# CHAPTER 3.0. GEOPHYSICAL METHODS FOR MAPPING VOIDS

A variety of geophysical techniques exist with the capability of locating near-surface voids. Each method has limitations in depth of exploration and resolution depending on the geological settings, target (void) size and orientation.

The general background of the methods, data acquisition, and the capabilities of these methods for mapping near-surface voids are based on the results of previous work and will be explained in more detail later in this report. The capabilities of the proposed methods for mapping near-surface voids within the particular geological settings at LBNM will also be addressed.

The geophysical methods described in this Chapter include:

- Electrical Resistivity.
- Ground Penetrating Radar.
- Magnetic Method.
- Electrical Conductivity.
- Seismic Refraction.
- Seismic Reflection.
- Gravity Method.

However, only the following geophysical methods were used at LBNM:

- Electrical Resistivity.
- Ground Penetrating Radar.
- Magnetic Method.
- Electrical Conductivity.
- Seismic Reflection.

The seismic refraction method was not selected because no specific refractors are expected to occur at the depth of interest. The gravity method, although potentially useful for locating voids, is slow and therefore expensive in the field, since great care has to be taken with each reading and all of the stations need accurate elevation control. In addition, significant processing may be required to account for all of the factors that can influence the gravity readings.

## 3.1 ELECTRICAL RESISTIVITY

### 3.1.1 General Background and Data Acquisition

Electrical Resistivity methods measure the apparent resistivity of the subsurface. Apparent resistivity is the term used for the field measurements since, without interpretation, the resistivity measurement does not refer to any particular geologic layer. Graphs of apparent resistivity against electrode separation are used to model the subsurface, thereby providing the vertical distribution layer thicknesses, depths and resistivities. The electrical resistivity equipment consists of a transmitter and a receiver along with the electrodes and wires. The transmitter passes low frequency square wave current into the ground using two electrodes inserted into the ground. The receiver measures the resulting voltage using two different electrodes. The measured apparent resistivity of the ground is found by dividing the measured voltage by the amount of current injected into the ground and multiplying this by a geometric factor that is derived from the geometry of the electrode array. The depth of investigation is a function of the array type and the electrode spacing. As the distance increases between the current and the potential electrodes, the depth of investigation increases. Figure 2 shows an electrode array with electrical current flow lines.

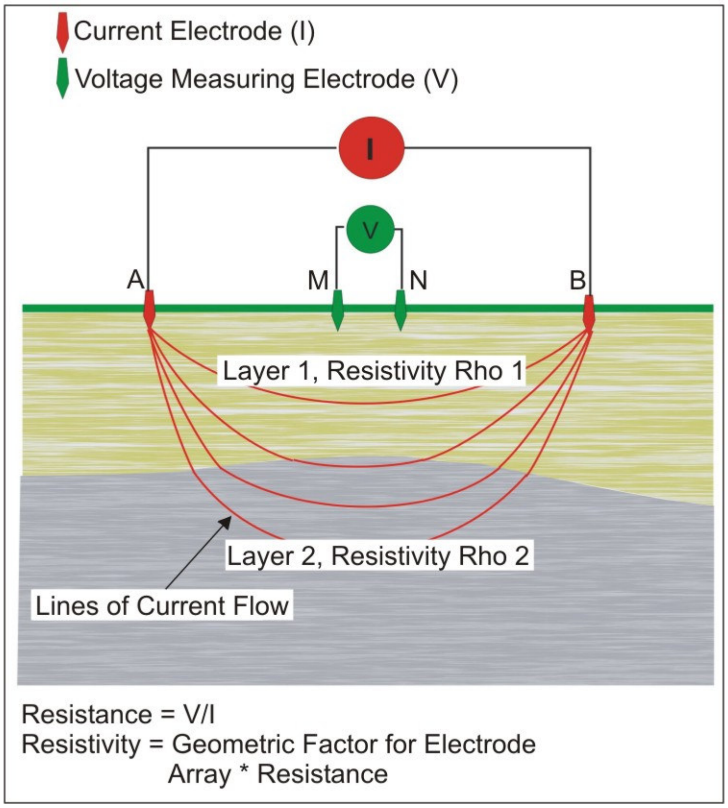

**Figure 2. Drawing. Electrode array for measuring ground resistivities.** (7)

There are basically two different types of electrical resistivity methods: the profile, or traverse, method and the sounding method. In electrical profiling, where the electrode separation is fixed, information concerning lateral variations in resistivity is obtained. In the electrical sounding method, the center of the electrode spread is maintained at a fixed location and the electrode spacing is gradually increased. Sounding arrays provide information about the subsurface at increasing depths; however, they give limited information about lateral changes. Electrical soundings and profiles (traverses) are now often combined for relatively shallow surveys. In these cases, a series of electrodes are positioned at regular intervals and all connected to the transmitter and receiver using cables. Using an automated switching mechanism, the transmitter and receiver collect data using the positioned electrodes by automatically selecting the appropriate electrodes. This procedure is repeated for different electrode sets until the whole line has been recorded.

