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

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Background and Motivation

- Currently, determining the plume location and extent of injected carbon dioxide (CO_2) is achieved by acquiring multiple 3-D seismic surveys. They provide value and detailed images of the subsurface, but have drawbacks…
  - Expensive.
  - Labor-intensive.
  - Long delays (planning to results can be longer than a year).
- An approach using the seismic method as an indicator to track plume position with minimal expense and delay is proposed.

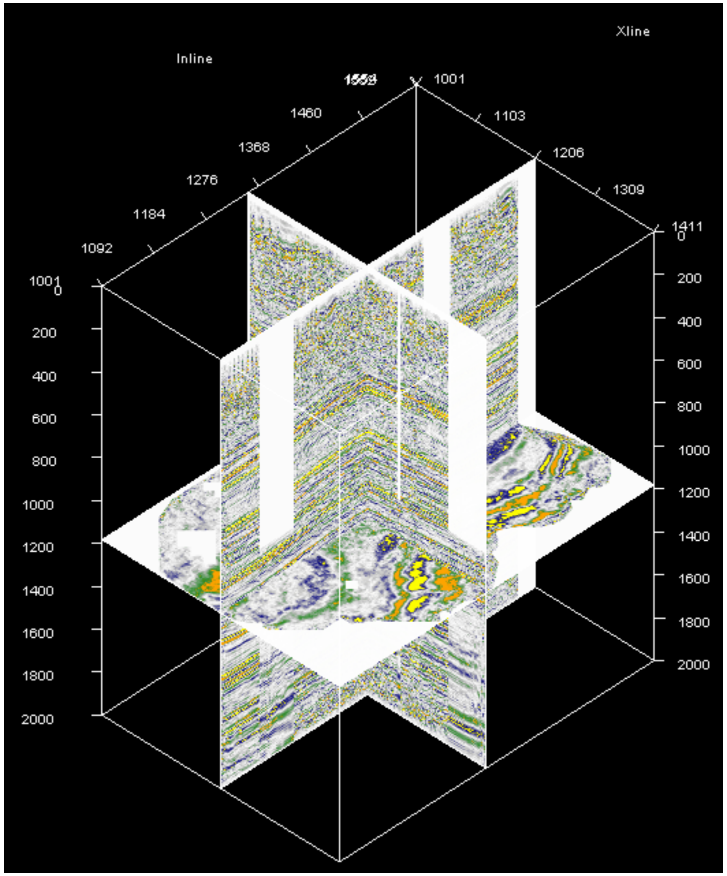


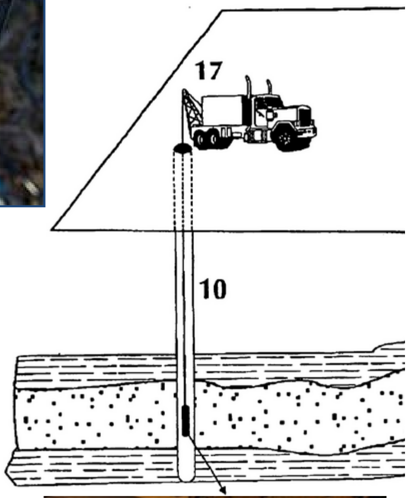
Image of Bell Creek 3-D Baseline Survey Data

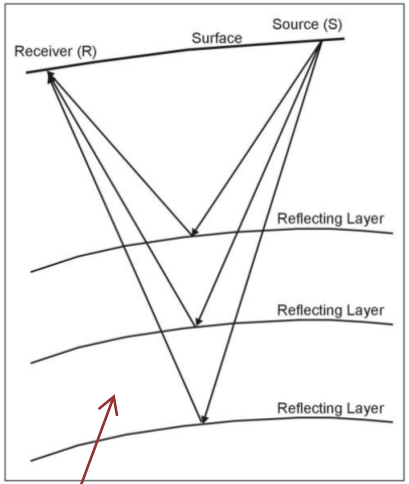
SASSA Concept

- **The seismic method is used as an indicator to track plume position with minimal expense and delay:**
  - Autonomous node-recording instruments.
  - Remote-controlled downhole seismic source.
  - *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.

