SCALABLE, AUTOMATED, SEMIPERMANENT SEISMIC ARRAY (SASSA) FOR DETECTING CO_2 EXTENT DURING GEOLOGICAL CO_2 INJECTION

FE0012665

Mastering the Subsurface Through Technology Innovation & Collaboration: Carbon Storage & Oil & Natural Gas Technologies Review Meeting

August 17, 2016

Amanda Livers

Research Scientist, Geophysics

Critical Challenges. **Practical Solutions.**

PRESENTATION OUTLINE

- Benefit to the program
- Project overview
  - Goals and objectives
  - SASSA (scalable, automated, semipermanent seismic array) concept
- Bell Creek Field study area
- Array
  - Design
  - Acquisition
- Preliminary data processing
- Reservoir simulations and 2-D line validation
- 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 practices manuals for monitoring, verification, accounting, and assessment.
- The SASSA method is a novel application of existing technology with the potential to track the location of a CO_2 miscible front in the subsurface in a timely and cost-effective manner:
  - To improve measurement and accounting of storage performance.
  - To provide a means of remotely detecting out-of-zone migration of CO_2 (ensuring containment effectiveness).
  - To contribute to best practices for monitoring, verification, and accounting (MVA).

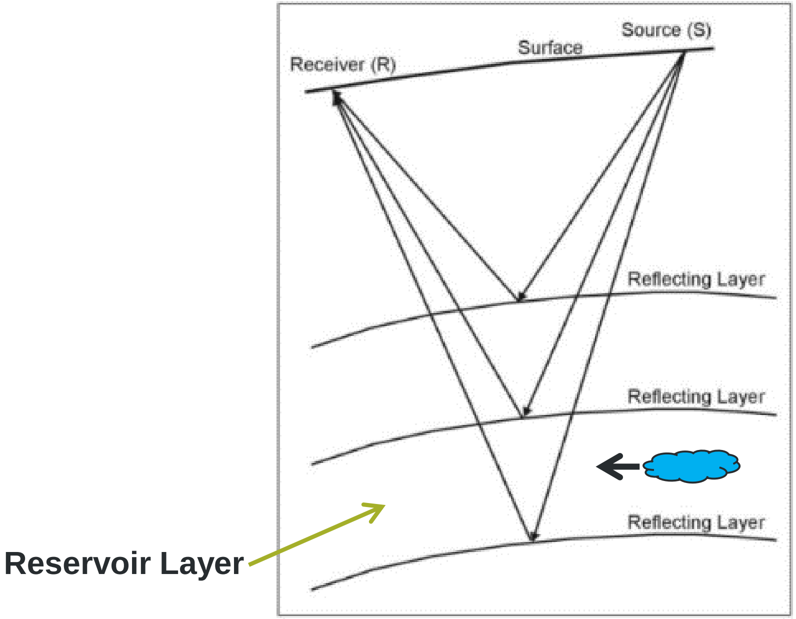
PROJECT OVERVIEW
GOALS AND OBJECTIVES

- Demonstrate and evaluate a novel seismic deployment method that can be operated remotely (and potentially automated) to show where and when a carbon dioxide (CO_2) miscible front passes a particular subsurface location.

- 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.

SASSA CONCEPT

- New application of the seismic method to track CO_2 movement in the reservoir.
  - Use of automated semipermanent array with sparse acquisition and one stationary source.
  - Monitor discrete locations in the reservoir.
  - 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 Vp of the interval.
  - Detectable changes to the reservoir reflection character over time may indicate the passing of the CO_2 miscible front.
- Why: Faster result, actionable information, possibly cheaper cost, lower impact.



