

A COMPARISON OF NON-INVASIVE GEOPHYSICAL METHODS FOR MAPPING NEAR-SURFACE VOIDS

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5th Biennial ITGUAM Workshop, April 20-23, 2004, Tucson, AZ

Purpose

CFLHD-FHWA in coordination with Blackhawk GeoServices established a comprehensive geophysical program to:

Determine the most effective geophysical method(s) for delineating subsurface voids

Objectives

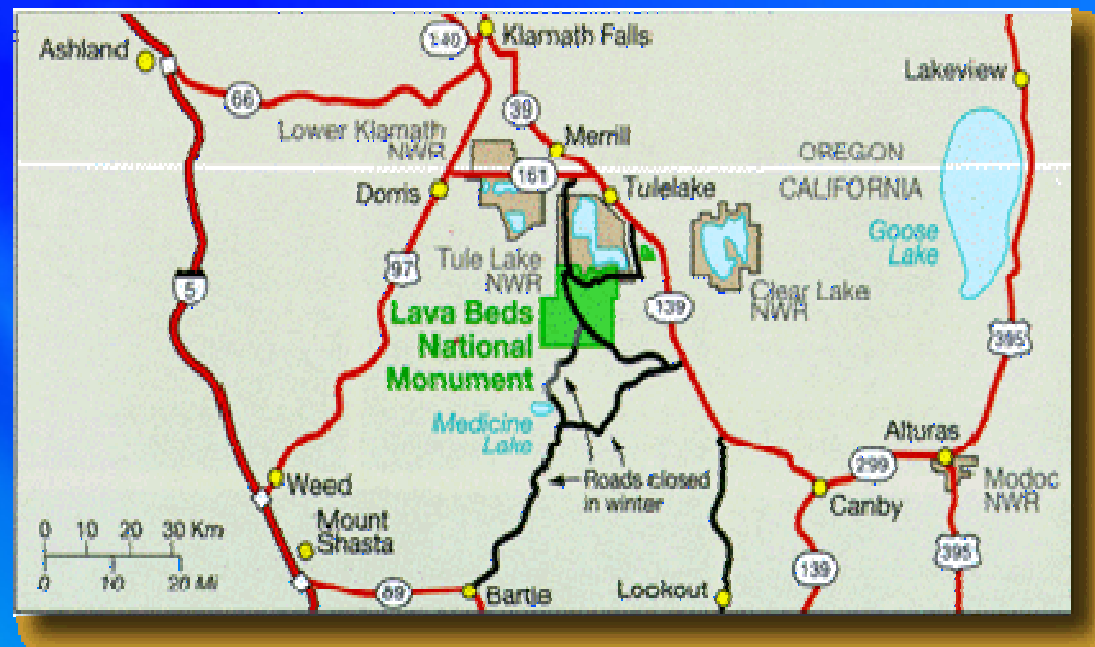
- **Detect subsurface voids under specific geologic setting**
- **Characterize void geometries**
- **Determine suitable geophysical methods and geophysical survey portability (economical and efficiency)**
- **Identify range of applications (nationwide)**

WHY?



Lava Beds National Monument, CA

- Siskiyou County, CA
- 73 square miles
- Hundreds known lava tubes

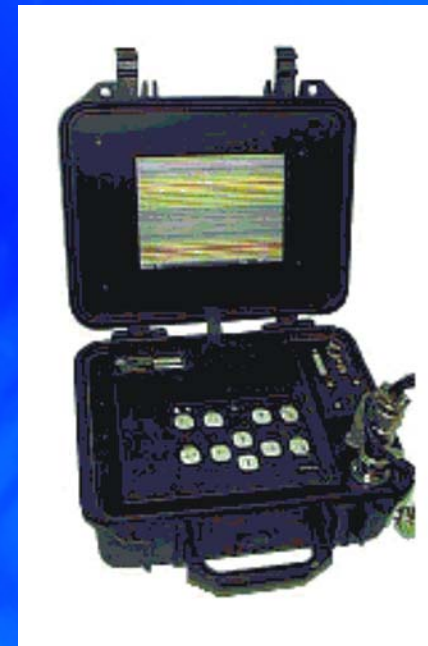


Geophysical Methods for void detection

- **Ground Penetrating Radar (GPR)**
- **Magnetic Method**
- **Electrical Resistivity (ER)**
- **High Resolution Shear Wave (HRSW) Seismic Reflection**
- **Electrical Conductivity**
- **Gravity Method**

