Do Air-Filled Caves Cause High Resistivity Anomalies? A Six-Case Study from the Edwards Aquifer Recharge Zone in San Antonio, Texas

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Introduction

Of course they do! But it is rarely that caves are purely filled with air. A variety of sediments accumulates in caves and can be preserved more or less intact for long periods of time (Palmer, 2007). Presence of sand and gravel and clay deposits, mineralization, faults and fractures, perched water in caves are the rules rather than the exception.

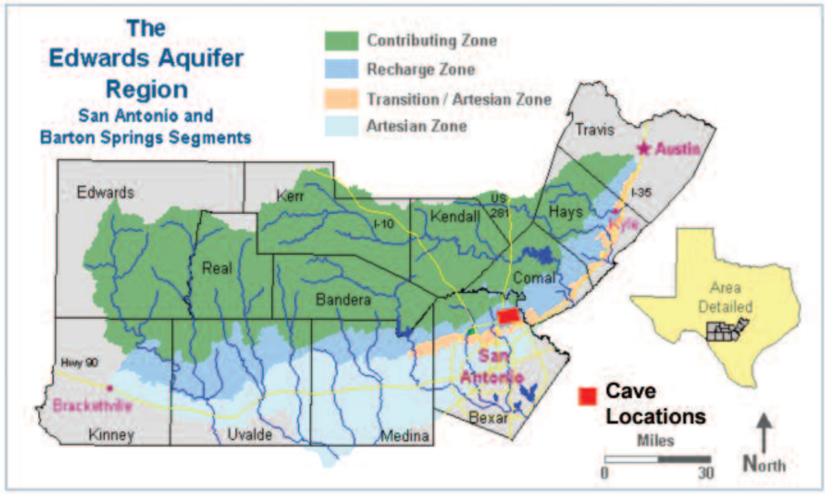

Figure 1 Map showing the Edwards Aquifer coverage and cave locations discussed in the text. The map is from the Edwards Aquifer Authority web site (www.eaa.org).

The existence of caves represents a hazard for urban areas. Therefore it is important to know the size, position and depth of caves before building or reconstruction. Cavity imaging using geophysical surveys has become common in the San Antonio area since early 2000 although their use has been going on in other parts of country for the last 25 years. It appears from these studies that the resistivity imaging method has been the primary technique among others, such as gravity, ground penetrating radar, magnetic, conductivity, etc. Resistivity values, in theory, increase dramatically over air-filled cavities. So it is expected to find high resistivity anomalies over the air-filled cavities.

This article describes only resistivity imaging data collected over six caves between the years of 2000 and 2005, which are air filled and are located in the northern part of Bexar County, San Antonio, Texas. All caves but one was encountered through drilling and/or excavation for building and utility lines or power pole reconstructions. The study area falls into the part of the Recharge Zone of the Edwards Aquifer region and it represents a well-developed karstified and faulted limestone (Figure 1).

The purpose of the study is to show that air-filled cavities do not always cause high resistivity anomalies due to the complex subsurface conditions, and they are sometimes are not separable as a cave anomaly from the surrounding rocks.

Resistivity Imaging Method and Field Survey Design

Resistivity imaging has been widely used in mapping con¬taminant plumes, karst features (voids), and subsurface structures, such as faults and fractures. In this study, the Advanced Geosciences (AGI) Super R1 Sting/Swift resistiv¬ity meter with the dipole-dipole resistivity technique is used. This technique is more sensitive to horizontal changes in the subsurface, and provides a 2D electrical image of near-surface geology. The depth of the investigation varied between 25 and 68 feet.

A resistivity profile with 28 electrodes was laid over the caves and perpendicular to their longitudinal axes. Electrode spacing was between 4 to 10 feet depending on the horizontal and vertical extension of each cave. The center of the profile corresponded to the center of the cave location.

Appropriate quality assurance/quality control procedures, such as testing contact resistance, were performed before data collection for each resistivity profile. Contact resistance measures the resistance to current flow at electrodes caused by imperfect electrical contact with the earth. Poor data quality or anomalous data can result from high or highly variable electrode contact resistance along a profile. To decrease the effect of contact resistance along each profile, we used a salt water solution on each electrode before the contact test was performed and/or we drilled holes into hard floor of limestone beds for the electrodes.

