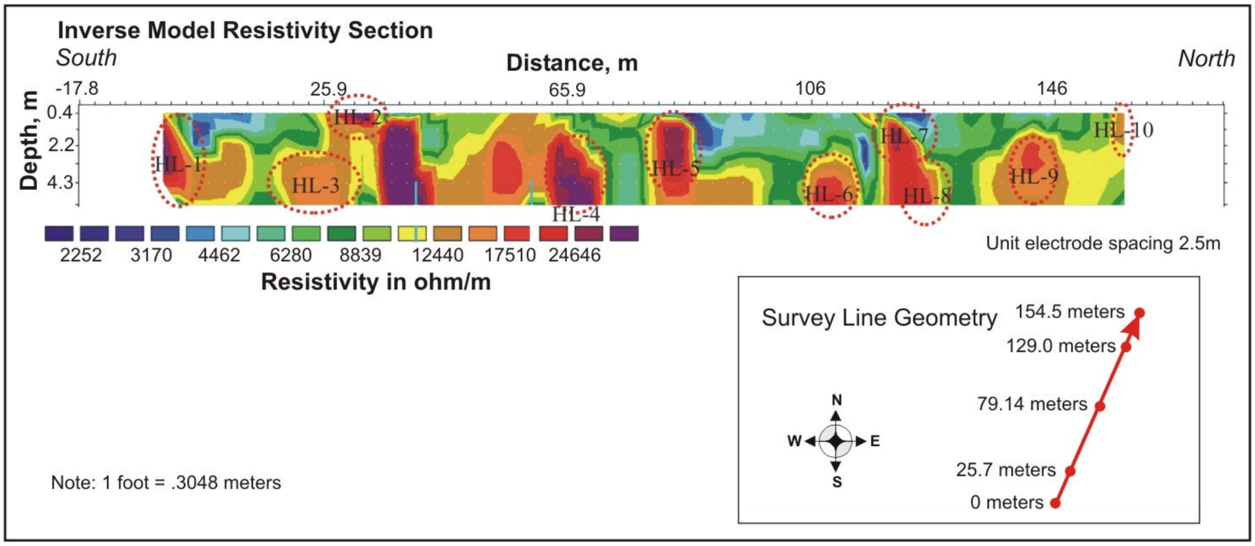

Figure 52. Cross Section. Electrical resistivity data collected over Hercules Leg Cave.

The south cave lies at approximately 42.0 m (137.8 ft) along the traverse and corresponds to a resistivity high at 40.8 m (133.9 ft). The maximum resistivity of this anomaly is 41,600 ohm-m. At this location, this cave passes under the road and immediately loops back under the road. Anomaly HL-3, while having a much smaller amplitude than the anomaly associated with the cave, could be the same cave going under the road. More information at a greater depth is needed to fully characterize this anomaly.

A more complex anomaly occurs at the second known cave, which appears to occur at a saddle between two resistivity highs, one of which is labeled HL-4. The resistivity data appears to indicate either a complex cave structure or possibly two caves.

Anomalies HL-1 and HL-10 are located on the south edge and north edge of the data, respectively. Anomaly HL-1 is quite resistive, whereas anomaly HL-10 is only mildly anomalous. Both anomalies are poorly defined since they are at the ends of the line. Therefore, it is difficult to characterize them without having more data to completely define their shapes. Anomaly HL-2 is a small, near surface anomaly with a maximum resistivity of 38,200 ohm-m. This shallow anomaly, 0.3 m (1.0 ft) below the surface, could be a blister or small surface tube. Anomaly HL-5 is located at 82.3 m (270.0 ft) and has an interpreted depth of 1.2 m (3.9 ft). This too has the potential to represent a small cave. Anomaly HL-6 is shown at 107.0 m (351.0 ft). Since this anomaly is probably located deeper than 5.5 m (18.0 ft), more information at depth is needed to characterize this anomaly. Anomalies HL-7 and HL-8 are shown as two anomalies; however, due to their close proximity, they may have resulted from the same physical feature. Their maximum resistivity values are 25,500 and 21,100 ohm-m respectively. Anomaly HL-9 is an isolated anomaly located at 142.0 m (465.9 ft) at an interpreted depth of 2.0 m (6.6 ft) to the top of the anomaly.

Electrical Conductivity

Electrical conductivity was not a proposed method for testing at LBNM due to the fact that, prior to conducting the surveys, the area was suspected as being generally resistive, with the voids being highly resistive. Although measuring the electrical conductivity is an effective method based on physics, obtaining conductivity measurements using the EM31 in this resistive environment may be difficult. However, due to the rapid data collection rate and the availability of the instrumentation, it was decided to conduct a single test of the EM31 at the Hercules Leg Cave site, taking measurements across the known cave and the region where potential, but unknown, caves may occur.

