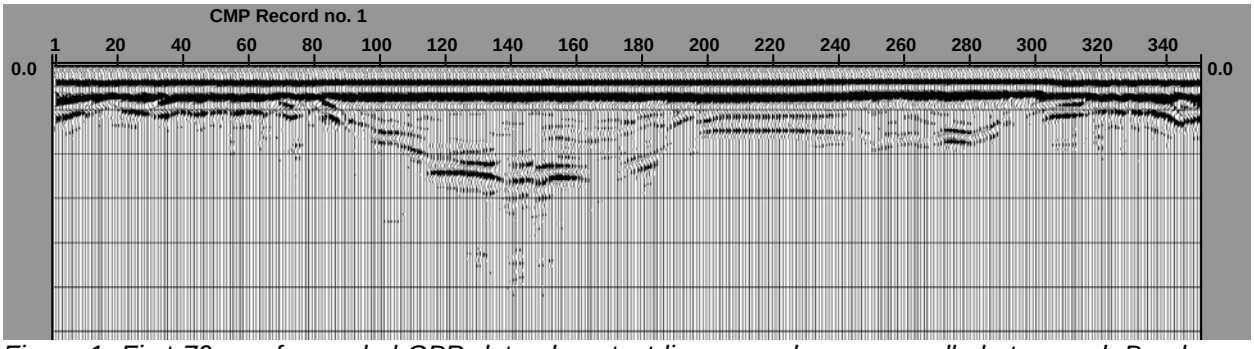


Figure 1. First 70 ns of recorded GPR data along test line up and over a small chat mound. Band-pass filter applied, but no amplitude gain applied. Distinct interface is due to water within the granular material above the clay-rich soil.

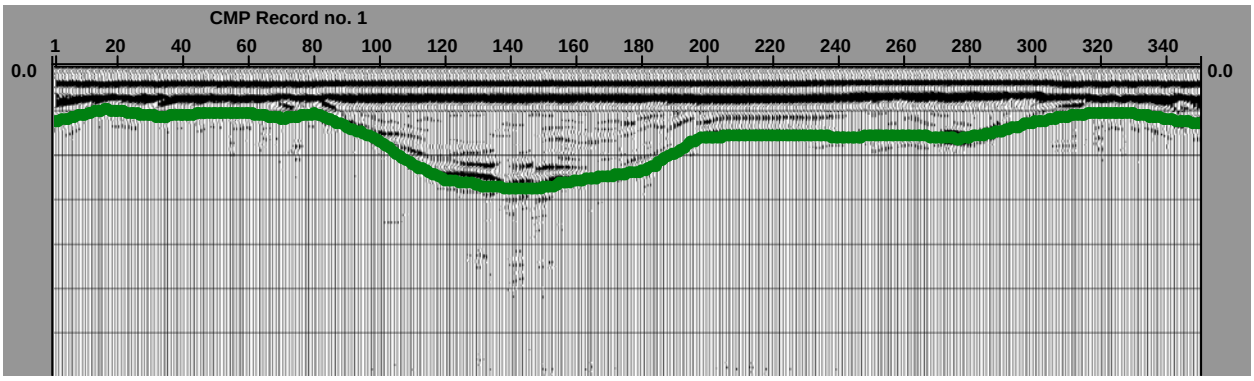


Figure 2. Interpreted first 70 ns of recorded GPR data along test line up and over a small chat mound (same as in Figure 1). Band-pass filter applied, but no amplitude gain applied. Distinct interface is due to water within the granular material above the clay-rich soil.

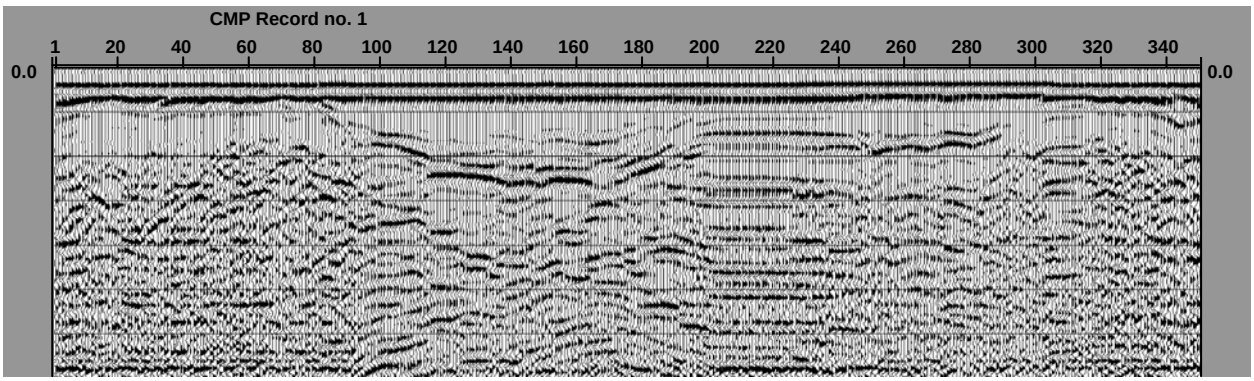


Figure 3. First 70 ns of recorded GPR data along test line up and over a small chat mound (same as in Figures 1-2). Amplitude gain function and band-pass filter applied. Chat-to-soil interface as well as water table evident.