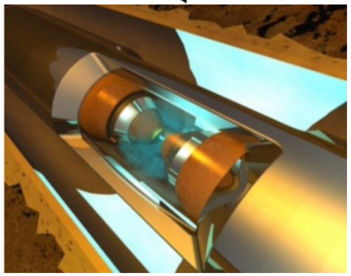
- **New concept:**
  - Clever placement of source and receiver allows the use of the seismic method as a yes/no switch to determine when the CO_2 plume has moved past a monitored location.
  - Sensor placement guided by modern 3-D modeling to account for structure and velocity variations.
  - Short delay for processing and interpretation.
  - Real time may be possible in the future.

Fairfield Nodal





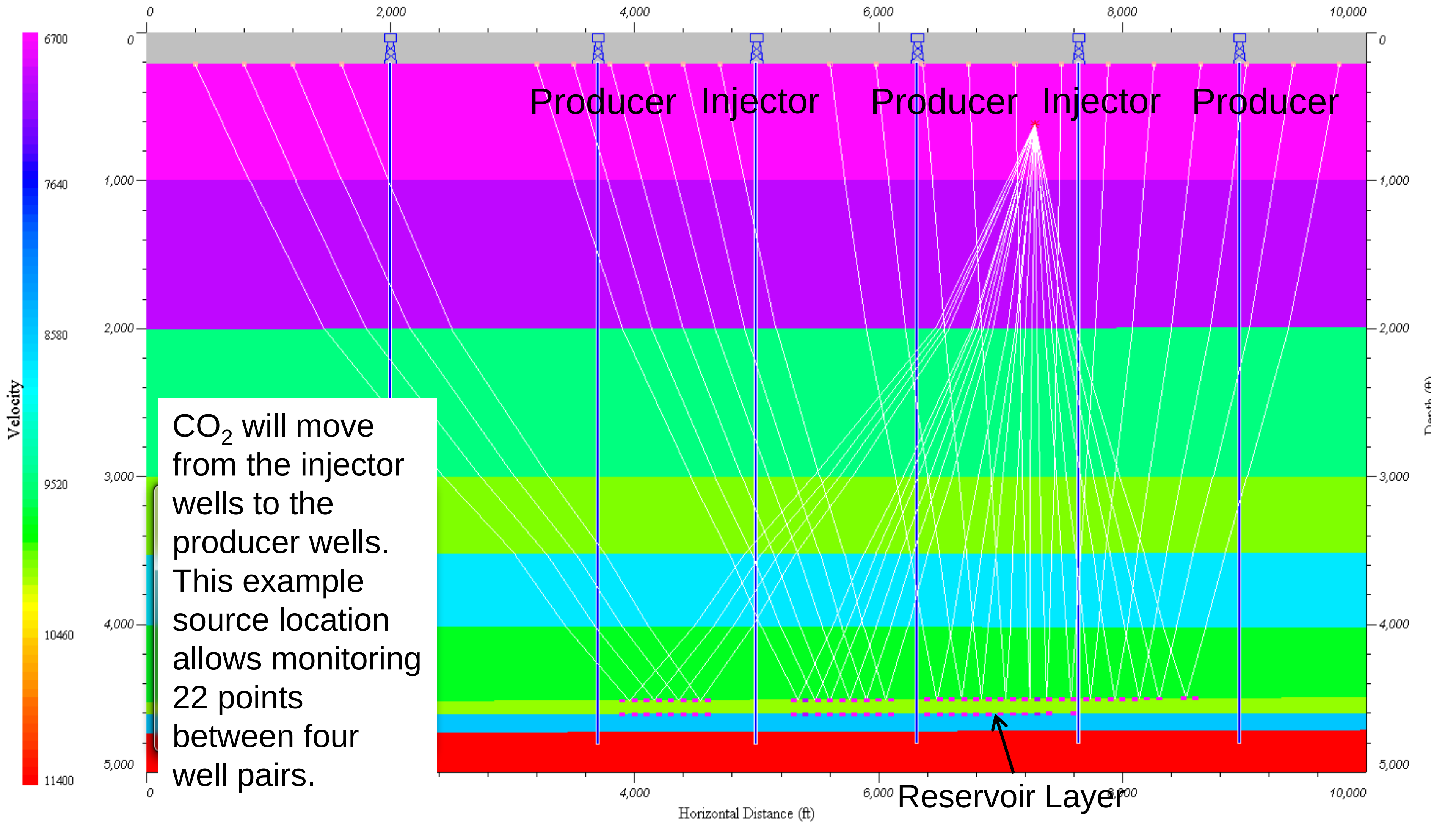
Reservoir Layer



Example Surface Layout (2-D)