Geophysical Survey Equipment and Data Acquisition

- **Method 1: Ground Penetrating Radar (GPR)**
 - Geophysical Survey Systems, Inc. (GSSI) – SIR2000 Control Unit
 - 200 and 400 MHz antennas



Geophysical Survey Equipment and Data Acquisition

➤ Method 2: Magnetic, Geometrics G858 Magnetometer (G858)

Single sensor, shoulder harness

Cesium vapor sensor

Magnetic data collection using DGPS for positioning



Geophysical Survey Equipment and Data Acquisition

➤ Method 3: Electrical Resistivity, Geometrics OhmMapper TR2

Data collection with TR2



Rugged OhmMapper recording console
One transmitter, Two receivers



Geophysical Survey Equipment and Data Acquisition

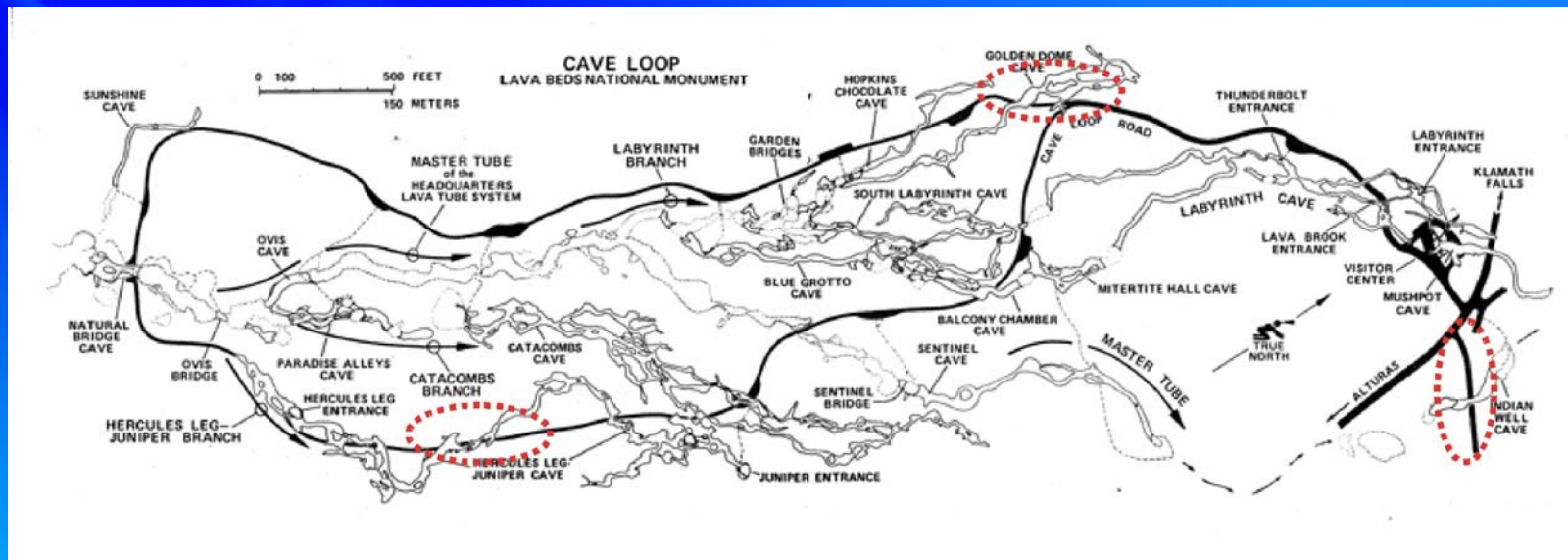
➤ Method 4: High Resolution Shear Wave (HRSW) Seismic Reflection

Bay Geophysical's patented MicroVibrator

- 96-Channel Land Streamer
- Self contained recording trailer



Geophysical Survey Locations



- Golden Dome Cave
- Hercules Leg Cave
- Indian Well Cave
- Monument Road Cave (location not shown)



