Imaging and Mapping of Karst Related Geohazards in Central and West Texas Using Geophysical Methods

International Petroleum Environmental Conference

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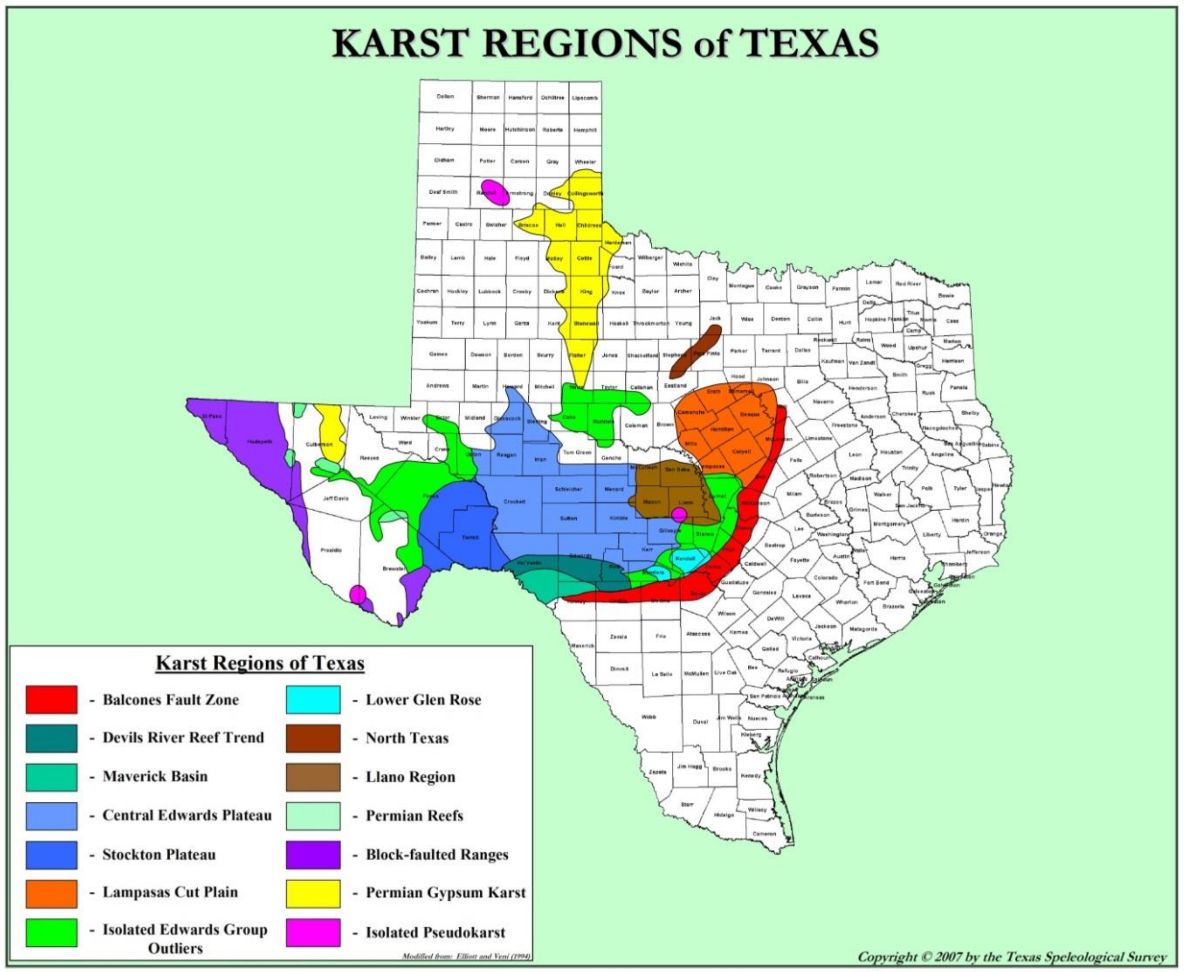
Karst in Texas



- Over 10,000 caves mapped in Texas
- The Edwards Plateau is one of the largest contiguous karstic regions of the United States
- Caves have developed preferentially along fractures associated with regional structural features
- Evolution of flowpaths within major aquifers has governed the morphology, distribution, and orientation of caves (Kastning, 2015)

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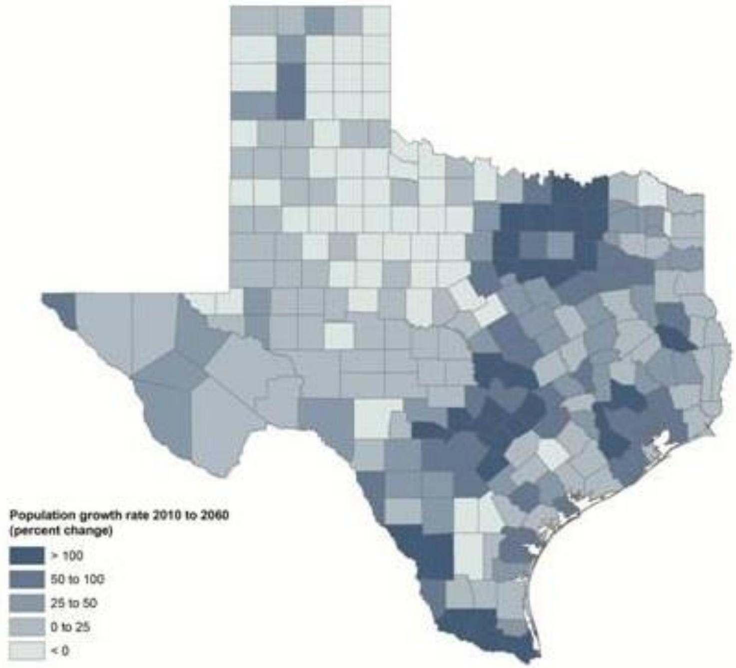
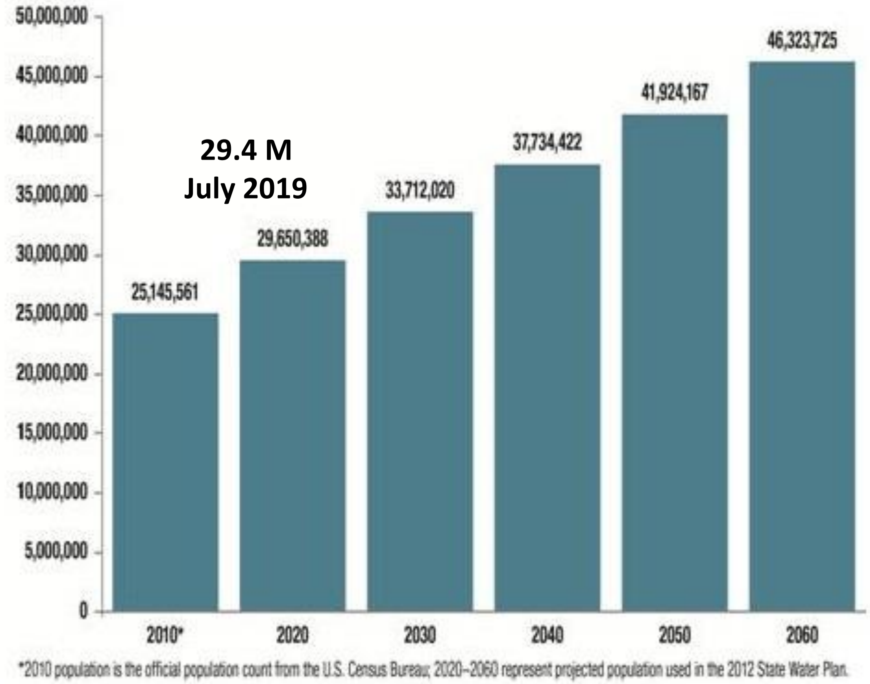
The Issue - *Growth and Construction over Karst*





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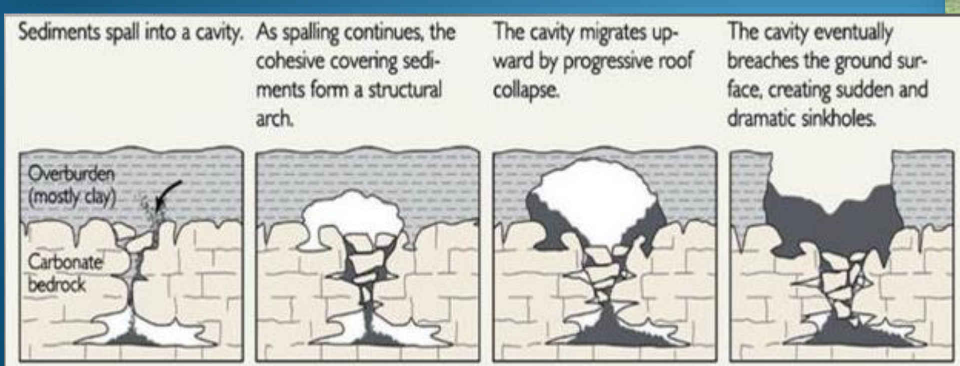
Types of Sinkhole Collapses



Cover Collapse

Geophysics

What is that?

