Multiple Geophysical Methods for Identifying and Mapping Caves in the Recharge Zone of the Edwards Aquifer, Texas

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Abstract

The hydrogeophysics class at The University of Texas at Austin evaluated five geophysical methods for identifying caves in the recharge zone of the Edwards Aquifer of Central Texas. Two sites were selected both of which occur in the Kainer Formation. Site 1 overlies a known, mapped cave; at site 2, a cave is inferred from surface observations. Electrical resistivity (ER) and electromagnetic (EM) methods were used to conduct line surveys along two subparallel transects crossing over the known cave at site 1, and nearly orthogonal transects at site 2. Based on the electrical resistivity data, additional subsurface cavities were inferred. Two such locations at each site were chosen for collecting ground penetration radar (GPR) data in a gridded network. Gravity and seismic data were collected only at site 1. The results from the dipole-dipole ER surveys indicated areas of anomalously high resistivity, which are interpreted as air-filled caves. The resistivity signal at the known cave site was smaller, presumably due to highly conductive moist cave sediments (principle of suppression). In comparison, EM data collection was fast and efficient. In many cases, the EM-34 data confirmed the ER inferences about cave locations; however, EM31 and EM34 instruments were extremely sensitive to interference from power lines. Seismic data showed zones with very large attenuation indicating the presence of unconsolidated material or intense fracturing. Any inference about the known cave, however, remains unsubstantiated by current processing of the seismic data. The GPR data from site 1 showed a low velocity zone which correlates well with the ER data and provides confidence for locating an additional nearby cave. The GPR data also showed influence from conductivity of near surface soils which resulted in reduced resolution of near surface features. The gravity data showed an anomaly consistent with the location of the known cave at site 1; however, the signal was on the order of the noise level, and it was determined that a gravimeter with accuracy in micro Gals would be needed to precisely locate the cave. Our conclusions are that field observations coupled with the EM method provide best reconnaissance at these sites. This combination should be followed by ER, GPR, and seismic methods, perhaps in this order.

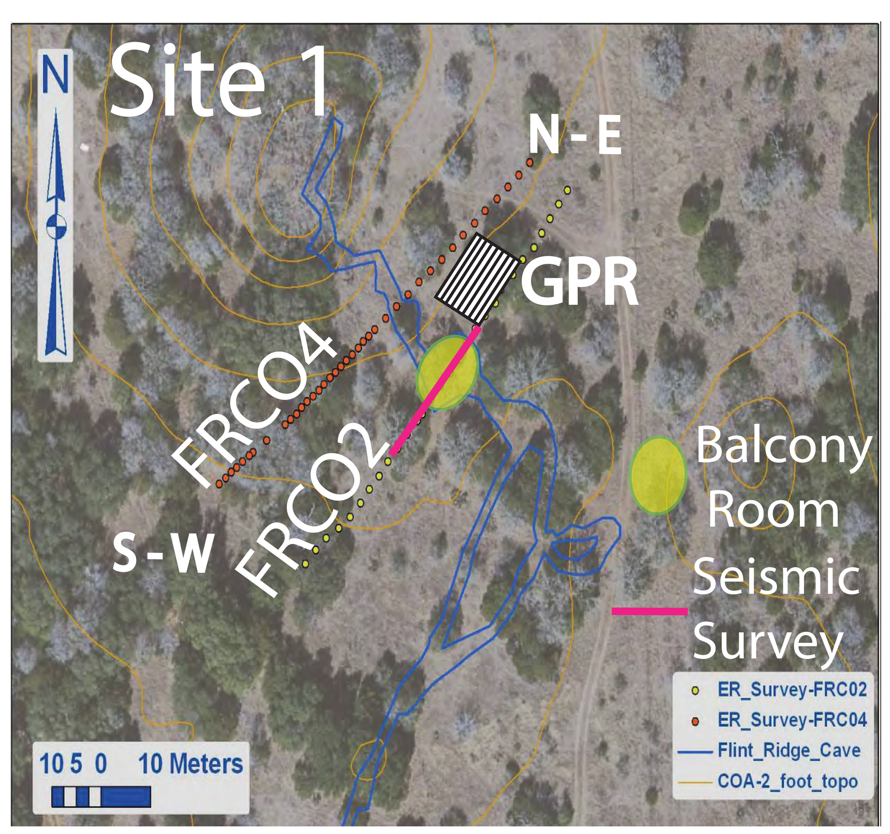


Figure 1. Location of line and grid surveys at site 1

Figure 2. Location of line surveys at site 2

Electrical Resistivity

Two different electrode array geometries, the Schlumberger array and the dipole-dipole array were used to conduct line surveys in two subparallel transects over a known cave at site1, and nearly orthogonal North South and East West transects at site 2 (Figures. 1 and 2). The dipole-dipole array provides better depth and resolution than the Schlumberger array, however, results from both array are presented here.