Geology

The Edwards aquifer, which comprises the Kainer and Person Formations of the Edwards Group and the overlying Georgetown Formation in rocks of Lower Cretaceous age is a dissolution-modified, faulted limestone, and has a well-developed karst system (Stein and Ozuna, 1996).

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In Bexar County, the Edwards aquifer consists of approximately 450 ft of limestone, dolomite, and evaporate (primarily anhydrite/gypsum. The Kainer and Person Formations, deposited in shallow to very shallow marine wters (Rose, 1972), are subdivided into informal members. The thickness of Kainer Formation ranges from about 260 to 310 ft in Bexar County. The lithology of the Kainer Formation includes marine sediments consisting of mudstones with evaporates.

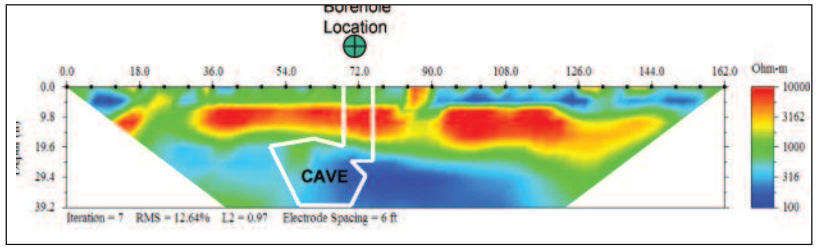

Figure 3 Resistivty data across Cave 1. White lines indicate the borehole location and geometry of the Cave.

The Person Formation is about 170 ft thick in Bexar County. The base lithology of the Person Formation is a dense mudstone, which underlies layers of collapsed breccias, mudstones, and limestone. A depositional hiatus occurred before the open marine, biomicritic Georgetown Formation was deposited (Table 3). The Georgetown Formation, a marly limestone, is 20 to 50 ft thick in the study area, and consists of dark reddish-brown weathered and fiable material with some shaly limestone. Specifically, the six cave locations are located on the Kainer Person Formations of Edwards Aquifer Recharge area (Stein and Ozuna, 1995, and Figure 2).

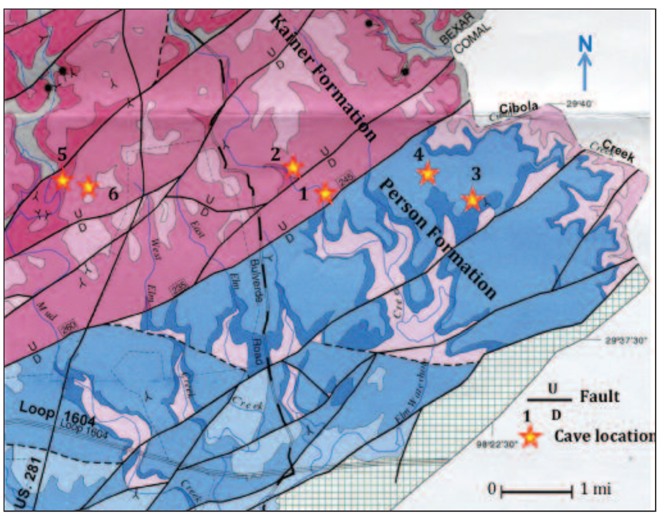

Figure 2 Geological map indicating the Lower Cretaceous Person and Kainer Formations of Edwards Aquifer and cave locations (Modified from Steina and Ozuna, 1996).

Figure 4 A picture showing a passage from Cave 1.

Interpretation of Resistivity Data

None of these caves had names because they were discovered during the drilling for transmission poles and/or excavation for foundations for reconstruction. Thus we will describe these caves as Cave 1 through Cave 6.

Cave 1

Resistivity imaging of Cave 1 is given in Figure 3. The cave was located during the drilling for a transmission pole. The diameter of the hole was about 7 feet. The cave was encountered at about 25 feet depth. The cave was inspected by a karst geologist and determined that it was air-filled, dry and highly mineralized. The geometry of the cave is superimposed on the resistivity data based on the visual inspection of the cave. A picture of the cave is given in Figure 4. The resistivity imaging show data does not indicate any high resistivity anomaly over the cave; instead the cave shows resistivity values that range between 100 and 1000 Ohm-m. This is probably due to the extensive mineralization observed in the cave.