Geometries of Surveyed Voids, and the geophysical methods used

Subsurface Voids	Overburden Thickness m (ft)	Void Width Under Road m (ft)	Void Height Under Road m (ft)	Geophysical Methods
Monument Road Cave	5.5 (18)	12 (40)	5.5 (18)	GPR, Magnetic, ER, HRSW
Indian Well Cave	8.8 (29)	7.9 (26)	8.5 (27.8)	GPR, Magnetic, ER, HRSW
Golden Dome Cave	4.0 (13)	3.8 (12.5)	2.6 (8.8)	GPR, Magnetic, HRSW
Hercules Leg Cave - North	3.3 (10.7)	9.8 (32)	0.8 (2.5)	GPR, Magnetic, ER, HRSW
Hercules Leg Cave - South	2.7 (8.7)	22.3 (73)	2.4 (8)	GPR, Magnetic, ER, HRSW

Known Caves Geometries – two known caves

- **Hercules Leg North**
 - 11 feet of overburden
 - 2.5 feet high and extends for 32 feet beneath road



- **Hercules Leg South**
 - 9 feet of overburden
 - 8 feet high and extends for 73 feet beneath Cave Loop Road



Known Cave Geometries

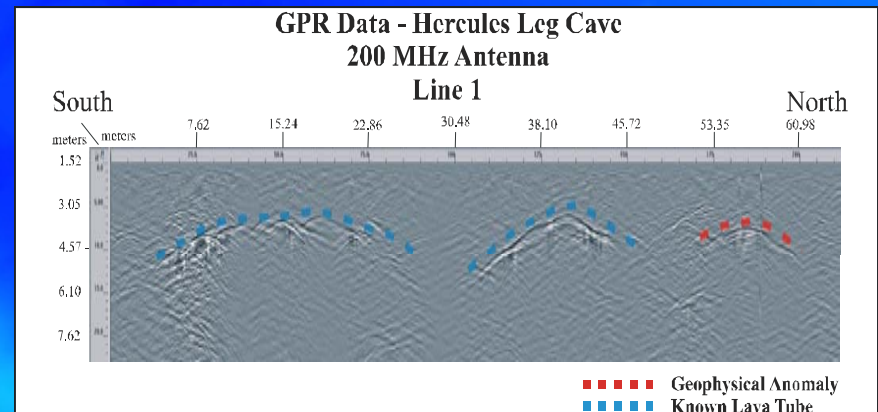
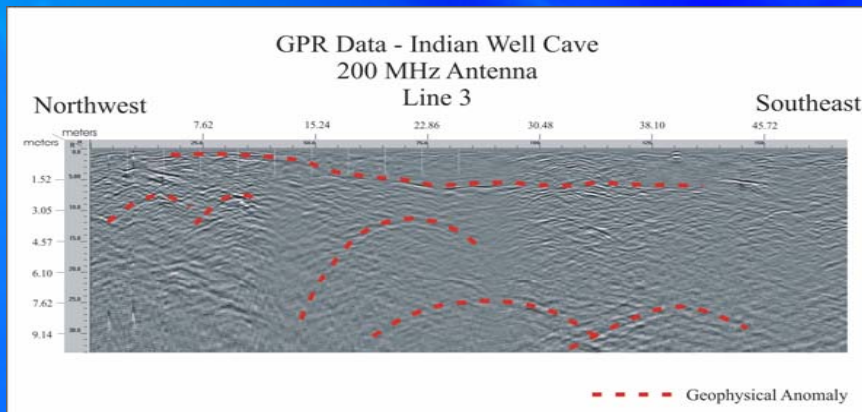
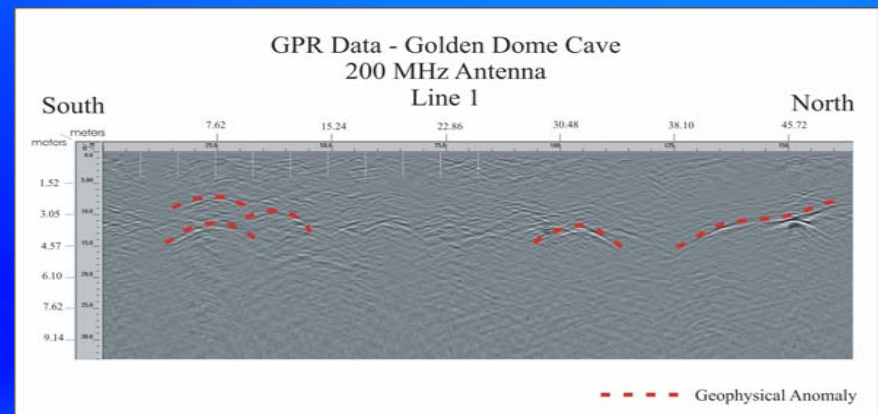
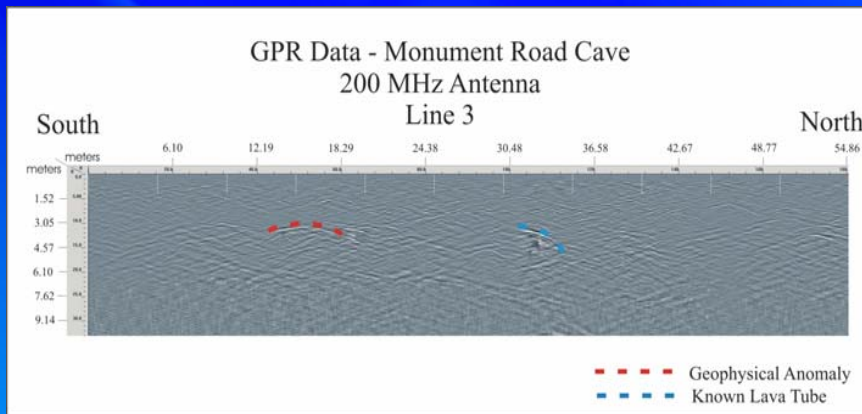
- **Indian Well Cave**
 - 29 ft of overburden
 - 28 ft high and 26 ft wide beneath road surface



