Table 6. GPR survey line coordinates over Indian Well Cave.

Line #	Northwest End Point		Southeast End Point	
	Easting (m)	Northing (m)	Easting (m)	Northing (m)
Line 1	624182.01	4619014.98	624230.48	4618991.35
Line 2	624181.94	4619012.17	624229.39	4618988.42
Line 3	624182.77	4619009.44	624228.24	4618985.81
All coordinates are listed in NAD 83/UTM Zone 10				

Approximately 53.3 m (174.9 ft) of data were collected along each of three profiles (two profiles for the 100 MHz antenna) at Indian Well Cave. In general all profiles correlate well with another and show many of the same characteristics. To simplify the discussion, only the 200 MHz data, shown in figure 25, which was collected along Line 3 is discussed. Although the 200 MHz antenna does not have the resolution of the 400 MHz antenna, the lack of resolution and increased depth of investigation provided an interpretable GPR cross section. Due to a possible wiring problem the 100 MHz antenna produced no interpretable profiles.

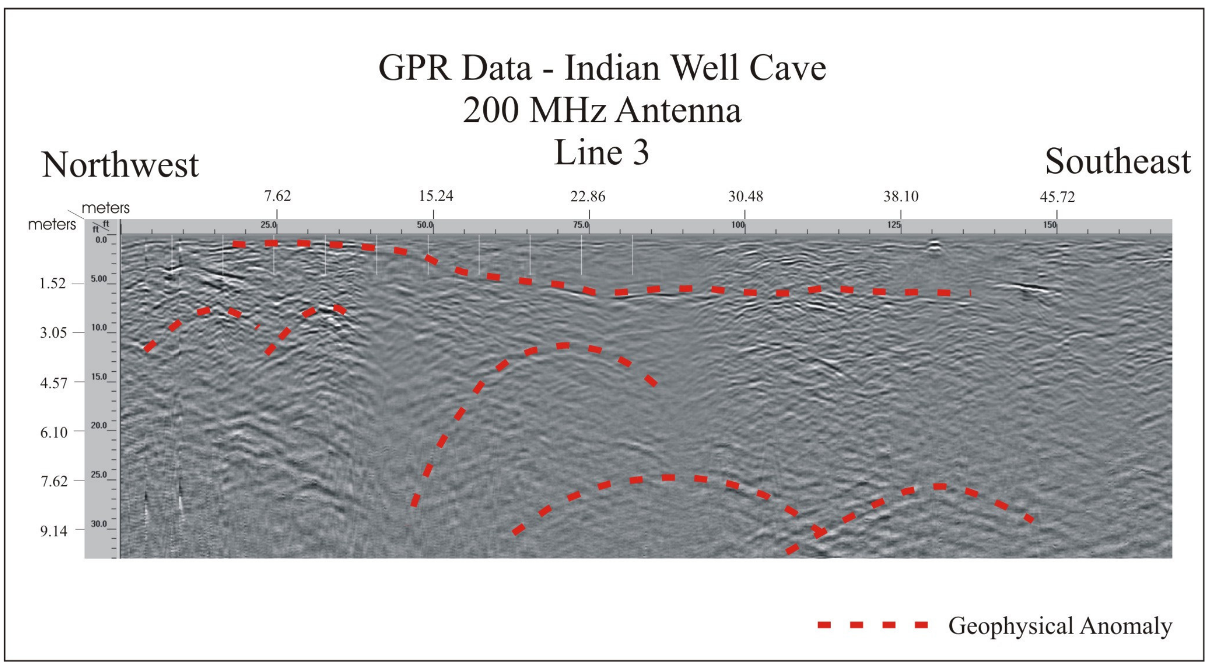

Figure 25. Cross Section. GPR data collected over Indian Well Cave.

Generally, the data quality is good and shows numerous anomalies. The profile shows areas of low amplitude response from 11.6 to 14.3 m (38.1 to 46.9 ft) and from 22.9 to 28.3 m (75.1 to 92.8 ft) and areas with multiple diffractions from 0 to 11.6 m (0 to 38.1 ft) and from 28.4 to 37.5 m (93.2 to 123.0 ft). The low amplitude areas might be the result of little or no fracturing in the basalt since, in this case, there would be no boundaries to reflect the EM waves. Areas with numerous diffractions may indicate areas of severe fracturing resulting in multiple rock-void boundaries. Although many anomalies exist in the data, only the six most prominent features were selected from the GPR data collected along Line 3. The remaining features are not likely to represent caves. The anomalies have been marked on figure 25. These were selected based on shape, depth and estimated size (width of anomaly) and are the most likely to be associated with caves.

