MAPPING SUBSURFACE IN KARST TERRAIN USING 2-D ELECTRICAL RESISTIVITY TOMOGRAPHY

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Abstract

Karst terrain is a unique and complex environment and has been a subject of increasing investigation for engineering, geotechnical, environmental, and archeological purposes. In this study, the electrical resistivity tomography (ERT) technique was used to image a test site in southwestern Missouri with the goal to map variable depth-to-bedrock and to characterize subsurface lithologic conditions. The ERT technique employed a multi-electrode resistivity system, powered by a 12–volt deep cycle marine battery, 5 feet electrode spacing, and a dipole-dipole array configuration with the intent to map the subsurface to a depth of at least 100 feet. The output, a two-dimensional (2-D) resistivity profile, was verified and constrained with active multichannel analysis of surface waves (MASW) data. The resistivity of the soils and pervasively fractured bedrock was observed to be mostly controlled by moisture content. Based on the moisture content, the soils and rocks were classified into moist soil (<50 ohm.m), dry soil (125 ohm.m), moist rock (≥125 ohm.m), and dry rock (≥1500 ohm.m). The bedrock surface topography in many instances appeared to depict the ground surface topographic expression.

Karst, Electrical Resistivity Tomography, Subsurface Investigation, MASW, Sinkhole

Introduction

Karst terrain is a complex and profoundly heterogeneous environment formed from the dissolution of carbonate or evaporite bedrock and is characterized by features such as sinkholes, depressions, pinnacles, and sinking streams. Over the years, karst terrain has been an object of environmental, geotechnical, engineering, and archeological investigations or explorations. This study aimed to map variable depth-to-bedrock and characterize subsurface lithologic conditions in karst terrain. Karst terrain investigation or exploration techniques have generally involved conventional methods (such as borings or drilling) and geophysical techniques to map surface or subsurface characteristics, locate artifacts or objects of significant interest below the ground, determine soil moisture content, estimate the engineering properties of soil or rock, find groundwater pathways or contaminant plumes, etc.

Unlike the conventional methods, geophysical techniques have frequently been used to investigate karst terrain because they are noninvasive, less expensive, and less time-consuming. Also, the use of geophysical techniques for an investigation in karst terrain has the potential to minimize ground collapse hazard/risk. Some geophysical methods which have been used to investigate karst terrain include resistivity (Kruse et al., 2006; Gibson, 2004), ground penetrating radar (Kruse et al., 2006; Grandjean et al., 2000), microgravity (Debeglia et al., 2006; Styles et al., 2005), and seismic surveys (Šumanovac et al., 2001). For example, Gibson (2004) used resistivity and magnetometry to discover a cave and a large collapse feature underneath glacial surficial sediments in Ireland. Kruse et al. (2006) imaged the structure of a 15-m sinkhole in west-central Florida, USA, using ground penetrating radar (GPR) and resistivity techniques. Styles et al. (2005) located and characterized karstic cavities with the microgravity method, while Šumanovac et al. (2001) conducted hydrogeological mapping in karst terrain by combining electrical and seismic geophysical techniques.

In this study, the electrical resistivity tomography (ERT) technique was used to map a karst terrain which has been a subject of geophysical study in southwestern Missouri, USA over the past three years. The ERT technique basically involves the passage of electrical current into the ground through a pair of electrodes and the measurement of potential difference by another pair of electrodes to estimate subsurface resistivity distributions that can be used for geological interpretations.

Methods

A multi-electrode resistivity system of 168 electrodes was used to acquire ERT data along west-east traverses spaced at 100 feet. The electrodes were spaced at 5 feet interval with the intent to image the subsurface to a depth of at least 100 feet. The dipole-dipole array configuration which has produced very reliable and high quality ERT data in previous studies (Bansah & Anderson, 2017a) at the test site was employed. The field data (resistivity measurements) were processed into 2-D ERT profiles using the RES2DINV software. To verify and constrain the ERT interpretations, 1-D active multichannel analysis of surfaces waves (MASW) data were acquired along north-south traverses as depicted in Figure 1. The active MASW survey adopted a multi-channel seismograph with 24 geophones spaced at 5 feet, geophone frequency of 4.5 Hz, 20-pounds sledge hammer as an acoustic source, and a source offset of 10 feet. Borehole control was acquired as an additional verification; however, only the ERT and active MASW are presented in this paper.