Cave 2

Resistivity imaging of Cave 2 is given in Figure 5. During the drilling for a transmission pole, this cave was encountered at about 30 feet. The cave's geometry was investigated by a karst geologist and is superimposed on the resistivity data. The cave, based on the visual inspection, is air-filled, wet and highly mineralized. The resistivity data does not show any high resistivity anomaly over the cave location. The resistivity values over the cave vary between 300 and 800 Ohm-m. This is probably due to the wet condition and the observed mineralization in the cave.

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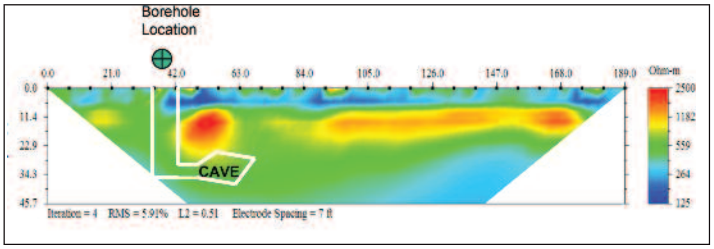

Figure 5 Resistivity data across Cave 2. White lines indicate the location of the borehole and the geometry of the Cave.

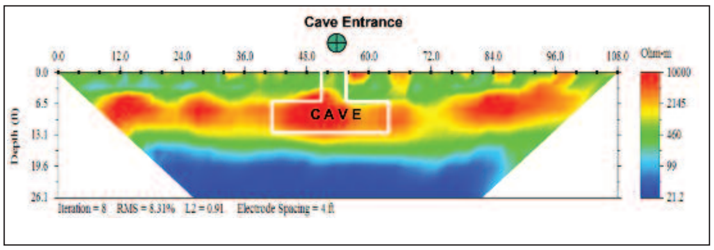

Figure 6 Resistivity data across Cave 3. White lines indicate the geometry of the Cave.

Cave 3

We observed the entrance to cave 3 during the fieldwork for setting the transmission poles. We entered the cave and defined the cave dimension. It was 6 feet deep from the surface and its longest axis was 24 feet along the resistivity profile. The height between the ceiling and the floor of the cave varied between 5 and 8 feet. The cave was dry, air-filled and no significant mineralization was observed.

Resistivity imaging data over the cave is given in Figure 6, which indicates medium (green color), high (red color) and low (blue in color) resistivity layers. The cave's geometry is also superimposed on the resistivity data. The cave location appears to be restricted within the high resistivity values of red color, which range between 2,000 and 10,000 Ohm-m. This high-range of resistivity value is correlative with what is expected of an air-filled cave; however, the high resistivity values are present along the entire length of resistivity profile and the cave geometry is not defined by the resistivity data. In other words, there is no discernible resistivity difference between the cave and the surrounding limestone beds.

Figure 7 A picture that shows the location of Cave 4 along a trench. The ceiling of the Cave is 12 feet from the surface.

Cave 4

Cave 4 was observed along a utility trench in the north of San Antonio (Figures 2 and 7). The trench was about 15 feet deep and 112 feet long. The cave was air-filled and the ceiling was 12 feet below the ground, and its width along the trench was about 12 feet. Its depth was determined to be 30 feet by lowering a measuring tape into the cave.

Cave 5

Cave 5 was discovered when an area of 300 x 100 feet weathered limestone was stripped down about 15 feet for reconstruction of a building (Figure 2). During the trenching of the limestone for utility lines, a cave entrance of 5 feet wide was observed on the side of the trench. We crawled into the cave and determined the that the cave had a height of 7 feet and extended 70 feet along the long axis, which was parallel to the trench. The cave was dry and air-filled. There was no sedimentary deposit or significant mineralization observed.

