Scalable, Automated, Semipermanent Seismic Array (SASSA) for Detecting CO_2 Plume Extent During Geological CO_2 Injection

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National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Transforming Technology through Integration and Collaboration

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Presentation Outline

- Benefit to the Program
- Project Overview
  - Goals and objectives
- Technical Status
  - SASSA Concept, Location, Source
- Plans
  - Recording System, Geophysical modeling, Processing, Simulations
  - Validation methods, Plume image
- Accomplishments
- Synergy Opportunities
- Summary

Benefit to the Program

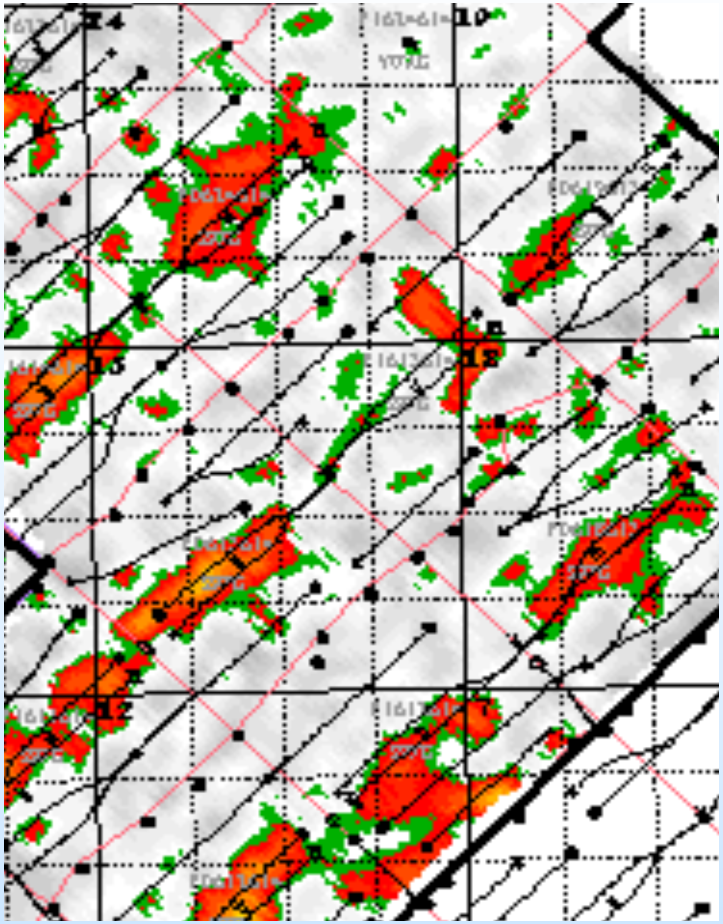
- Addresses three of the major Carbon Storage Program goals:
  - Develop and validate technologies to ensure 99% storage performance.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.
  - Develop Best Practice Manuals for monitoring, verification, accounting, and assessment.
- The SASSA method may track the location of a CO_2 plume in the subsurface in a timely and cost-effective manner:
  - Improve measurement and accounting of storage performance.
  - May provide a means of remotely detecting out-of-zone migration of CO_2 (ensuring containment effectiveness).
  - Novel application of existing technology may contribute to best practices for MVA (monitoring, verification, and accounting).

Project Overview: Goals and Objectives

- Demonstrate and evaluate a novel seismic deployment method that can be operated remotely (and potentially automated) to show where and when a pressure front or carbon dioxide (CO_2) plume passes a particular subsurface location.
- Two Phases
  1. Planning, Procure Equipment, Modeling, Deployment, Testing
  2. Data Acquisition, Data processing, and Interpretation
- Goals
  1. Install a semipermanent seismic system in the field that includes a safe and remotely operated seismic source.
  2. Collect and process data records to identify time-lapse changes that can be verified as being due to the presence of CO_2.

Background and Motivation

- Currently, to determine plume location and extent of injected CO_2 requires multiple 3-D seismic surveys. They provide value and detailed images of the subsurface, but have drawbacks…
  - Expensive and relatively high impact
  - Labor intensive
  - Periodic with intervals of years.
- A DOE Funding Opportunity Announcement sought technologies that would be relatively inexpensive and allow tracking of CO_2 within the reservoir with minimal delay.
  - An approach using the seismic method as an indicator to track plume position was submitted and awarded funding.



4D Image from Weyburn showing CO2 Plumes

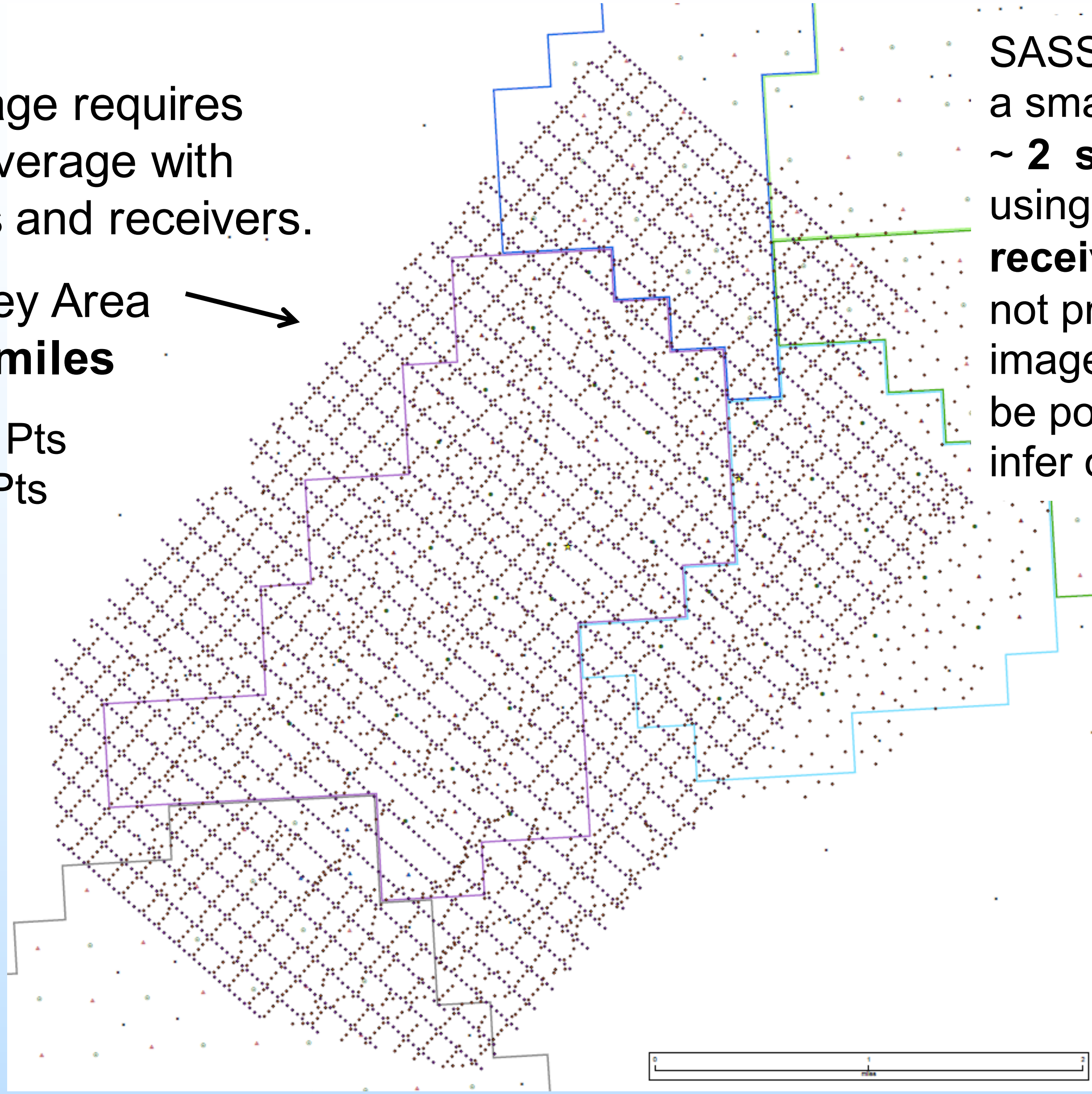
SASSA Advantage

Smaller Impact, Faster Results

To get an image requires saturation coverage with source points and receivers.

Monitor Survey Area
11.4 square miles

3030 Receiver Pts
3427 Vibrator Pts



SASSA to survey a smaller area of **~ 2 sq miles** using only **96 receivers**. It will not produce an image, but it may be possible to infer one.

