CHAPTER 5.0. DISCUSSION OF RESULTS

The lava tubes profiled at Lava Beds National Monument manifest themselves in each of the geophysical methods. However, each of the lava tube sites has unique aspects with regard to the data collected and interpretation. All of the data interpretations were performed by field personnel, and then reviewed by more experienced geophysicists. The data from each method was interpreted independent of the other data sets, but with an understanding of the local geology at each site. The results of the geophysical surveys, by cave location, are summarized below.

Golden Dome Cave

- Although the GPR cross sections did not cross the known cave location, as mapped by the compass and chain method, there were numerous diffractions present in the data. It is unclear if the GPR method would have detected the Golden Dome Cave.

- The Golden Dome Cave location was very distinct in the magnetic data profile. Two spatially close magnetic highs were present with the cave location being positioned at the depression between the two highs. Two other anomalies, possibly indicating cave locations, were located northeast of the known lava tube.

- The seismic section over Golden Dome Cave is dominated by reverberating reflection events, indicating the presence of shallow scoria beds in this area. An obscure reflection event occurs at the top of the cave, as well as diffractions on each side.

Indian Well Cave

- The thick overburden present severely limited the usefulness of the GPR method. Numerous diffractions are present in the data but are not considered to be associated with the cave.

- Indian Well Cave was successfully located with the magnetic data profile. Two other possible cave locations were selected northwest from the known lava tube. Both anomalies indicate a positive anomaly in one line of the profile data while the other two profile lines show a negative response.

- Several anomalies, including one selected over the cave, are visible in the resistivity (TR2) data. The anomaly over the cave is just visible at the deepest portion (bottom) of the section. An increase in the array length (increasing the dipole separation) might be useful for future surveys to delineate deep, large voids.

- The seismic section over the Indian Well Cave is relatively free of reverberating seismic energy, indicating an absence of shallow scoria beds. The tube can be identified by a reflection from the cave top, a diffraction from the west edge, and a zone of relatively noisy data later in time.

Monument Road Cave

- Multiple diffractions are present in the GPR data, but vary in amplitude from line to line. This lava tube was not imaged using GPR.

- Monument Road Cave was successfully located with the magnetic method. In the magnetic profile, a positive magnetic anomaly is observed. Another anomaly is found to the north of the known cave location and was proposed as a possible lava tube site.

- Two well-defined anomalies are clearly evident in the electrical resistivity data. The known cave was easily interpreted from the data as well as a second anomaly to the south.

- The Monument Road Cave is evident from the arcuate reflection in the HRSW data from the top of the cave. However, the section is composed of predominantly reverberating seismic energy, bouncing back and forth between a shallow scoria bed and the surface.

Bearpaw Bridge

- The electrical resistivity data were successful at locating the lava tube at Bearpaw Bridge. High resistivity values indicate the location of the lava tube.

Hercules Leg Cave

- The known caves were clearly identified by the GPR data. The depth to the roof and the width of the caves were easily distinguished from the raw and processed data.

- Magnetic anomalies were observed over the two known caves. Information concerning the locations of these caves aided in the selection of these anomalies. Two other anomalies, with profiles similar to the profile over the known caves, were selected in this section. Within the unknown section of the Hercules Leg Cave survey site, a very distinctive trough in the data appears in the middle of the line, suggesting a cave. Also, one possible cave location was proposed to the southwest and two others were proposed northeast of the middle of the survey line.

- Several anomalies are present in the electrical resistivity data, but do not have the continuity associated with them compared to the anomalies at Indian Well or Monument Road Cave. This may indicate that the source of these anomalies is comparatively small, suggesting small voids.

- The EM31 data collected showed no anomalies in the vicinity of the known cave.

- Hercules Leg Cave is wide enough under the seismic line that it traps seismic energy between the top of the cave and the ground surface, causing strong reverberations. Again the thin overburden present may be disguising the exact shape and size of the known voids.

Overall, each known lava tube was detected with at least two geophysical methods. Table15 is a reference guide of the final results from all geophysical surveys. It is important to note that

although the lava tube was interpreted at each location, the data processing and interpretation for certain geophysical methods were aided by knowledge of the general lava tube location.

The large voids at the Indian Well and Monument Road Cave sites were easily detected with the magnetic and electrical resistivity data. The ease of data acquisition using the magnetic or electrical resistivity methods makes them more favorable for lava tube detection at LBNM, especially for data collection over long distances. These data sets may also be relatively quickly processed and interpreted. Anomalies interpreted from the magnetic or electrical resistivity methods may then be further investigated using the HRSW or GPR method.