Four, Six, and 12 Receivers Sample Between Four Well Pairs

Surface receivers can sample any subsurface location within range of the source.

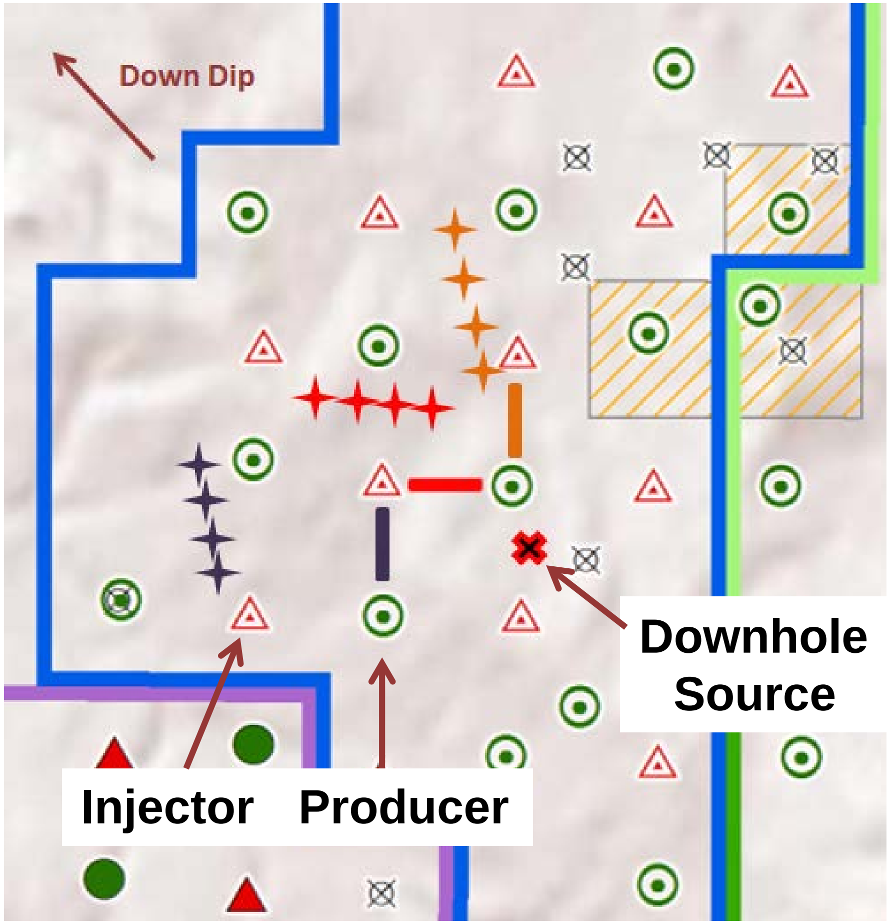


CO_2 will move from the injector wells to the producer wells. This example source location allows monitoring 22 points between four well pairs.

Proposed Method

- Sample between injectors and producers to monitor 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 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



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.