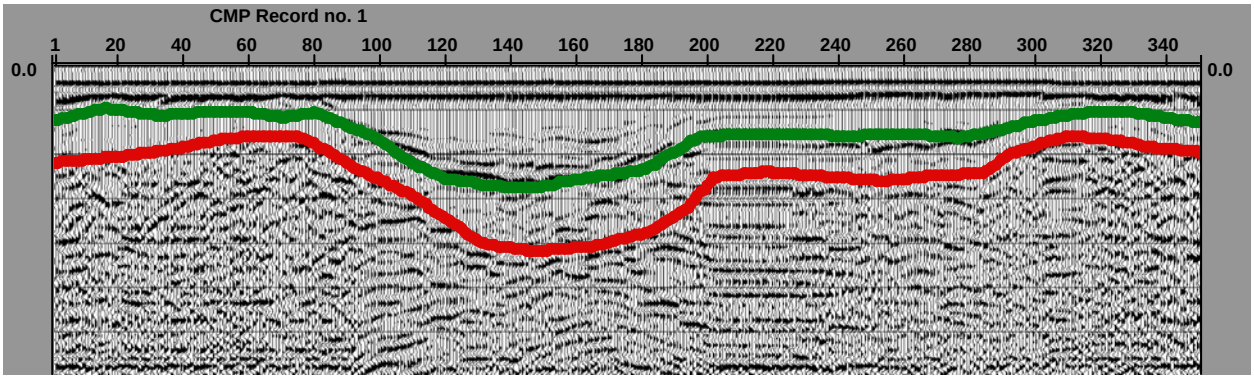


Figure 4. Interpreted first 70 ns of recorded GPR data along test line up and over a small chat mound (same as in Figures 1-3). Amplitude gain function and band-pass filter applied. Chat-to-soil interface as well as water table evident.

RESULTS

Analysis of the GPR records allowed us to create spreadsheet data for all the chat sites surveyed. Chat thickness was estimated along GPR survey lines every 2 meters or less, and at many sites every meter. Chat thickness estimates are based on:

1) picking the radar reflection time at the base of chat (below the chat-with-soil-matrix layer), and

2) using one dielectric constant (27.9) from a test line where we dug down through all layers for ground truth (dry chat, wet chat, chat-with-soil-matrix, down to "no-chat").

IMPLEMENTATION

The integration of GPS and GPR is easily applied where granular material covers clay soil. GPR profiles can be collected in areas covered with silt, sand or gravel to allow highway designers to estimate the volume of granular material available as fill. Natural gravel deposits could be addressed with GPR during the roadway soil survey, mapping their extent and quantifying their volume. Highway designers need to know how much “borrow” is available before construction and survey control in brought into the new area. The use of differential GPS expedites the mapping of the materials and provides the elevations and profile line lengths necessary to calculate volumes. This method could also be used at existing rock mills and quarries where the depth of milled rock is unknown, however, the GPR technique is not recommend for tall piles that exceed the limit of radar depth penetration. Pile volumes above ground can be estimated with DGPS alone as long as elevations are acquired at the top and bottom.

SUMMARY

Ground penetrating radar proved to be very effective in imaging the interface between soil and granular overburden at the sites in this study. Estimates of overburden thickness based on the high quality GPR data can be used for estimating granular material volume at all sites investigated. An average radar velocity was applied to all data. Additional ground truth would allow for the calculation of variable radar velocity parameters across the site, for even more accurate thickness estimations.

Quick and accurate volume estimates of available gravel and other granular material will reduce the possibility of cost overruns and prevent shortages and acquisitions of additional fill. Highway designers can anticipate the calculated volume to exist in the field and design their subbase or fill heights accordingly. Soil surveys would also benefit by the ability to delineate and quantify natural gravel or sand deposits.

The integration of GPS and GPR to provide accurate positions proved to be both reliable and beneficial. The time and cost savings using the GPS unit are tremendous, as a survey crew would be required to bring in survey control well beyond the established right of way. The work GPS was able to do simultaneously with GPR data acquisition would have taken a 6 person survey crew 2 weeks to perform. It is recommended that this marriage of technologies continue with future projects.