EM31 data were collected along three lines positioned along the center and along both sides of the road at Hercules Leg Cave. Data were recorded in the vertical dipole mode giving a depth of investigation of up to about 6 m. The quadrature (conductivity) and in-phase components of the electromagnetic field were recorded at 2 hertz using a Polycorder 720 to control the data recording and store the data. The data were coupled with DGPS for positioning.

During processing, the DGPS data were imported into Trimble Geomatics Office (TGO) program and it was reformatted and exported. The EM31 data were imported into the DAT31 program and analyzed for completeness. The reformatted DGPS data were then combined with the EM31 data in DAT31 and it was exported in *.xyz ASCII format. These ASCII files were then read into Oasis montaj where figures were created.

The data, shown on figure 53, are displayed using a scale of 0 to 10 millimhos/meter (mmhos/m). There is one small conductive anomaly visible in the data and outlined in red. The anomaly is located farther north than the surveyed location of Hercules Leg Cave. This anomaly is not supported by the magnetic method, which was the only other method used at that location. The shape of the anomaly suggests a vertical electrically conductive feature. It is possible that either a spatially rapid increase in the depth of fill, or a change in its composition, could produce the anomaly.

Seismic Reflection

Figure 54 displays the approximate location of the HRSW survey line, which traverses over Hercules Leg Cave [(6)], continuing across an area where caves may occur. Table 14 gives the location of every tenth geophone along the geophysical survey line. The Hercules Leg Cave seismic sections are illustrated in figure 55 and also included in appendix D.

