New Jersey Geological Survey
Open-File Report OFR 91-1

DETECTION OF AN ABANDONED MINE USING HIGH-RESOLUTION GEOPHYSICAL METHODS IN RANDOLPH TOWNSHIP, MORRIS COUNTY, NEW JERSEY

N.J. Department of Environmental Protection - Division of Water Resources

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Cover illustration: The King Mine (about 2 miles NW of the Lawrence Mine). Over 300 mines and prospects for iron are known in New Jersey. Many were small and produced only a few hundred or thousand tons of ore from within one or two hundred feet of the surface. All but a few of the 120 mines operating at the time of the 1879-80 census had closed by 1884, made uneconomical by the opening of mines in the Lake Superior area. The geophysical methods presented here will be useful in locating potentially hazardous workings from abandoned mines.

The cover illustration is reproduced from a woodcut in the 2nd annual report of the New Jersey Geological Survey (1855).

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Detection of an Abandoned Mine Using High-Resolution Geophysical Methods in Randolph Township, Morris County, New Jersey

by
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Detection of an Abandoned Mine Using High-resolution Geophysical Methods in Randolph Township, Morris County, New Jersey

ABSTRACT

This investigation reports the applicability of five geophysical methods to locate potentially hazardous, near-surface workings at the abandoned Lawrence Iron Mine in Randolph Township, Morris County, north-central New Jersey. The mineral deposit consists of magnetite veins in an amphibolite host rock surrounded by a microantiperthite granite or a diorite. The veins are as much as 2.5 feet thick. Workings extend to about 110 feet deep. This investigation was designed to detect openings within a few tens of feet of the surface.

Geophysical methods used to detect mine workings and the remnants of the mineral deposit were magnetic, electromagnetic, resistivity-induced polarization profiling, microgravity, and seismic reflection. Each technique was carried out along two traverses at right angles to the strike of the magnetite mineral deposit. Data were collected at 5-foot station intervals.

The magnetic, electromagnetic and induced polarization methods successfully detected the mineral deposit and may also have resolved a near-surfac;e mine working. Resistivity profiling in the gradient array delineated what was either a near-surface mine working or a fracture zone. Microgravity and seismic reflection data show anomalies attributable to mine workings and a fracture zone. An integrated interpretation using two or more geophysical techniques provided the best results in resolving abandoned mines. The location of the mine working was subsequently confirmed by trenching.

INTRODUCTION

In July 1988, New Jersey Geological Survey was asked by the New Jersey Department of Labor and Industry to investigate the abandoned Lawrence Iron Mine in Randolph Township, Morris County (fig. 1). The investigation was designed to test the applicability of geophysical methods to locating subsurface cavities of old mine workings. Two test lines were run at right angles to the strike of the mineral deposit. The following geophysical techniques were used: magnetic, electromagnetic, electrical resistivity-induced polarization, microgravity, and seismic reflection.

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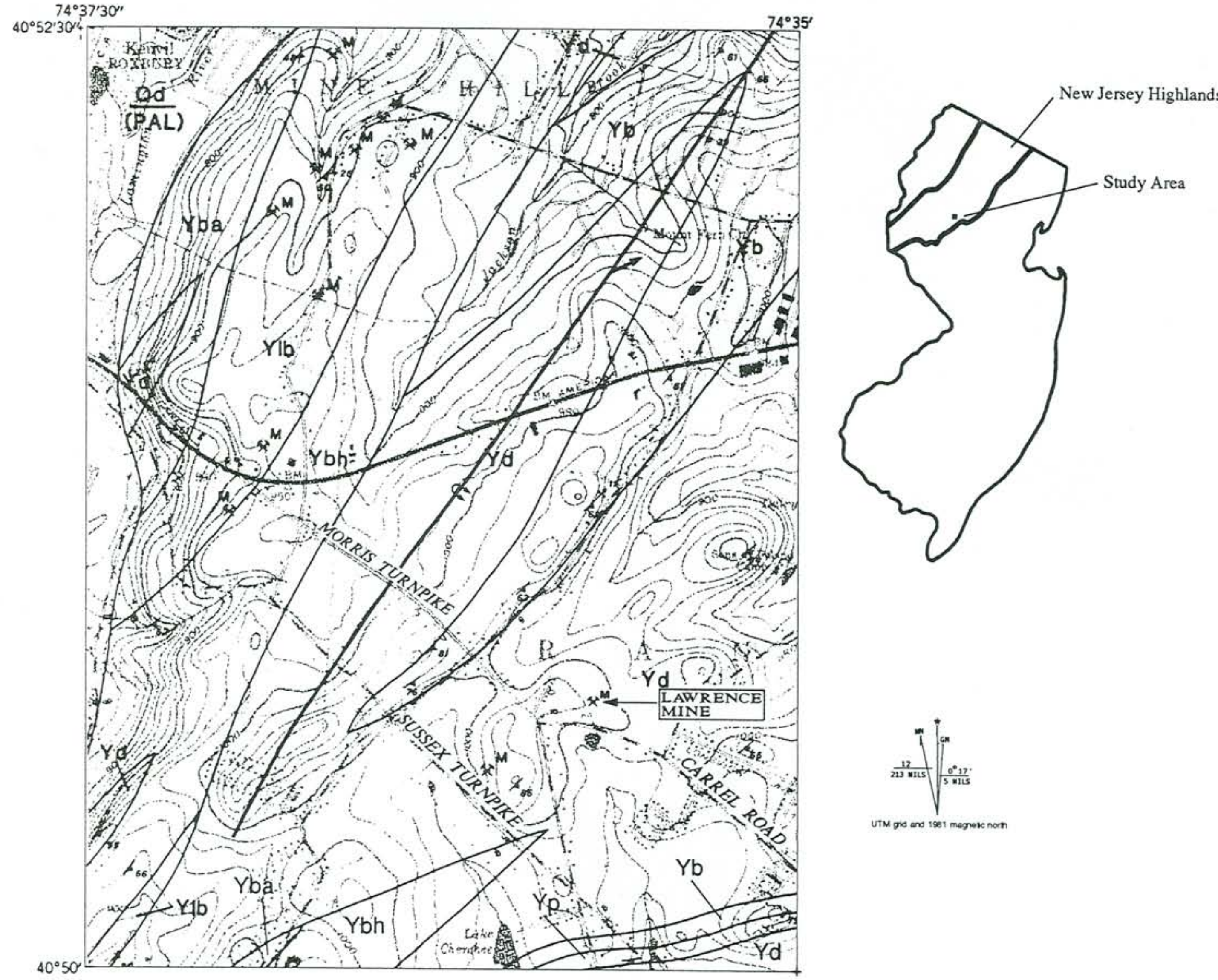
Site description and survey design