<u>Geophysics</u>: **The subsurface site characterization of the geology, geological structure, groundwater, contamination, and human artifacts beneath the Earth's surface, based on the lateral and vertical mapping of physical property variations that are remotely sensed using non-invasive technologies.**

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Geophysical Methods in the Tool Box

- **Ground Penetrating Radar (GPR)**
- **Resistivity**
- **Seismic**
- **InSAR – Satellite Radar**

- Electromagnetics (EM)
- Gravity
- Magnetics

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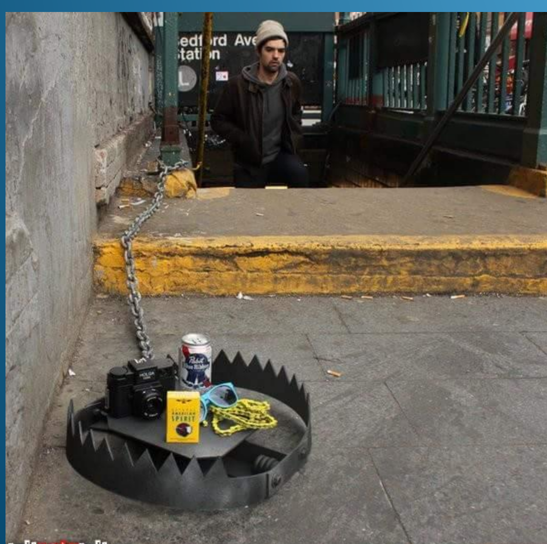
Karst - Know Your Target

- Presence
- Lateral Extent
- Depth
- Thickness



- ✓ Lithologic units - Alluvium, limestone, shales
- ✓ Condition
- ✓ Water quality and quantity
- ✓ Air-filled voids
- ✓ Water- or clay-filled voids
- ✓ Vertical structural/lithologic features which may represent fracture, faults, and or subsidence

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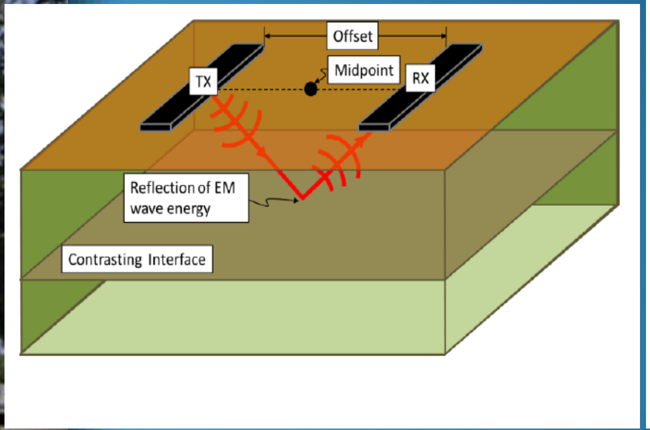
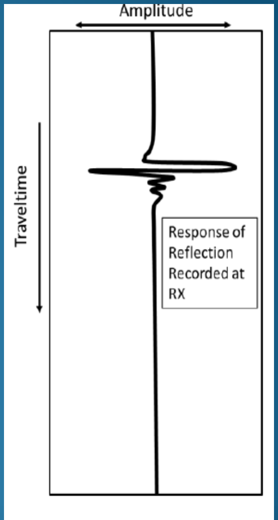
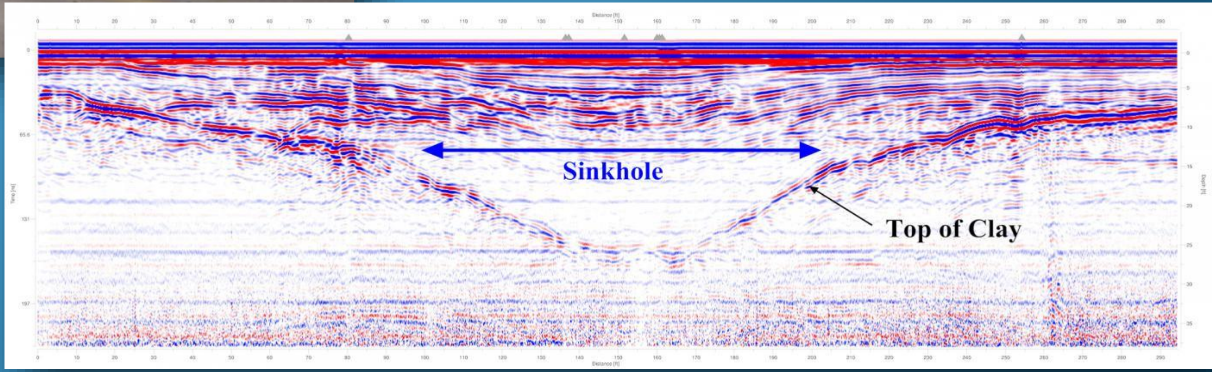
Tool #1 – Ground Penetrating Radar (GPR)







- Pulses of EM energy transmitted into ground
- Reflected energy is received by the GPR Antenna
- Energy is reflected by variations in earth layers
- Produces an image

- Highly Site Specific
- Depth based on antenna frequency and matrix
- Voids, buried objects, layers, faults, etc

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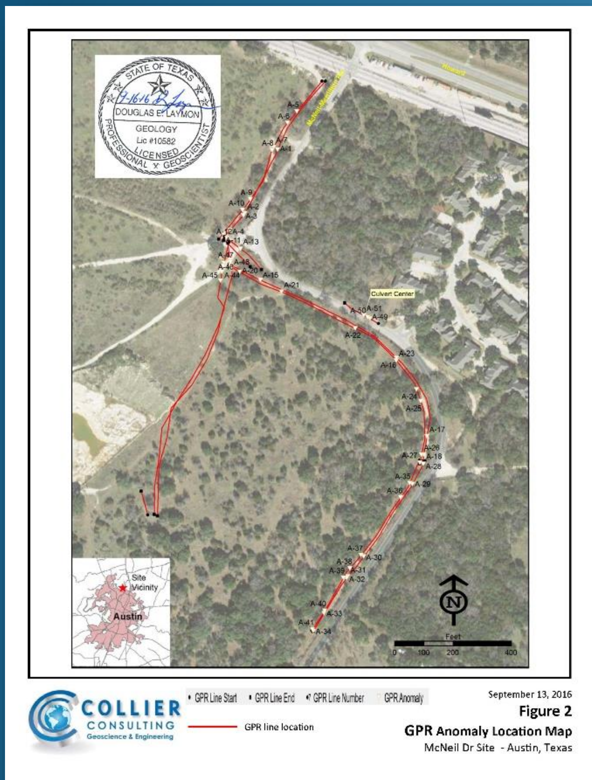
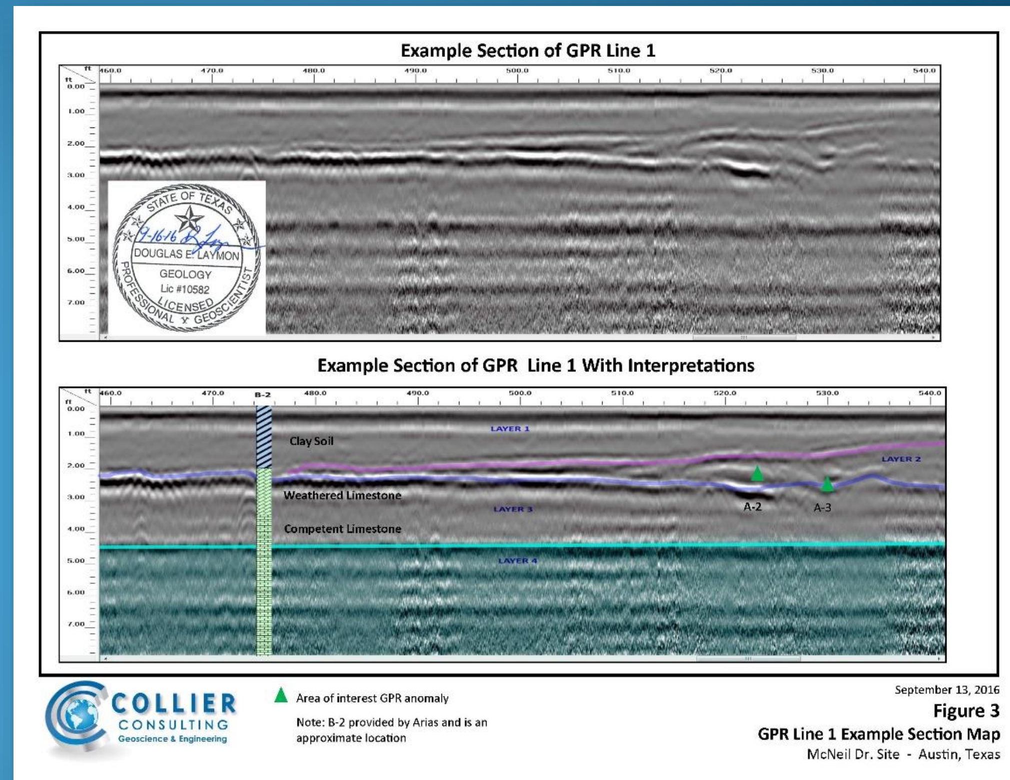
Screening Utility Runs For Potential Karst