The Indian Well lava tube was expected to cross Line 3 at approximately 44.2 to 45.7 m (145.0 to 149.9 ft) from the start of the line. A selected anomaly, outlined in red to denote an interpreted lava tube, is centered at approximately 39.6 m (129.9 ft). This anomaly is located at an estimated depth of 7.6 m (24.9 ft) using a dielectric constant $\varepsilon_r = 8$ and produces a broad hyperbolic shape measuring approximately 13.7 m (44.9 ft) wide. Another large hyperbola is centered from 26.5 to 26.8 m (86.9 to 87.9 ft) and measures approximately 15.2 m (49.9 ft) wide. These hyperbolae were difficult to interpret because of the low amplitudes associated with them. Three other anomalies, two diffraction hyperbolae and one interpreted layer, are visible at shallower depths along the profile. A low amplitude hyperbola is centered at 21.9 m (71.9 ft) and has a depth of 3.4 m (11.2 ft) and a width of 10.7 m (35.1 ft). The interpreted layer is characterized by regions of high amplitude response (dark black color) from 20.4 to 23.2 m (66.9 to 76.1 ft) and 23.7 to 27.4 m (77.8 to 89.9 ft) and extends for a total length of 35.7 m (117.1 ft). An anomaly having a partial hyperbolic shape is centered at 10.4 m (34.1 ft) at a depth of 3.0 m (9.8 ft). Both the left side and right side of the hyperbola are still evident in spite of being in an area of muted response. Another hyperbolic anomaly is centered at approximately 4.3 m (14.1 ft) and is at a depth of 2.1 m (6.9 ft). The apex of the hyperbola is much more visible (higher amplitude values) than the tails, as is the case with the previous hyperbola discussed. The tails of the diffraction hyperbolae are lost in the interference resulting from multiple diffractions in this area. GPR data collected over Lines 1 and 2 are shown in appendix C. These profiles show the same basic characteristics and were not interpreted individually.

Magnetic Method

The magnetic data collected over Indian Well Cave is displayed in figure 26. The top of the figure shows gridded data from all three lines along the road. The bottom of the figure shows profiles from all three lines along which data was recorded. The direction of the magnetic profile is SE-NW. Three main magnetic anomalies are observed, and are shown outlined on the plan map of the site. The highest amplitude anomaly correlates spatially with the known cave location. The anomalies from all of the lines are similar at this location, although the amplitude of one of the lines is less.

Two other significant anomalies are seen to the northwest of the known cave location. The shape of the magnetic anomalies slightly differs from the magnetic anomaly over the known cave location. In both of these anomalies, one of the three survey lines indicates a magnetic high while the other two survey lines indicate a magnetic low. These anomalies may indicate unknown caves.

