

Case histories of dc resistivity measurements to map shallow coal mine workings

WILLIAM J. JOHNSON, D'Appolonia Engineers, Monroeville, Pennsylvania, U.S.

Two recent events have focused attention on the need for mapping underground mine workings: the failure of the Martin County Coal Corporation tailings impoundment near Inez, Kentucky on 11 October 2000 and the 24 July 2002 Quecreek Mine inundation that trapped nine miners for 77 hours in Somerset County, Pennsylvania. In both cases, unexpected conditions related to abandoned mines were the sources of the accidents. In the first case, the overburden between an abandoned mine and the base of a slurry impoundment was too thin and the slurry broke into the mine. The consequence was that the slurry broke out and flooded two separate watersheds with coal refuse. In the second case, miners accidentally excavated into the flooded workings of the abandoned Saxman Mine, which they thought was hundreds of feet away.

Conditions such as these require that the location of underground workings be defined. This is not easy. Detailed mine maps may be unreliable or missing. Conventional exploration (drilling) can easily miss targets as small as a mine entry. Because of these difficulties, the National Resource Council appointed the Committee on Coal Waste Impoundments to evaluate remote sensing technologies to locate mine workings. In Pennsylvania, a Commission on Abandoned Mine Voids and Mine Safety, convened in September 2002 as a result of the Quecreek inundation, has also identified various geophysical technologies that could be applied to the mapping of mine workings.

Most geophysical techniques have been around for many years and the physics used to detect underground mines hasn't changed. Basic interpretation strategies also haven't changed. What has changed is the ability of the geophysicist to gather data rapidly. Multielectrode systems have greatly improved the efficiency of data acquisition with the dc resistivity method—e.g., measurements can now be made automatically. Until recently, the dc resistivity method was limited by the need to perform complex calculations to model subsurface electrical properties. However, the development of high-speed PC computer systems and improved 2D and 3D processing software has greatly reduced this handicap and the technique has seen increased application, including detection of subsurface openings. This article presents three recent case histories where modern data acquisition and processing systems have been applied in the detection of coal mine voids.

Locating mine workings at the Regency Park Subdivision, Plum Borough, Pennsylvania. The Regency Park subdivision is over shallow mine workings associated with the Plum Creek Mine operated in the late 19th and early 20th centuries. The subdivision has been the location of numerous foundation failures over the past several decades since the homes were constructed. This is not surprising, as many homes were constructed with 25 ft or less of overburden above the Pittsburgh coal seam. This site has recently been remediated under the Abandoned Mine Land Reclamation Program directed by the Pennsylvania Department of Environmental Protection (PADEP).

The resistivity survey was conducted before the mine was stabilized with grout, but after the injection borings were drilled. The boring logs from these holes were made available by PADEP.

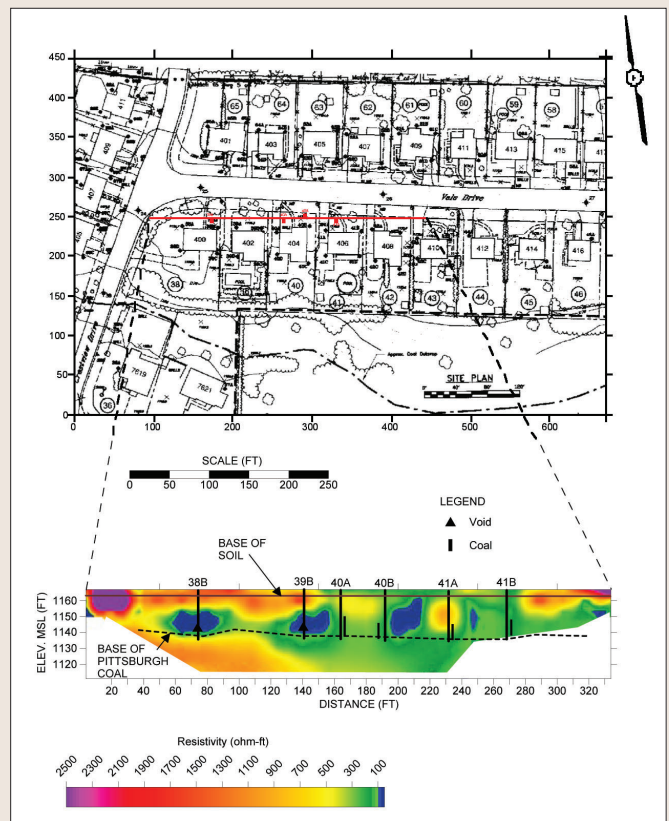


Figure 1. The profile defines the rooms as being of relatively low resistivity with respect to the coal.