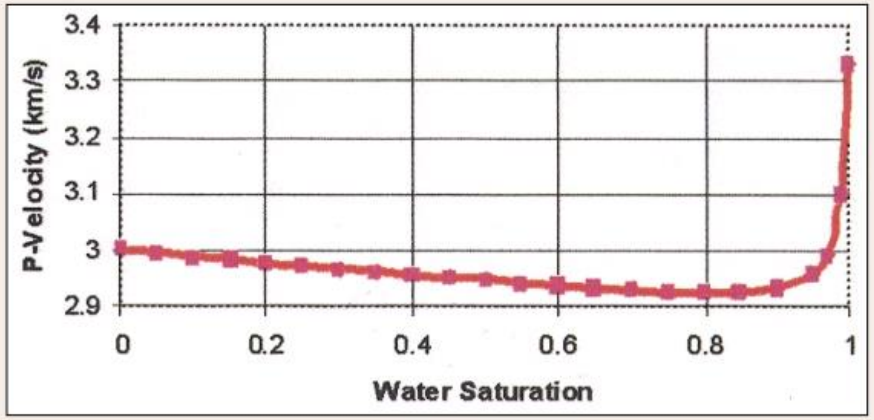
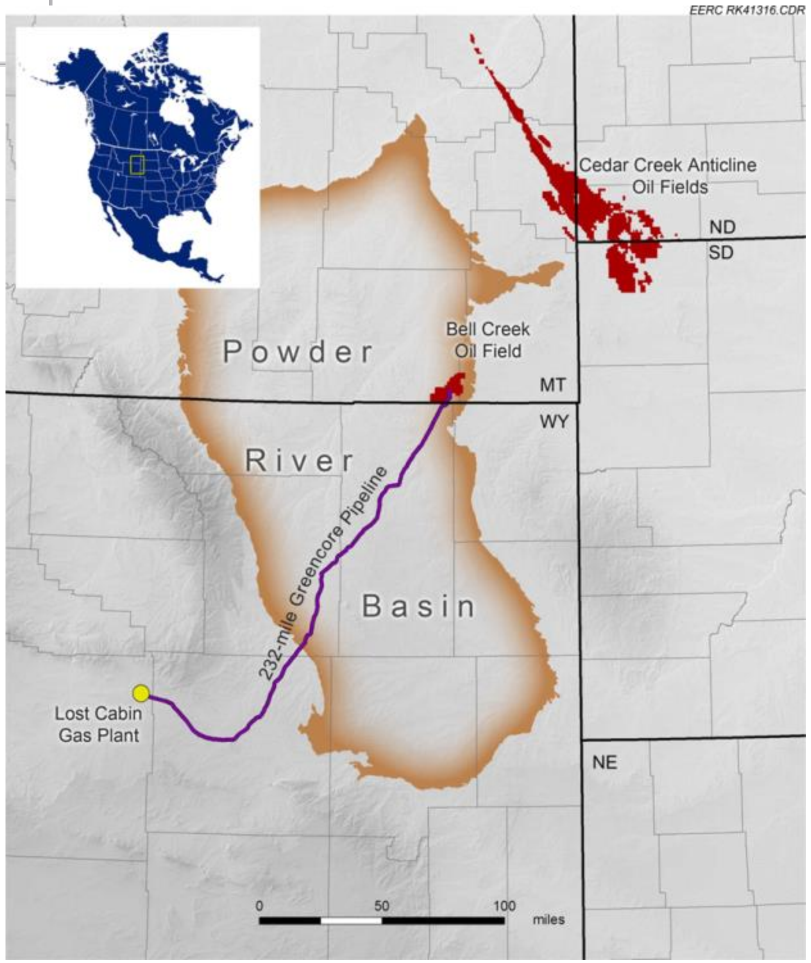
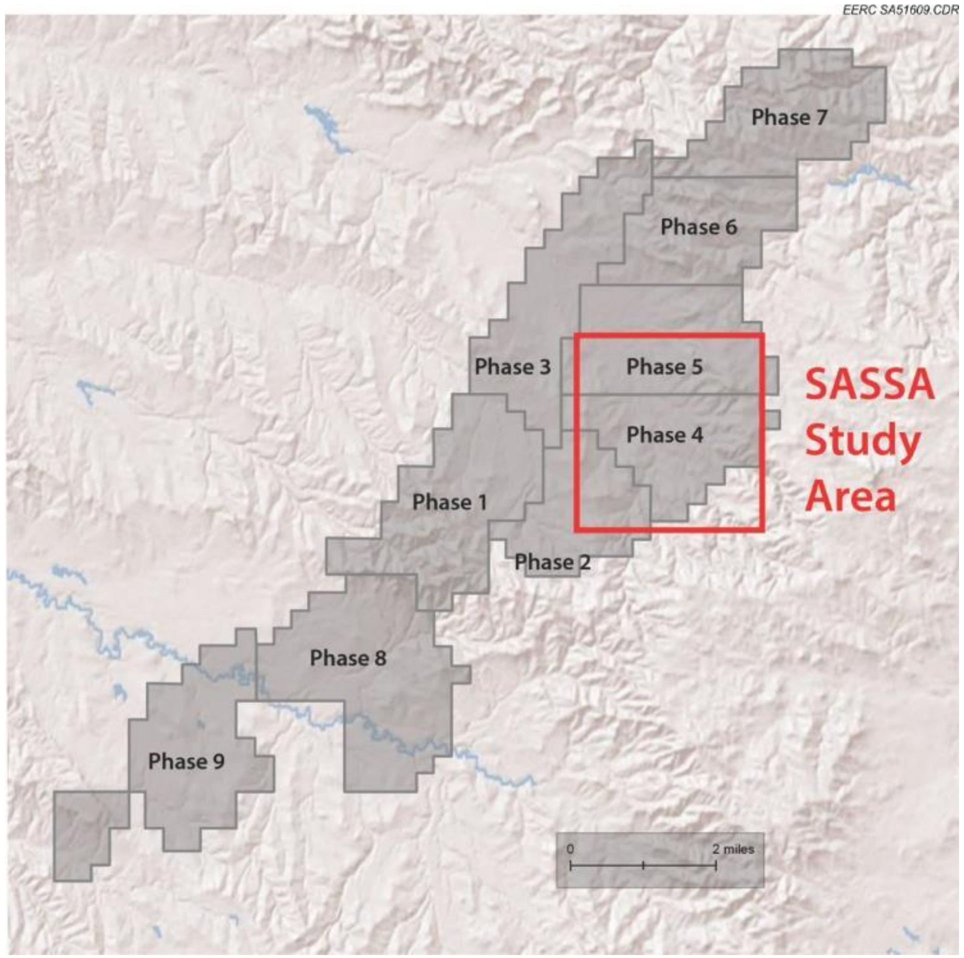