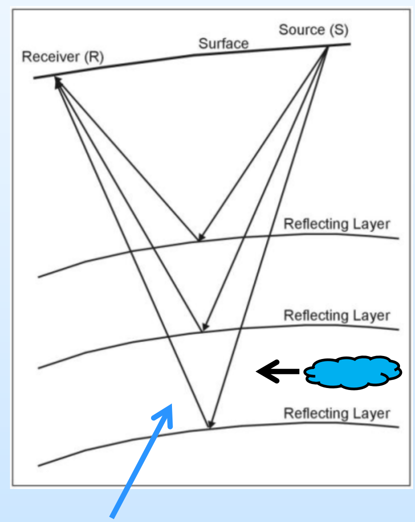
SASSA Concept

- **The seismic method used as an indicator to track plume position with minimal expense and delay:**
  - Autonomous node-recording instruments and a stationary remote-controlled seismic source make regular time-lapse recordings.
  - *Concept*: Repeatability of the seismic method.
  - *Concept*: Introduction of a small percentage of gas to the reservoir may change the character of the reservoir's seismic reflection in a detectable way.

- **New concept:**
  - Clever placement of source and receivers employs the seismic method as a **yes/no switch** to determine when the CO_2 plume has moved past a monitored location within the reservoir.
  - 3-D geophysical modeling that accounts for structure and velocity variations is used to determine surface receiver positions.
  - Short delay for processing and interpretation.

Fairfield Nodal

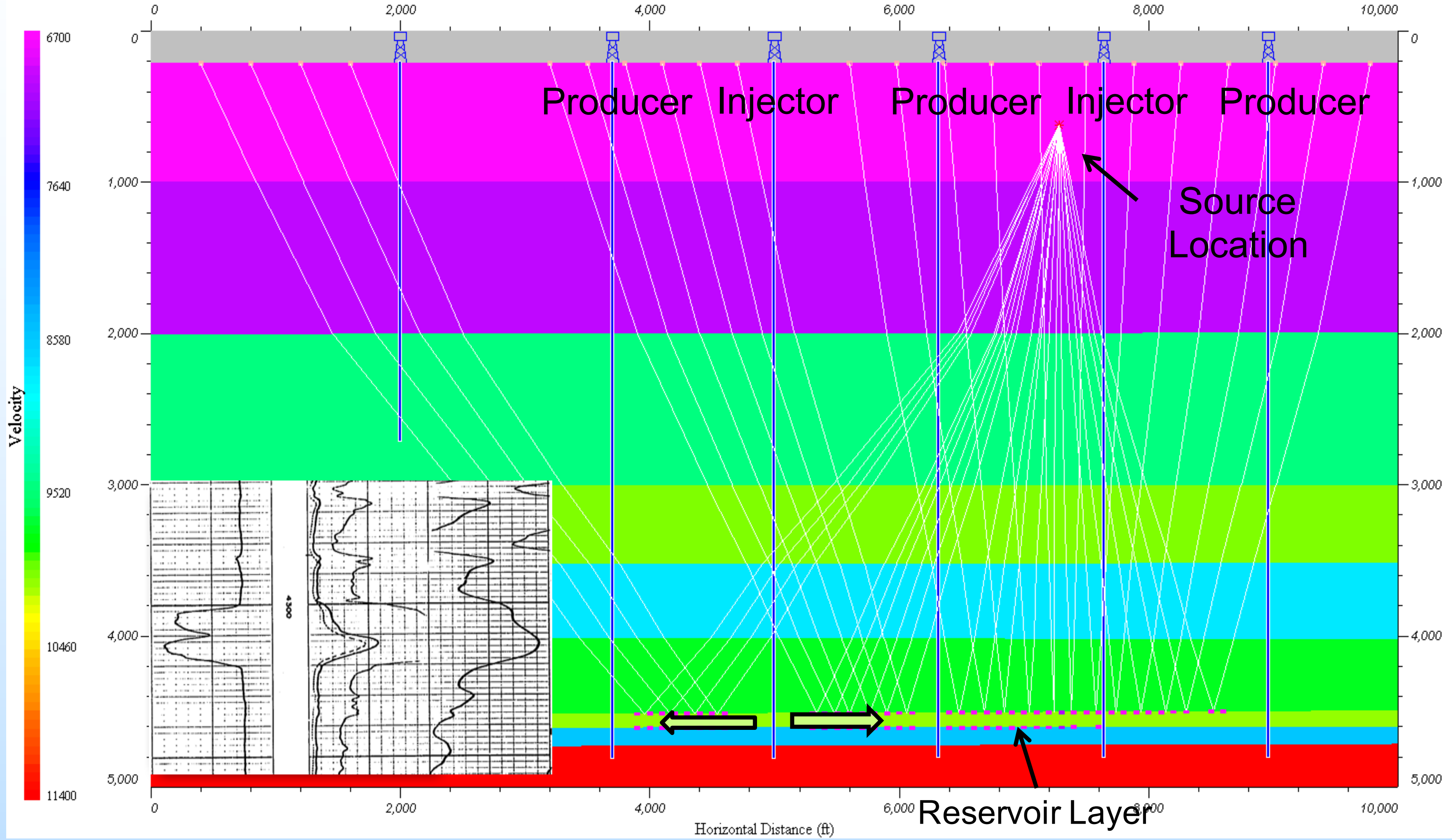
Gisco Accelerated Weight



Reservoir Layer

Concept: 2-D Profile View

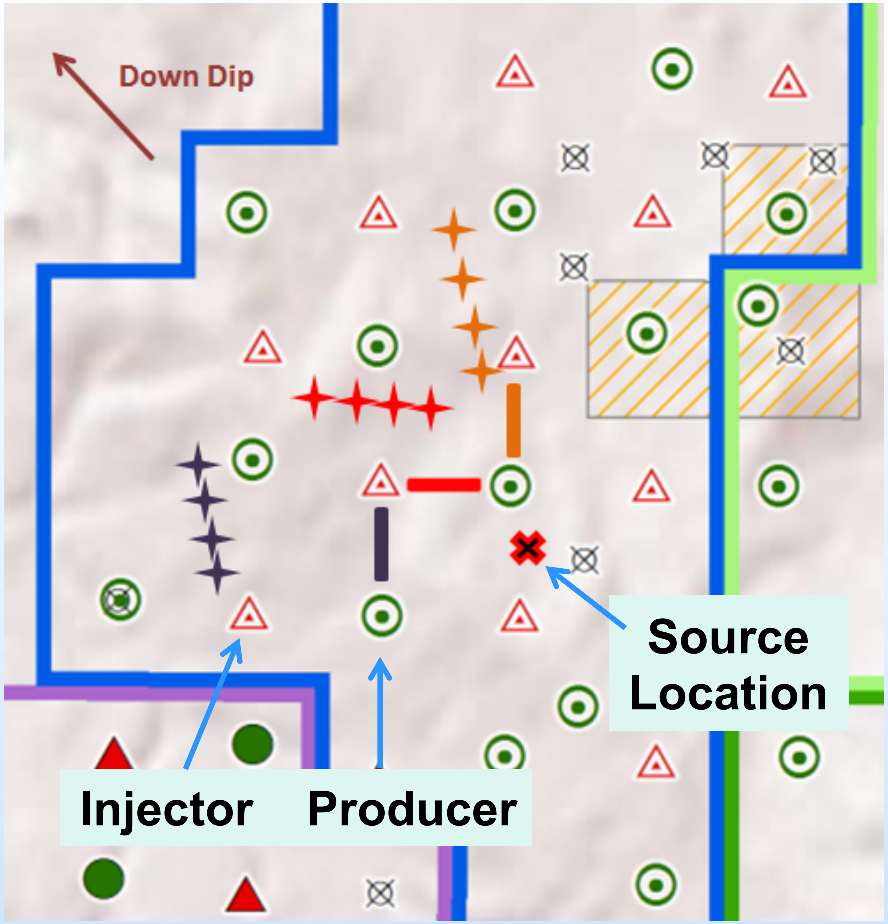
A single source location and 4, 6, and 12 Receivers Sample Between Four Well Pairs. Surface receivers can monitor any subsurface location within range of the source.



Concept: Overhead View

- Monitor between injectors and producers.
- Track plume progress.
- 3-D modeling determines the surface position of receivers.
  - Example: Colored stars show notional receiver positions to monitor four points on the reservoir along the three like-colored bars.
  - Accounts for ray path complications due to dip and velocity.
  - Analogous arrangements would be used to sample other locations within range.
- Closed system. Over time, only gas content at the reservoir reflection changes.
- A monitored reflection point changes character as CO_2 passes.
- Change is expected to be visible on easily processed time-lapse “difference” displays of the seismic shot records.

Overhead Areal Display – Phase 3



Physical Basis

P-Wave Velocity (Vp) Changes Significantly with a Small Amount of Gas

- The introduction of a small percentage of gas to the fluid in a low-pressure reservoir (less than 3000 psi) causes a large change in the P-wave velocity of the interval.
- The 10% drop in Vp with a small percentage of gas should be noted.
- Detectable changes to the character of routinely repeated seismic reflection records over time may indicate plume migration.