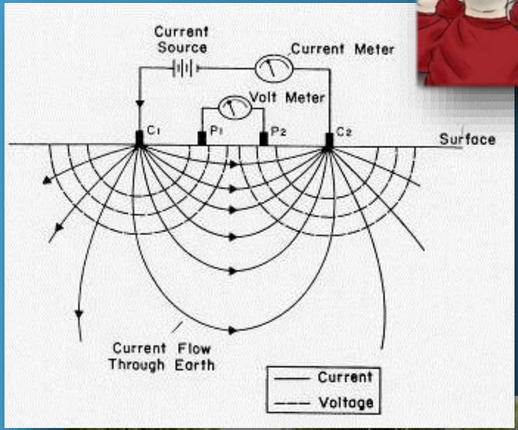


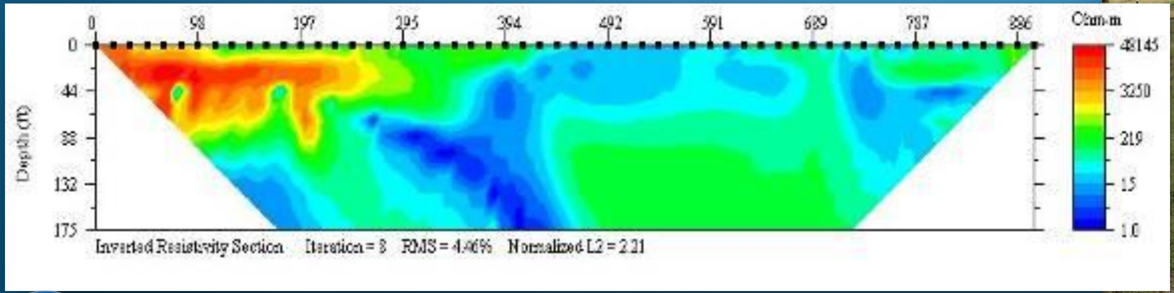


- **Find subsurface voids or sinkholes along a proposed drainage improvement ditch**
- **Possible surface mining of portions of the study area**
- **Several potential karst features in the area**
- **Approximately 7,000 linear feet of GPR data along twelve lines**
- **Several small anomalies but no obvious karst features identified in this GPR investigation**

Tool #2 – Resistivity

- **Electrical current injected through two current electrodes.**
- **Voltage drop is measured across potential electrodes.**
- **Electrode array is expanded to increase depth of penetration.**
- **Resistivity of formation/fluids measured in ohm-meters (Ω-m).**
- **Modern systems use many electrodes with automated switching.**
- ***Karst* - <u>Low Resistivity</u> = water or clay filled cavity – <u>High Resistivity</u> = air filled cavity**





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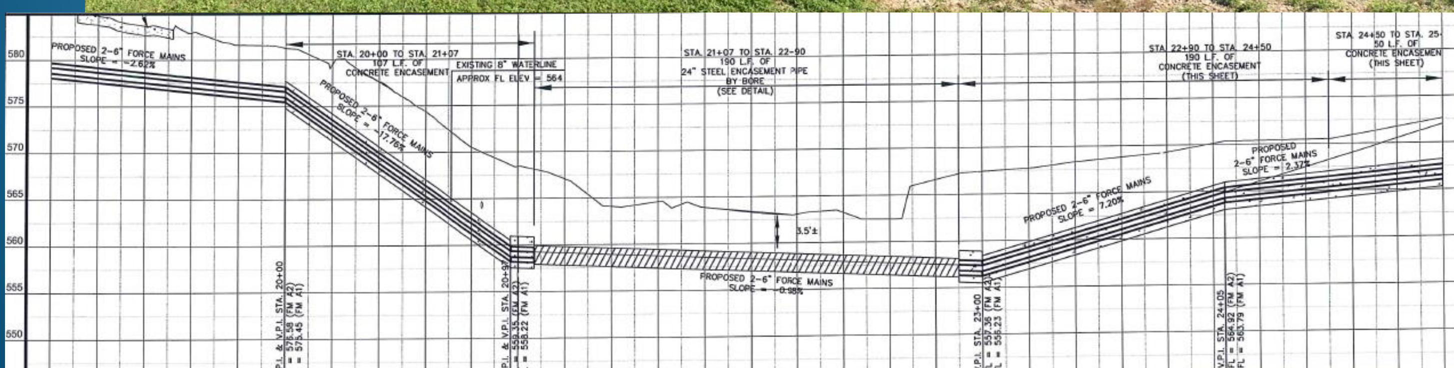
Pipeline Crossing/Salado Creek



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Pipeline Crossing/Salado Creek

Geology

- Edwards and Comanche Peak Limestone
- Approximately 130 feet thick in this area.
- Karst features are common and are known to be present in this region.
- Edwards Limestone - massive to thin bedded limestone and dolomite.
- Comanche Peak Formation - consists of a poorly bedded limestone and clayey limestone interbedded with some thin shale beds.

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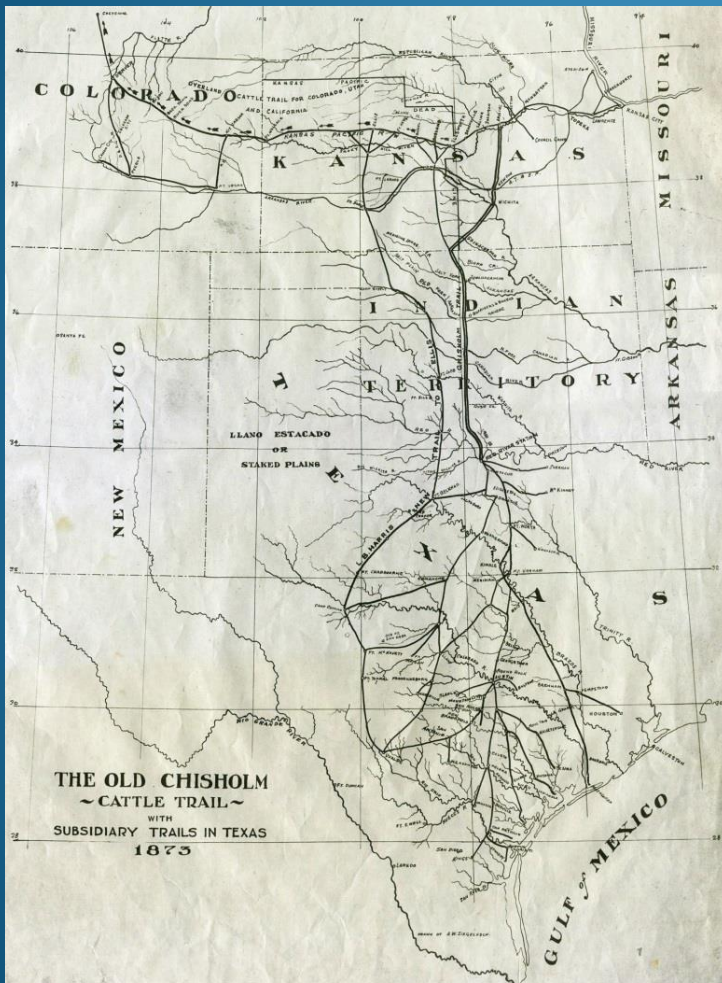
Pipeline Crossing a Creek



- Of particular concern is that the artesian head in the area and related spring flow is protected, ultimately protecting water quality and threatened species (Salado Salamander) in the area.