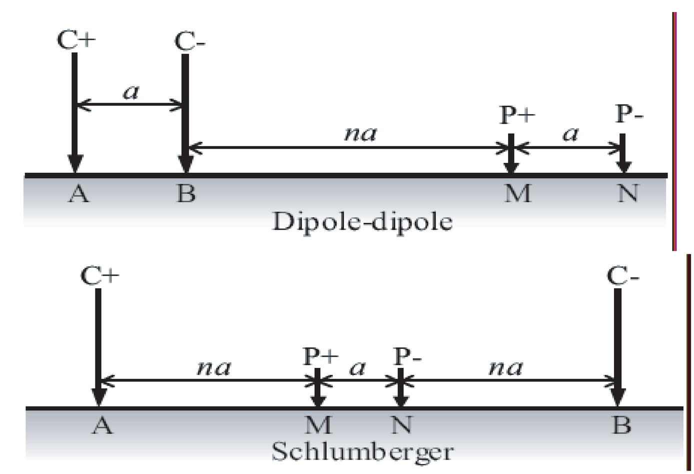


Figure 3 Dipole-dipole and Schlumberger electrode configuration. A and B electrodes are transmitters, M and N electrodes are receivers. Modified from Rubin and Hubbard (2005)

Data synthesis

The electrical resistivity meter recorded apparent resistivity data from the earth model. A Earth Imager 2D electrical resistivity processing software was then used for resistivity inversion to provide the actual subsurface resistivity sections. These earth model resistivity section are presented henceforth.

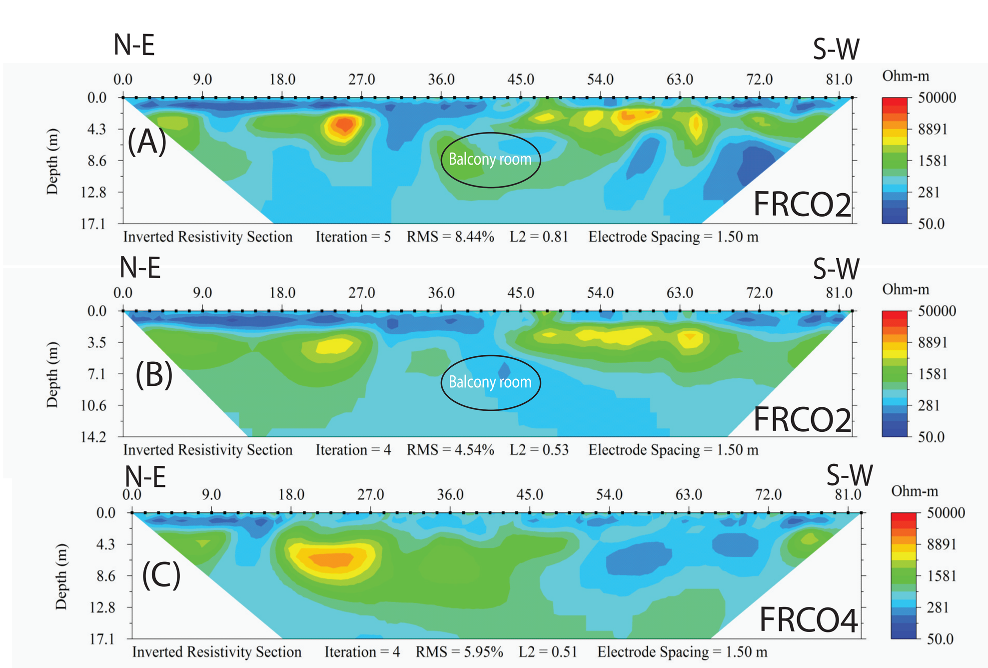


Figure 4. Electrical resistivity models for the cave balcony room (site1). (A) dipole-dipole survey (FRC02), (B) Schlumberger survey (FRC02), and (C) dipole-dipole survey (FRC04)