Geophysical Data Interpretation

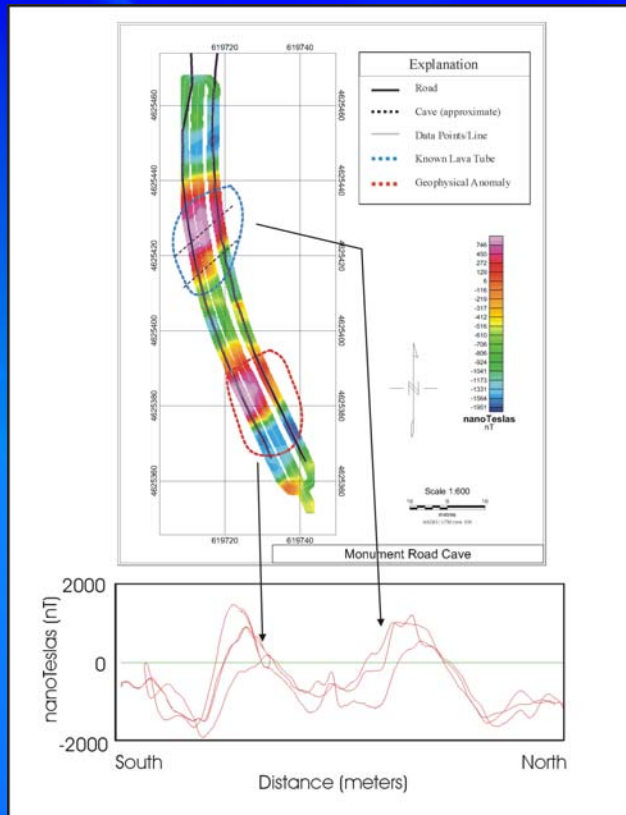
Ground Penetrating Radar (GPR) Profiles

Known caves are outlined in blue. Additional geophysical anomalies are outlined in red.