The common unit for electrical resistivity is ohm-m.

### 3.1.2 Advantages for Mapping Subsurface Voids

Resistivity methods have been successful in locating voids providing there is a resistivity contrast between the void and the surrounding host rock. Water filled voids, depending on salt content and acidity, have a resistivity range between 40 and 500 ohm-m (8), whereas air filled voids are considered infinitely resistive. Figure 3 is an example of a geoelectric cross-section showing an air filled void.

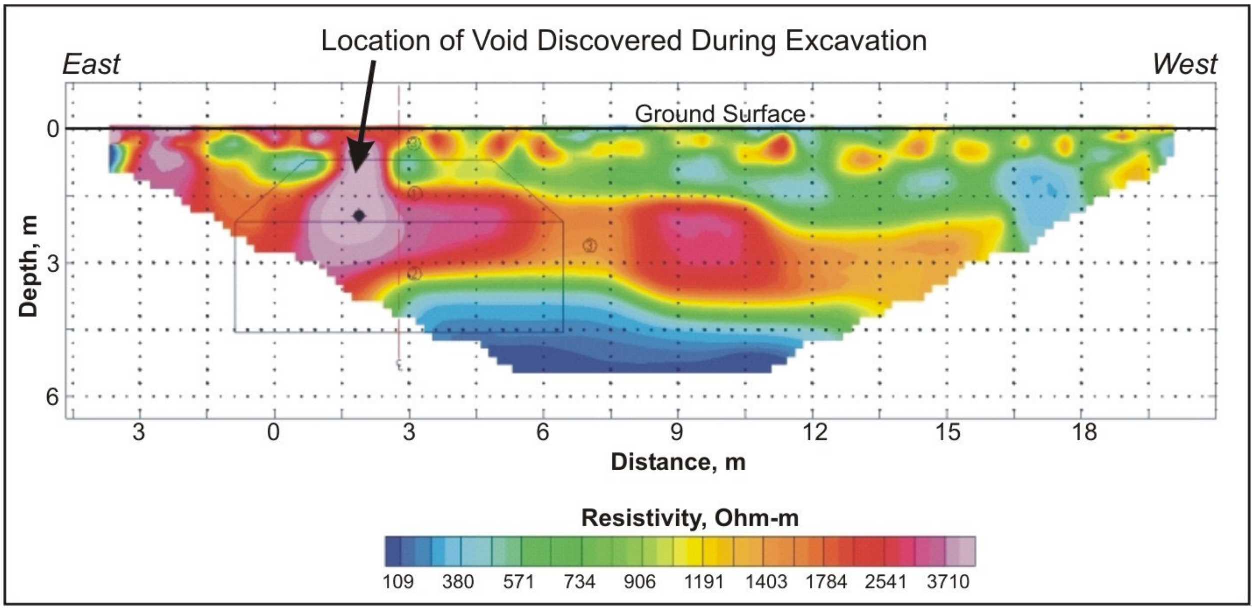

**Figure 3. Cross Section. Data collected over a void plotted as a pseudosection.** (9)

### 3.1.3 Limitations for Mapping Subsurface Voids

Electrical resistivity methods are usually quite labor intensive and time consuming in the field, especially in areas of hard rock where electrodes may need to be pounded into the ground. Also, it is often difficult to lower the contact resistance, or the ability for current to pass from the electrode into the subsurface, in resistive ground. Advances in technology have generated electrodes that inject current into the ground using capacitive methods and arrays have been developed that are towed along the ground by a single operator. However, these are only effective in resistive conditions and at fairly shallow depths. Finally, if a lava tube is filled with water, data interpretation searching for voids may be difficult because the difference between the resistivity of the host rock and that of the water-filled void may not vary enough to generate an interpretable anomaly.