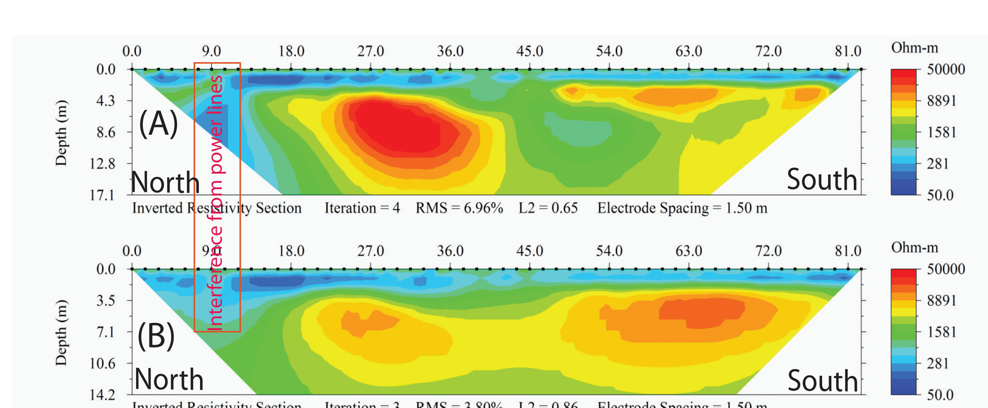


Figure 5. Resistivity earth models for north-south transect at site 2, (A) dipole-dipole survey and (B) Schlumberger survey .

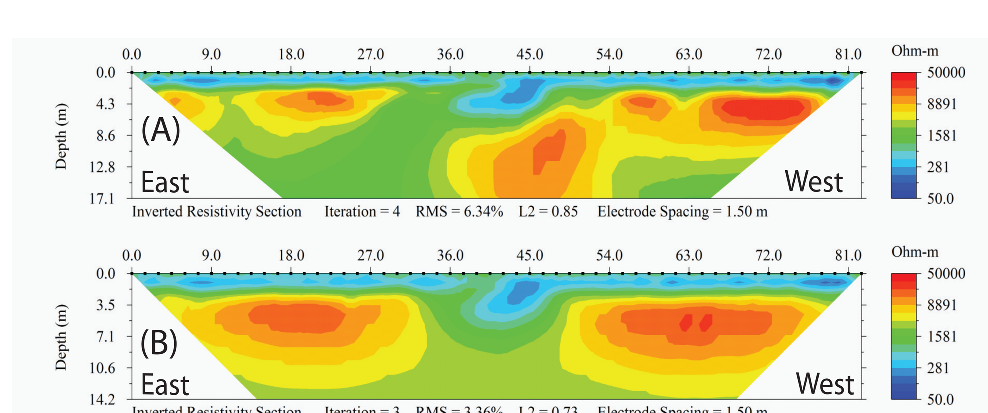


Figure 6. Resistivity earth models for East-West transect at site 2, (A) dipole-dipole survey and (B) Schlumberger survey.

Electromagnetic method

A combination of three EM devices (Geonics EM 31, EM 34-3, and EM 38) were used to conduct line surveys in the same transects as described earlier in the electrical resistivity section (Figures. 1 and 2). The EM 34-3 and the EM 31 data were collected in vertical dipole mode and at a 3 m and 1.5 m intervals, respectively. The EM - 38 data was collected in both the vertical and horizontal dipole mode at a 2 m interval. The data collected and its analysis are presented below.