- Objective was to identify potential karst features under the Salado Creek prior to construction.

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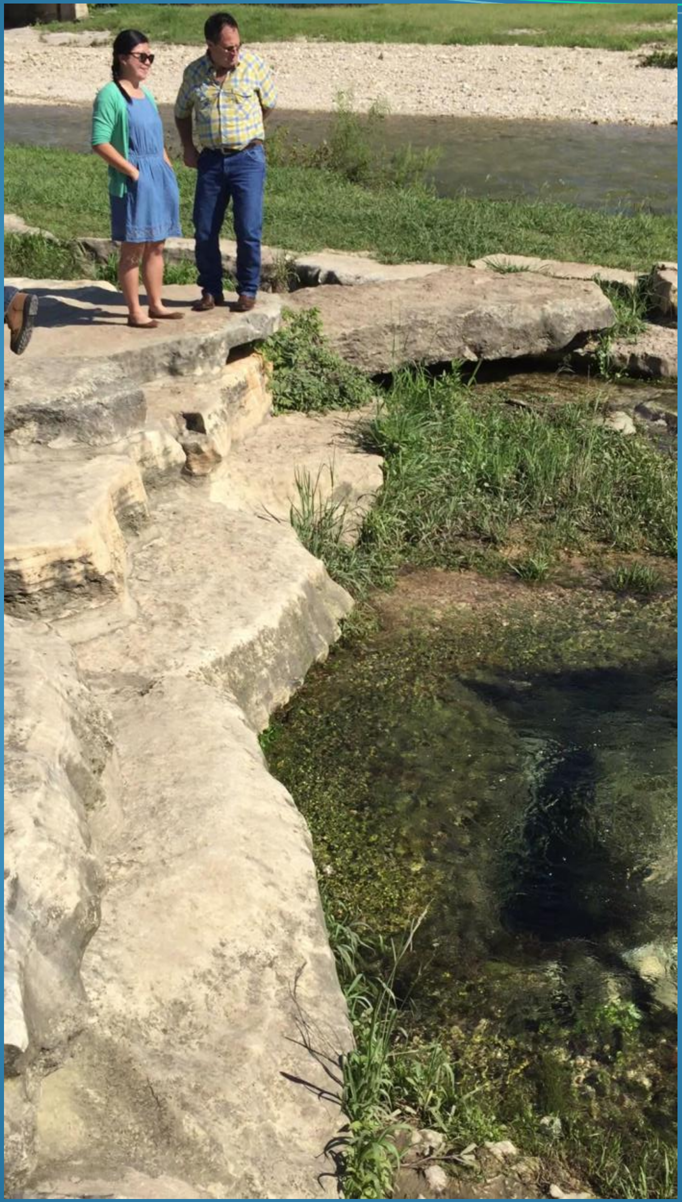
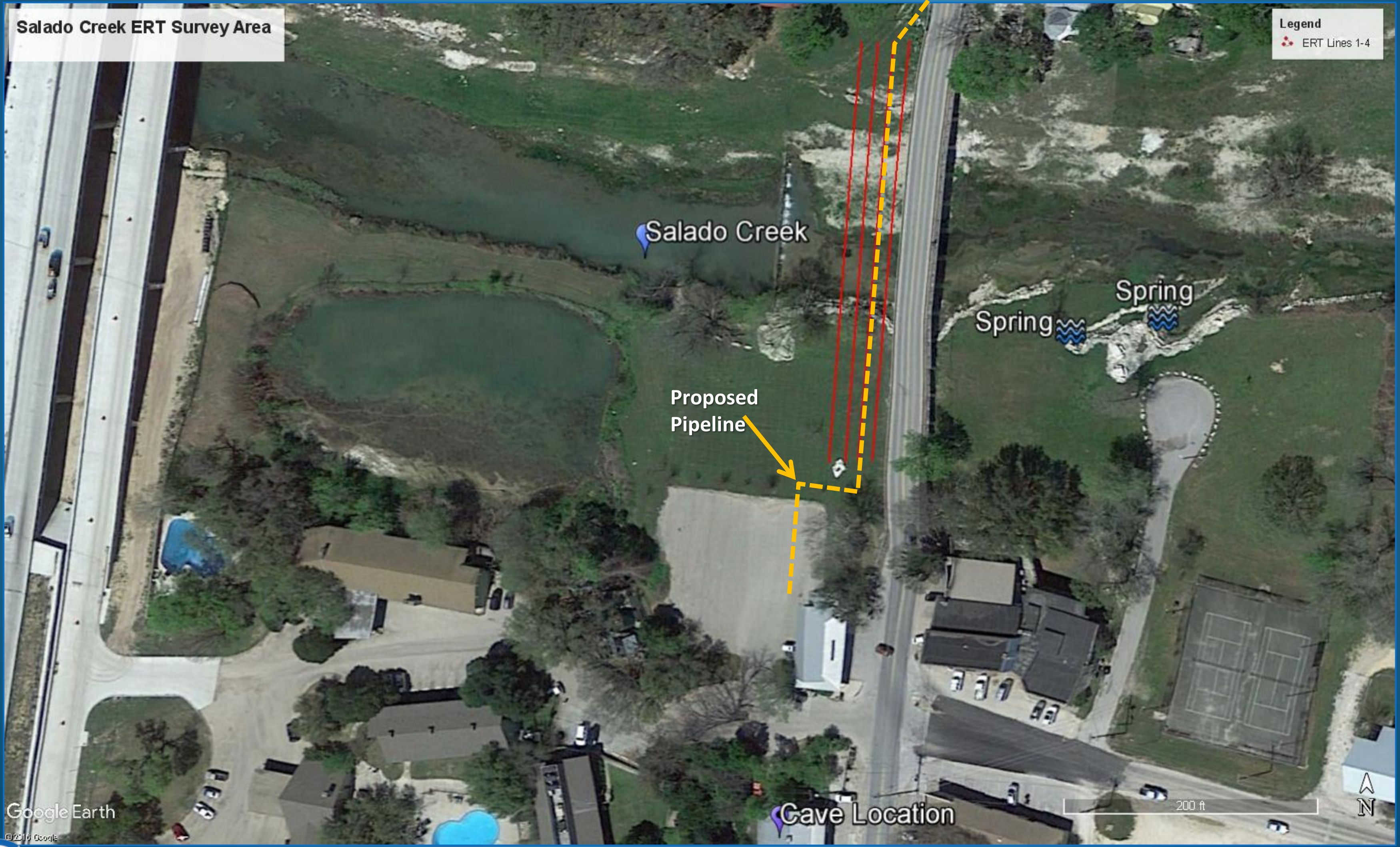
Case 2 – Pipeline Crossing/Salado Creek