The geophysical investigation was conducted at a construction site adjacent to Carrel Road, off the Morris Turnpike, Randolph Township, Morris County, in the vicinity of the abandoned Lawrence Iron Mine (figs. 1,2). At the time of the survey the site was being developed into a residential block, and access was via an unimproved dirt road. The site was devoid of any powerlines, pipelines or other source of cultural noise. The survey lines were oriented N40°W. Line 2 is 550 feet N51°E of line 1 (fig. 2). Data were collected at 5-foot station intervals.

Geology

The study area, located within the New Jersey Highlands (fig. 1) is underlain by highly metamorphosed rocks of Precambrian age. The Highlands rocks consist of gneiss, gneissoid granite and schist, marble and dolomitic limestone, and igneous intrusives, most of which have been greatly deformed and are complexly folded and faulted.

The Lawrence Mine was opened in the late 1800s for iron. It is in the Dalrymple Ore Belt, one of three northeast-trending ore belts in the area (Sims, 1958). The magnetite ore occurs as massive veins in an oligoclase-quartz-biotite gneiss, the host rock. The country rock is shown by Sims (1958) as a microantiperthite granite that locally contains thin layers of amphibolite. The veins are 2.5 feet thick and have been worked to a depth of about 110 feet. A recent geologic map (Volkert, 1988) shows the country rock in the study area as diorite which commonly contains layers of magnetite-bearing amphibolite and mafic-rich quartz plagioclase gneiss (fig. 1).



Miles: 0, 1/2, 1
Kilometers: 0, 1/2, 1

Qd	Quaternary deposits
PAL	Paleozoic (undifferentiated)
Ybh	Hornblende granite
Yba	Microperthite alaskite
Yb	Biotite-quartz-feldspar gneiss
Ylb	Biotite-quartz-oligoclase gneiss
Yd	Diorite

Contact

Overturned antiform - showing trace of axial surface, direction of dip and limbs, and direction of plunge

Strike and dip of crystallization foliation

Abandoned magnetite mine

Figure 1. Geologic map of part of the Mendham quadrangle, New Jersey, showing location of the abandoned Lawrence Iron Mine (modified from Volkert, 1988).