### 3.1.4 Case Studies for Mapping Subsurface Voids

Electrical resistivity has been used to identify voids in several cases. “In eastern Ohio, subsidence features were identified on Interstate 70” (*9*). It was determined that they were caused by collapsed mines found beneath the highways. Since the mines were not adequately mapped and drilling was a costly investigative tool, it was imperative to know if a geophysical method was capable of locating potential collapse zones. The resulting research was a joint effort between the Wright State University and the Ohio Department of Transportation and is summarized in a report titled *Identifying Potential Collapse Features Under Highways (9).*

In phase I, several geophysical methods were applied over an area with known subsidence to determine the method, or combination of methods, that would be most viable at detecting subsurface cavities. At the Jackson County, Ohio site in phase I, electrical resistivity data were collected using a dipole-dipole electrode array with Advanced GeoSciences, Inc. (AGI) Sting/Swift R1 resistivity meter to locate voids in a coal seam that was located 1.5 to 6.1 m (4.9 to 20.0 ft) below the subsurface. Data were collected on both the north and south sides of the road. Data from the north side of the road was recorded using an electrode spacing of 1.5 m (4.9 ft) whereas that along the south side of the road had an electrode spacing of 3 m. The resistivity data were modeled with RES2DINV software written by Geotomo Software. From ground truth information, it was discovered that areas of low resistivity (0.6 to 5.5 ohm-m) corresponded well with voids. This information suggested that the voids were saturated with electrically conductive moisture. After extensive excavations were performed on the area, it was determined that the resistivity data accurately mapped the voids (figure 3).

Electrical resistivity was also used in the Pellissippi Parkway Study, showcased on the AGI website (*10*). After numerous “cave-ins” occurred near a highway, a dipole-dipole electrical resistivity survey was conducted to determine if there were other voids that could lead to future cave-ins. The Sting/Swift system was utilized for data collection. The survey line consisted of 56 electrodes with 3 m (9.8 ft) electrode spacing and was established parallel to the highway. The data were interpreted using the RES2DINV program. The results showed two air filled voids with high resistivity values (over 20,000 ohm-m) and one void filled with water or mud with a resistivity value less than 200 ohm-m. The voids were located between 5 and 20 m (16.4 and 65.6 ft) below the subsurface.

### 3.1.5 Application of the Electrical Resistivity at LBNM

The resistive nature of the basalt that comprises much of the subsurface at LBNM provides an ideal setting for using the capacitive electrode system mentioned previously in this report. Since electrical resistivity methods have proven successful in detecting voids, a Geometrics OhmMapper TR2 system was used to detect lava tubes at LBNM. The OhmMapper is pictured in figure 4. The OhmMapper is a capacitively-coupled resistivity meter that measures the electrical resistivity of the ground without grounded electrodes. It is a towed, non-invasive instrument that is both quick to deploy and easy to use under the right survey conditions. The electrodes are configured in a dipole-dipole array, which allows for good lateral resolution at different depths.

**Figure 4. Photo. Data collection with the OhmMapper.**

## 3.2 GROUND PENETRATING RADAR

### 3.2.1 General Background and Data Acquisition

Ground Penetrating Radar (GPR) is a non-invasive geophysical method that uses electromagnetic waves to map boundaries between lithologies or objects that have different electrical properties. As the GPR system is towed along a surface, pulses of electromagnetic energy penetrate the subsurface. A fraction of the wave is reflected back to the surface when it encounters a boundary where there is a change in electrical properties (commonly referred to as relative dielectric constant). The relative dielectric constant of a material is the ratio of the permittivity of that material to the permittivity of free space. A receiver records the reflected waves.

A variety of frequencies are used depending on the survey target and geologic setting. Higher frequencies are able to provide more detail of the subsurface structure; however, high frequency signals attenuate rapidly as they propagate into the subsurface, thus limiting the depth of exploration. Lower frequencies provide less resolution but are capable of obtaining information to greater depths. A schematic showing a GPR system, and associated waves, over a void is shown in figure 5. Figure 6 shows a GPR cross section where two voids have been interpreted to exist in the subsurface.

### 3.2.2 Advantages for Mapping Subsurface Voids

GPR is advantageous for mapping relatively shallow subsurface voids. This method can provide good depth estimates if the dielectric constant is known, along with the lateral extent of subsurface features.