Pipeline Crossing/Salado Creek



Pipeline Crossing/Salado Creek

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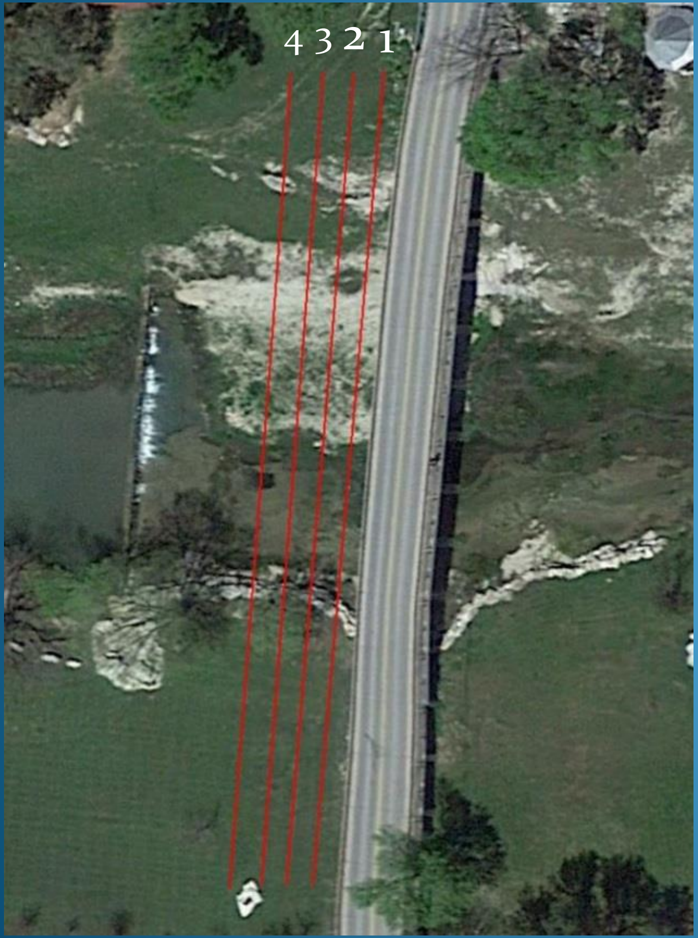
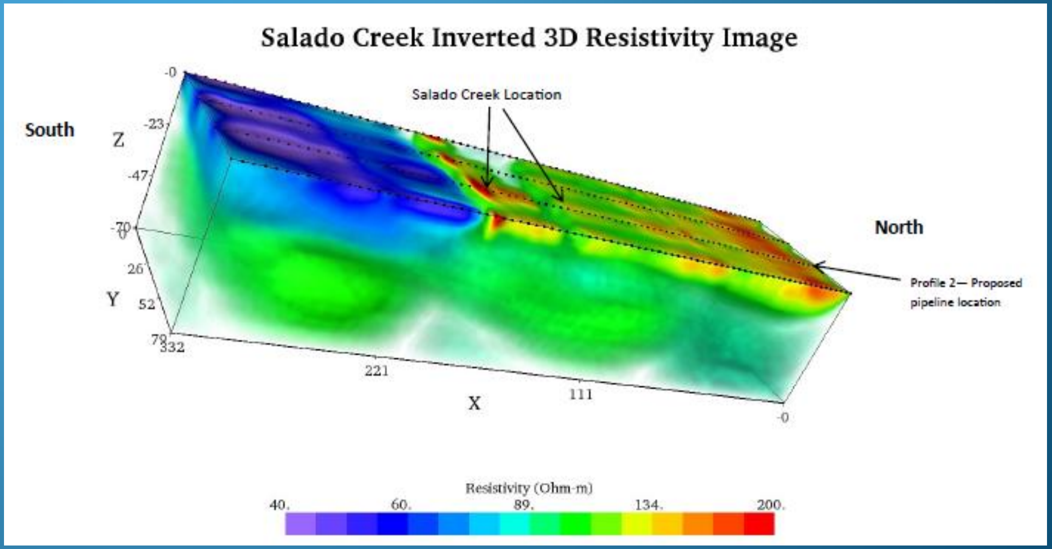
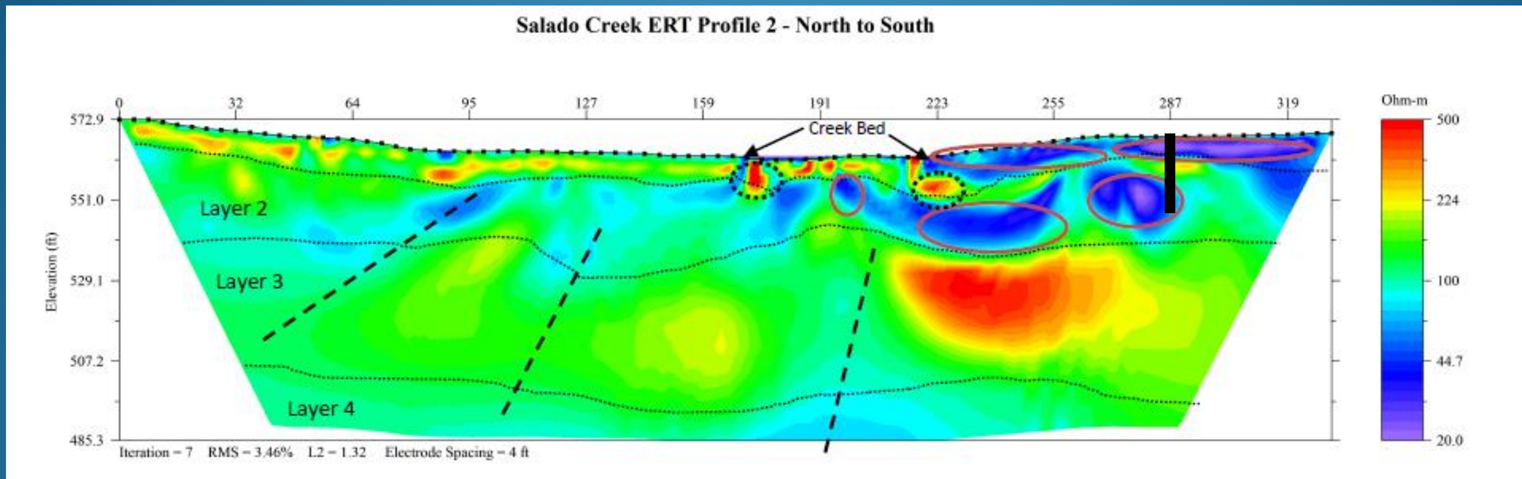
Pipeline Crossing/Salado Creek



- Land and marine cables
- 84 Electrodes @ 4 ft spacing
- 4 lines 332 ft long 8 feet apart
- **2D and 3D analysis**



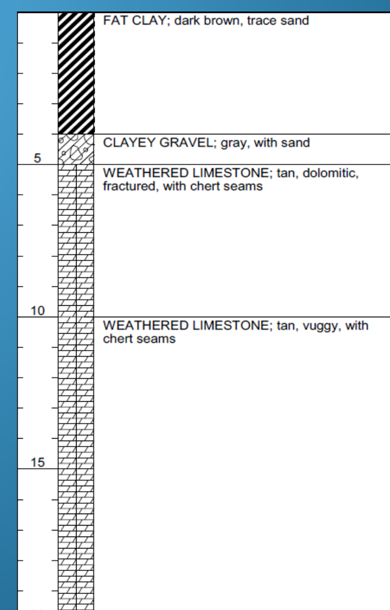
Pipeline Crossing/Salado Creek



High Resistivity Anomaly - Possible air filled karst, processing artifact, or lithologic change in limestone (e.g, dry fractures or more massive beds)

Low Resistivity Anomaly - Possible water filled karst, clay filled fractures, or shale beds

Potential fracture zone



No large air filled caves identified in the data

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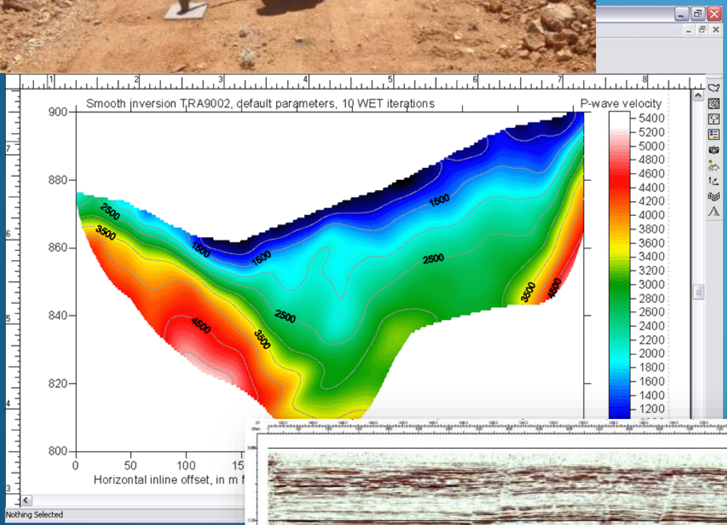
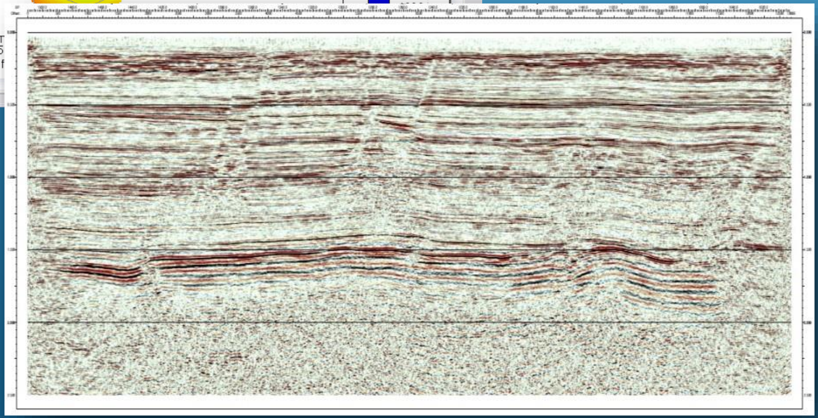
Tool #3 - Seismic Methods





- Reflection, Refraction, Tomography, MASW, Cross & Downhole
- Generation of Sound Wave Into Subsurface
- Geophones & Seismograph to Measure the Travel Time of the Wave
- Measures Seismic Velocity - P&S Wave
- Map Lithology & Structure
- *KARST* – Low Velocity Features!