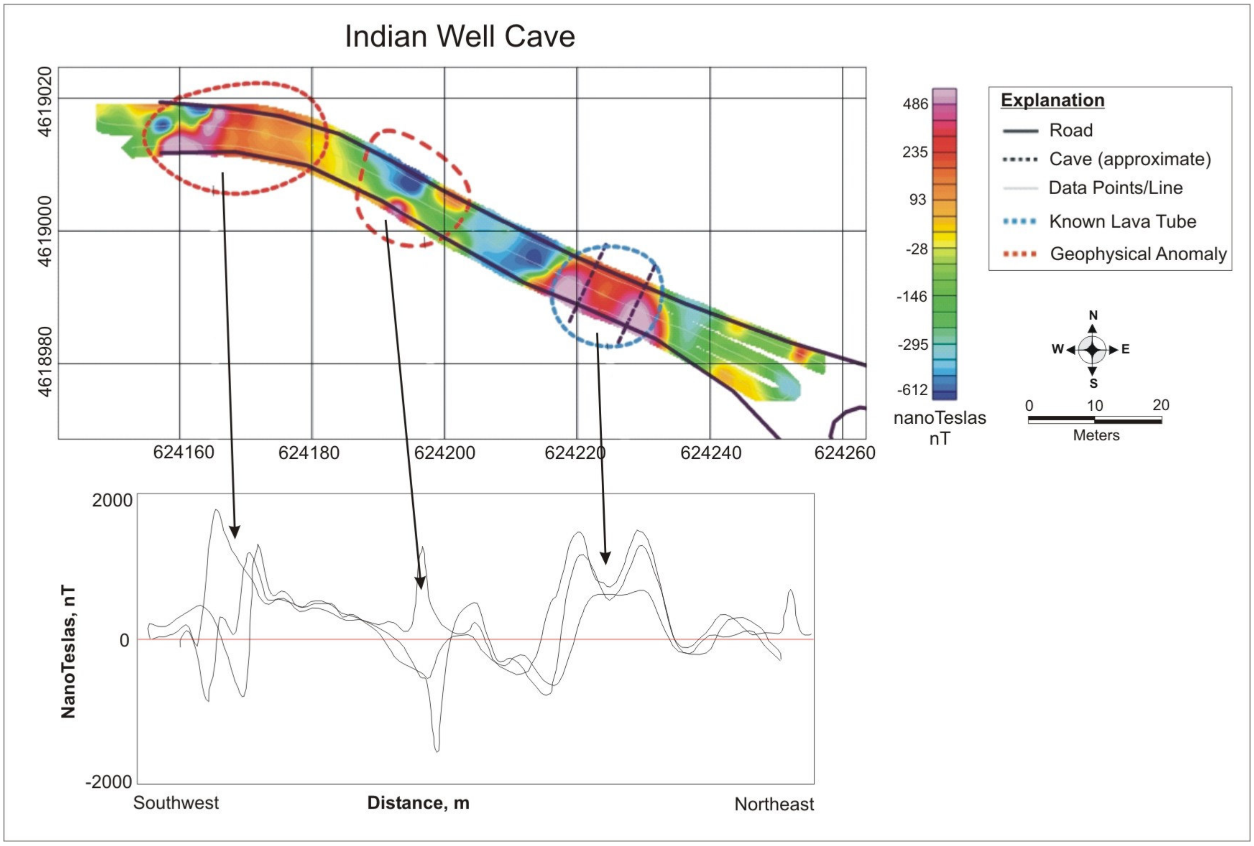

Figure 26. Map. Plan and profile view of magnetic data collected over Indian Well Cave.

Electrical Resistivity

A single line of electrical resistivity data was collected with the OhmMapper TR2 along the roads at each of the four sites. The OhmMapper TR2 array consisted of two receiver dipoles and one transmitter dipole. A non-conductive rope separates the 10 meter (32.8 ft) dipole transmitter and 15 meter (49.2 ft) dipole receivers. The length of the non-conductive rope along with the dipole lengths determines the depth of investigation. At LBNM, two different non-conductive rope lengths, 5 and 10 m, were used giving three different ‘n’ spacings of 0.5, 1.0, and 1.5 m (1.6, 3.3, and 4.9 ft). The data acquisition parameters are listed in appendix B.

A survey line was marked along the road and the location of the line was surveyed with DGPS. A person manually towed the system along the ground surface, recording data at a rate of 2 hertz. Marks were placed in the data for positioning.

During data collection, an additional dipole cable was placed between the two receivers (a total of two dipole cables instead of one). The additional dipole cable resulted in an asymmetric 15 meter (49.2 ft) dipole receiver for both receivers.

The OhmMapper TR2 data was first imported into MagMap2000, where the data quality was checked and the array parameters were verified. A despiking filter was applied to the data to remove abnormal spikes in the data. The position of the data was corrected using the marks in the data and the surveyed locations. The corrected data were then exported from MagMap2000 and imported into RES2DINV where the data was inverse modeled using a robust, 2-D finite-difference method. The inversion performed in RES2DINV is based on the smoothness-constrained least squares method. The 2-D model used in the inversion process divided the subsurface into a fine mesh of rectangular blocks from shallow to deep that are limited at depth by the approximate depth of investigation provided by the largest electrode spacing. The program iteratively determines the resistivities of the model blocks that will produce an apparent resistivity pseudosection that matches the field data. Through inversions, the electrical resistivity method produces a geoelectric cross-section. The cross section is developed by gridding the resistivity as a function of depth. The cross section does not show the exact structural characteristics of the subsurface. Instead, it shows a cross section with exemplified areas of extremely high or low resistivities compared to the bulk resistivity of the entire cross section.

The final RMS error, which is the difference between the successive 2-D model inversions and the measured data, was less than 5% for all sites. Fortunately, there were very few bad data points. These are usually caused by ambient noise, poor coupling, or system problems. Those that did occur were removed from the data. The final results are bitmaps displaying the measured apparent resistivity pseudosection, a calculated apparent resistivity pseudosection, and an inverse model resistivity section. These bitmaps are shown in appendix E. Only the inverse model resistivity section is shown in the following figures.