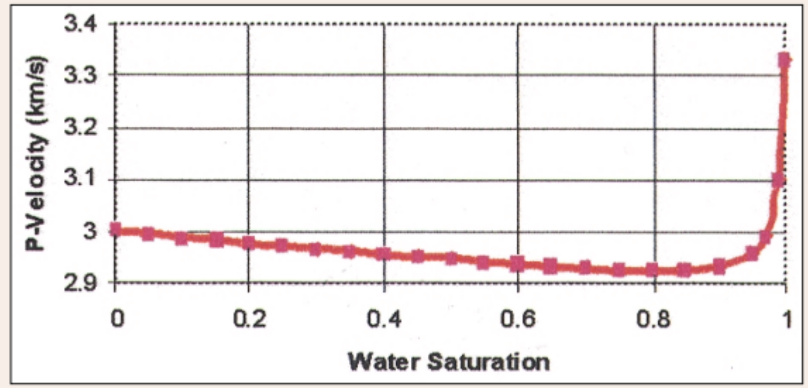
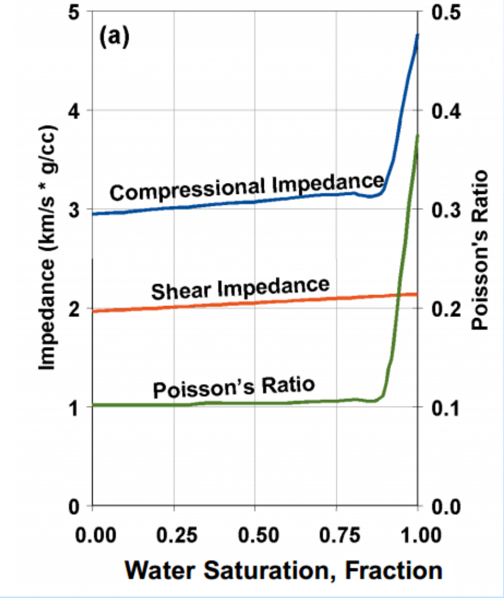


Figure 1. Typical effect of gas saturation on *P*-velocity of rocks under shallow conditions.

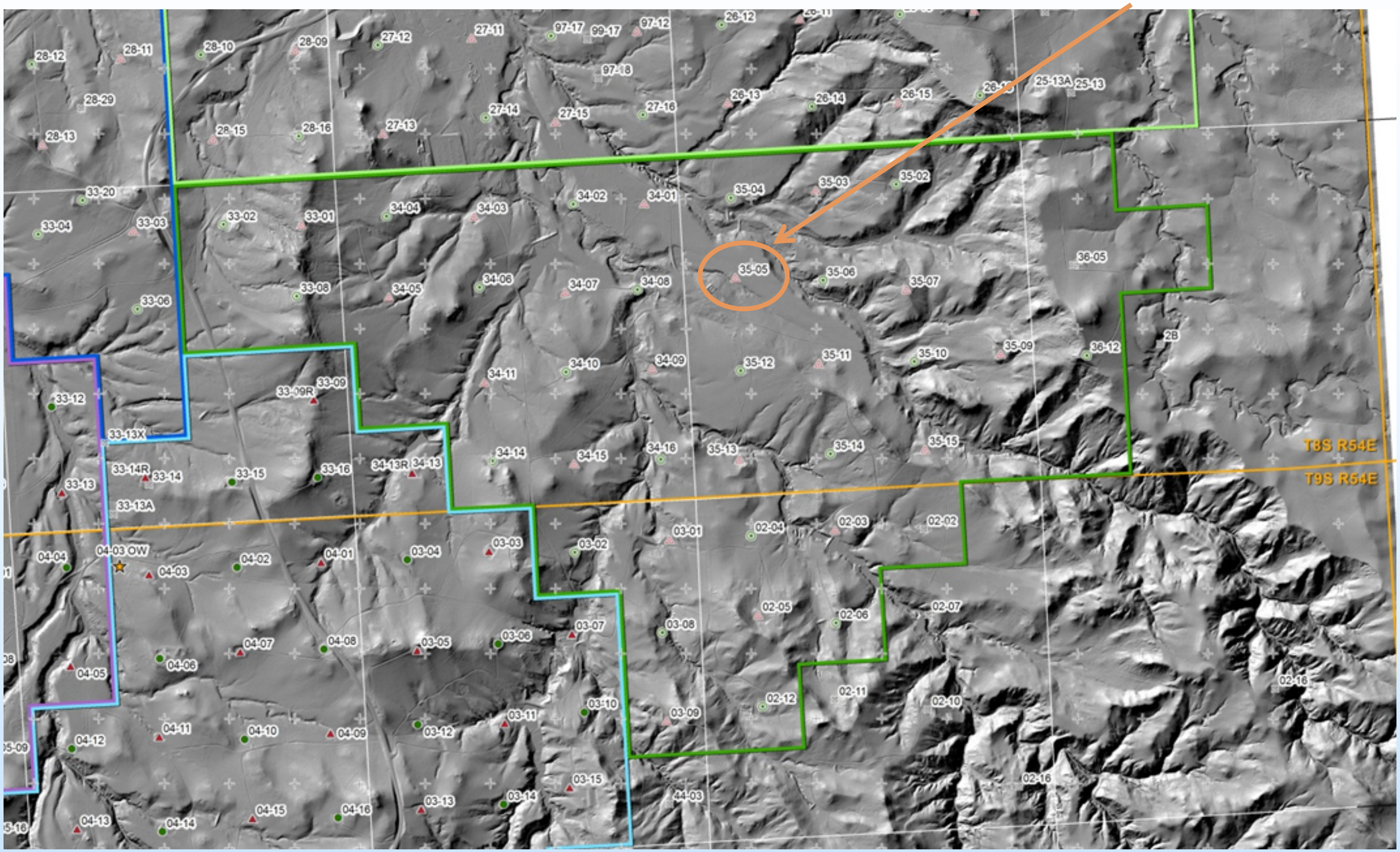


Han, D.H., and Baztle, M, 2002, Fizz water and low gas saturated reservoirs: The Leading Edge, April 2002.