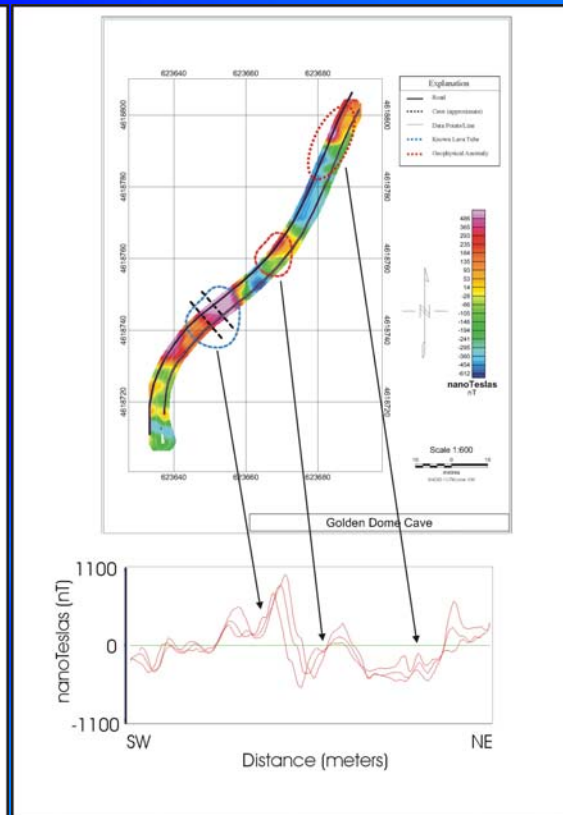


Magnetic Profiles

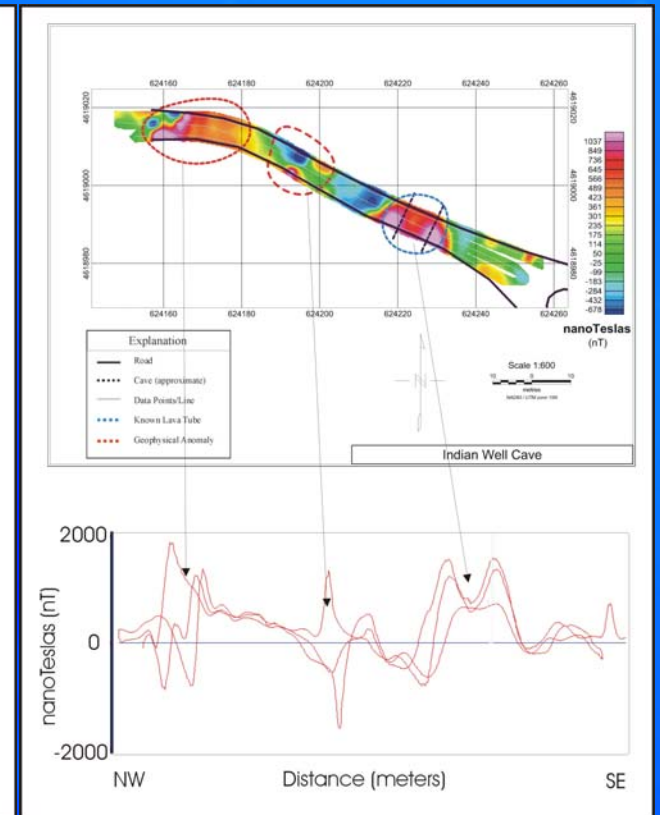
Monument Road Cave



Golden Dome Cave



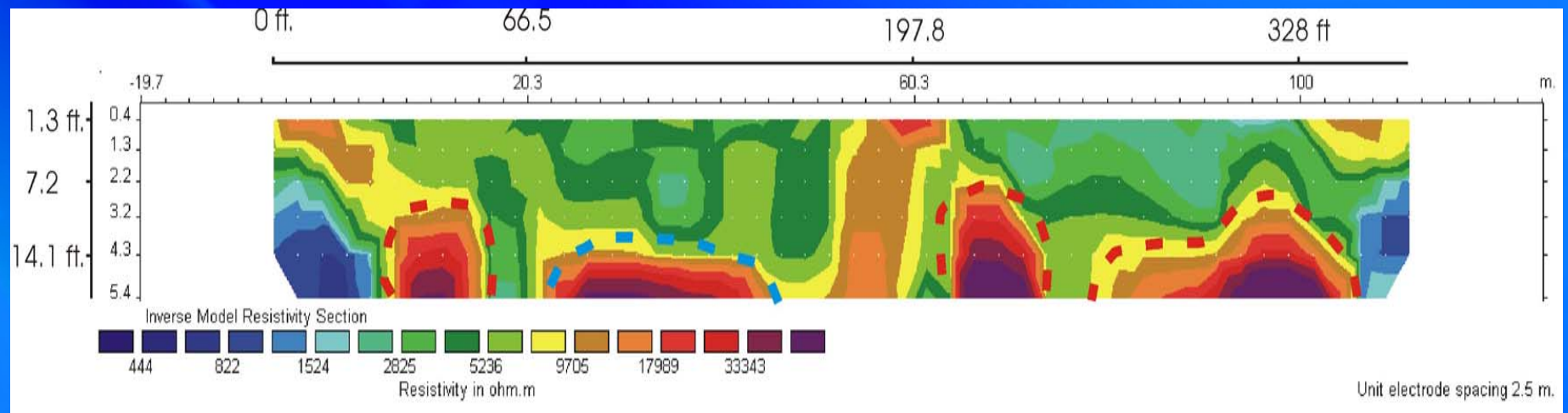
Indian Well Cave