The test site is located near the city of Springfield in southwestern Missouri. Bedrock is Mississippian limestones and cherty limestones which are underlain by Ordovician and Cambrian rocks. The bedrock, which is exposed in some places, is pervasively fractured and extensively karsted. The active MASW procedure, test site location, and geological setting are further described by Bansah and Anderson (2017b).

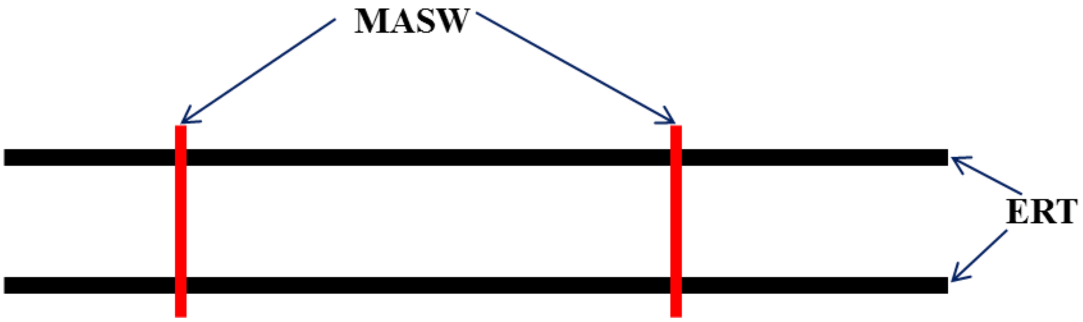

Figure 1: An illustration of the ERT and MASW configurations. The figure is not drawn to scale. ERT traverse is 835 feet long; MASW is 115 feet long.

Results

An example 2-D ERT profile with superposed geologic interpretations is shown in Figure 2. The 2-D ERT profile shows that the rock is pervasively fractured with varying depth-to-top of rock. The top of rock is depicted by the dark dotted line (125 ohm.m contour) and can be located at depth as deep as 40 feet and as shallow as 7 feet. Resistivity of the subsurface is a function of moisture content, clay content, salinity, porosity, and permeability. Resistivity at the test location is largely controlled by moisture content and thus, in the 2-D ERT profile, soil and rock have been classified into dry soil, moist soil, moist rock, and dry rock. Dry surficial soil has resistivity 125 ohm.m and is underlain by moist soil with resistivity <50 ohm.m. Moist rock has resistivity at least 125 ohm.m, while dry rock has resistivity more than 1500 ohm.m. Additionally, the presence of moist soil (clay) in the pervasively fractured bedrock impacts the resistivity of moist rock since moist clay is usually conductive. The topography of the pervasively fractured bedrock shown in the 2-D ERT profile in many instances appeared to portray the surface topography; that is, depressions in the top of rock in many areas, manifest in the surface topography.