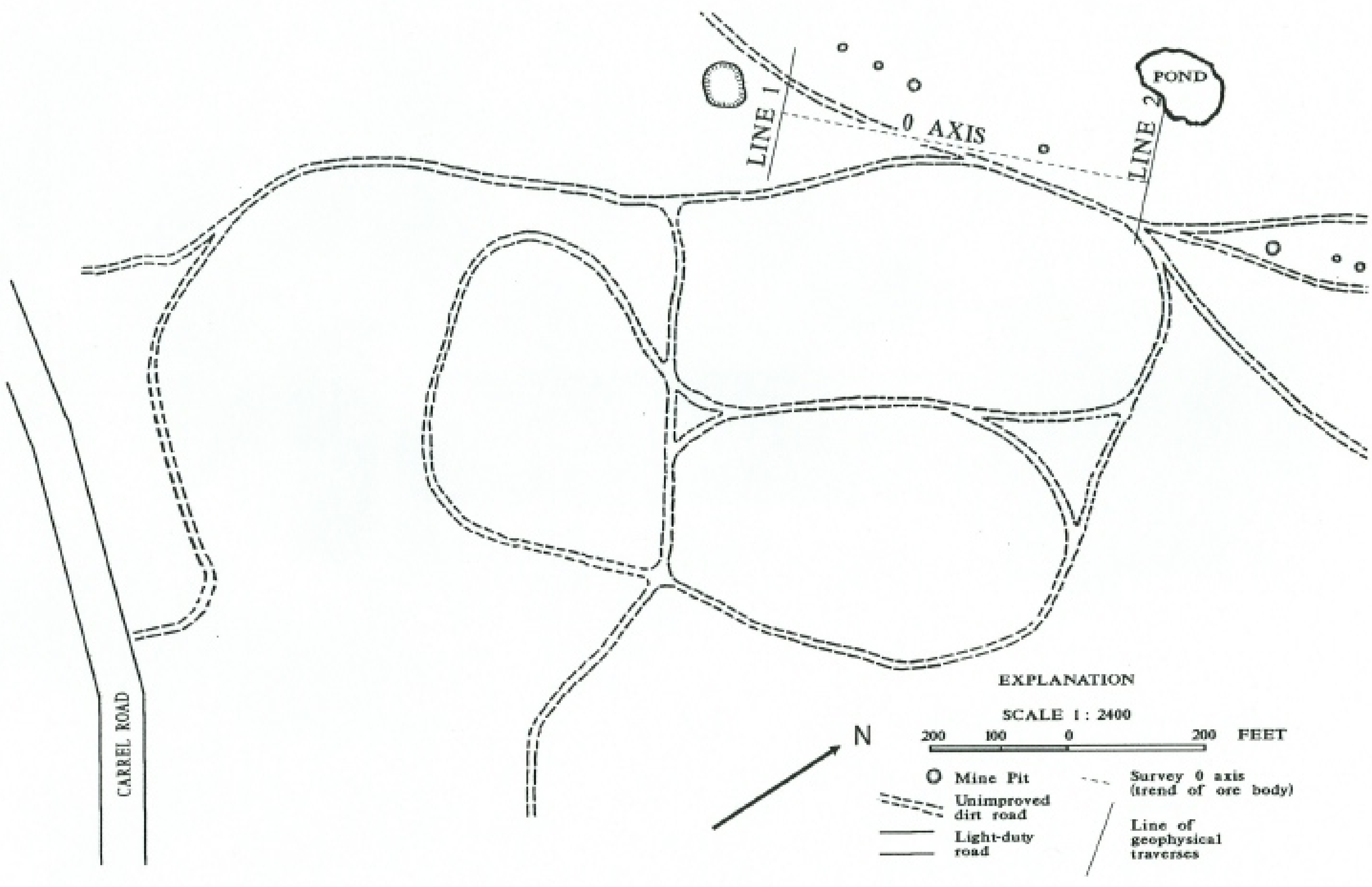


Figure 2. Site map of the abandoned Lawrence Iron Mine showing location of geophysical lines.

GEOPHYSICAL METHODS AND INTERPRETATION

Magnetic

The magnetic method is used to detect small variations in the earth's magnetic field due to differences in susceptibility between rock types. In this study, the magnetic method was used to locate the magnetite mineral deposit exploited at the Lawrence Mine.

An Omni IV proton precession magnetometer was used. Readings were taken at 5-foot intervals along the two survey lines. A second Omni IV served as a field base station so that diurnal corrections could be applied to the total-field magnetic data.

The total field magnetic data from the two lines were plotted in profile form (fig. 3) and modeled interactively using software developed by the New Jersey Geological Survey. Interpretation of magnetic data is non unique because many possible models may result from the same magnetic anomaly unless the model is constrained by assigning specific values to susceptibilities and depths. The magnetic profiles have been interpreted assuming values for susceptibilities and depths of the bodies; no geologic constraints were used. Inherent remnant magnetism is not included in the models.

Line I shows a high-amplitude (4200-nanotesla (nT» anomaly near the mid-point as a high-susceptibility body, presumably the magnetite-bearing host rock. The cavity or mine working is not resolved in the magnetic profile due to the high susceptibilty of the mineral deposit. On the profile for line 2 (fig. 3b), a magnetic high (amplitude 500 nT) near the midpoint may be due to the surficial magnetic material dumped from the mine and lowered susceptibility of the host rock after removal of the magnetite ore. Within this magnetic high is a magnetic low which may be due to a mine working.

Electromagnetic (EM)

The electromagnetic method is used to map lateral variations in electrical conductivity of near-surface geologic materials. In this study electromagnetic profiling was used to locate the magnetite-bearing host rock, which has high conductivity (low resistivity), and to search for the mine workings within the rock.

The frequency-domain electromagnetic method was used to profile in the horizontal loop configuration (Dobrin, 1976). A Geonics EM-31 electromagnetic meter was used. In the horizontal loop configuration, a high-frequency alternating current is transmitted through a coil. This induces a time-varying magnetic field which, in turn, induces electrical currents in the ground. These electrical currents generate a secondary field which is detected, along with the primary field, by the receiver coil. Electromagnetic measurements were taken every 5 feet. The effective depth of exploration of the instrument is about 6 meters or 19.7 feet (McNeill, 1980).