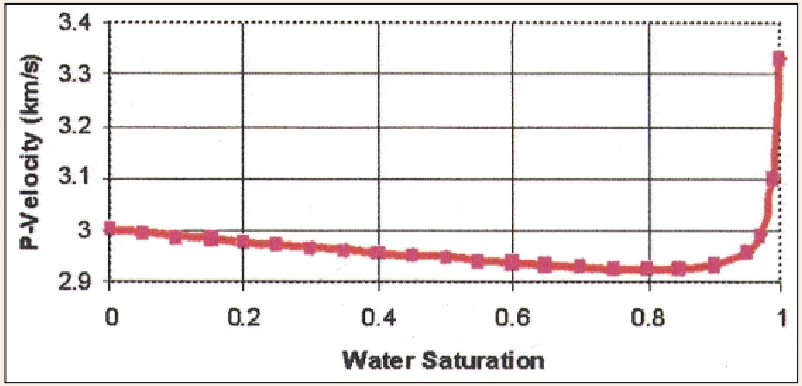
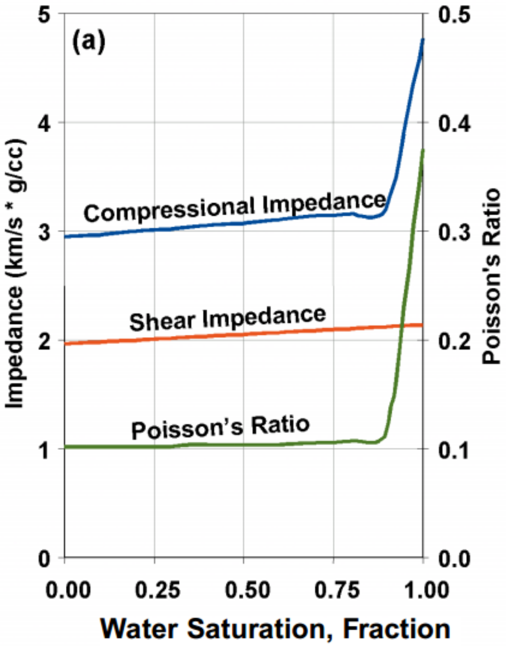


Figure 1. Typical effect of gas saturation on *P*-velocity of rocks under shallow conditions.



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

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Project Objectives

1. Demonstrate that a sparse array of carefully placed surface receivers paired with a remotely controlled source can detect a passing CO_2 plume using minimally processed time-lapse shot records.

2. Check if detected changes correspond to the reservoir-modeling result, and predict when the next farthest receiver will be affected.

3. Validate the results with independent data.
   - Production logs from producing wells.
   - Well log data, e.g., pulsed neutron or sonic scanner.

4. Evaluate if the method has other uses.

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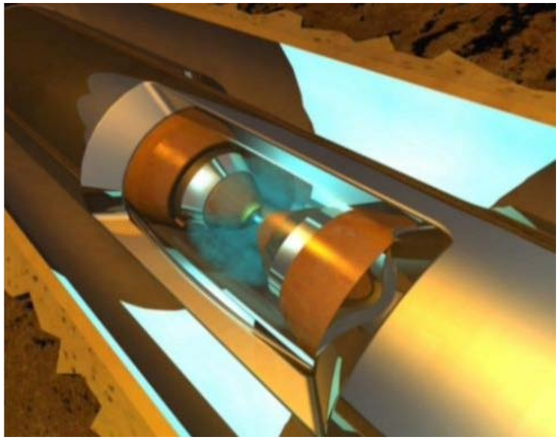
Equipment Selection

Two main types of equipment need to be chosen:

- Downhole source
- Autonomous surface receiver units

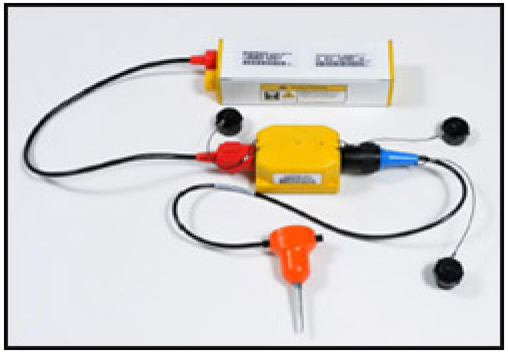


Downhole Source

- Apex HiPoint (a Sigma^3 wholly owned subsidiary) is building a prototype electrical source.
- Electrical implosion has advantages: hangs freely in the well, easily powered.