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Electrical Resistivity (ER) Profiles

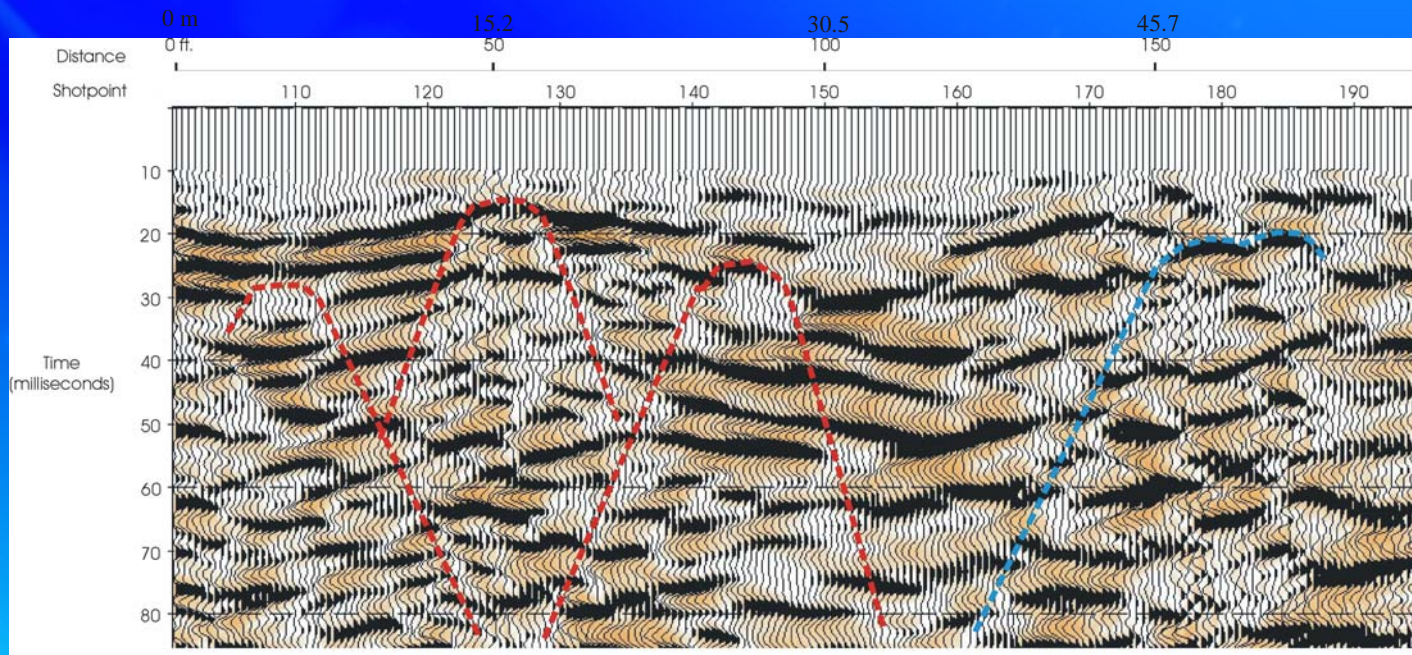
Indian Well Cave



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High-Resolution Shear Wave Profiles