The electromagnetic data have been plotted as resistivity in ohm-meters (the inverse of conductivity) for ease in interpretation (fig. 4). The profiles show resistivity lows (high conductivity), probably due to the host rock. High resistivity (low conductivity) within the area of low resistivity are probably due to near-surface fracture zones. The mine working is not clearly resolvable.

Electrical Resistivity and Induced Polarization

The electrical resistivity method is used to detect vertical or lateral variations in the electrical properties of geologic material. The induced polarization (IP) method measures the voltage decay in the ground following an impressed current pulse. Resistivity and IP data were collected simultaneously. The resistivity method was used to detect the lateral variations in electrical resistivity between the high-resistivity rock and low-resistivity mine working (presumably water-filled). Peters and Burdick (1983) have used electrical resistivity for detecting abandoned-mine workings.

Electrical and IP profiling were done using a Huntec M4 2.5-kilowatt, resistivity-induced polarization system. Resistivity and IP data were taken in the gradient array configuration. The current electrodes were 656 feet apart and the dipole length was 20 feet.

Figure 4 shows the apparent resistivity in ohm-meters and chargeability in milliseconds for lines 1 and 2. The low in the center of the apparent-resistivity profile of line 1 indicates low resistivity material due to a water-filled mine working, conductive mineral concentration or fracture zone. The IP data show high chargeability, indicating a mineral deposit. This corroborates the magnetic and electromagnetic interpretations. The apparent resistivity profile of line 2 shows a significant low in its center, indicating a low-resistivity material, possibly the waterfilled mine working or a fracture zone. A magnetic low is also seen in magnetic line 2 at the same location (fig. 3). The IP data (fig. 4) show high chargeability at the midpoint of the profile, indicating the mineral deposit identified by the electromagnetic and magnetic methods.

Microgravity

The microgravity method is used to detect small variations in the earth's gravitational field due to differences in density between rock types or between a cavity (such as a mine working) and the surrounding rock. Arzi (1975) and Omnes (1975) have successfully used microgravity to detect subsurface voids.

Microgravity data were collected along the profile lines using a Lacoste and Romberg microgal gravimeter