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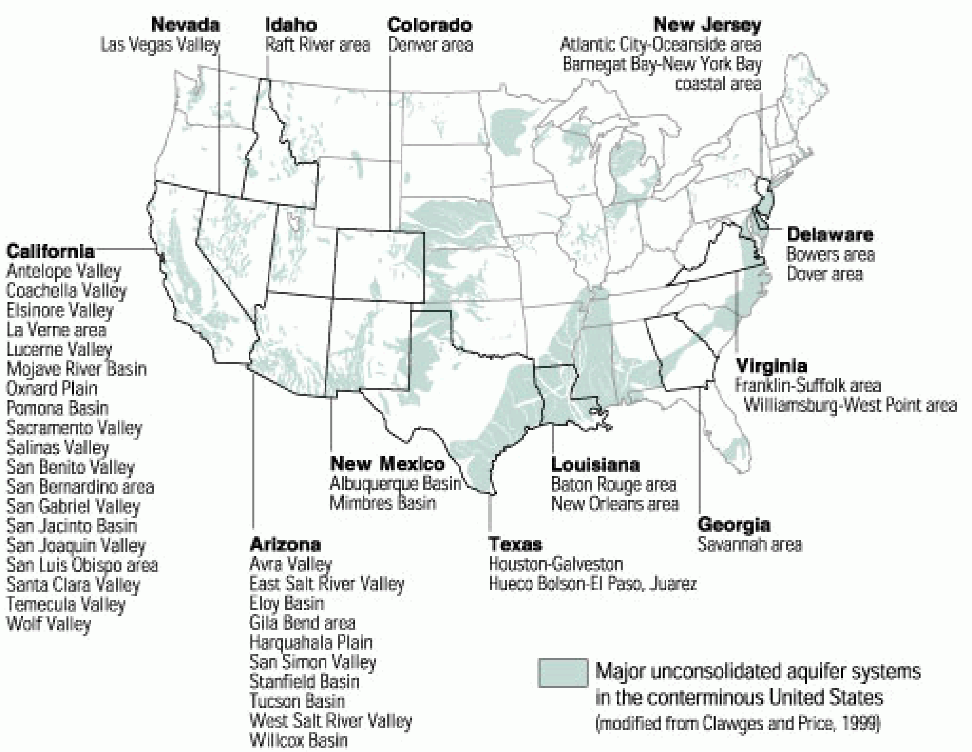
Subsidence – Anthropogenic

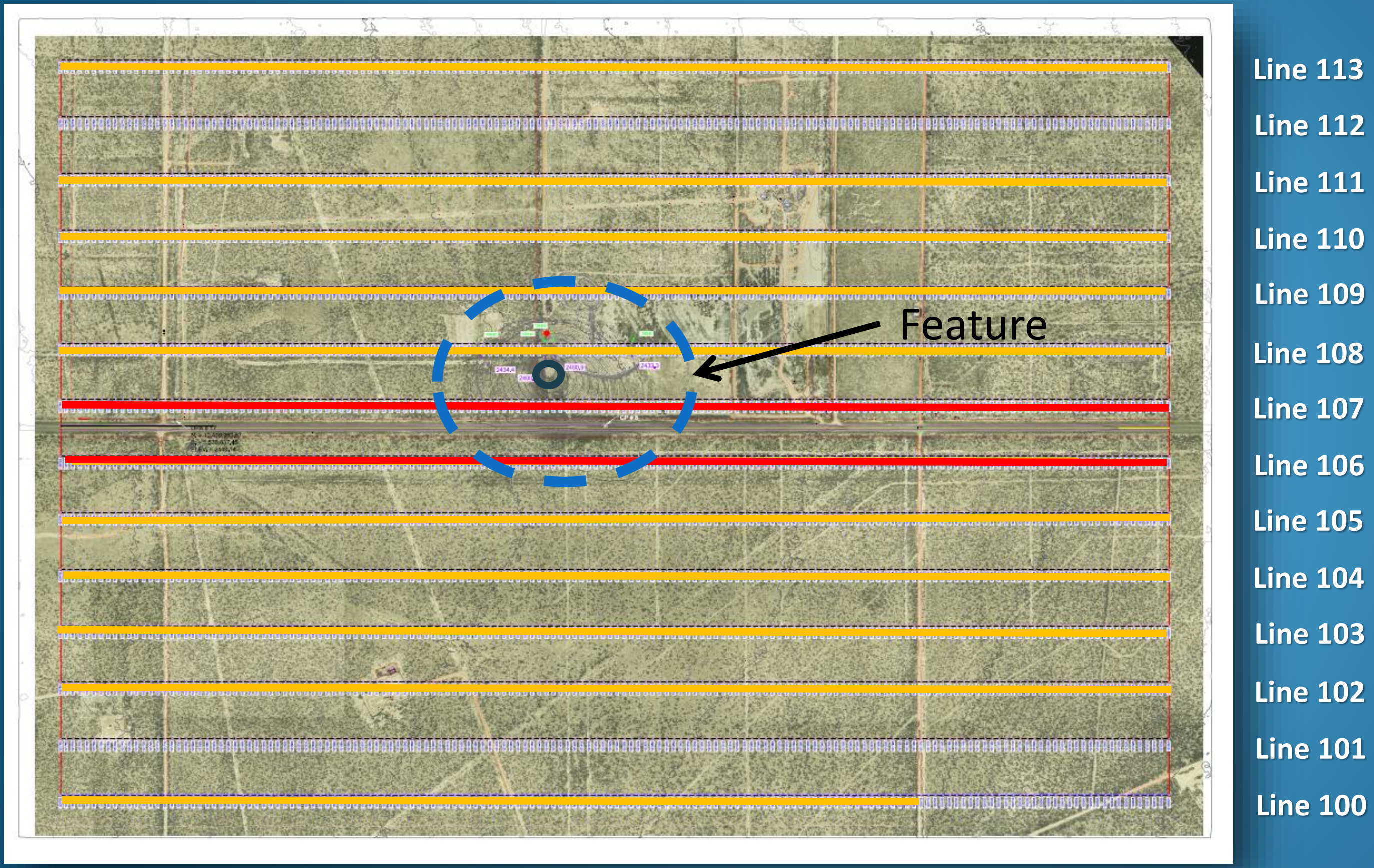
Groundwater pumping and land subsidence

- Excessive groundwater pumping is by far the single largest cause of subsidence.
- Excessive pumping of such aquifer systems has resulted in permanent subsidence and related ground failures.
- **This type of subsidence is occurring along the Texas coastal areas and in the Permian Basin area.**
- **Dissolution of Anhydrites**

Areas where subsidence has been attributed to the compaction of aquifer systems caused by groundwater pumpage



2D Seismic Survey of Subsidence Feature West Texas



Seismic Survey Line Spacing = 400 ft

Seismic Line Geometry
396 geophones at 20ft spacing for each seismic line (7,920 ft per line)

198 energy source points at 40 ft spacing for each seismic line.

Completed:
Approximately 19 miles of seismic data acquisition.

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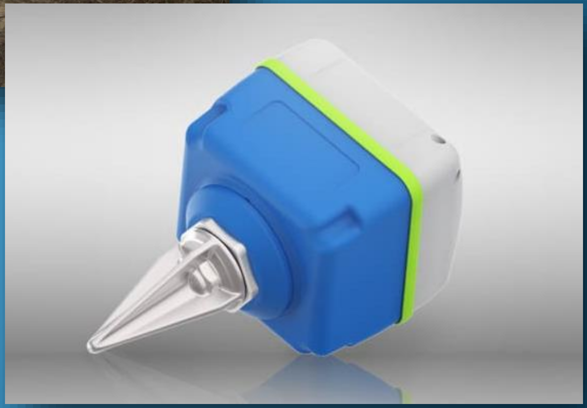
Seismic Survey Instrumentation

Combined the use of an environmentally friendly and non-destructive Accelerated Impact Source (AIS), and the cable-free seismic data acquisition system.

The cable-free seismic system eliminates any requirement for cables between geophone stations.

Seismic Line QA/QC
Geophone stations are checked along a cleared line prior to data acquisition.



Single Geophone and Data Acquisition Unit.