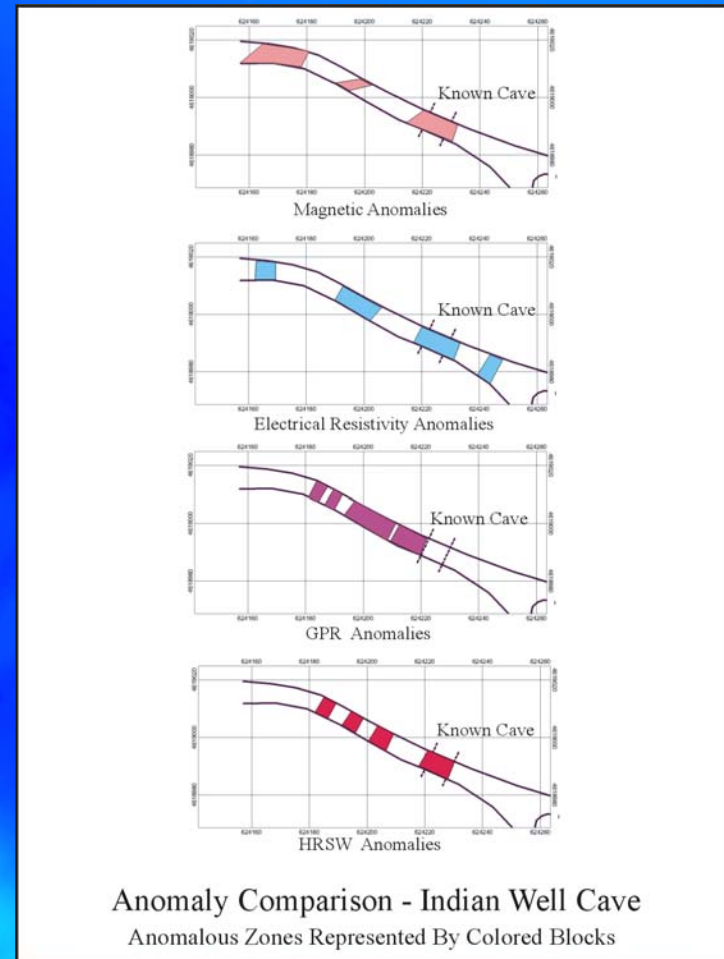
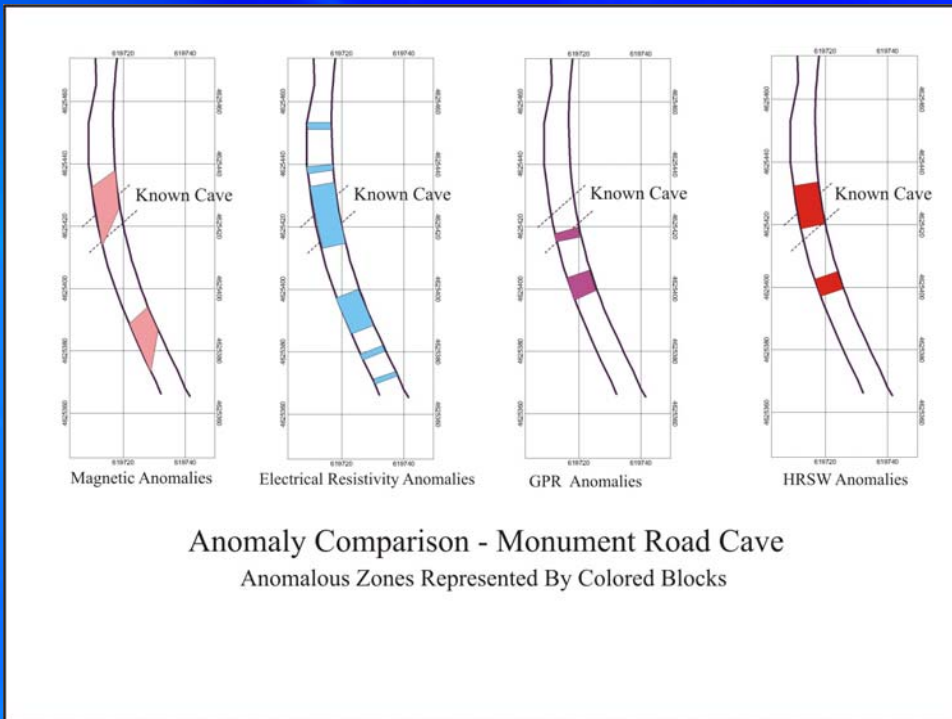
Indian Well Cave