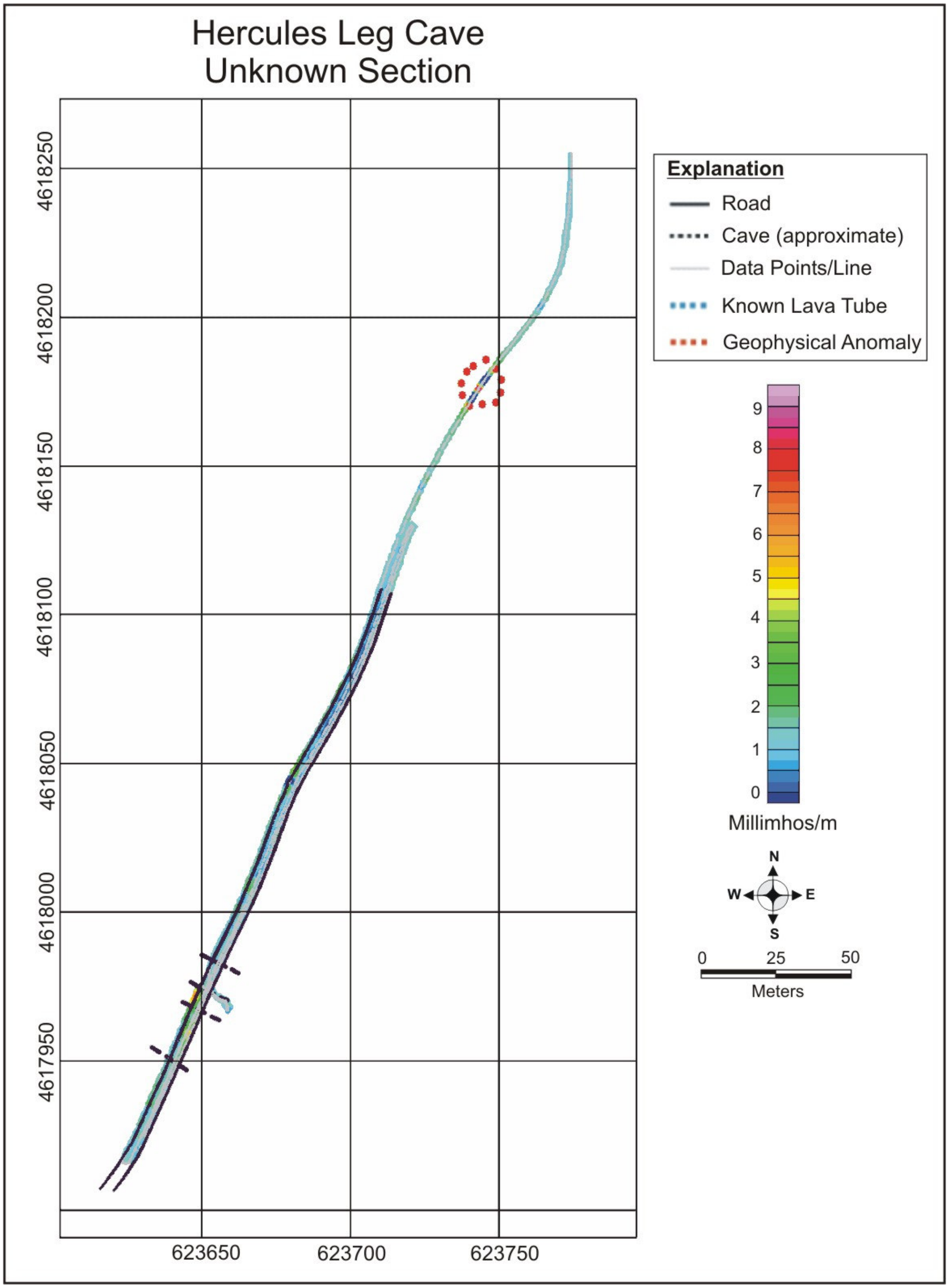

Figure 53. Map. Electrical conductivity data collected over Hercules Leg Cave.

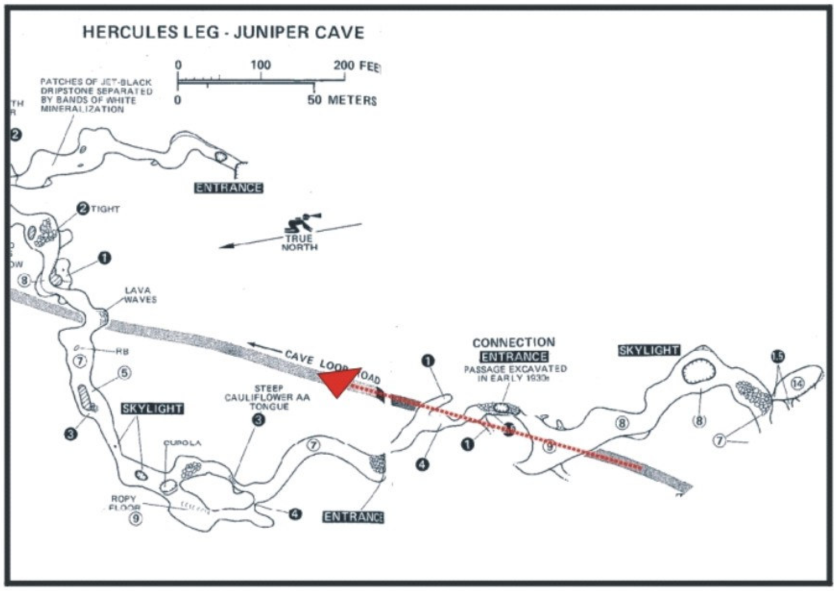

Figure 54. Map. HRSW survey line over Hercules Leg Cave. (6)

Table 14. Geophone coordinate locations over Hercules Leg Cave.

ID	Easting (m)	Northing (m)	Elevation (m)
Geophone 101	623633.94	4617988.64	1502.51
Geophone 111	623636.44	4617994.16	1502.23
Geophone 121	623638.94	4617999.71	1501.92
Geophone 131	623641.44	4618005.24	1501.56
Geophone 141	623643.94	4618010.73	1501.14
Geophone 151	623646.41	4618016.23	1500.70
Geophone 161	623648.9	4618021.71	1500.27
Geophone 171	623651.41	4618027.22	1499.85
Geophone 181	623653.93	4618032.73	1499.42
Geophone 191	623656.43	4618038.25	1499.01
Geophone 201	623658.93	4618043.66	1498.61
Geophone 211	623661.38	4618049.09	1498.17
Geophone 221	623663.88	4618054.55	1497.73
Geophone 231	623666.36	4618060.02	1497.34
Geophone 241	623668.88	4618065.48	1497.00
Geophone 251	623671.39	4618070.97	1496.69
Geophone 252	623671.65	4618071.5	1496.66
All coordinates are listed in NAD 83/ UTM Zone 10			