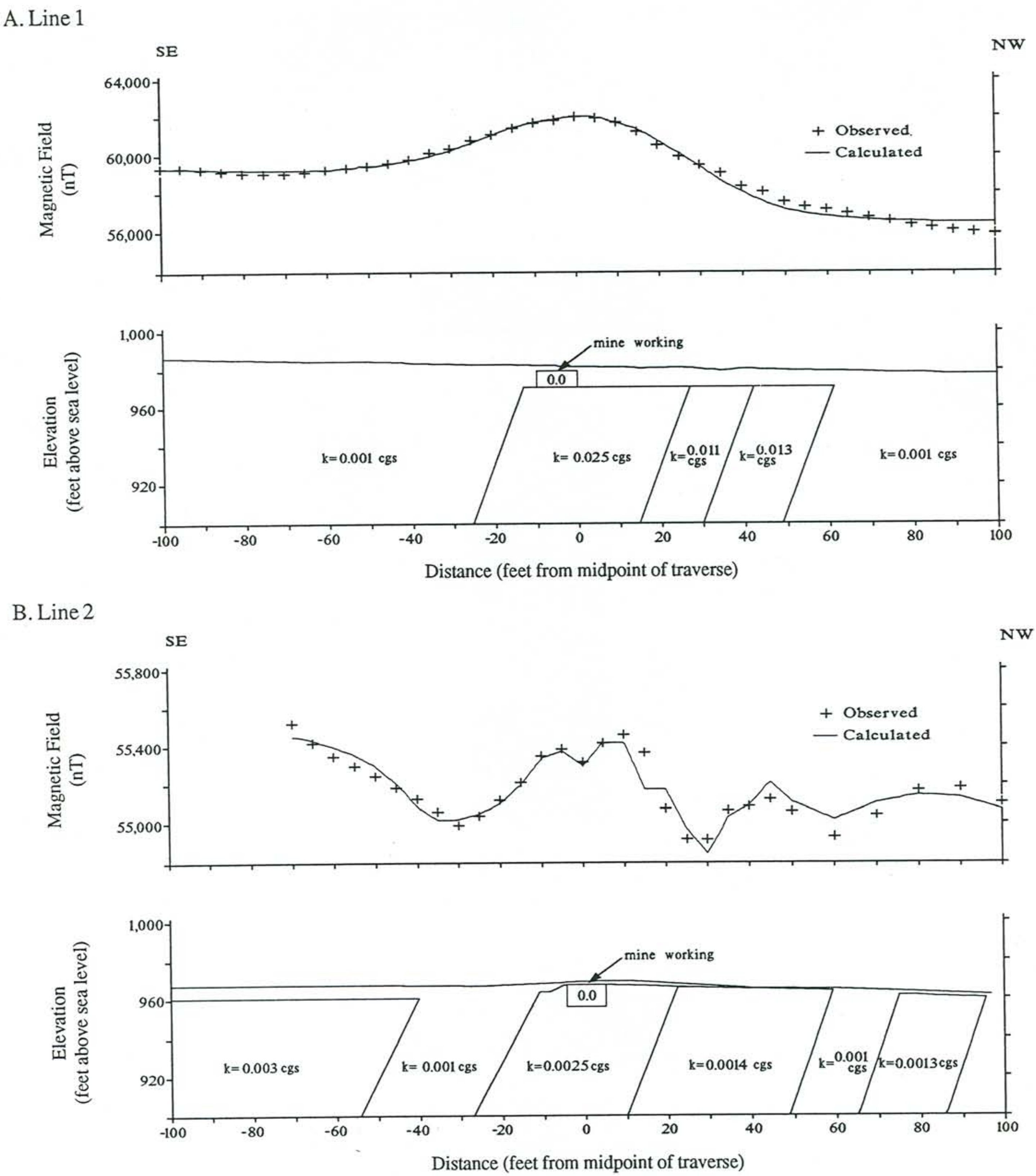


Figure 3. Magnetic profiles for lines 1 and 2 showing observed magnetic data with calculated data from models.

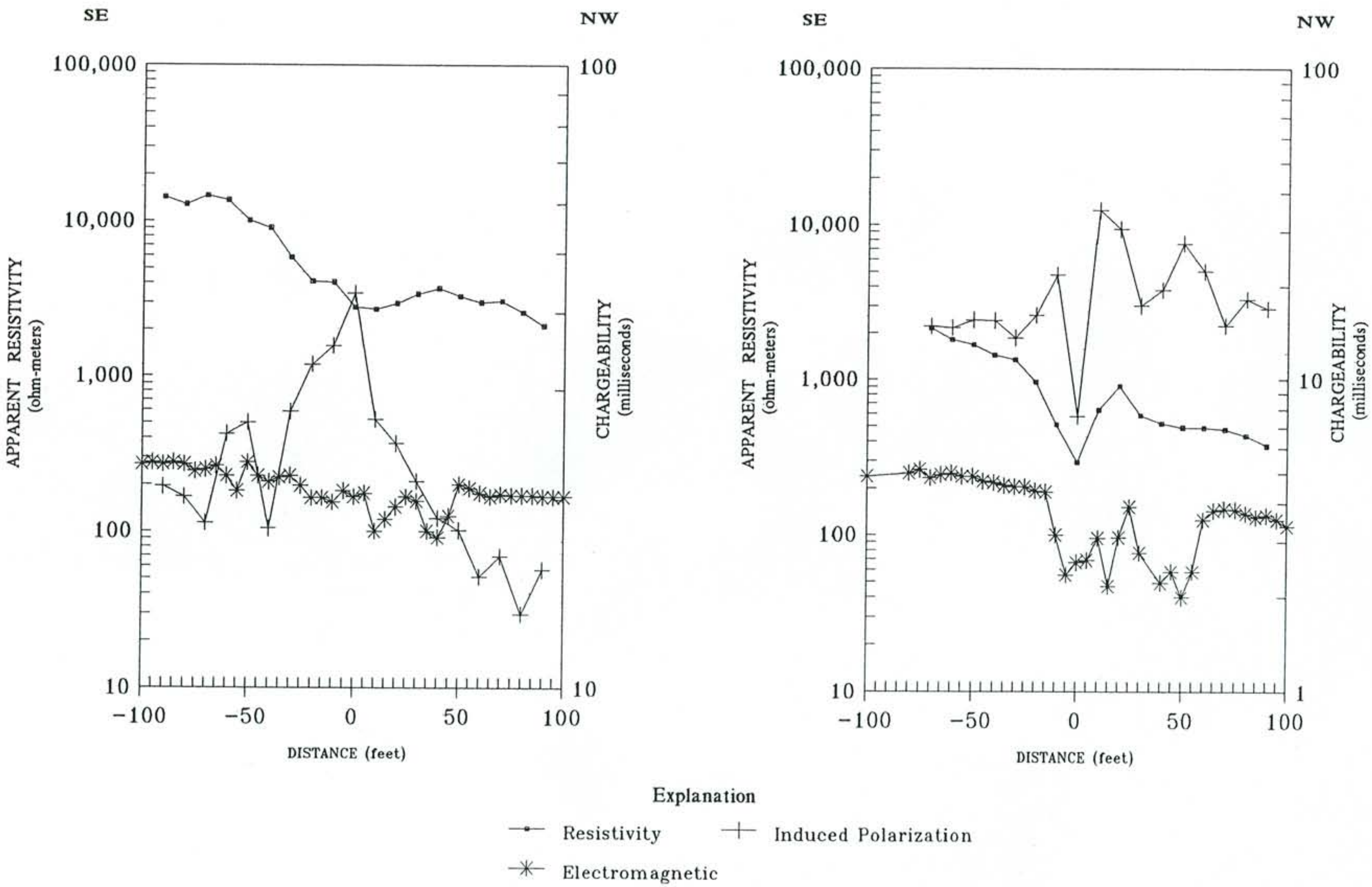


Figure 4. Electromagnetic, electrical resistivity, and induced polarization data for lines 1 and 2. Electromagnetic data are plotted as apparent resistivity in ohm-meters (inverse of conductivity) to compare with the resistivity data.

rock. Ani (1975) and Dmnes (1975) have successfully used microgravity to detect subsurface voids.