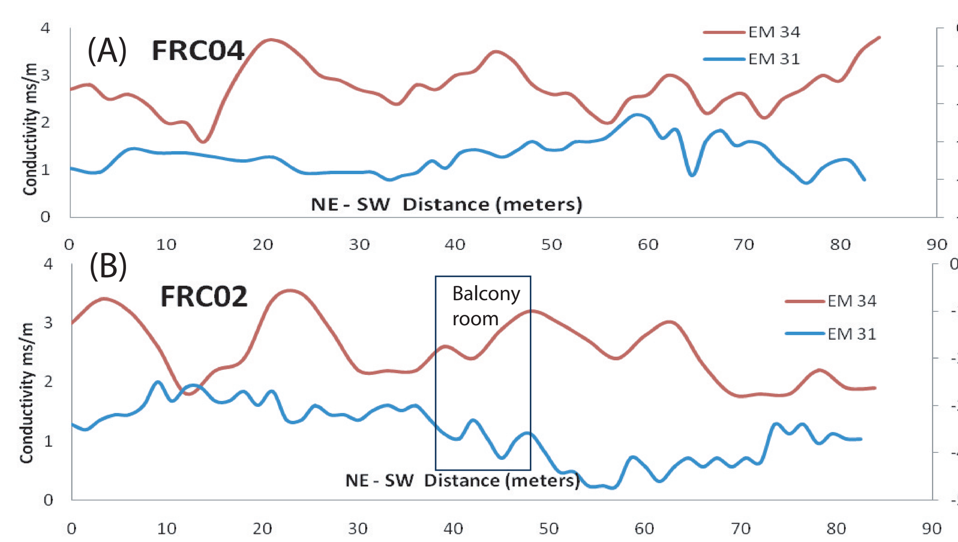


Figure 7. EM 34-3 and EM 31 survey data from site 1. (A)FRCO4 and (B)FRCO2. For location refer Figures 1 and 2.

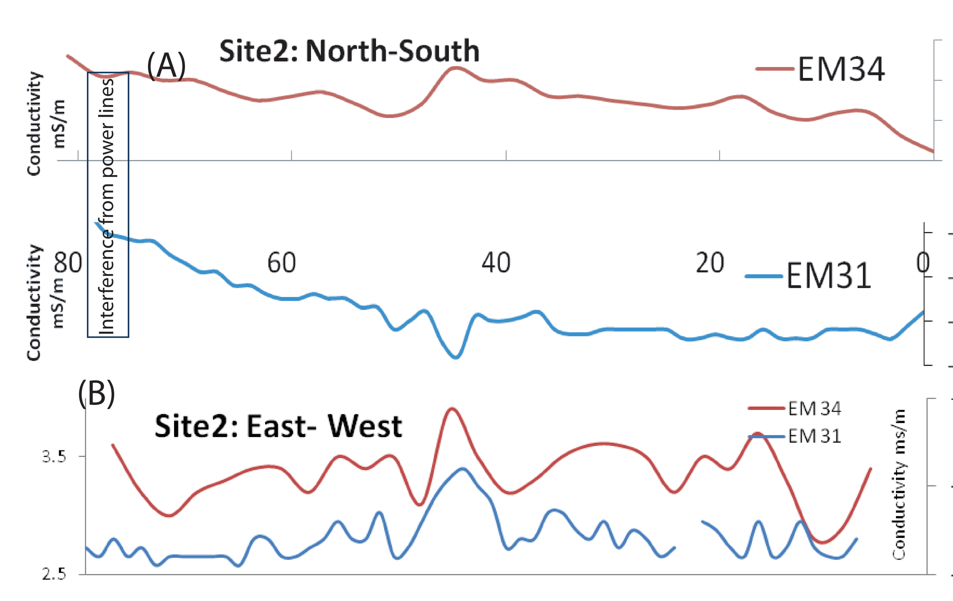
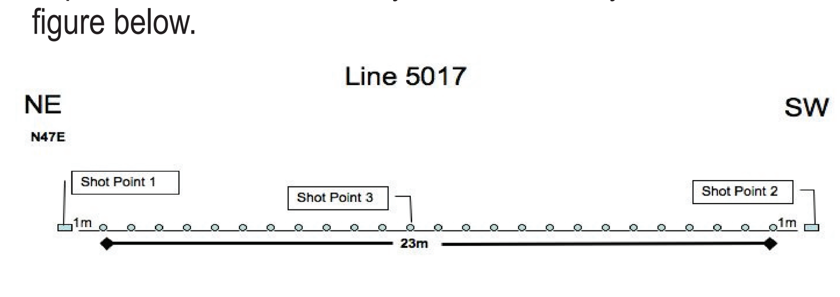


Figure 8. EM 34-3 and EM 31 survey data from site 2.(A)North South transect and (B)East West transect. For location refer Figures 1 and 2.

Seismic Survey

A seismic survey was conducted over the Balcony Room at site1. The survey used 24 geophones of 10 mHz frequency. Multiple shots and geophone spacings were used to achieve relevant depths and resolutions. A layout of the survey is shown in the figure below.



Data processing of the seismic survey was performed using the Seislab Matlab program. An Ormsby passband filter was applied and the data were normalized to decrease the range in amplitudes. A decay in the amplitude near the top of the plot is due to presence of top soil at the location. The direct arrrival showed slower velocities than expected for a typical limestone unit (3.9-6.2 km/s). This could be caused by loose sediments or the subsurface voids. Additional analysis are needed to locate the cave.