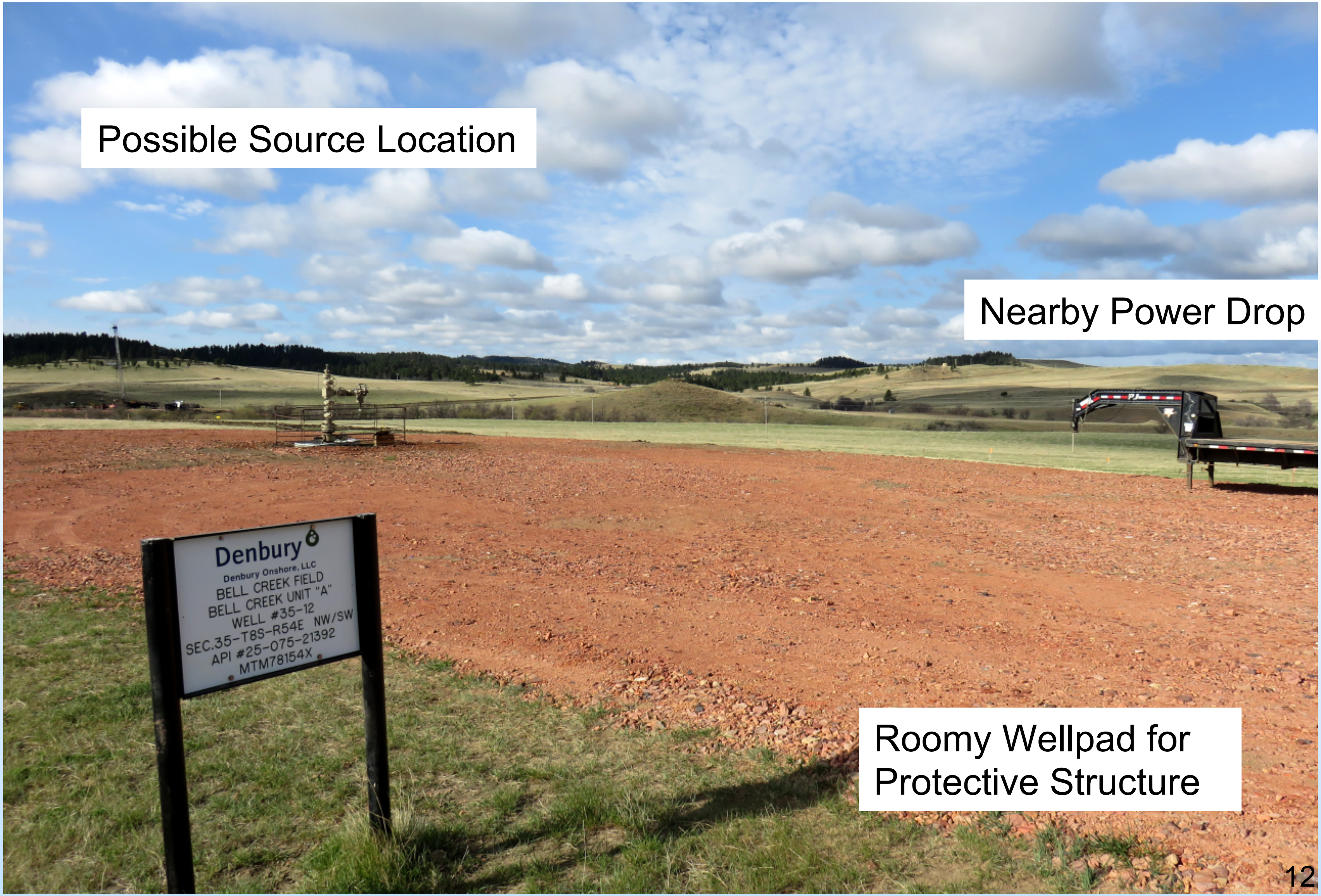
Phase 4 Study Area

Lidar Image shows topography

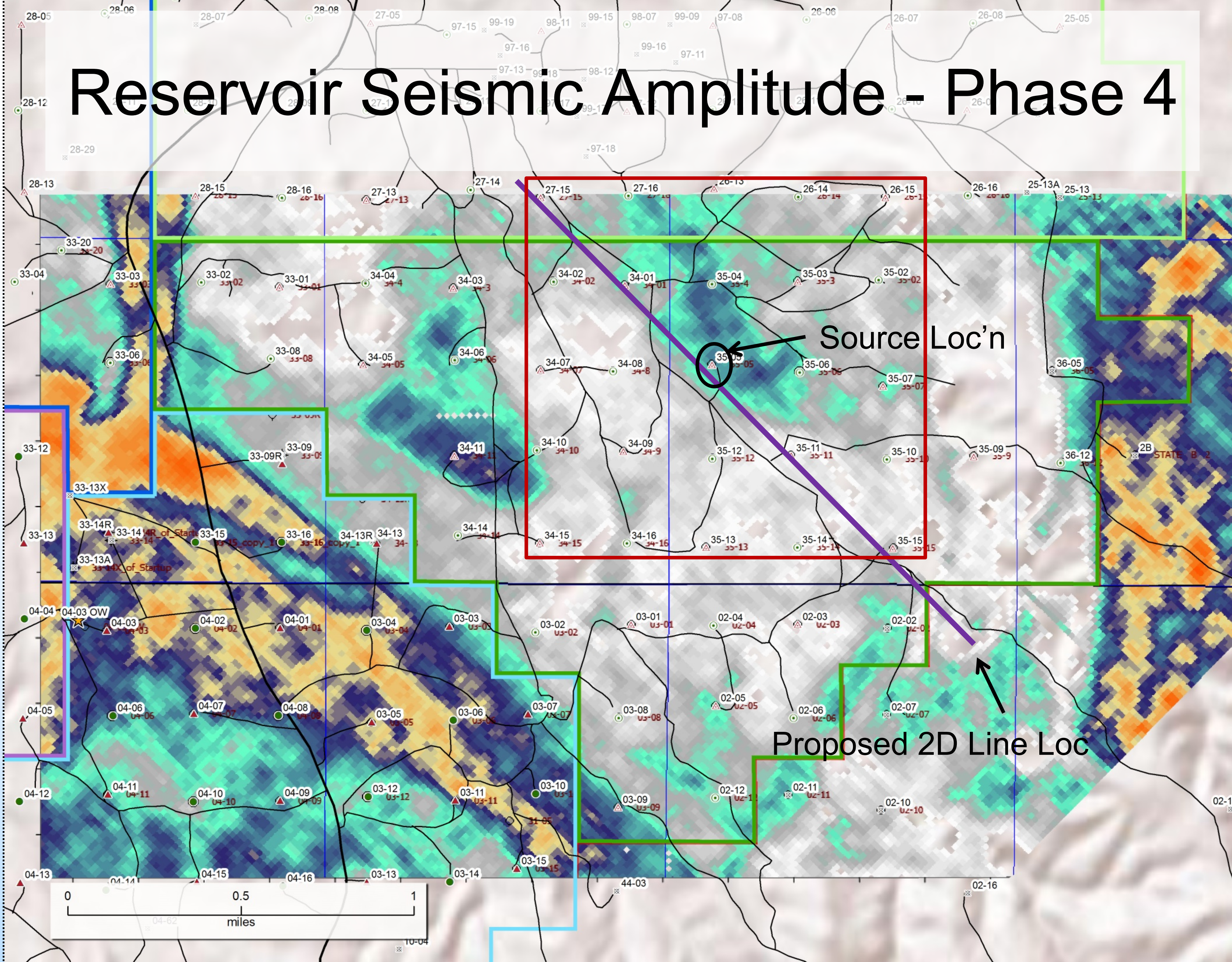
Proposed Source Location



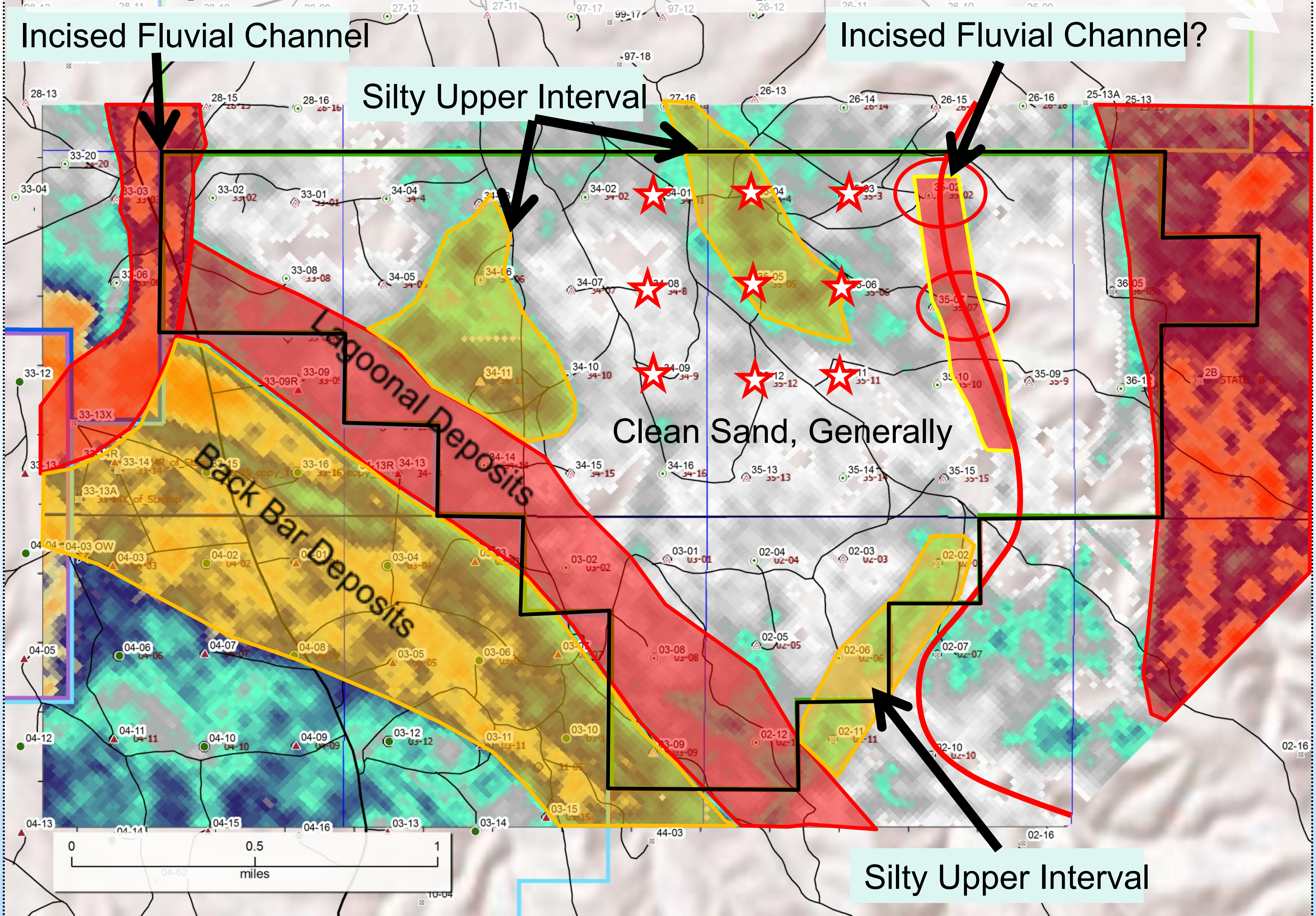
Phase 4 Topography



Reservoir Seismic Amplitude - Phase 4

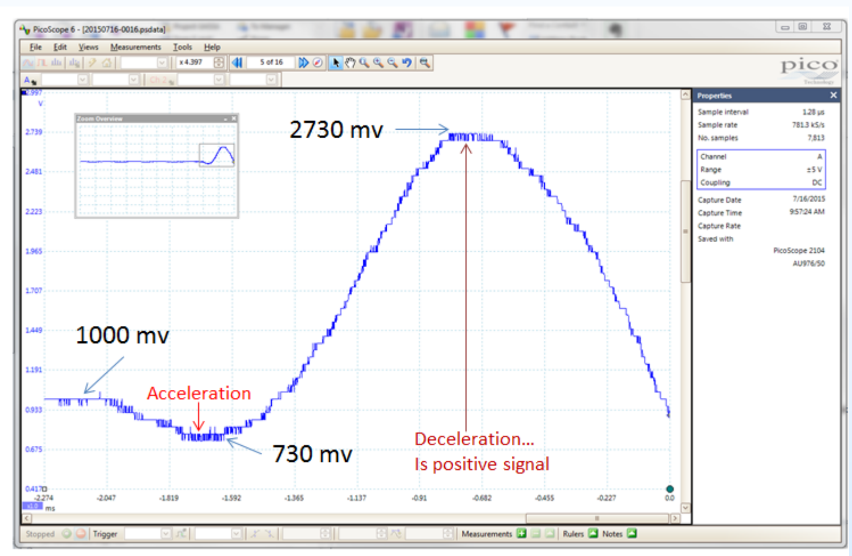


Interpreted Seismic Amplitude - Phase 4



Accelerated Weight Drop Seismic Source

- **Offers strength, flexibility and safe, remote operation at an affordable cost:**
  - Gisco ESS 850 – an 850-lb weight accelerated with a sling-shot.
  - Electrically powered, remotely operable safely within a locked structure.

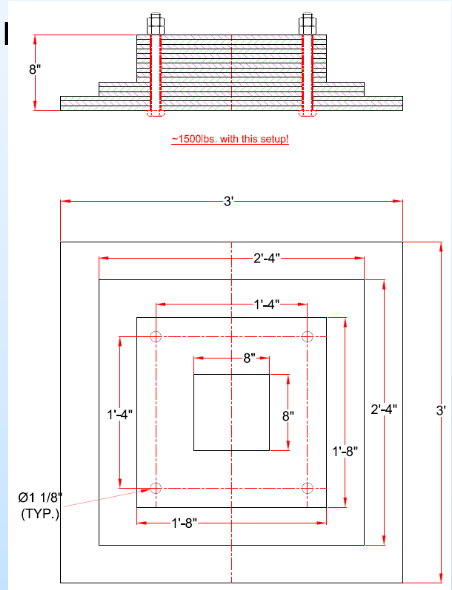


- Using a sensitivity of 30 millivolts/g of acceleration
  - Acceleration is (1000-730)/30 = 9 g
  - Deceleration is (2730-730)/30 = 33.3 g
- Force=mass * acceleration
  - F = 386 kg * 9 * 9.81 m/s^2 = 34,080 N = 7660 lb.f

Source Structure, Footing, Control

- **Source protective structure:**
  - Metal building similar to other Bell Creek wellhead buildings. 10’ x 14’ with garage door.
  - Insulated and heated with a power hookup.
  - Sound-proofing to maintain landowner relations.
- **Source footing:**
  - Consistent source signature over the course of the project is strongly desired.