It is important to note that an extra dipole cable used during data collection influenced the data in three ways. Due to this cable, multiple position corrections, and gridding factors, the position of the data is only approximate. The extra dipole cable caused the geoelectric cross-section to have generally higher resistivity values; however, the overall pattern of the geoelectric cross-section will remain constant. Finally, the extra cable made anomalies' location in the data shallower than its actual depth. These three factors were considered during data interpretation.

Areas of high resistivity, compared to the average for that particular geoelectric cross section, were selected as possible cave locations since the caves in this area are filled with air (infinitely resistive). This method does not show accurate boundaries of voids or any other subsurface features; however, it does give an approximate location of the middle of the void. A hole drilled into the center of the highly resistive area would verify if an anomaly exists. The dashed outlines on the geoelectric cross sections are only outlines of highly resistive areas and do not necessarily represent the true size or existence of the void. The approximate depth and size of the voids were estimated from the edges of highly resistive areas in the inverse resistivity section. Where the highly resistive area is near an edge of the geoelectric cross section, more data is needed to characterize the anomaly.

The descriptions of the procedures for the data acquisition, processing, and interpretation for the electrical resistivity method apply to all cave sites in this report.

Figure 27 displays a segment of the electrical resistivity survey line where it travels over Indian Well Cave [(6)] and table 7 gives the coordinates of the end points and center point used as markers along the survey line. Figure 28 displays the resistivity data collected at Indian Well Cave. This data was recorded from northwest to southeast. A blue arrow indicates the known cave. The anomalies are circled in red. The background resistivity values for this site lie between 1,500 ohm-m and 5,000 ohm-m, which is high for basalt, whose resistivity often ranges from 100 to 1000 ohm-m. The maximum resistivity value, 48,100 ohm-m over known cave, is located at 32.0 m (105.0 ft) at an interpreted depth of 5.5 m (18.0 ft). Since the cave appears as a half circle, with the other half of the circle below the collected data, we are unable to predict the true depth or height of the cave. The interpreted width of the cave is 6.1 m (20.0 ft), which is reasonably close to the surveyed width of the cave, which is 7.9 m (25.9 ft).

Table 7. Electrical resistivity survey line coordinates over Indian Well Cave.

ID	Easting (m)	Northing (m)
Point 1 (SE end point)	624252.03	4618976.38
Point 2	624147.62	4619017.32
Point 3	624206.04	4619000.05
Point 4	624206.04	4619000.05
Point 5 (NW end point)	624147.62	4619017.32
All coordinates are listed in NAD 83/UTM Zone 10		

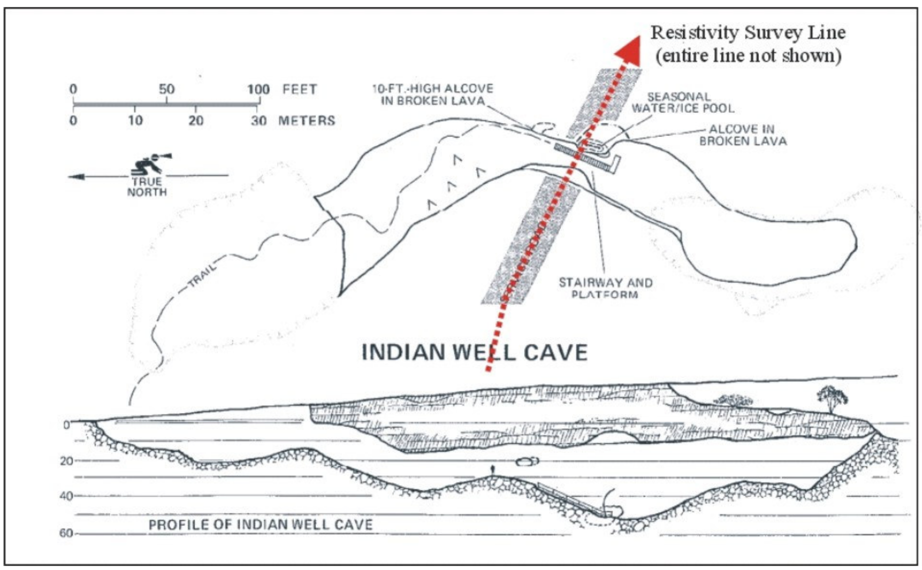

Figure 27. Map. Electrical Resistivity survey line over Indian Well Cave. [(6)]