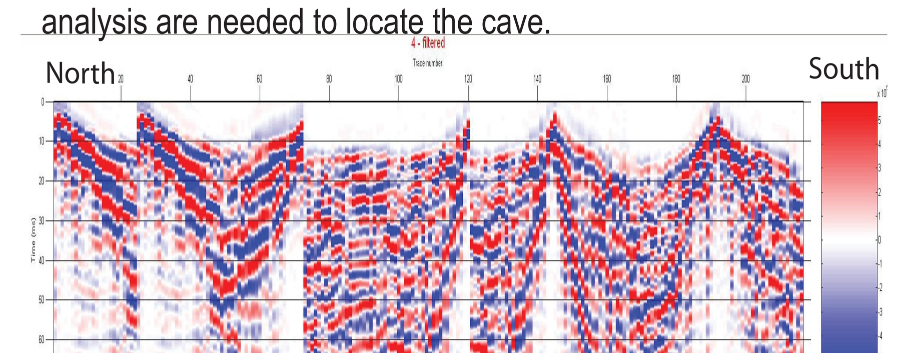


Figure 9. The Seismic survey data representation after filtering and normalizing.

Gravity Method

A LaCoste - Romberg model-G gravimeter was used to survey the known cave at site 1. Point data were collected over and around the location of the Balcony Room at site 1. The relative gravity data obtained from the insturment were edited for terrain, latitude, and tidal corrections. Analytical solutions determined the gravity anomaly that would be associated with approximate cave volumes. The theoretical calculations show that the void space would produce a gravity anomaly of approximately 5.1 mGal (10E-5m/s2). The data obtained from the field show a relative gravity anomaly of approximately 1 mGal associated with the spatial location of the cave.The relative gravity anomaly is interpreted to represent the missing mass of the subsurface cavity.

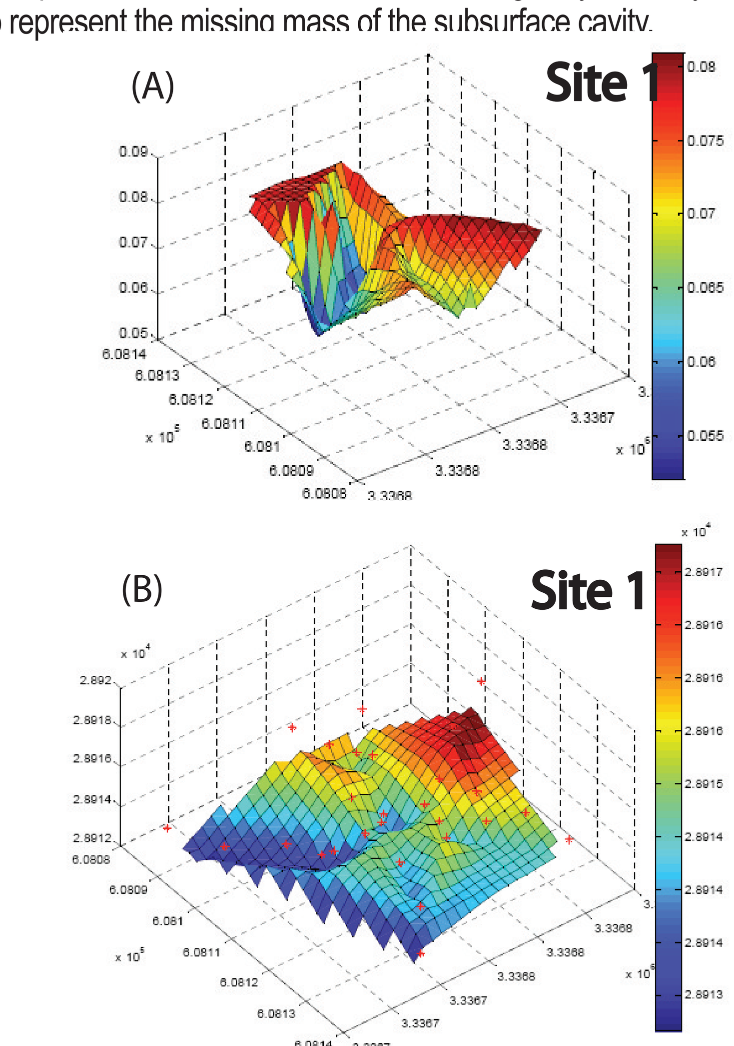


Figure 10. (A) Map of the combined terrian, Lat-Long, and tidal corrections superimposed on one another. (B) Map of corrected gravity data. the vertical axis is relative gravity in mGals ($10^{-5}m/s^2$).