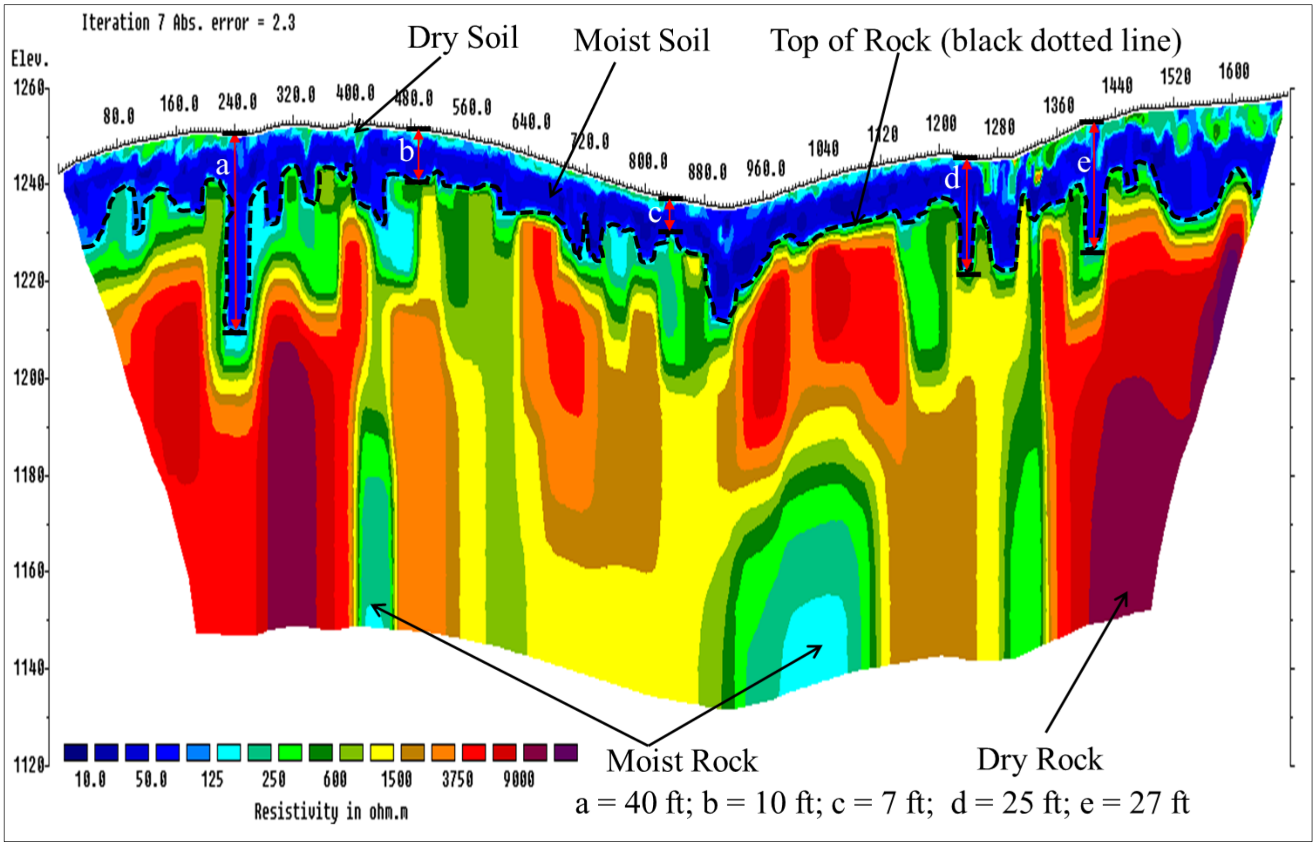

Figure 2: Example 2-D ERT profile with superposed geologic interpretations.

Figure 3 is a 1-D MASW profile acquired with the goal to verify and constrain the ERT interpretations. The shear-wave velocity of soil/rock on the 1-D MASW profile varies from 550 ft/s to about 4300 ft/s, an indication of marked variation in stiffness. Based on the National Earthquake Hazard Reduction Program's (NEHRP) soil/rock classification criteria, soil and rock at the test location were classified into stiff soil (1200 ft/s), soft soil (550 ft/s), soft rock (1500 ft/s to 2400 ft/s), and rock (> 2500 ft/s). In Figure 4, the 1-D MASW profile was superposed on the 2-D ERT profile. At the 700 foot mark, where the MASW ties with the ERT, estimated depth-to-top of rock on the 1-D MASW profile is 11.5 feet, while that on the 2-D ERT profile is 12 feet.

The MASW data and interpretations were observed to be consistent with the ERT interpretations; the MASW data reasonably verifies and validates the ERT data. Similar observations on the consistency of ERT and MASW data in the study area have previously been reported by Bansah and Anderson (2017b). Thus, in the absence of borehole control and other data verification techniques, active MASW could be a useful technique for verifying and constraining ERT data.