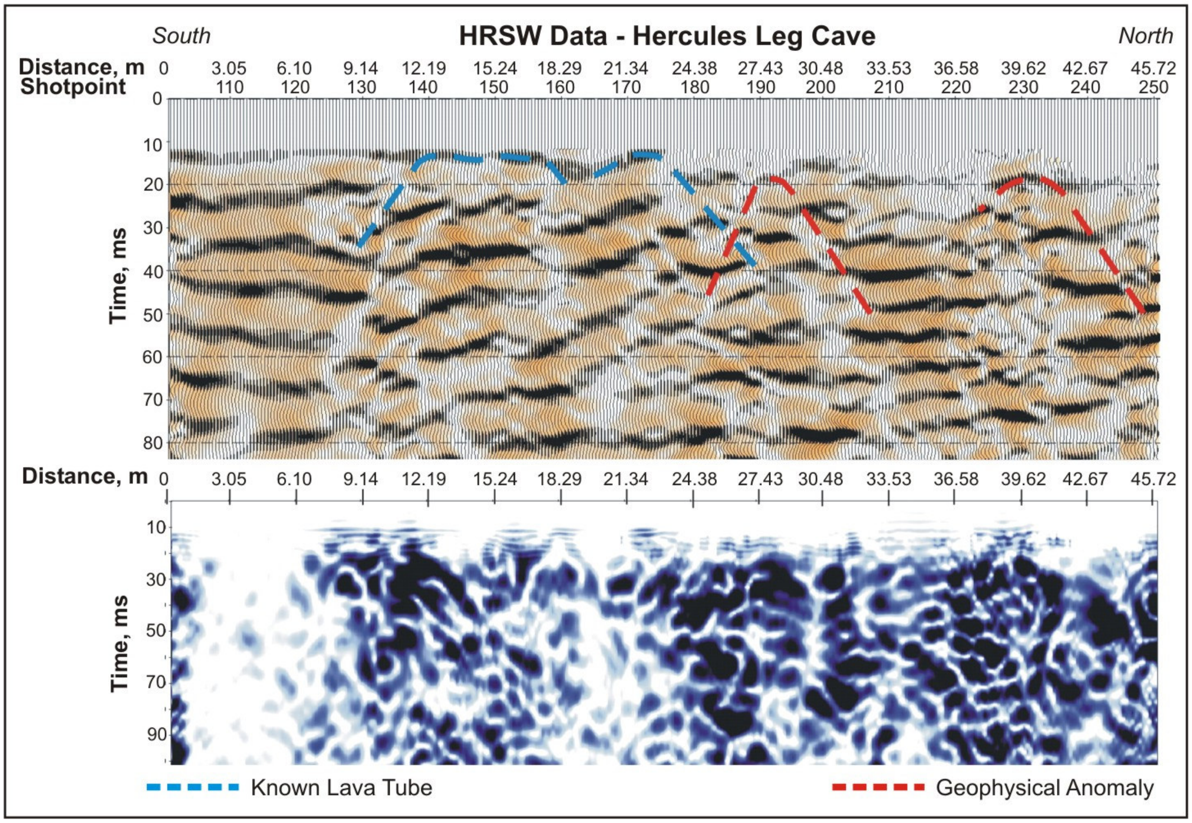

Figure 55. Cross Section. HRSW data collected over Hercules Leg Cave.

The Hercules lava tube passes twice under this profile. The southern cave, located at shot point 145, has a width of approximately 22.3 m (73.2 ft) under the seismic line. The northern cave located at shot point 174 has a width of approximately 9.8 m (32.2 ft) under the line. Both tubes are approximately 3.0 m (9.8 ft) below the ground surface. The seismic velocity in the vicinity of the known cave is 1524 m/sec (5000 ft/sec), so the reflection from the cave should occur about 4 ms below the top of the data. Zero time on this section is at an elevation of 1508.0 m (4947.5 ft).

The reflections from the top of the known caves merge to form the shallowest event between shot points 139 and 176. The top of this wide cave causes a prominent reverberation, as the s-wave energy bounces back and forth between the top of the cave and the ground surface. The reverberating energy continues to the bottom of the section. Faint diffractions are interpreted at the edge of the caves. The small separation between the two caves is not readily evident.

Although sometimes detected, caves within the top 3 to 5 m (9.8 to 16.4 ft) of the subsurface pose a significant problem in HRSW data interpretation. With targets this shallow, the acoustic waves sent into the ground may be distorted and very difficult to separate from other acoustic waves (i.e. ground roll).

Two suspected lava tubes are also interpreted on this profile. The first, centered on shot point 191.5 (628.3 ft), is interpreted based on the presence of both an arcuate reflection and faint diffractions on both sides of this reflection. This source of the anomaly is interpreted to be approximately 7.6 m (24.9 ft) deep with a horizontal dimension of about 2.4 m (7.9 ft).

The second interpreted lava tube is centered on shot point 231, and is evidenced by an arcuate reflection overlying a zone of incoherent reflectors. A faint diffraction occurs on the south side of this anomaly. The interpreted depth to the top of this possible lava tube is approximately 7.6 m (24.9 ft) and its interpreted width is about 4.6 m (15.1 ft).