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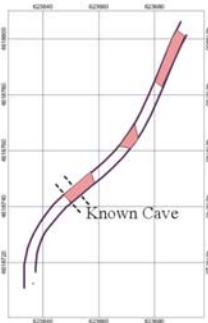
Comparison of Geophysical Methods

Monument Road and Indian Well Caves

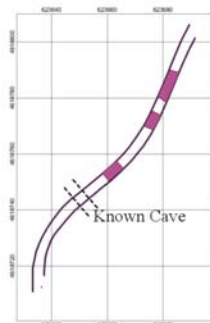


Comparison of Geophysical Methods

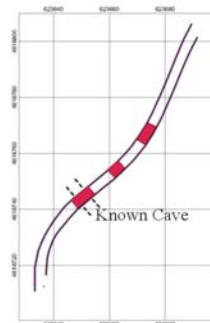
Golden Dome and Hercules Leg Caves



Magnetic Anomalies

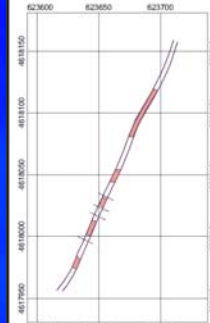


GPR Anomalies

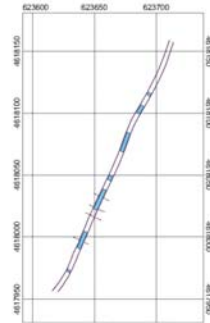


HRSW Anomalies

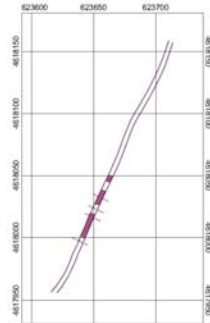
Anomaly Comparison - Golden Dome Cave
Anomalous Zones Represented By Colored Blocks



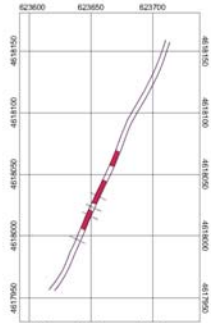
Magnetic Anomalies



Electrical Resistivity Anomalies



GPR Anomalies



HRSW Anomalies

Anomaly Comparison - Hercules Leg Cave
Known and Unknown Sections
Anomalous Zones Represented By Colored Blocks

Conclusions

➤ **Method 1: Ground Penetrating Radar**

- **Effective in detecting voids to 4.0 m without calibration**
- **Practical for determining shallow void characteristics – Not well defined by other geophysical methods**

➤ **Method 2: Magnetic**

- **Rapid data collection, processing and interpretation**
- **Field survey can be conducted over large areas**

Conclusions

➤ **Method 3: Electrical Resistivity**

- **Effective in detecting voids at each site**
- **Difficult data collection in confined areas/single lane roads with tight curves**

➤ **Method 4: High-Resolution Shear Wave**

- **Effective in identifying each of the known caves, their extent and depth**
- **Effective in locating voids at greater overburden**

Conclusions

Magnetic Method



Combined



GPR Method



- Most economical
- Least time consuming

In detecting voids to a depth of 0 to 9 m (0 to 30 ft)

Recommendations

- **Magnetic or Electrical Resistivity surveys to be conducted first to rapidly obtain data over large areas**
- **GPR survey to be conducted in areas of concern to more accurately determine the depth and void geometries**

Benefits

What will High-Resolution Geophysical Imaging do for me?

- Provide better knowledge of subsurface conditions
- Reduce cost to contractors and liability to owners
- Improve safety to construction crew working in areas where subsurface voids may exist



Questions?