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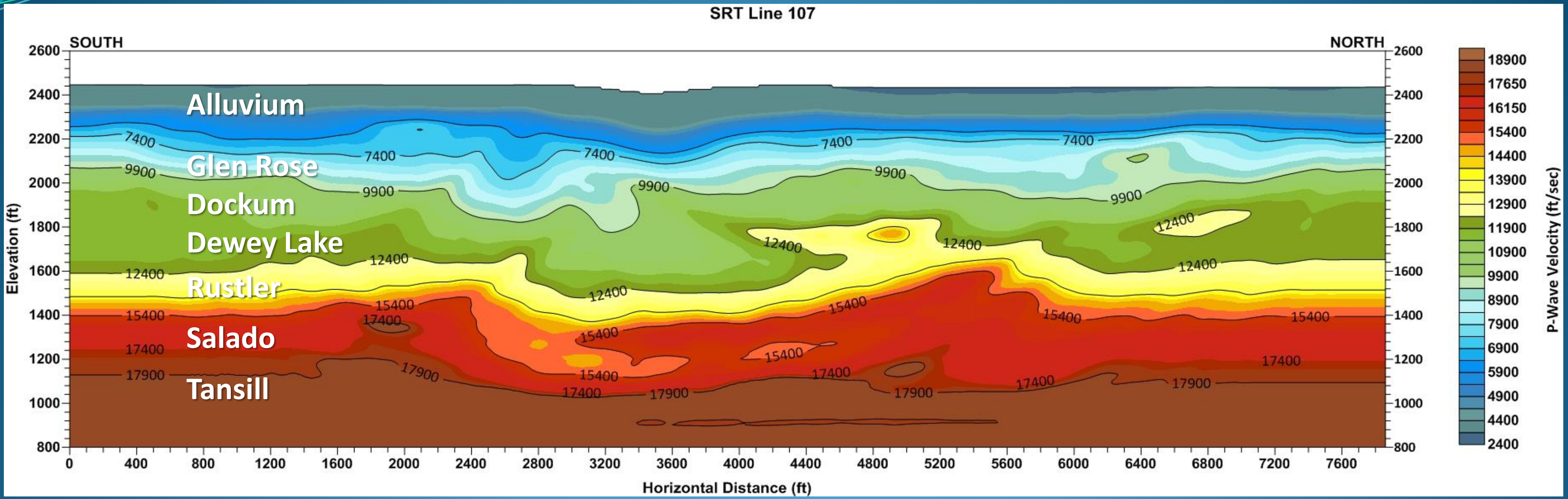
Seismic Tomography Imaging – Line 107



- Processing Seismic Line 107 using Full Waveform Inversion to map the vertical and horizontal distribution of P-Wave velocity.
- Dissolution and subsidence structure is identified below the Site.
- Subsidence is approximately 250 – 300 feet.
- Dissolution into the Salado (Halite / Anhydrite) formation is observed, along with indications of subsidence of the Glen Rose, Dockum, and Dewey Lake formations (Red Beds / Anhydrite / Sandstones / Shales).

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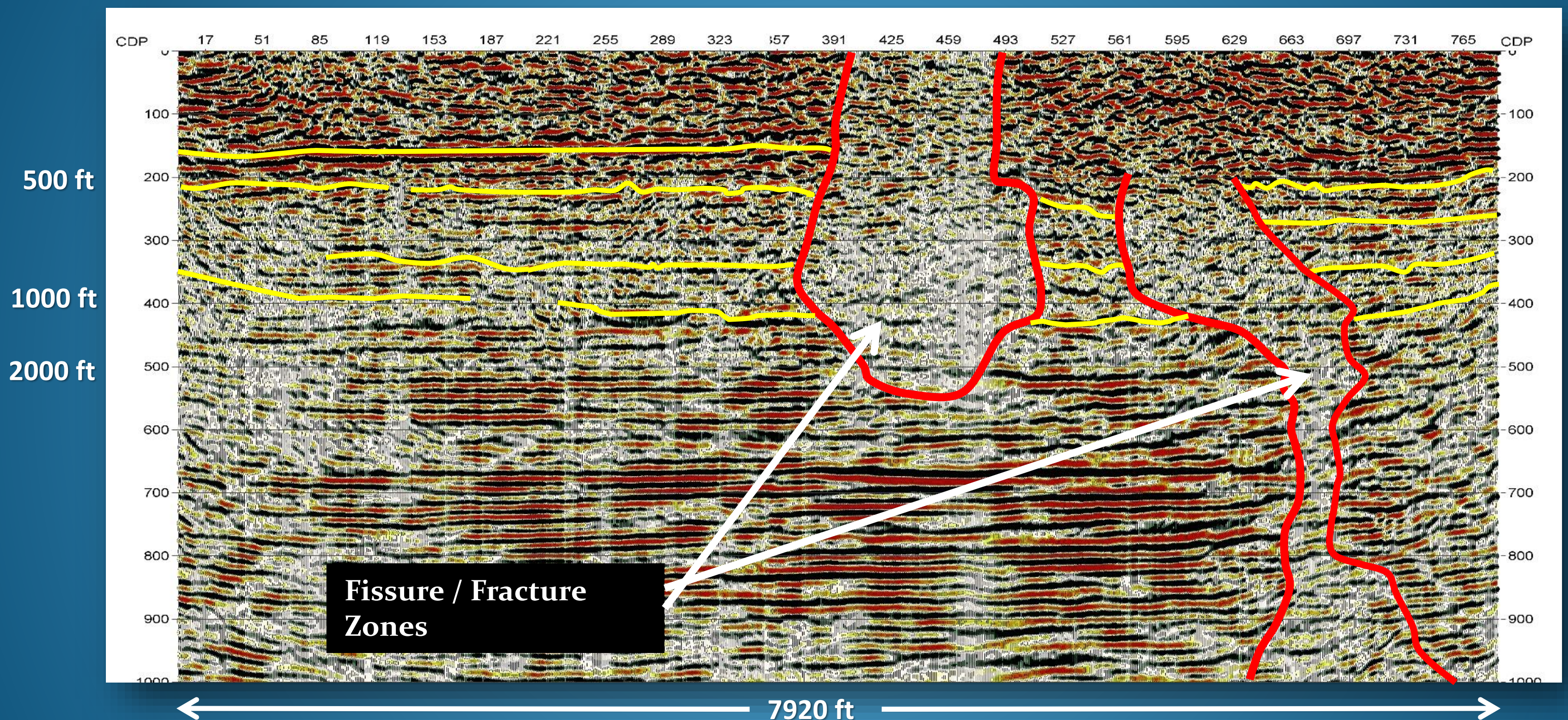
Seismic Line 106