A portion of the subdivision was surveyed with the dc resistivity technique using the pole-dipole configuration with a multielectrode automated measurement system manufactured by Iris Instruments. The data were processed with the RES2DINV program (Loke, 1999). The results (Figure 1) define a series of resistivity lows that bottom out at an elevation of 1140 ft MSL, consistent with the bottom of the Pittsburgh coal seam as known from available mine maps and borings drilled along the profile. Where borings were drilled within 5 ft of the profile, resistivity lows corresponded to mine voids (partially collapsed). Zones of relatively high resistivity between the lows contained coal. The anomaly pattern and the results of the borings indicate that the resistivity lows and highs above an elevation of 1140 ft MSL correspond to rooms and pillars, respectively. An unusual aspect of these results is that the mine is not completely flooded. Typically, no more than about 2 ft of water is in the mine, so it is not obvious why the entire height of the rooms (the Pittsburgh coal seam is 10-12 ft thick at this location) would be characterized by resistivity lows. The reason might be oxidation phenomena where the pillars are exposed to air and water, or simply the trickling of water down the pillars.

The data required to prepare the electrical cross-section were acquired quickly and efficiently. The results identify the mine workings and show where mine voids and barrier coal should be expected to be encountered if additional borings are drilled.

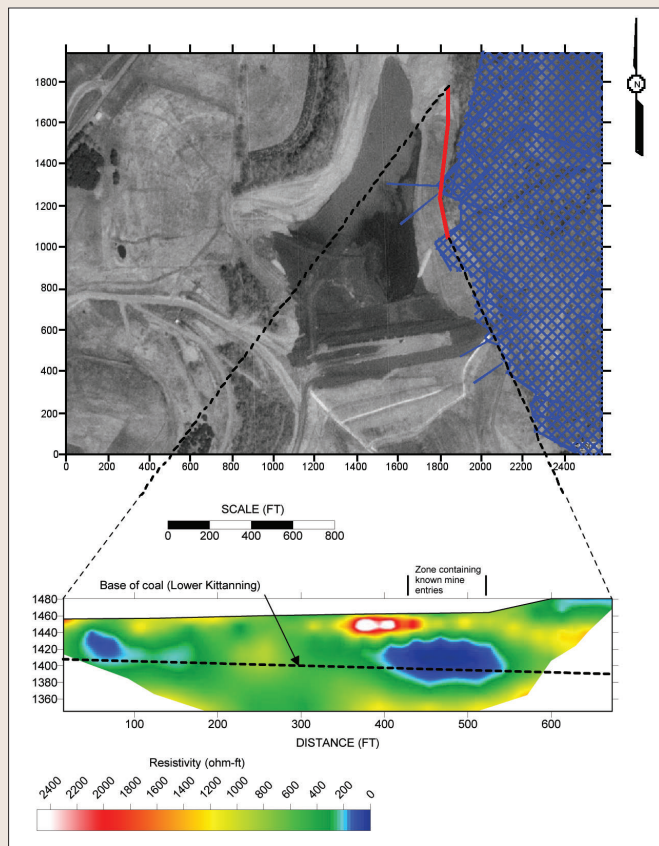


Figure 2. In addition to the known workings believed flooded with low pH water, the results also identified the known barrier coal and a second area centered about 50 ft along the profile where unmapped workings might be present.