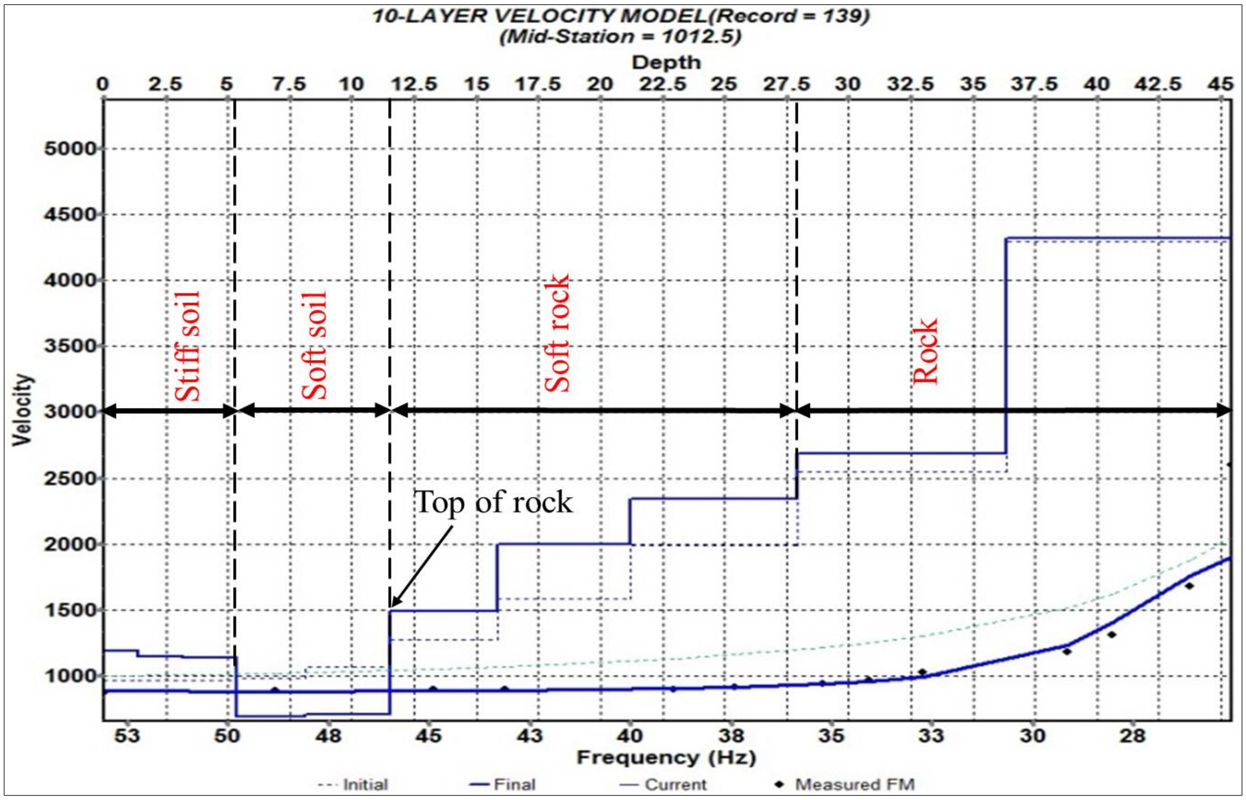

Figure 3: 1-D MASW profile. MASW data were acquired transversely to ERT traverse.