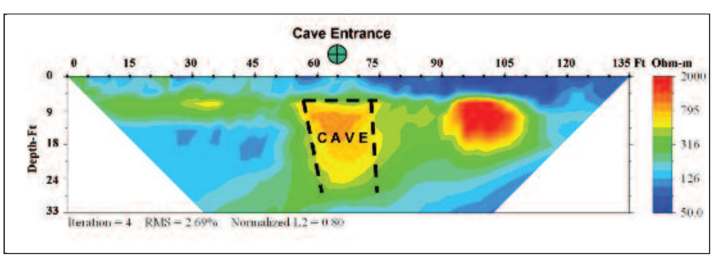

Figure 8 displays the resistivity data along the utility trench. The cave's dimensions are also superimposed on the resistivity data. The resistivity profile indicates medium range resistivity values of 300 to 800 Ohm-m, not high resistivity values, across the air-filled cave. The cave's geometry defined by the resistivity data is quite correlative with the observed dimensions of the cave.

The resistivity imaging data collected across the the cave is shown in Figure 9a. Horizontal and vertical extents of the cave are drawn on the 2-D resistivity data. The resistivity data indicates high resistivity values up to 10,000 Ohm-m across the cave. However, there are similar high resistivity values along the entire profile and the high resistivity values observed over the cave are not unique from the rest of the profile. In other words, the resistivity data does not have enough resolution between the surrounding rocks and the cave to single out the

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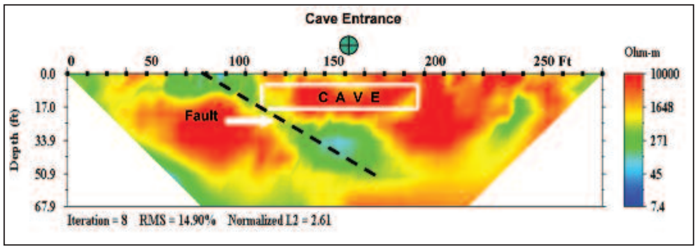

Figure 9a Resistivity data across Cave 4. Black lines indicate the geometry of the Cave.

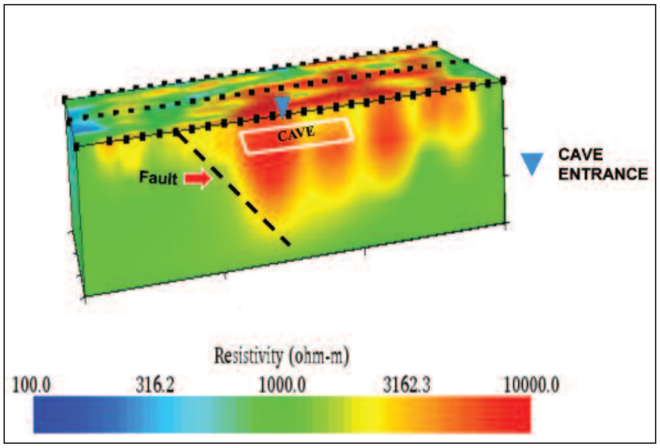

Figure 9b 3-D resistivity data across Cave 5. Note the sharp resistivity contrast where the major fault crosses the study area (Figure 2).

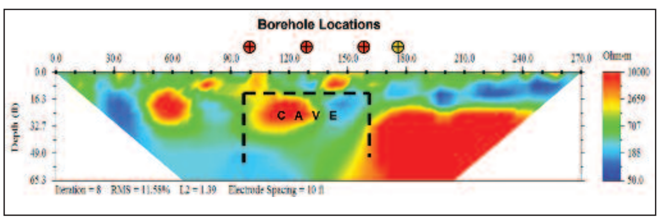

Figure 10a Resistivity data across Cave 6. Black lines indicate the geometry of the Cave.

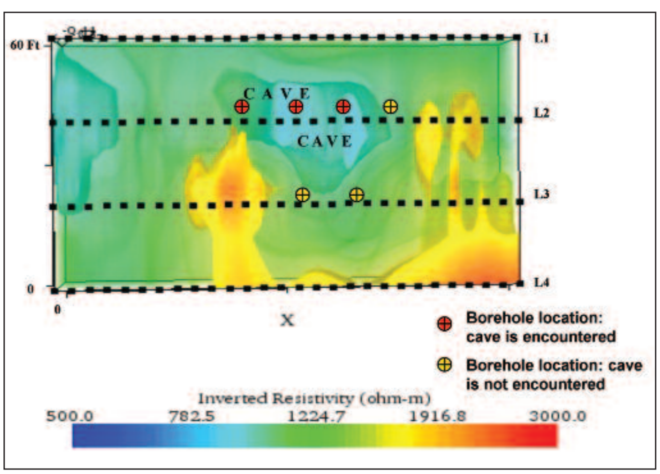

Figure 10b 3-D resistivity data across Cave 6.

cave formation. There is a major known fault that crosses the resistivity profile in the study area (Figure 2), and its location is marked on the resistivity profile (Figure 9a).