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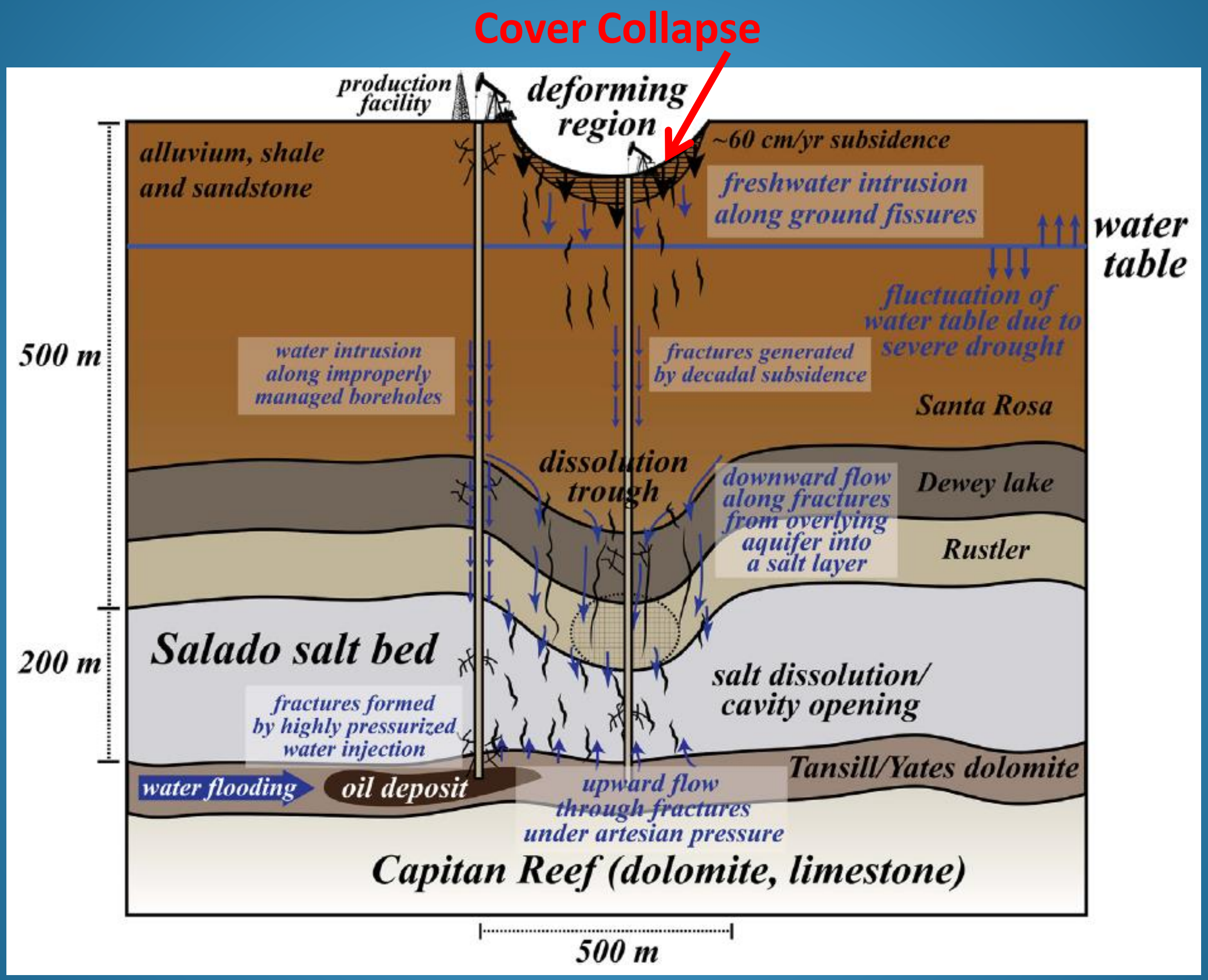
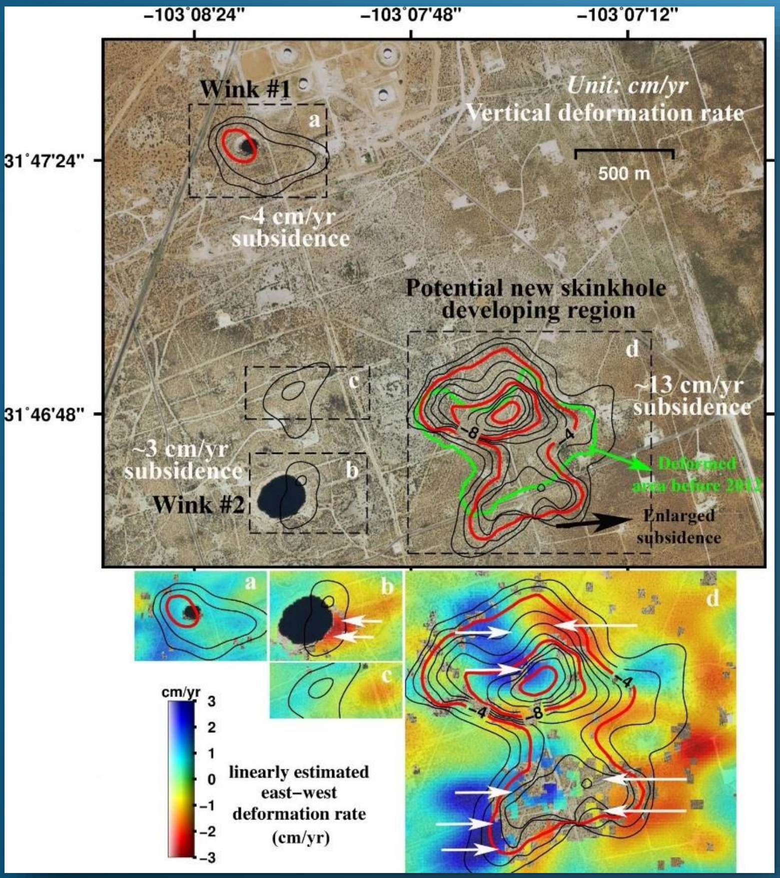
Conceptual Model



Source: J.W. Kim et al (2019)

Tool #4 – InSAR / LIDAR Mapping Subsidence Features Beneath Sites In West Texas



Source: Zhong Lu, et al (2016)

- **Since 2012, monitoring of a subsidence zone, is indicating the lateral growth and subsidence of 13 cm per year.**
- **Wink sinkholes #1 and #2 are growing at a rate of 3-4 cm per year.**
- **Subsurface geology is the same as previous case history.**

Now, with subsurface ERT and seismic imaging data, can we correlate these data with high resolution InSAR/LIDAR Imaging to identify hazardous subsidence zones.

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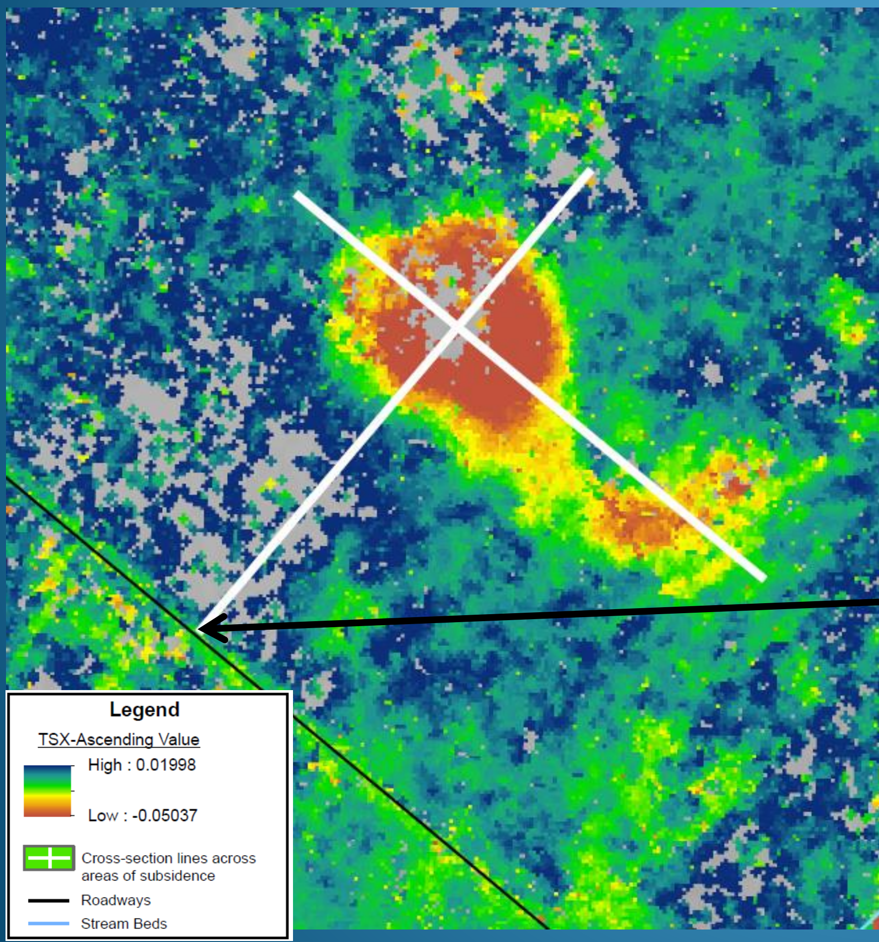
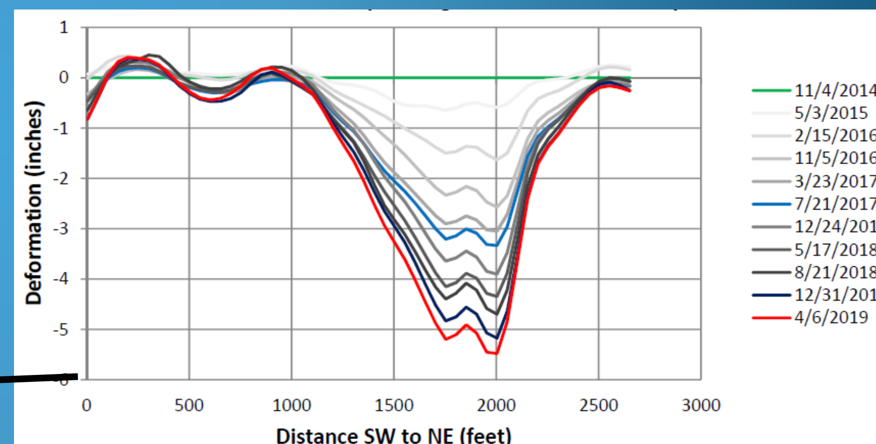
Current InSAR Project





Over 5 inches of subsidence in 5 years

Summary

- Population growth and increased urbanization and industrialization in karstic areas increase the consequences of geohazards related to karst features
- Geophysical tools such has ERT and seismic tomography are useful in helping to identify and mitigate these hazards
- Implementation in the early design phase and or pre construction phase is paramount to this end
- Use of geophysics can also be beneficial in other karst related inquiries or other subsurface investigations
- Knowing the local geology are essential to successful interpretation

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QUESTIONS

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