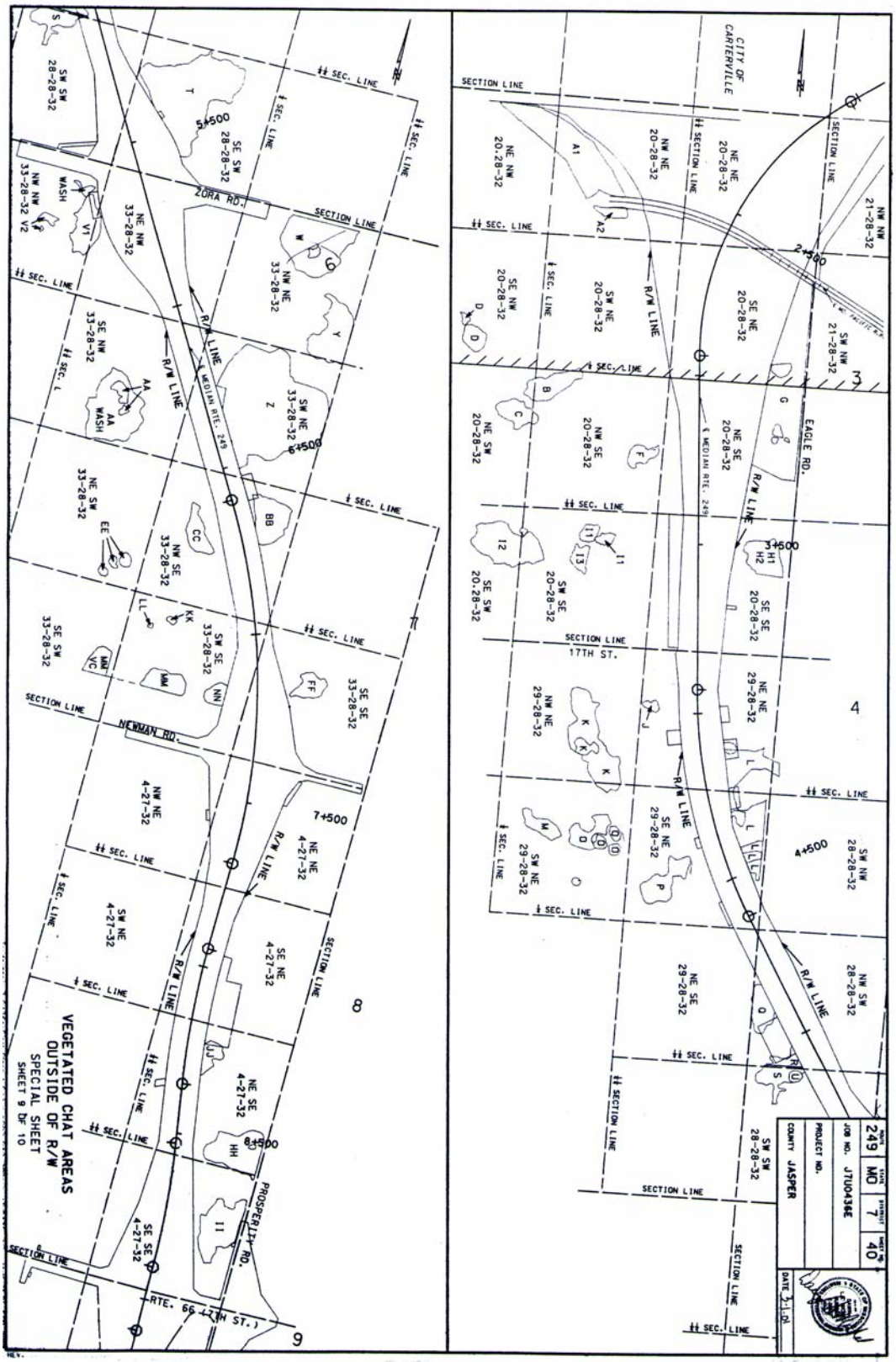
REFERENCES

Cardimona, S., M. Roark, D. J. Webb and T. Lippincott, 1998. Ground penetrating radar, *Highway Applications of Engineering Geophysics with an Emphasis on Previously Mined Ground,* pp. 41-56.