Surface Receiver Units

- Units include recorder, battery, and sensor.
- Must be capable of operating for at least 1 month prior to battery swap and data harvesting.
- Potential option would be wireless unit that transmits data back to the borehole array recording shack, foregoing the need for harvesting (battery swap still required).



Geospace GSR

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Modeling Source and Receiver Layout

- To accurately site equipment, the seismic wave field is modeled in three dimensions to account for dip and velocity variations.
- Surface units can be flexibly sited to avoid surface obstacles.
- Number of surface units will be approximately 64.

Geotomo Vecon

Source Well Drilling

- Source depth determined by modeling and equipment constraints (cable length, etc.).
- Wells will be cased water wells.
- Size based on source diameter:
  - 5½”
  - 4”
- Cement may impact source coupling or attenuation:
  - Bentonite slurry (typical)
  - Neat cement (option)
- Transfer to landowner after project completion.

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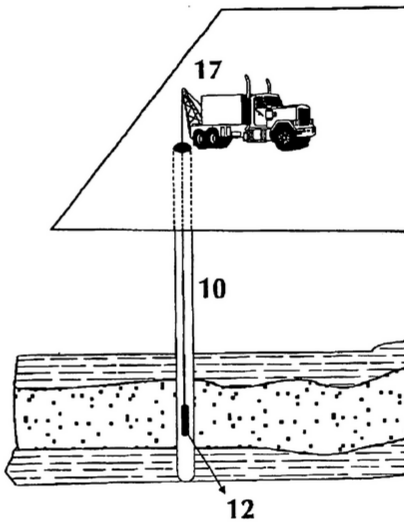
Source and Surface Array Installation

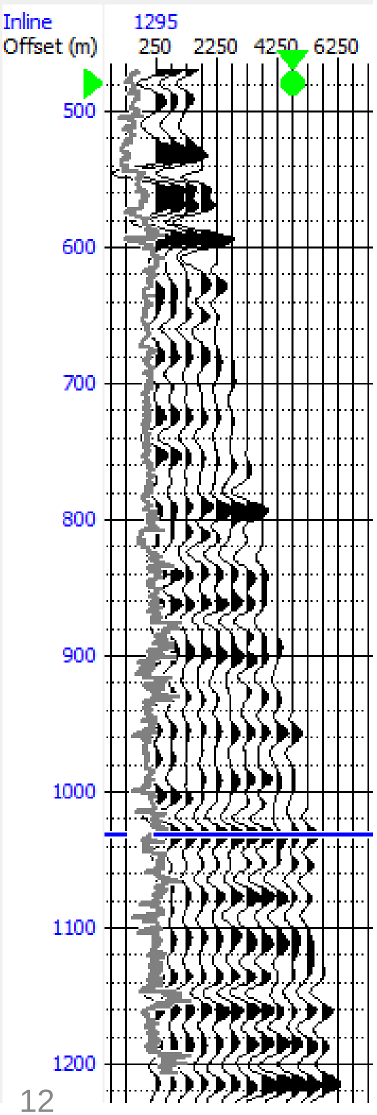
- **Source:**
  - Hung on a winch-lowered cable.
  - Power and telecom at the site for remote control.
  - Testing will be required.
    - ♦ Backup options
    - ♦ Winter weather considerations