Ground Penetrating Radar

GPR survey was conducted over a 10 m by 15 m grid in the North-East location of the Balcony Room. A Pulse Ekko instrument with 100 MHz antennas was used. A 0.25 m shot spacing with 61 shots per line and a 64 stack per shot were performed. Antennas were spaced 1m apart, with 0.5 m line spacing. Record length was 511.2 ns.

The GPR data underwent 3-d migration and processing to create a 3-d data volume with few artifacts from side echoes. The data analysis indicate a drop in signal amplitude in a region centered about 15-m depth, which is coherent through nearly the entire volume. We infer that this region of low amplitude is a cavity or a network of cavities. This is also in good agreement with high resistivity zone from the electrical resistivity data.

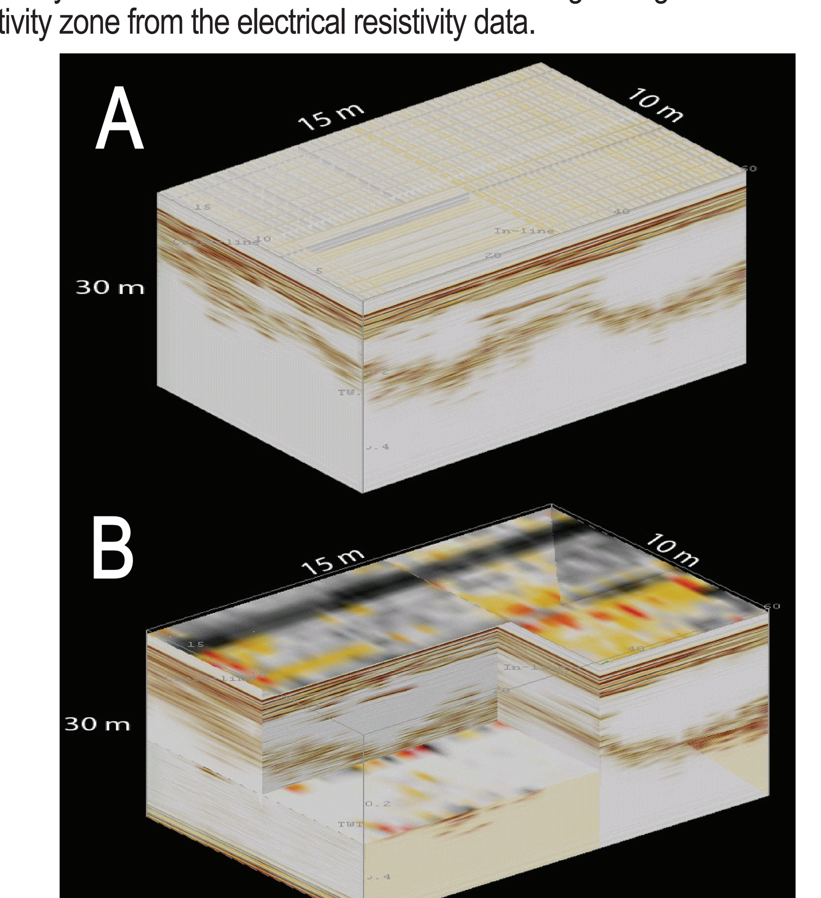


Figure 11. GPR data from site 1 (Fig. 1). (A) shows the 3-D volume created from the acquired radar lines.(B) shows a cutaway view of (A), where the first half of the data from each axis has been removed. "Time slices" (interpolated from the x-y plane) are shown at 15 m and near the top of the volume.

Role of GIS

The GIS proved to be effective tool in data and image presentation. The ER data were interpolated to provide 3-D concept of subsurface resistivity. Similary, the gravity data, its interpolation and a overlay with cave boundary shape file showed evective data representation.