Table 1. Average thickness for each of the areas in this study:

Area	**Average Thickness along GPR survey line (cm)**		
A	48 (line1)	63 (line2)	
AA	60		
B	60		
BB	96		
C	46		
CC	53		
E	83		
EE	55		
F	52		
FF	33 (line 1)	34 (line 2)	
G	65		
HH	27		
I	78 (line1)	56 (line2)	
II	64 (line 1)	95 (line 2)	
JJ	61		
K	62 (line1)	52 (line2)	
L	75 (line1)	54 (line2)	70 (line3)
M	57 (line1)	47 (line2)	
MM	58 (line1)	44 (line2)	
besideMM	30		
NN	53 (line1)	86 (line2)	
O	55		
P	87		
R	94		
S	59		
T	68		
V	75 (line1)	50 (line2)	
W	38		
Y	50		
Z	69 (line1)	68 (line2)	

Figure 5. Map showing planned Route 249 and the corresponding chat areas.

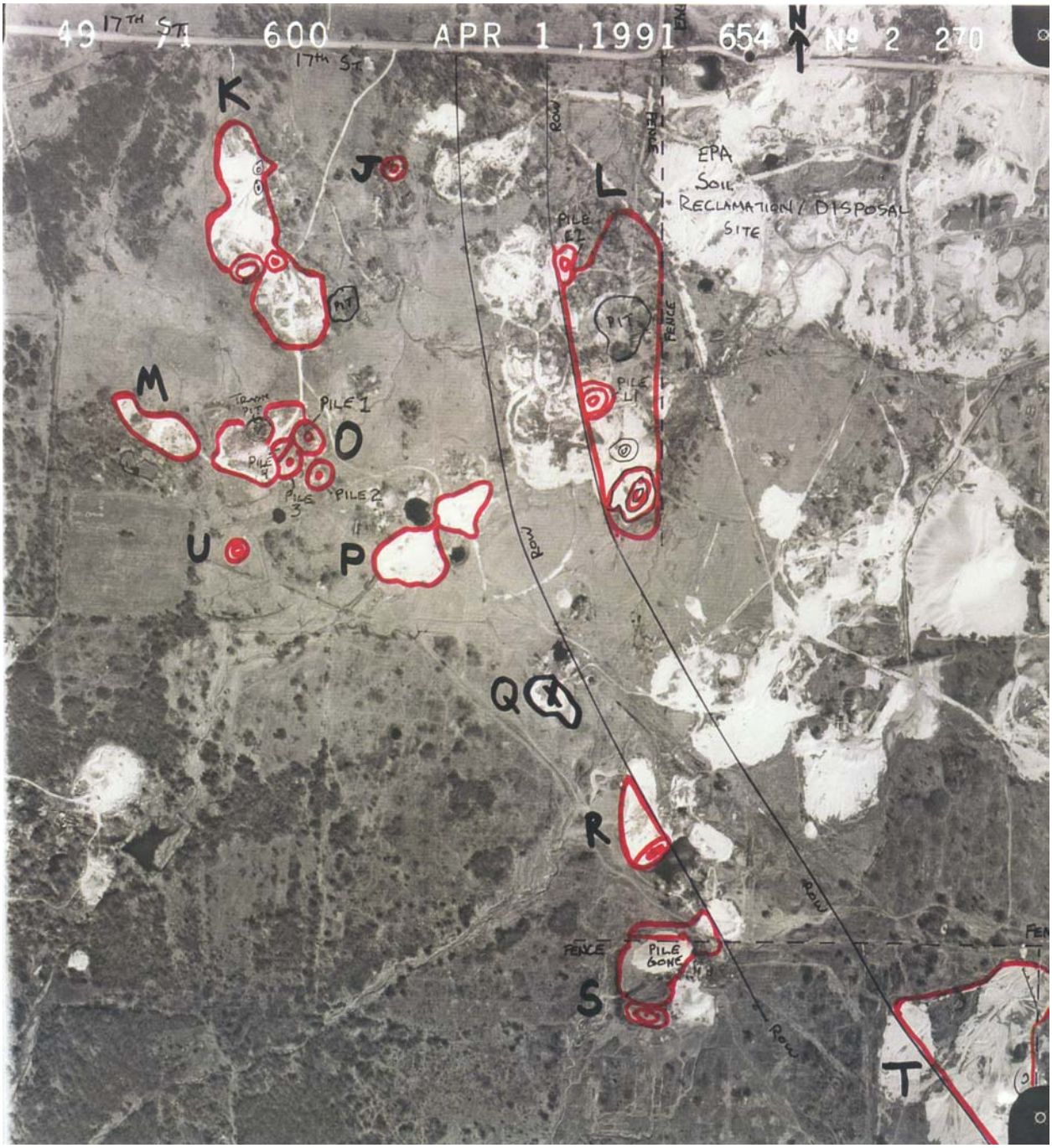


APPENDIX A – Photos

Representative Photos of Chat Piles and Chat Covered Ground

APPENDIX A – Photos

Ground Penetrating Radar Equipment

APPENDIX A – Photos

Aerial Photo of Portion of Study Area