A 3-D image of the resistivity data was created by using the three parallel resistivity lines over the cave. A side 3-D image of the cave area is presented in Figure 9b. Results of 3-D data does not delineate the location well either because resistivity values of both the cave and the limestone surrounding the cave appear to be within the same ranges. The 3-D data defines the known major fault better than 2-D profile.

Cave 6

A series of voids were encountered during the installment of piers into the limestone for a construction project. These voids had a depth of about 15 feet and appear to be connected. A combination of lowering a tape and a video camera indicated that the cave extended as deep as 50 feet. The cave was wet and air-filled.

Four resistivity profiles were acquired across these voids. Figure 10a displays one of the resistivity imaging profiles along with 4 borehole locations, three of which encountered the cave. The resistivity data show that the cave's 2-D volume encompasses high resistivity 10000> Ohm-m, medium resistivity of 750 Ohm-m and as well as low resistivity values of 200 Ohm-m.

Four resistivity imaging profiles were used in order to create a 3-D image of the cave. A 3-D top-view of the cave area is shown in Figure 10b. The known void locations encountered by borehole drilling are shown with red circles. Three borehole locations that did not encounter the cave are shown with yellow circles. Note that the boundaries of the cave defined by the borehole data include the low and medium resistivity values as in the 2-D resistivity profile. Although the 3-D image of the resistivity data appear to define the geometry of the cave much better than the 2-D resistivity data.

Discussion/Conclusions

Caves 1 and 2 were air-filled with significant mineralization. Cave 1 was dry but cave 2 was wet due to presence of groundwater. Low to medium resistivity responses of 100 to 800 Ohm-m were obtained over these caves, respectively.

Two air-filled caves (3 and 5) out of 6 caves showed high resistivity values; however, they had no significant resistivity contrast with the surrounding rocks so that their presence could not be determined with the resistivity method. Cave 4 showed a significant resistivity contrast and geometry with the surrounding rocks. However, the resistivity values over the cave were medium, not high. Cave 6 consisted of low, medium and high resistivity values over the span of the cave.

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Thus this study shows that 2D resistivity imaging method does not always successfully delineate the location of air-filled caves. Furthermore, air-filled caves are usually associated with mineralization, clay-filled pockets or other sedimentary deposits and highly fractured rocks such that their resistivity responses may not be as high resistivity values.

The 3-D resistivity data over caves 5 and 6 provided additional information on the geology and the geometry of the cave. Thus, where it is possible, by using multiple profiles, a 3-D resistivity data can improve the interpretation.

This study demonstrate that the resistivity method is not always a reliable predictive technique, but is useful in karst terrains to cover large areas quickly and, the merits of integrating other geophysical techniques, along with the resistivity imaging, in order to reduce the ambiguity in the interpretation are evident (Saribudak, 2011, Ahmed and Carpenter, 2003, Dobecki and Church). ■

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References

Ahmed, S. and P.J. Carpenter, 2003, Geophysical response of filled sinkholes, soil pipes and associated bedrock fractures in thinly mantled karst, east-central Illinois, *Environmental Geology*, v. 44, p. 705-716.

Dobecki, T., and Church, S., 2006, Geophysical applications to detect sinkholes and ground subsidence, *Leading Edge*, v.25, v.3 p. 336-341.

Palmer, N. A., 2007, *Cave Geology*, published by Cave Books.

Rose, P.R., 1972. Edwards Group, surface and subsurface, central Texas, Austin, University of Texas, Bureau of Economic Geology Report of Investigations 74, 72p.

Saribudak, M., 2011, Urban geophysics:Geophysical signature of Mt. Bonnell Fault and its karstic features in Austin, Texas, Houston Geological Society *Bulletin*, October issue, p.49-54.

Stein and Ozuna, 1996 Geologic framework and hydrogeologic characteristics of the Edwards Aquifer recharge zone, Bexar County, Texas, USGS Water-Resources Investigations Report 95-4030).