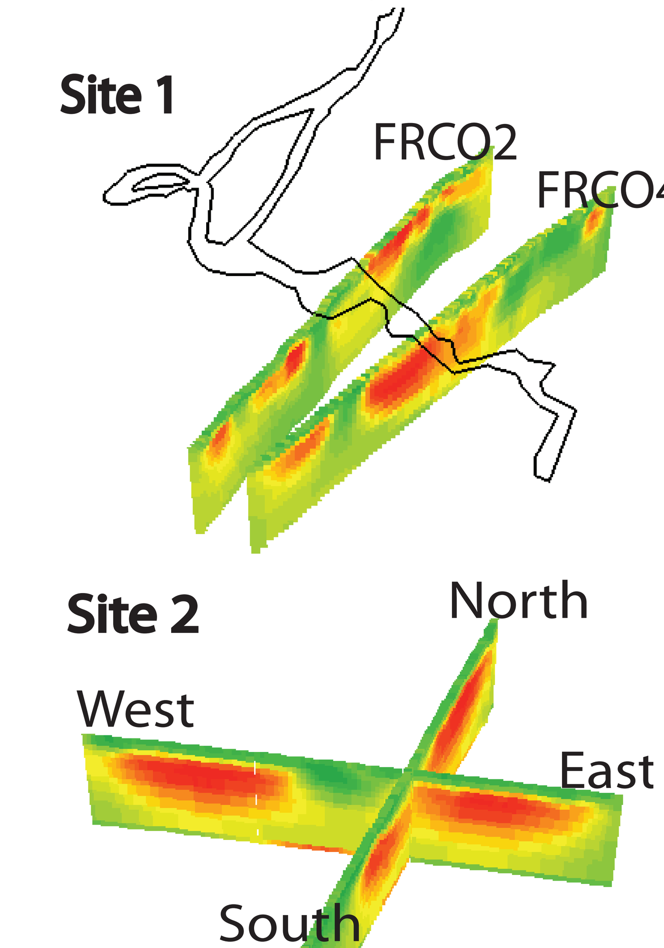


Figure 12: Schlumberger ER data interpolated in Arc GIS. Red is high resistivity and green is low resistivity.

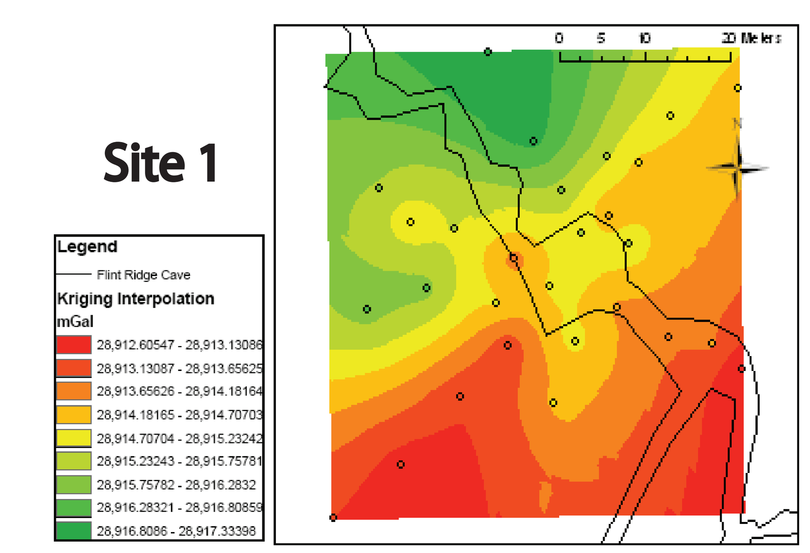


Figure 13: Arc GIS interpolation of the gravity data at site 1.

Conclusions

Electrical resistivity data provide good evidence of soil zone - bedrock (limestone) interface at about 1.5 m. The Schlumberger electrode array provided data with inferior resolution and shallower depth coverage. The dipole-dipole array on the other hand provided good evidence of the cave location (Balcony Room) at site 1.

The electromagnetic surveys provided a quick and effective reconiassiance method. The EM 34-3 and EM 31 in general showed mediocre response of the known cave at site 1. EM 38 is representative of shallow 2 m and, therefore, was inconclusive about the cave location (data not presented here). Both the ER and the EM data show interference from power lines at site 2.

The gravity survey shows reasonable anomaly associated with the cave location. The magnitude of the anomaly was, however, found to be small (~ 1 mGal), which was perhaps due to low resolution of the gravimeter.

The seismic survey showed slower velocities than expected from a typical limestone formation, which was perhaps due to effect from the soil zone and the fractured bedrock. Further data processing is, however, required to locate the cave by seismic method. The GPR data indicated an additional cave, which is in close aggrement with the ER data from site 1.

Acknowledgements

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