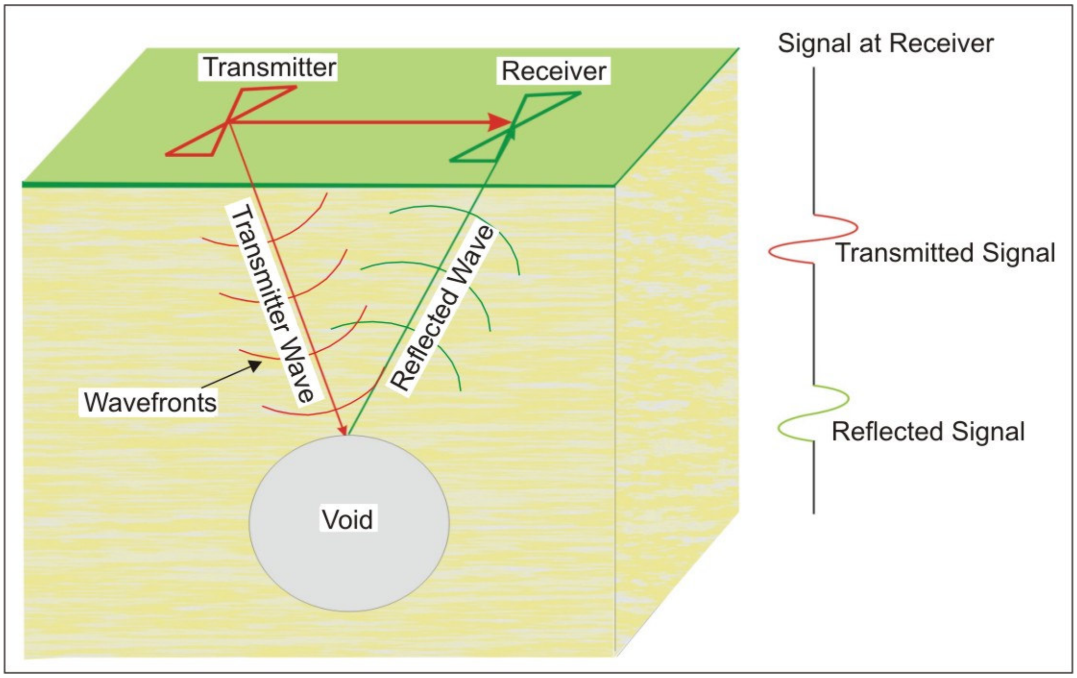

**Figure 5. Drawing. Ground Penetrating Radar system over a void.** (7)

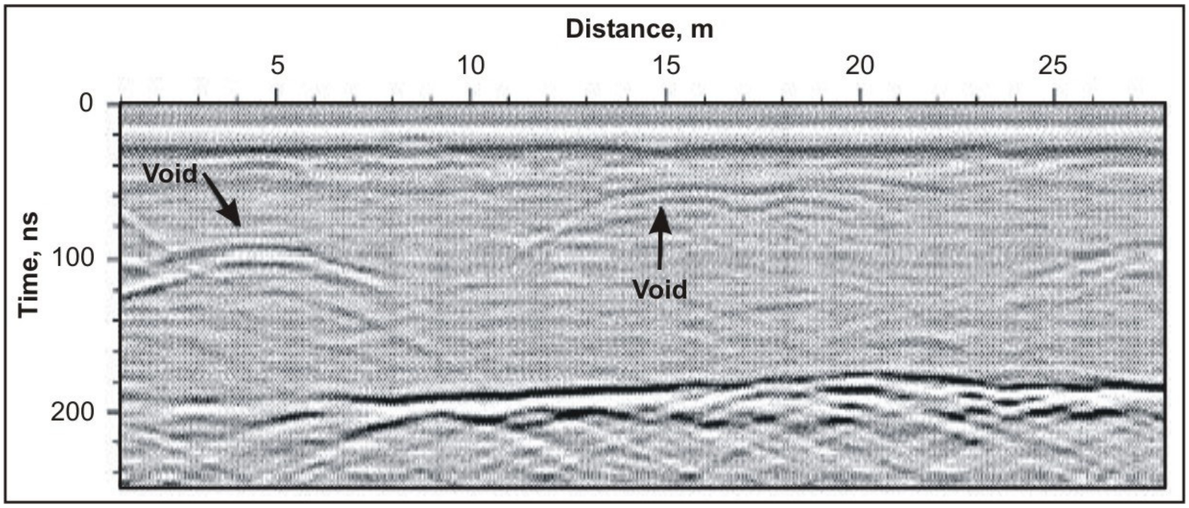

**Figure 6. Screen Capture. Ground Penetrating Radar data over interpreted voids.** (7)