  - Repeated firing may tend to pack or “dig” a hole.
  - 1500 lb engineered immovable sub-grade footing and strike plate to ensure consistency through the project.
- **Source remote control:**
  - Via commercial satellite Internet link.
  - Webserver controlled relay box has been built.
  - Outputs from sensors, internet camera, and the source signature recorder will allow remote assessment of shot quality.

Typical Structure shown



1500 lb footing & strike plate

Recording System

- **FairfieldNodal Zland System:**
  - Ship date September 4.
- **System components:**
  - 96 nodes – 3-component 5 Hz geophones; sufficient for flexible deployments.
  - Data server station.
  - Handheld units for GPS location and mapping of node locations.
  - Charger and data download racks.
- **Field and technical staff training:**
  - 5-day hands-on training at the Energy & Environmental Research Center (EERC) for field team and technical staff.

Fairfield Nodal

Deploy nodes

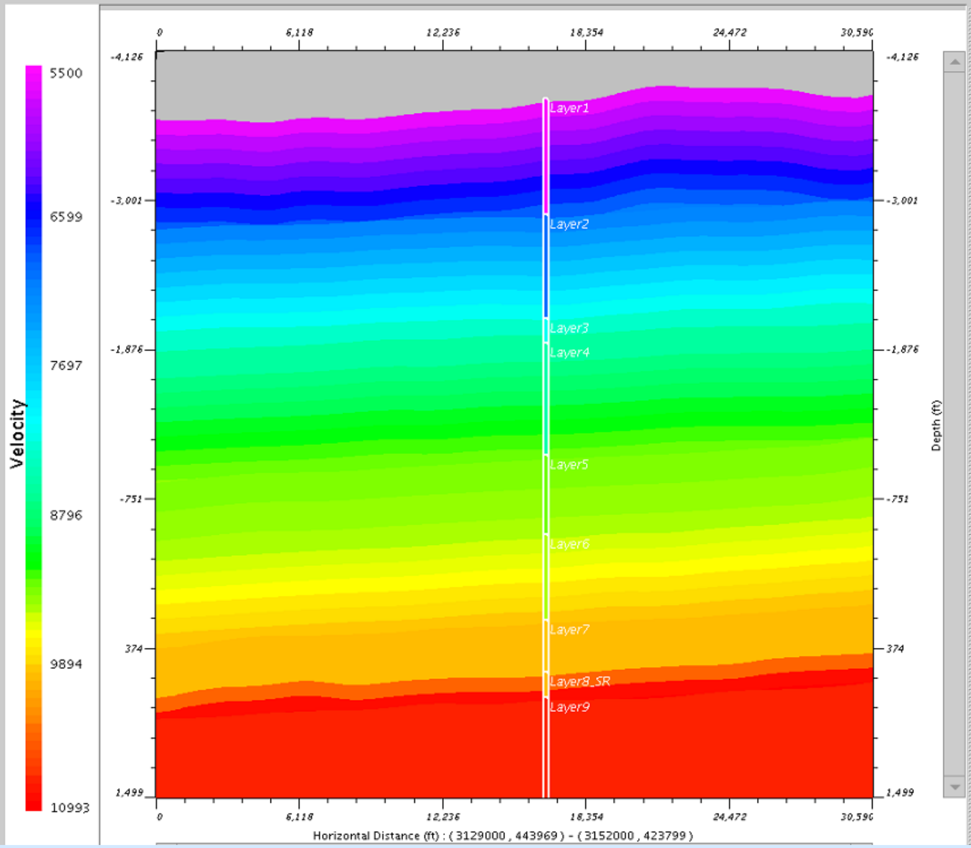
Pick up the nodes

Monthly Data Harvest, Recharge Batteries

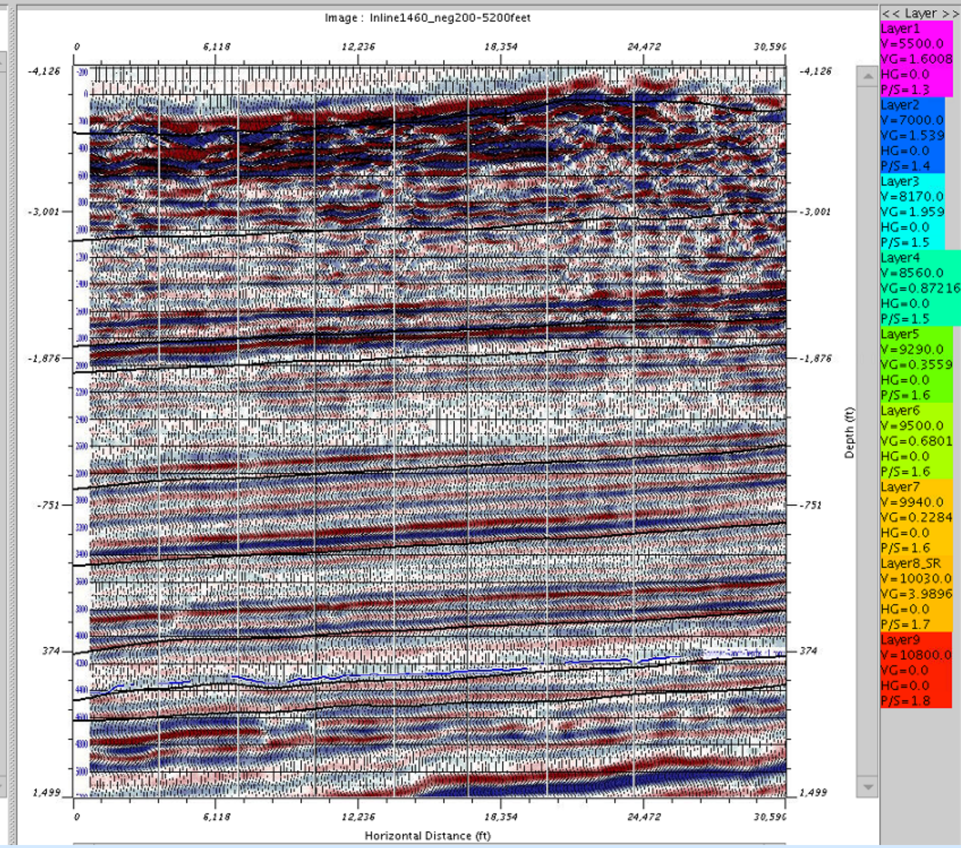
Output data

Geophysical Modeling

3D Model Construction with GeoTomo Vecon in progress to determine receiver locations