Microgravity data were collected along the profile lines using a Lacoste and Romberg microgal gravimeter (model D-25). The measurements were taken every 5 feet. After each reading, the station elevation was surveyed using a transit and stadia rod. The gravity readings were then corrected for tidal and instrument drift, elevation, and latitude on a microcomputer using standard procedures (Dobrin, 1976) to obtain Bouguer gravity values.

Interactive microcomputer software developed at the New Jersey Geological Survey was used to model two-dimensional gravity data along the two lines. Interpretation of gravity data is nonunique, as in the case of the magnetic data, because many possible models may result from the same gravity anomaly. Hence, constraints (assigning specific values to densities or depths) are required to model gravity data. The density of the country rock, and densities and depths of the other bodies, have been assumed based on the available geologic data (Sims, 1958; Volkert, 1988) and values presented in Dobrin (1976). The density of the soil- and water-filled mine workings have also been assumed.

Two gravity lows are seen in both line 1 (fig. 5a) and line 2 (fig. 5b). A possible mine working in the center of line 1 is indicated by the broad anomalous low. The narrow gravity low may be due to a fracture zone. In line 2 a similar broad gravity low (fig. 5b) may be due to a mine working, as shown in the model. The other narrow gravity low may be due to a fracture zone within the host rock. The location of the narrow gravity lows in both of the gravity profIles coincides with anomalies in the electromagnetic data (fig. 4) attributed to a fracture zone. In gravity line 2 (fig. 5b), the anomaly associated with the fracture zone also coincides with the resistivity anomaly (fig. 4).

Seismic Reflection

The seismic reflection method detects variations in seismic or acoustic velocity of geologic materials. Both p- and S-wave reflection methods have been shown to display three phenomena associated with cavities: 1) free oscillations or resonance of the cavity walls, 2) anomalous amplitude attenuations, and 3) delay of arrival times (Cook, 1965; Watkins and others, 1967; Branham and Steeples, 1988, Dobecki, 1988).

Seismic reflection data were collected using a 24-channel, 8-bit, signal-enhancement, nonsaturating seismograph using the common-offset profiling technique. A 12-pound sledge hammer was used as the seismic source with the shotpoint offset 5 feet from the recording geophone. The geophones were single, feedback-sensitive accelerometers. Analog band-pass filters (75 Hertz to 375 Hertz) were used to reduce noise and optimize frequency resolution.

The seismic data were processed using the Kansas Geological Survey (KGS) processing system. As the target is too close to the surface, reflections from the mine working and water table cannot be delineated. No static corrections or frequency filtering of the data were applied. Marked areas of amplitude attenuation and delayed first breaks are shown in both lines (fig. 6). These areas coincide closely with the gravity lows (fig. 5) and the anomalies shown by other methods (figs. 3, 4). The location of the mine workings is not resolved in the seismic data owing to the scattering effect of fractures and variability in the depth of the water table.