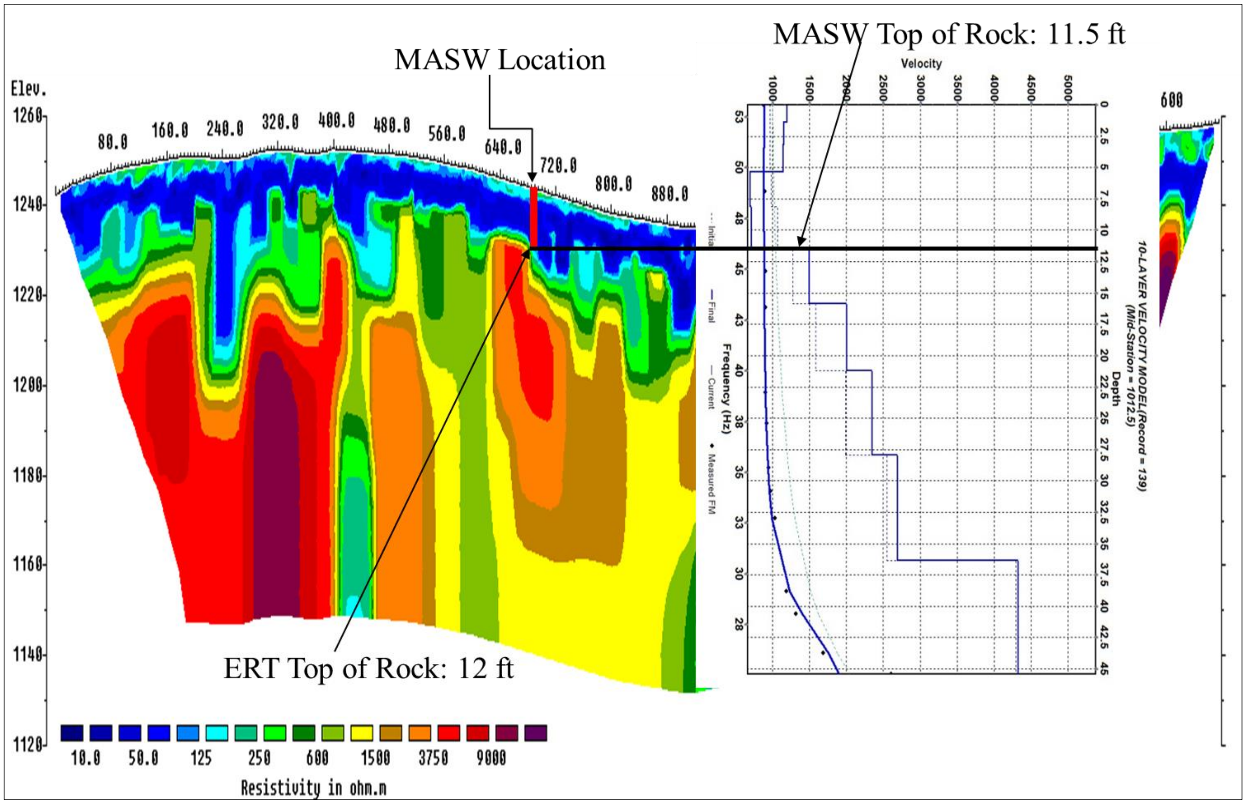

Figure 4: 2-D ERT profile with superposed corresponding 1-D MASW profile.

Conclusion

The ERT technique was used to map variations in depth-to-top of rock and to characterize soil/rock in a complex karst terrain. The ERT data were acquired with a multi-electrode resistivity system at a study location in southwestern Missouri, USA. MASW data acquired perpendicular to the orientation of the ERT traverses were used to verify and constrain the ERT interpretations. Rocks at the study location were pervasively fractured and showed marked variations in depth-to-top of rock.

Resistivity of soil/rock was mostly controlled by moisture content; thus, soil and rock were classified into dry soil (125 ohm.m), moist soil (<50 ohm.m), moist rock (125 ohm.m or more), and dry rock (>1500 ohm.m). Based on the shear-wave velocity data from active MASW survey and reference to the NEHRP criteria, the soil profile consisted of stiff soil (1200 ft/s), soft soil (550 ft/s), soft rock (1500 ft/s to 2400 ft/s), and rock (>2500 ft/s). Depressions in the pervasively fractured bedrock in many areas were observed to manifest in the surface topography; thus, the topography of the pervasively fractured bedrock in the study area can be described as being a function of the surface topography. The active MASW data were consistent with the ERT data; hence, active MASW can be a technique of choice for verifying and constraining ERT data.

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