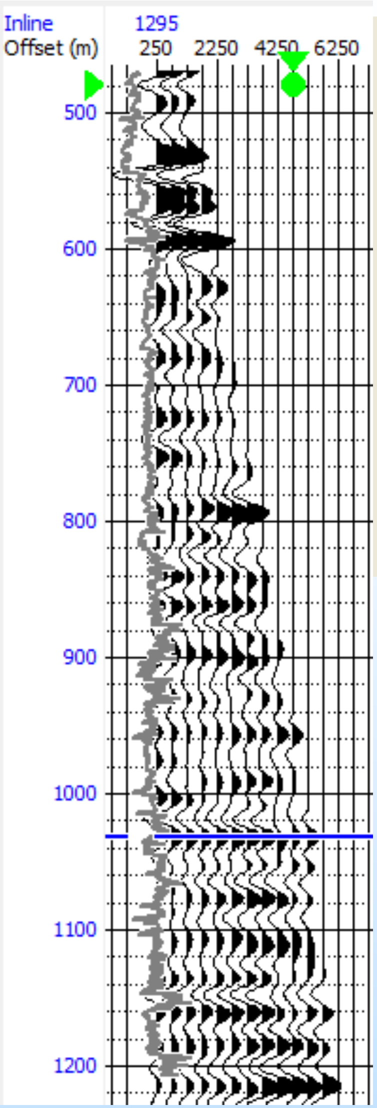
3D Layer Model: Interval Velocities with Vertical Gradients, Topography, and 3 dimensions.

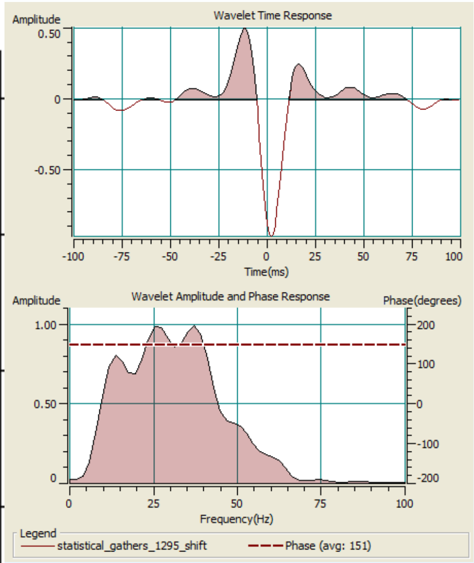


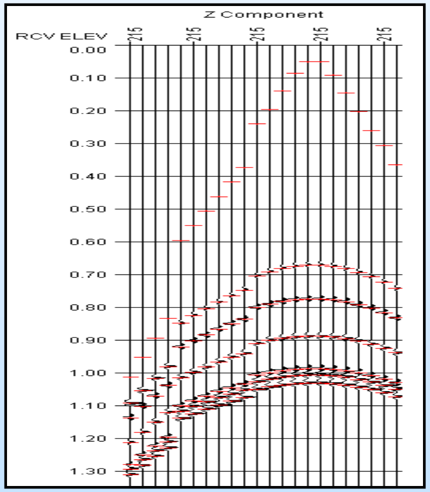
Depth Converted Seismic

Processing Workflow

- **Data processing of the SASSA data:**
  - Simple trace processing:
    - Extract records
    - Spherical divergence and gain
    - Noise filtering
    - Time-lapse differencing
  - RadExPro PC-based processing software
  - Seismic Un*x

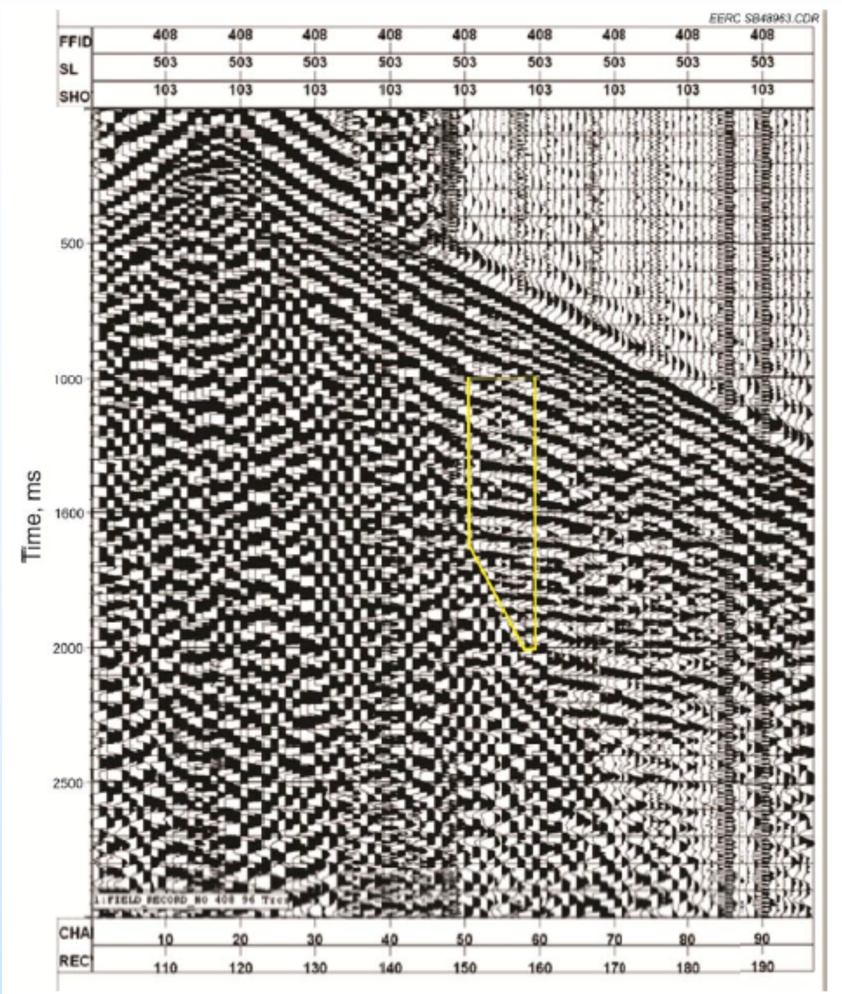




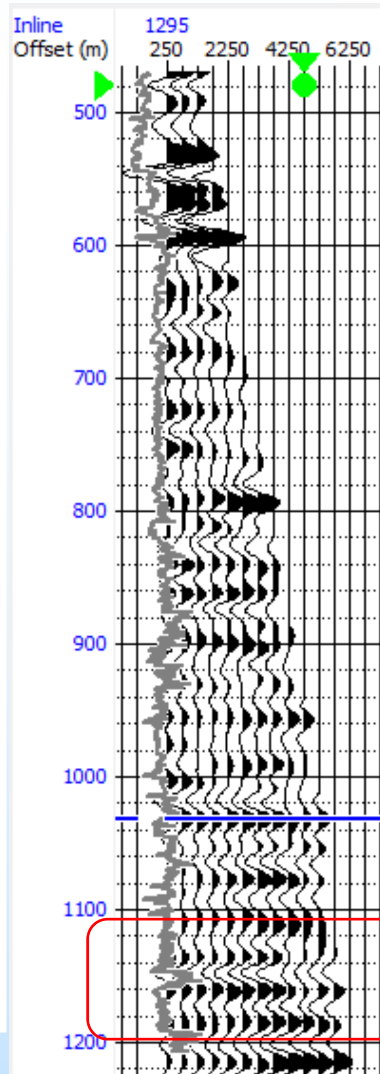


What will a SASSA Record Look Like?