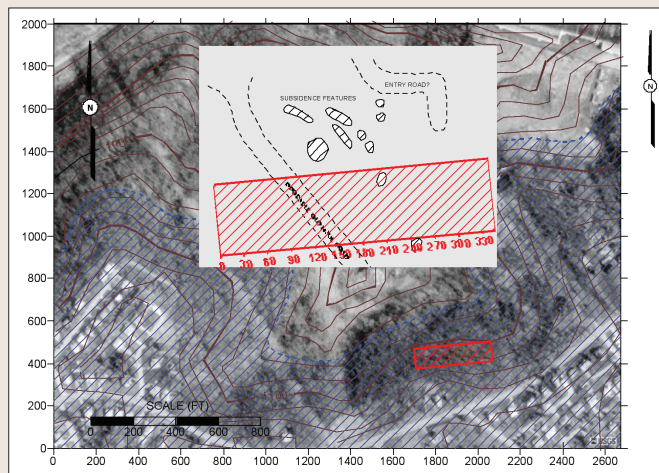


Figure 3. Location of survey block over Oak Hill No. 4 Mine (Monroeville, Pennsylvania) with subsidence features associated with its collapse of this mine.

Locating mine workings at a mine tailings impoundment in Jefferson County, Pennsylvania. A dc resistivity survey was conducted at a mine tailings impoundment to determine the practicality of mapping mine workings known to be present beneath the pool level of the tailings. This facility was designed by D'Appolonia in the 1980s and received tailings through the mid-1990s. The D'Appolonia borings provided control on the position of the coal seam and detailed coal maps were available so that the position of known entries could be accurately located in the field. The mine entries were known to be approximately 60 ft below ground surface.

The dc resistivity survey used the pole-dipole technique

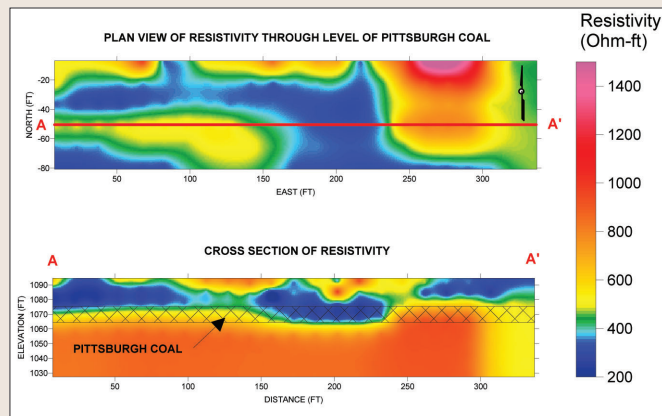


Figure 4. Plan view of resistivity through the level of the Pittsburgh coal and cross-section. An advantage of interpreting mine workings from resistivity data is that the top and bottom of the coal seam are normally known in advance and it is possible to distinguish mined-out areas (low resistivity in this case) with solid coal (relatively high resistivity).

with the remote electrode placed next to the reservoir water. Data processing was conducted in a manner similar to the Regency Park data set. The results (Figure 2) indicate the presence of a pronounced resistivity low in the area of the known entries. It is anticipated that the workings of the mine are flooded at this location and that the response is due to the presence of acidic water in the mine.

The results demonstrate the usefulness of this type of survey to delineate a known entry, to indicate where barrier coal can be reasonably assumed to be present, and to target possible unknown mine workings. Although the anomaly is not as strong, a resistivity low that could also be indicative of mine workings is present just above the coal seam and 50 ft along the profile.

Locating mine workings at the Oak Hill No. 4 Mine, Monroeville, Pennsylvania. The Oak Hill No. 4 Mine operated throughout most of the latter half of the 19th century up to the beginning of the 20th century. Old mine maps are not reliable. Therefore, a surface-site investigation and a geophysical survey were conducted to determine the extent of coal barriers left over after the mining. The presence of mine subsidence craters within and near the survey area (Figure 3) provides some indication of the location of mine workings. This area was surveyed with a 3D dc resistivity technique. The previous case histories provide the results of 2D electrical profiling, but recent developments of software and computer technology now allow processing electrical data in three dimensions.