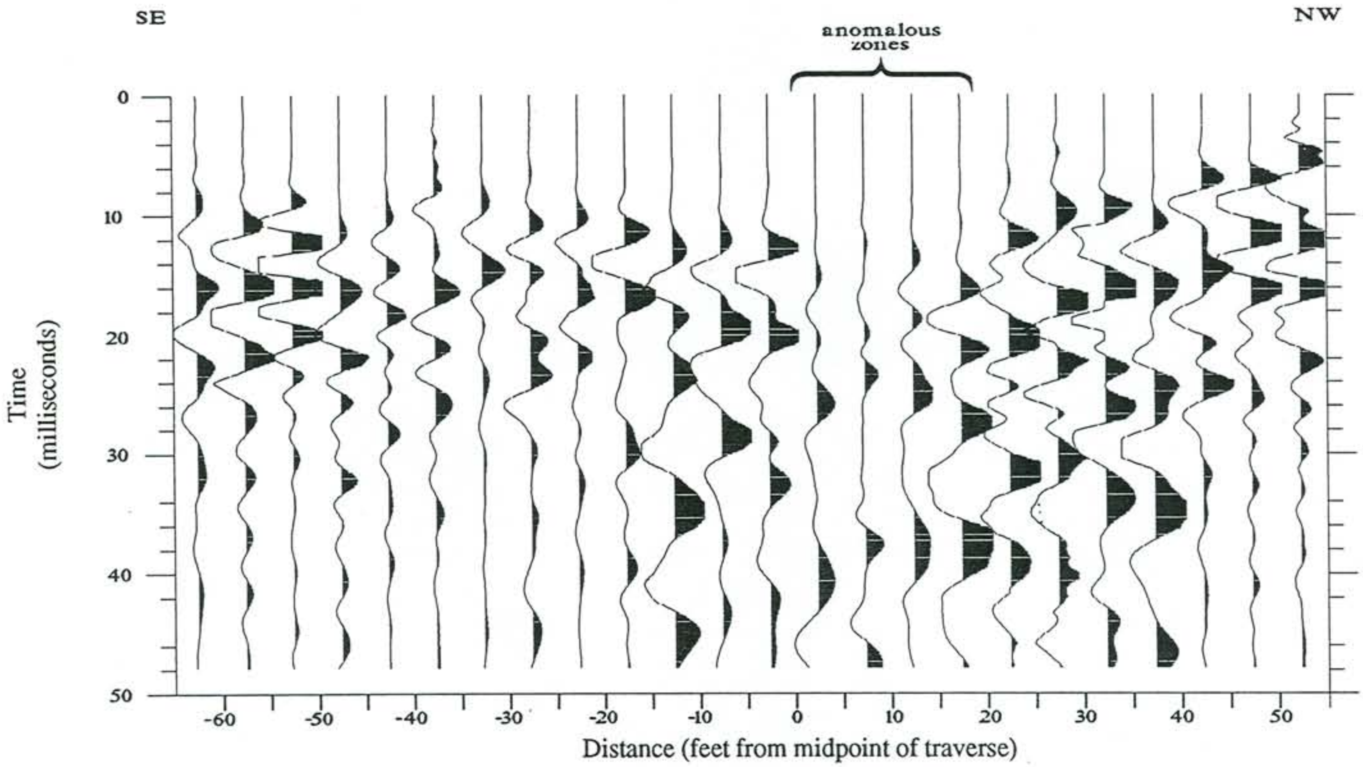
SUMMARY AND CONCLUSIONS

Five surface geophysical methods have been tested for their ability to detect subsurface workings at an abandoned mining site. The magnetic, electromagnetic and induced polarization methods successfully detected the mineral deposit due to its anomalously high magnetic intensity, high conductivity (low resistivity), and high chargeability. The resistivity method could not differentiate the mine workings from the fracture zones; both are associated with resistivity lows. Broad gravity lows indicated mine workings and narrow gravity lows indicated narrow fracture zones. Amplitude attenuations and delayed first breaks in the seismic data were indicators of mine workings and/or fractures. The success of the geophysical methods was later confirmed by trenching. The mine workings have since been capped and covered.

The resolution of these geophysical methods depends on the size of the mine, instrument accuracy, the station spacing, elevation control, and cultural noise. Most of the techniques, such as seismic reflection, electrical resistivity and IP, electromagnetic and magnetic methods may not work at all in heavily developed areas containing metallic fences, powerlines and pipelines. The microgravity technique is not susceptible to these interferences but elevation control and station spacing is of utmost importance and is time-consumming to establish.

Best results in locating abandoned near-surface mine workings were obtained by the use of more than one geophysical method aided by computer modeling.