The HRSW method is effective at determining depths as well as providing width estimates over voids thought to have more than 3.0 m (9.8 ft) of overburden. Although the lava tubes are visible in the HRSW data sets, they would be difficult to locate without some prior knowledge of their locations. A known site is important to be able to calibrate the processing and interpretation steps. Once the characteristics of a known cave are observed in the data, then other anomalies can be interpreted using similar criteria. It is therefore recommended that, for future work, shear wave reflection surveys be "calibrated" against a known cave in the local area.

The GPR method was effective at detecting voids down to depths of 4.0 m (13.1 ft) without "calibration," and may be a more practical method for determining shallow void characteristics where individual anomalies are not distinguishable in either the magnetic or electrical resistivity methods. GPR could be used to assist in determining the depths of anomalies in the magnetic or resistivity data, providing the sources of these anomalies were less than about 4.0 m (13.1 ft) deep.

5.1 SURVEY METHOD EVALUATION

The evaluation of the geophysical methods, based on the results described above, demonstrated their ability to detect the presence of subsurface voids and to characterize the vertical and horizontal extent of the voids. However, their ability to accurately and economically detect the presents of voids under specific geologic settings varies from method to method. Table 16 summarizes the methods' detection capabilities, their production rates, and their cost effectiveness for lava tube detection. In examining the table, it shows that none of the methods are capable of determining the height of the lava tube.

Table 15. Reference guide of the final results from the geophysical surveys at LBNM.

Location	Method	Detected Known Lava Tube	Surveyed Dimensions			Interpreted Dimensions from Data		
			Depth (m)	Width (m)	Height (m)	Depth (m)	Width (m)	Height (m)
Golden Dome Cave	GPR	NA	4	4	2.7	NA	NA	NA
	Magnetics	Y	4	4	2.7	NA	4 to 10	NA
	Electrical Resistivity	NA	4	4	2.7	NA	NA	NA
	HRSW	Y*	4	4	2.7	4	3	NA
Indian Well Cave	GPR	NA	8.8	7.9	8.5	NA	NA	NA
	Magnetics	Y	8.8	7.9	8.5	NA	8 to 18	NA
	Electrical Resistivity	Y	8.8	7.9	8.5	6	7	NA
	HRSW	Y*	8.8	7.9	8.5	9	8	NA
Monument Road Cave	GPR	N	5.5	12.2	5.5	3 to 5	3 to 5	NA
	Magnetics	Y	5.5	12.2	5.5	NA	3 to 10	NA
	Electrical Resistivity	Y	5.5	12.2	5.5	2 to 3	12	NA
	HRSW	Y*	5.5	12.2	5.5	12	6	NA
Bearpaw Bridge	GPR	NA	6.4	15.2	3	NA	NA	NA
	Magnetics	NA	6.4	15.2	3	NA	NA	NA
	Electrical Resistivity	Y	6.4	15.2	3	2 to 3	10	NA
	HRSW	NA	6.4	15.2	3	NA	NA	NA
Hercules Leg North	GPR	Y	3.4	9.8	0.9	2	12	NA
	Magnetics	N	3.4	9.8	0.9	NA	NA	NA
	Electrical Resistivity	Y	3.4	9.8	0.9	1	6	NA
	HRSW	Y*	3.4	9.8	0.9	3	9	NA
Hercules Leg South	GPR	Y	2.7	22.3	2.4	2	21	NA
	Magnetics	N	2.7	22.3	2.4	NA	NA	NA
	Electrical Resistivity	Y	2.7	22.3	2.4	1	4	NA
	HRSW	Y*	2.7	22.3	2.4	3	3	NA

* - Processing and interpretation were aided by the knowledge of the general lava tube location

Table 16. Geophysical survey methods' capabilities, production rates, and cost effectiveness for lava tube detection.

Geophysical Method	Data Acquisition Speed	Data Processing and Interpretation	Cost-effectiveness [1]	Survey Location Estimates [2]		
				Depth (m)	Width (m) [7]	Height (m)
GPR	Walking [3]	16 hrs/day of collection [5]	2	< 4m	< ±20%	NA
Magnetics	Walking [3]	16 hrs/day of collection [5]	2	3 - 9	< ±40%	NA
Electrical Resistivity	Walking [3]	16 hrs/day of collection [5]	2	3 - 9	< ±20%	NA
HRSW	200-300 shots/day [4]	6-10 days/day of collection [6]	4	3 - 9	< ±20%	NA

[1] – cost-effectiveness is based on scale of 1-5 with 1 being the best. Factors include collection rates, known lava tube detection rate, interpreted size and depth.

[2] – estimates are based on results from this report only.

[3] – in certain cases these instruments may be mounted to a vehicle or cart for higher data collection rates.

[4] – estimates using the Land Streamer instead of normal geophones.

[5] – higher collection rates may require more processing and interpretation time.

[6] – an increase in the days of data collection will not necessarily increase the processing and interpretation time.

[7] – the estimate of the width of the lava tube from the data was within listed percentage of the actual width of the known lava tube.