4.6.3 Comparisons

Figure 56 compares the anomalous zones in the data sets collected over both the known caves at this site along with the area where there are potential, but unknown, caves. These comparisons do not include the electrical conductivity measurements, which were taken using the EM31. The known caves at Hercules Leg Cave (North and South) were detected with the HRSW, electrical resistivity, and GPR methods. The known caves are identifiable in the magnetic data; however, the locations of the known caves were needed to make an accurate interpretation. The North Cave was detected at about the same location with each of the methods. The South Cave was detected in the same general area with the HRSW reflection, magnetic, and GPR methods but is offset approximately 15.2 m (49.9 ft) to the south in the electrical resistivity data. An anomalous zone is located to the southwest of the most southern known cave in both the electrical resistivity and the magnetic data. An anomalous zone is interpreted in all the data for each of the methods just to the north of Hercules Leg North Cave. There is a slight offset, approximately 4.6 m (15.1 ft), in the HRSW data compared to the electrical resistivity, magnetic, and GPR data sets. One additional anomaly was detected to the north with the HRSW data. This anomaly was not observed in the data from any of the other methods. One additional anomalous zone was detected further north in the magnetic data, which corresponds to two anomalous zones in the electrical resistivity data. Overall, the magnetic and electrical resistivity data show anomalies that are spatially coincident while the size of the caves and small overburden thickness benefited the GPR method.

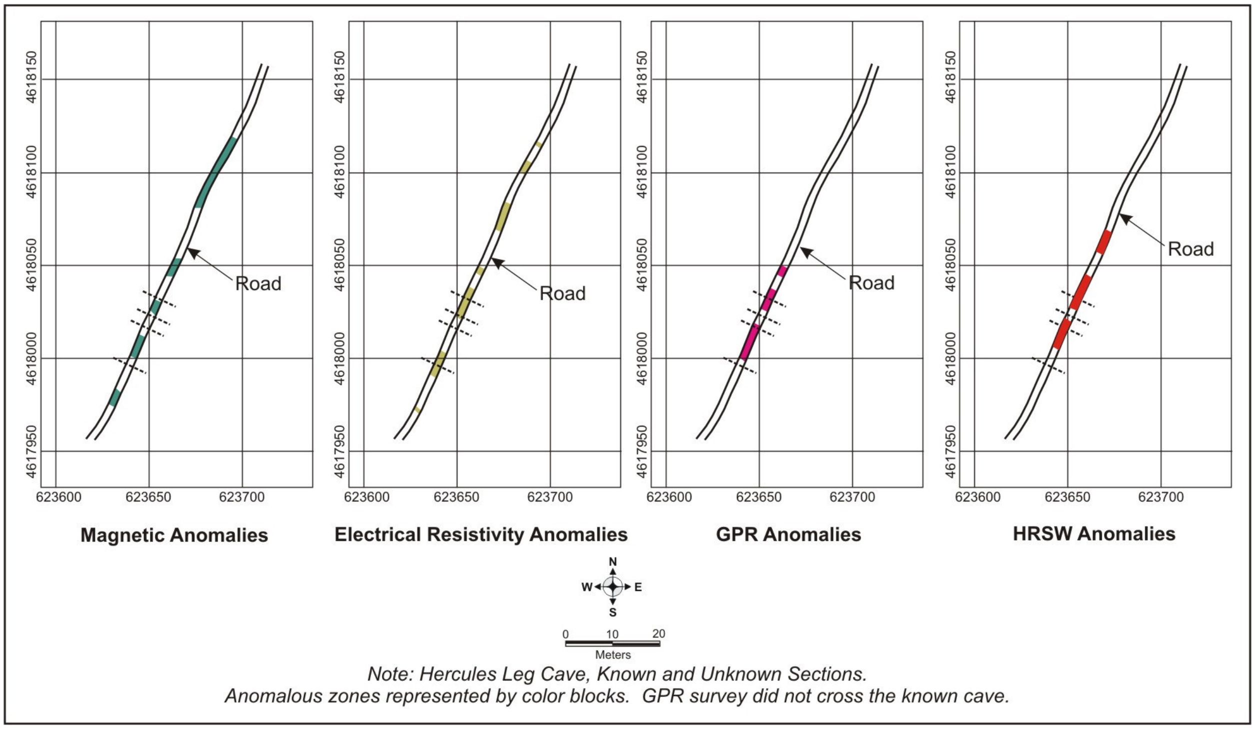

Figure 56. Map. Comparison of anomalous zones over Hercules Leg Cave.