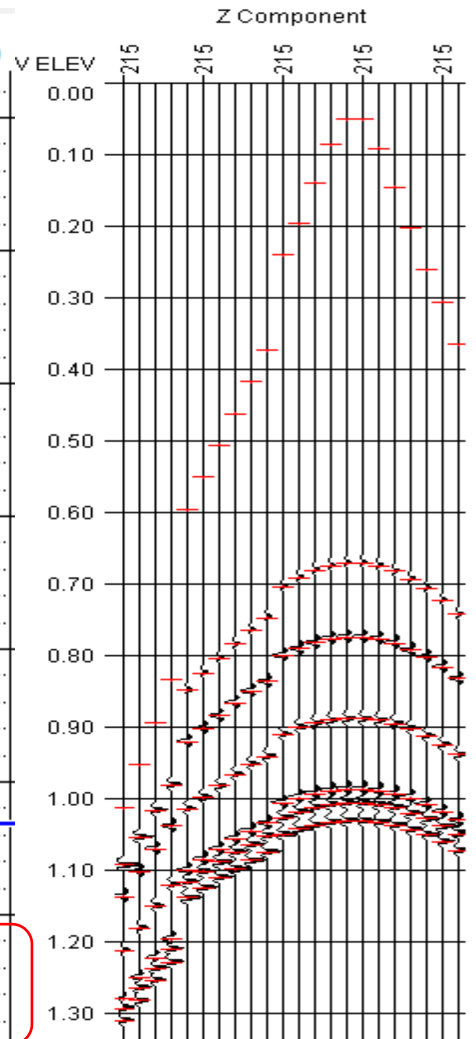
96 channel Vibe record



Gather from 3D



Modeled Data



It will have 96 channels with noise,
But not this much noise!

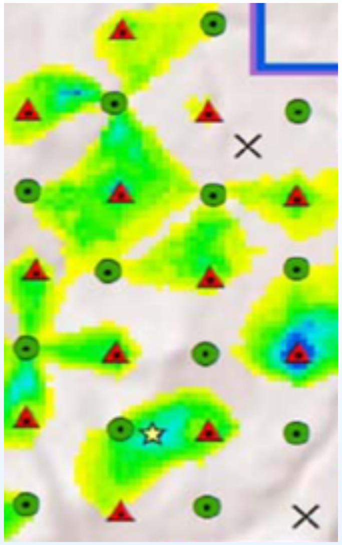
Target reflector amplitude will vary with offset

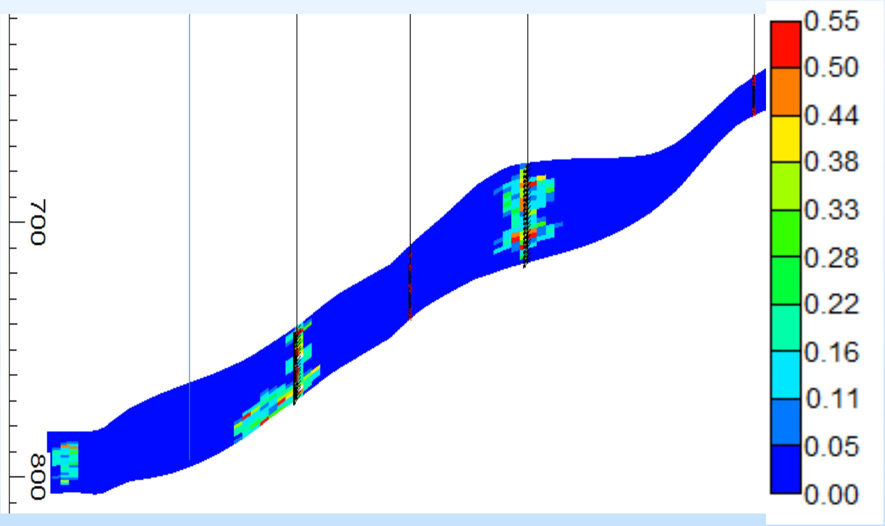
"Jumps" and time variations with offset

Dynamic Reservoir Simulation

- **Predictive simulations of plume migrations using Computer Modelling Group (CMG) software will be used to corroborate and help evaluate SASSA results:**
  - A subset of the Bell Creek static geological model covering Phase 4 - the SASSA area - will be the input for predictive simulation of plume migration.
  - SASSA results can be used to recalibrate the simulation.
  - Validation methods – PNL logs, production logs, and 2D seismic - will be used to evaluate SASSA and simulation results.

Simulation Results with CO_2 Plumes (using CMG software)

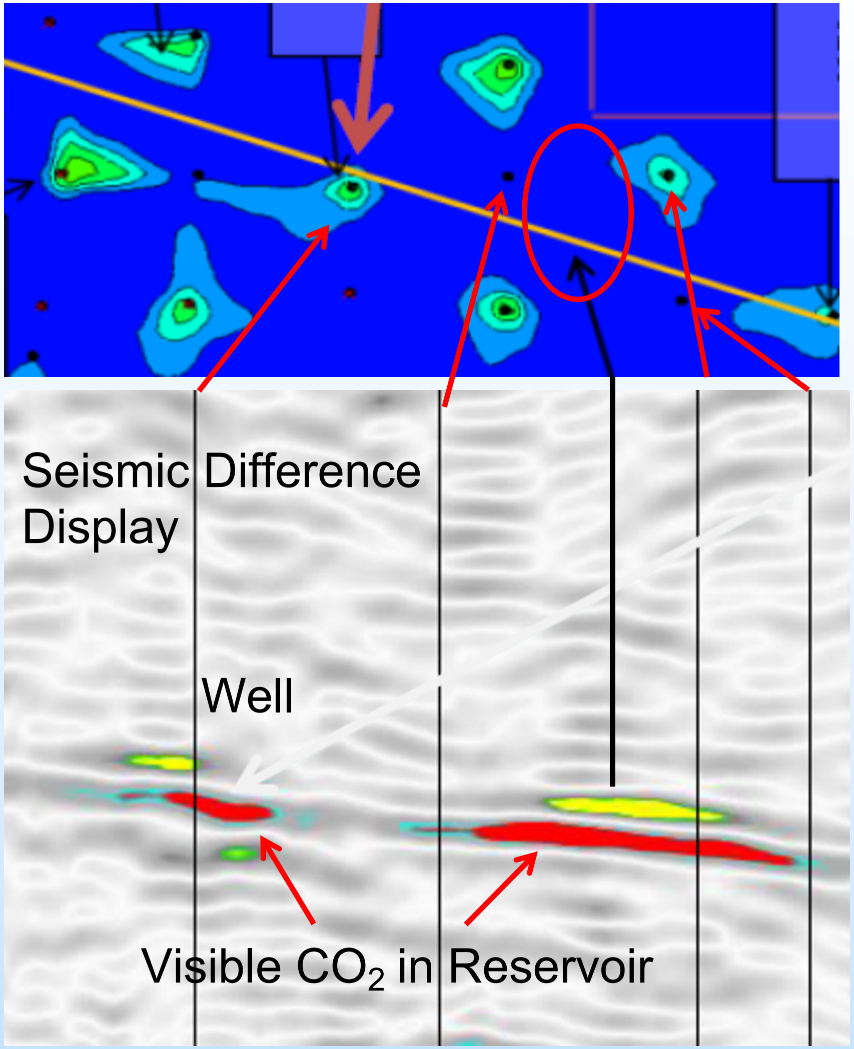




Baseline and Repeat 2D Seismic Line

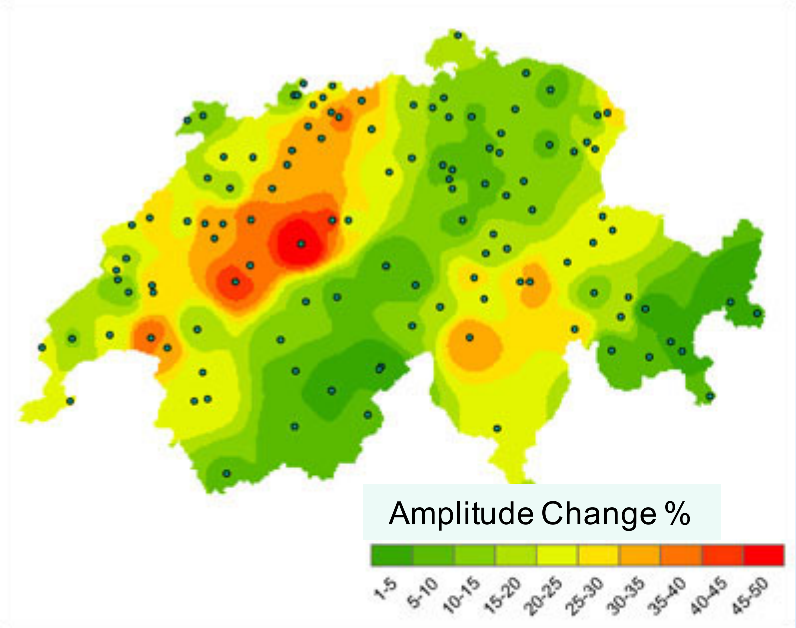
- **Validation method: 2-D seismic line:**
  - Before and after SASSA data collection period.
  - The recording system has sufficient nodes to acquire 2-D seismic lines.
- **A "2-D / 4-D" line recorded after injection could provide proof of CO_2 presence and location**
  - Compare with SASSA and simulation results.
  - 2-D seismic difference display shows CO_2 the simulation did not properly place.
  - An example of how SASSA may be used to calibrate the simulation.

Seismic Line Overlaying Simulation



Plume Image from SASSA Results

- Possibly a plume image can be inferred by kriging the time-lapse trace amplitude differences.
  - Krige the amplitude values and time-lapse difference the images.
  - We'll have up to 96 points.
  - They will need to be corrected for amplitude vs offset effects.