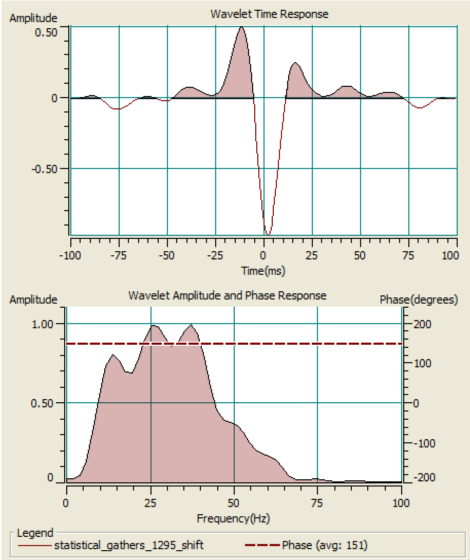


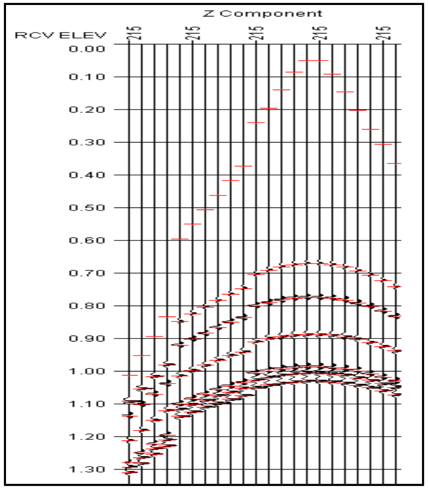
- **Surface receiver layout:**
  - A minimum of 60 receiver units, and a field service unit for battery charging and data harvesting.
    - ♦ Units will be in the field for extended lengths of time.
    - ♦ May need to shelter them from weather, livestock, etc.

System Testing and Optimization

- System will be tested and optimized:
  - Source to be tested on-site and remotely fired.
  - Surface receiver data harvested, downloaded, and processed.
  - Processing workflow will be established using test data.
    - Gauge the signal-to-noise ratio of data.
    - Identify receiver traces and target reflections.
    - Monitored reflection points – identify the reservoir reflection.
    - Create the difference display workflow.

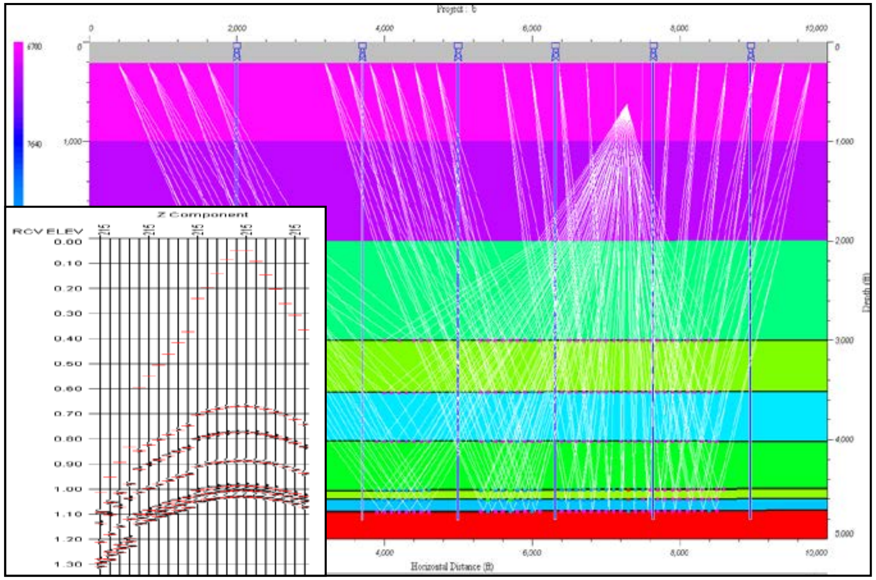






Operation Plan

- **Downhole source remotely fired weekly**
  - Same day/time during evening quiet hours each week.
  - Shots may be monitored in real time on the borehole seismic array.
- **Data gathered monthly for a period of 1 year**
  - Team travels to field at regular intervals (~monthly).
  - Swap out surface unit batteries, download data.
  - Service downhole source and equipment.
- **Data processing**
  - Isolate and sort records.
  - Simple processing to preserve amplitudes.
  - Generate difference displays.
    - ♦ Week to week, month to month
- **Visible change seen (possibly indicating the presence of CO_2)**
  - Check time and position against the reservoir simulation modeling.
  - Surface unit could remain in place or be moved to another location.



Progress/Current Status

Progress:

- Purchased RadExPro seismic processing software.
- Investigated purchase and lease options for surface receiver units.
- Modeling software purchase options identified.

Current Status:

- Project time line has been extended to coordinate with field operator’s seismic activities and operations.

Questions?

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