The survey was conducted along seven parallel profiles with the dc resistivity technique using the pole-dipole configuration and placing the electrode in moist soil at the base of a distant subsidence-related sinkhole. The data were then processed as a single block of data from which it was possible to extract both horizontal and vertical slices of the data set within the RES3DINV program (Loke, 1999). The slice of resistivity data through the level of the Pittsburgh coal seam depicts a pattern that appears to relate to rooms and pillars (Figure 4). Further analysis of the electrical-cross sections through the coal provide additional evidence of the relationship between the electrical measurements and the old mine. When depicted as a 3D block diagram, the interpreted results show where barrier coal is present as zones of high resistivity (Figure 5). A subsidence crater on the ground surface correlates with an entry location adjacent to a block of barrier coal in the eastern part of the survey.

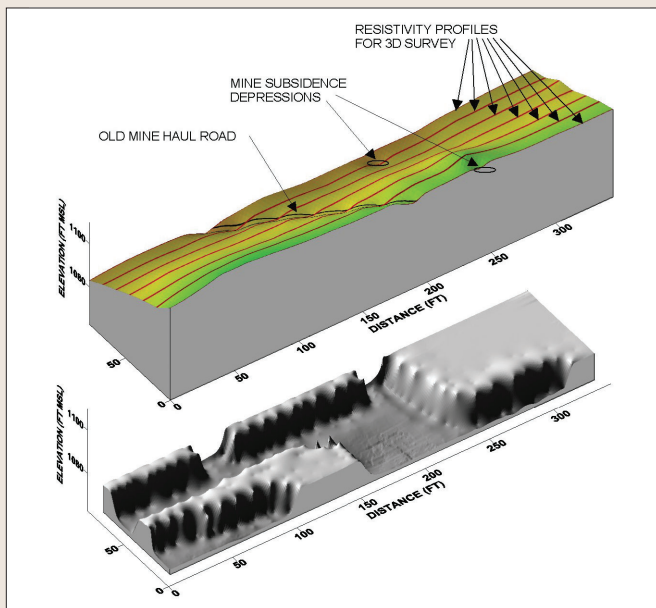


Figure 5. Location of survey profiles and interpretation of mine layout from dc resistivity data. Note that the mine subsidence depressions in the survey area are located at the edge of a block of unmined barrier coal.

One constraint associated with the technique is that it is not a practical method to determine if the mine workings have been backfilled (miners commonly used waste rock called “gob” to partially fill parts of the mine) or if the mine workings are still open voids. Similar to the Regency Park example, the mined-out areas have a marked resistivity low. This could mean that flooded or partially flooded open workings are present, but if the workings were backfilled with gob,

the gob would also be expected to have a resistivity significantly less than the solid coal. Thus, a postsurvey drilling program has to be done to complement the interpretation of the geophysical data.

This is another example of how the results of a geophysical survey could help define the scope of a drilling program. Borings could easily be targeted using the geophysical results to increase the probability of encountering mine workings. Conversely, the results also identify the continuity of zones where mine workings are not expected to be present.

Conclusions. For shallow workings (less than 100 ft beneath the surface), DC resistivity can reliably map the rooms and pillars of abandoned mine workings rapidly and relatively inexpensively. For deeper targets, the technique could be used to map the location of flooded workings, but without the resolution of specific rooms and pillars. The major advantage of dc resistivity is that it provides a continuous subsurface profile, allowing the targeting of boreholes in areas where voids will most likely be encountered. Perhaps more significantly, the method offers the possibility of identifying the places where mine voids will not be encountered, greatly enhancing the efficiency of a drilling program.

Suggested reading. Electrical Imaging Surveys for Environmental and Engineering Studies, a Practical Guide to 2D and 3D Surveys by Loke (<http://www.geoelectrical.com>, 1999). Report of Commission on Abandoned Mine Voids and Mine Safety (Pennsylvania Department of Environmental Protection, 2002). *Coal Waste Impoundments, Risk, Responses, and Alternatives* (National Academy Press, 2002). **TJE**

Corresponding author: wjjohnson@dappolonia.com