Accomplishments to Date

- Project location selected.
- Equipment procurement finishing up.
- Source location selection imminent.
- Source structure design complete and in procurement.
- Source remote control system in testing.
- Source strike plate design completed and ready for installation.
- Geophysical modeling underway to determine receiver positions.

Synergy Opportunities

– Aquistore and projects with fixed seismic sources and permanent or semi-permanent receiver arrays may be able to leverage the SASSA time-lapse seismic trace analysis process. An agreement to work with Aquistore data is pending.

Summary

– Nearing completion of Phase 1:
  - Planning, Procure Equipment, Modeling. Deployment and field testing are planned for next month (Sep).

– Field data collection, Phase 2:
  - Scheduled to begin Oct 1.
  - Data processing to start ~ Nov 1.

Contact Information

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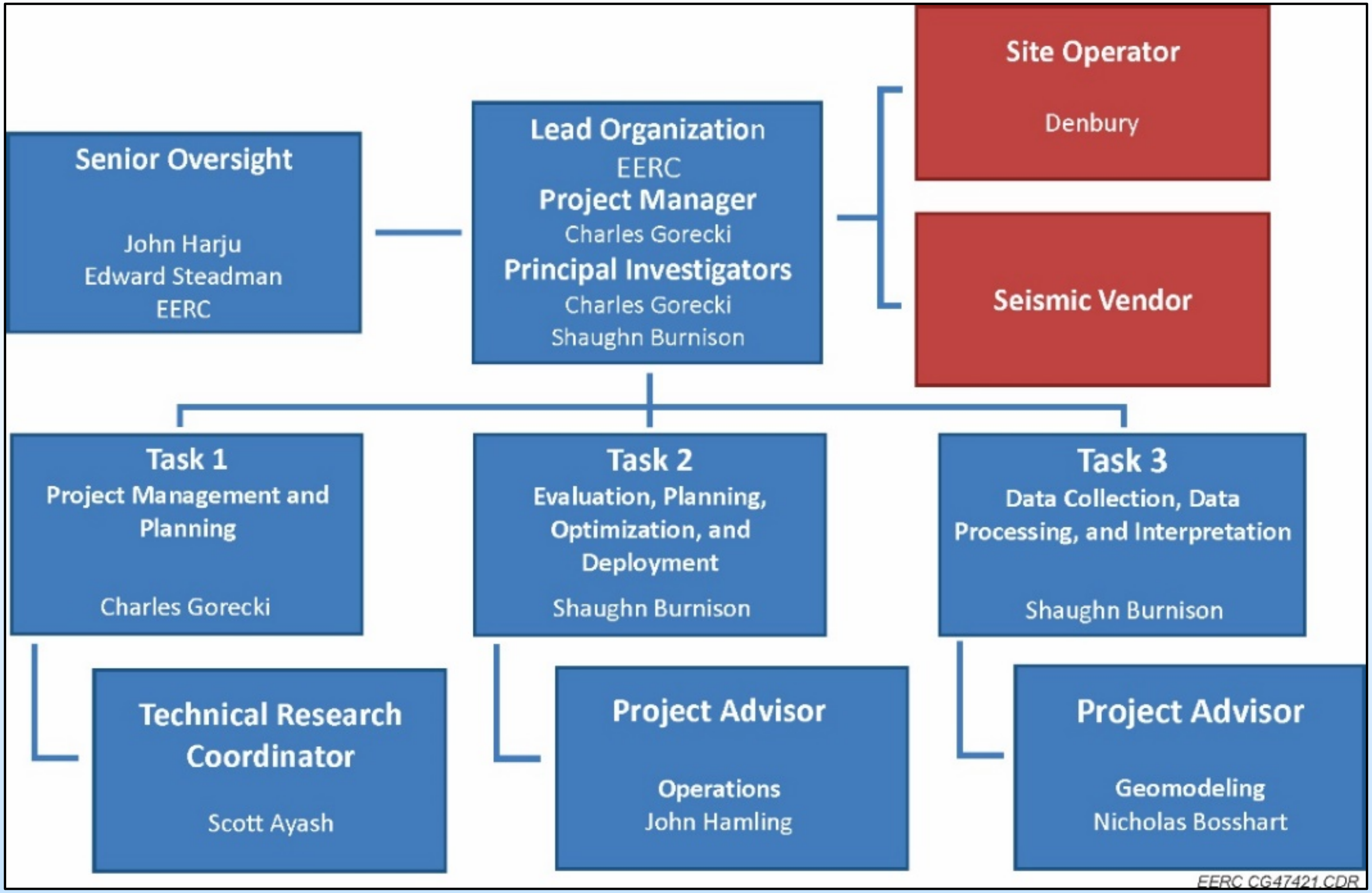
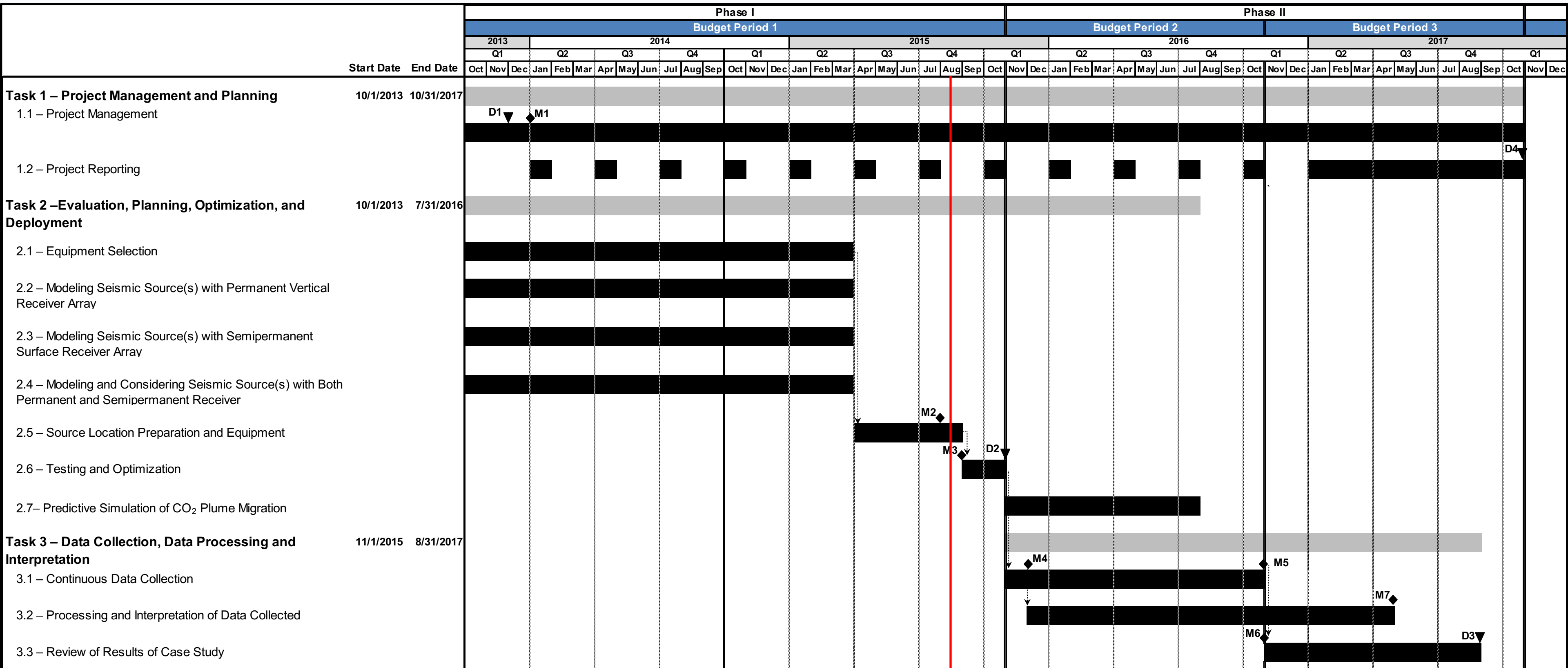
Appendix

– Questions?

Organization Chart



Gantt Chart



Summary Task

Activity Bar

Milestone (M) ◆

Deliverable (D) ▼

Critical Path

Key for Deliverables (D) ▼

D1 – Updated Project Management Plan (PMP)
D2 – Interim Report on Completion of Technical Design
D3 – Technical Paper or Journal Article Based on Processing and Modeling Results and Overall Recommendations
D4 – Final Report

Key for Milestones (M) ◆

M1 – Project Kickoff Meeting Held
M2 – Source Location Preparation Initiated
M3 – Start Optimization and Testing of Equipment
M4 – First Data Available for Processing
M5 – Data Collection Completed
M6 – Comparison to Conventional Seismic and History Match to Geological Model and Simulation Initiated
M7 – Data Processing Completed

Revision – June 30, 2015

Bibliography

- No peer-reviewed literature to date.