A. Line 1



B. Line 2

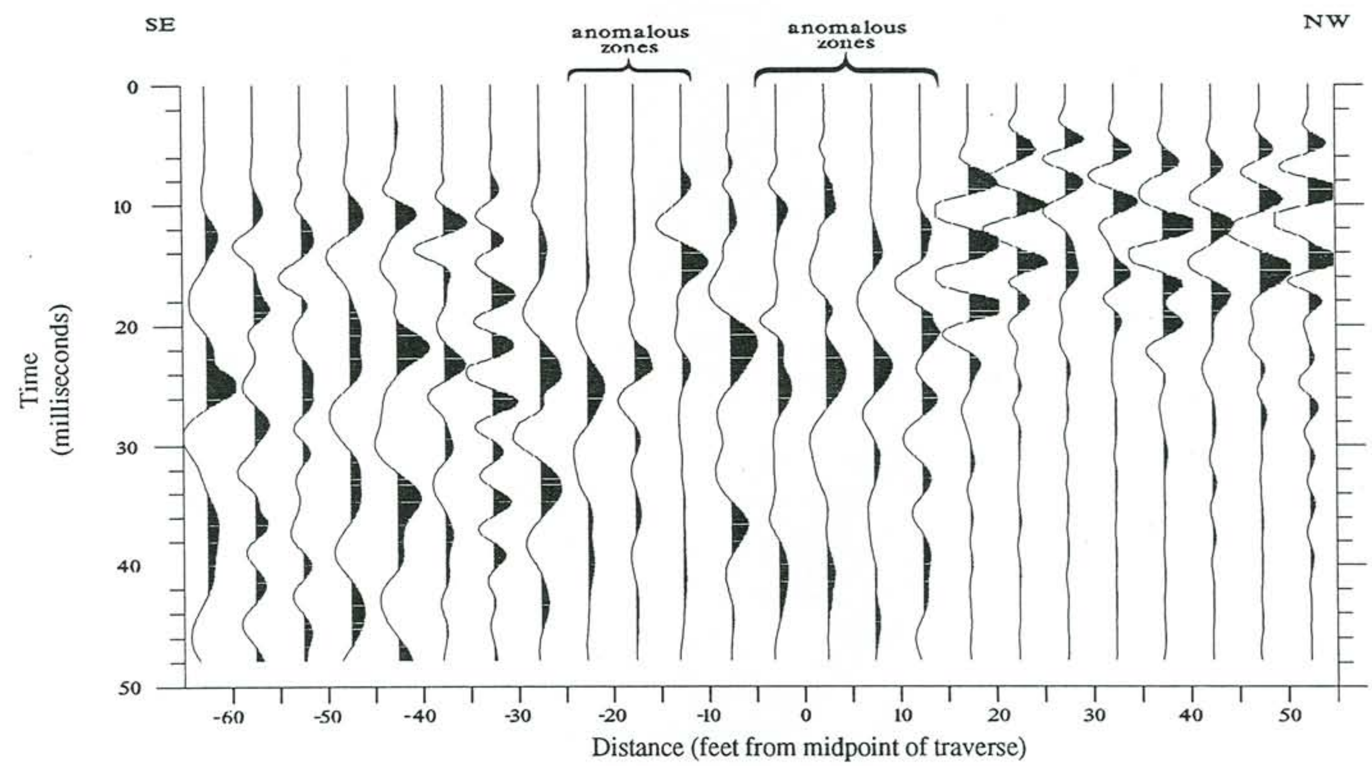


Figure 6. Common-offset reflection data for lines 1 and 2. Traces are positioned at midpoint locations between shotpoint and geophone. Anomalous zones are indicated by delayed first arrivals, and attenuated amplitudes.

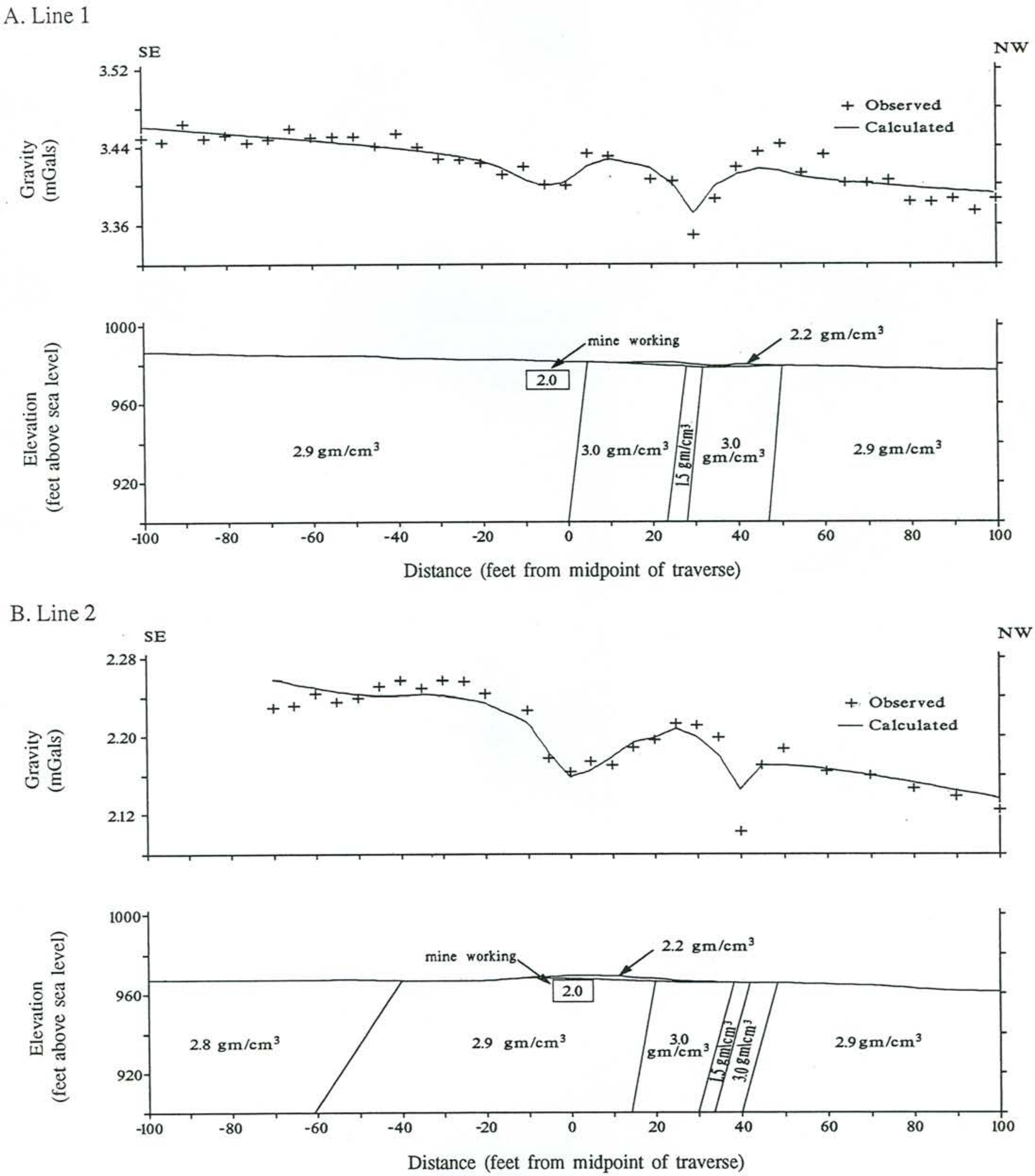


Figure 5. Gravity profiles for lines 1 and 2 showing observed gravity data with calculated data obtained from models.

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