Figure 1. Typical effect of gas saturation on *P*-velocity of rocks under shallow conditions.

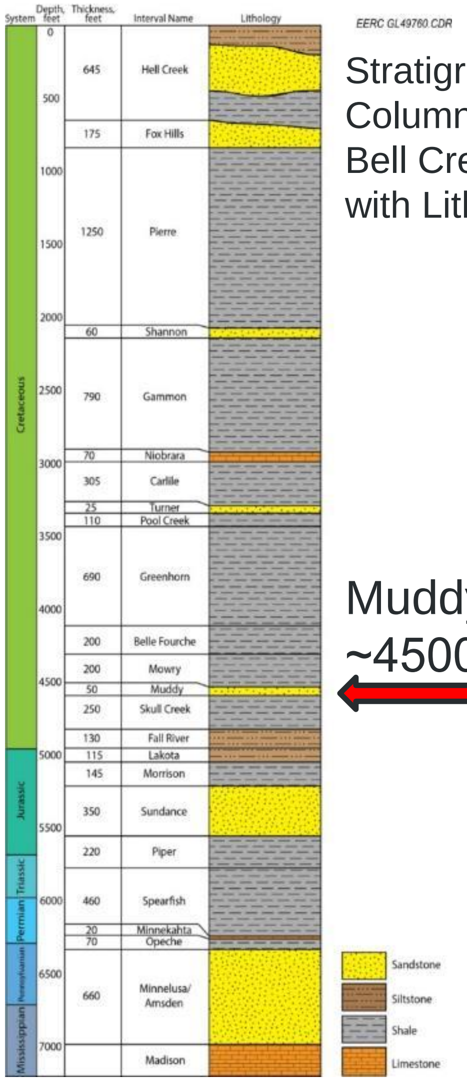
Han, D.H., and Baztle, M, 2002, Fizz water and low gas saturated reservoirs: The Leading Edge, April 2002.

SASSA STUDY AREA AND TARGET





Bell Creek Oil Field

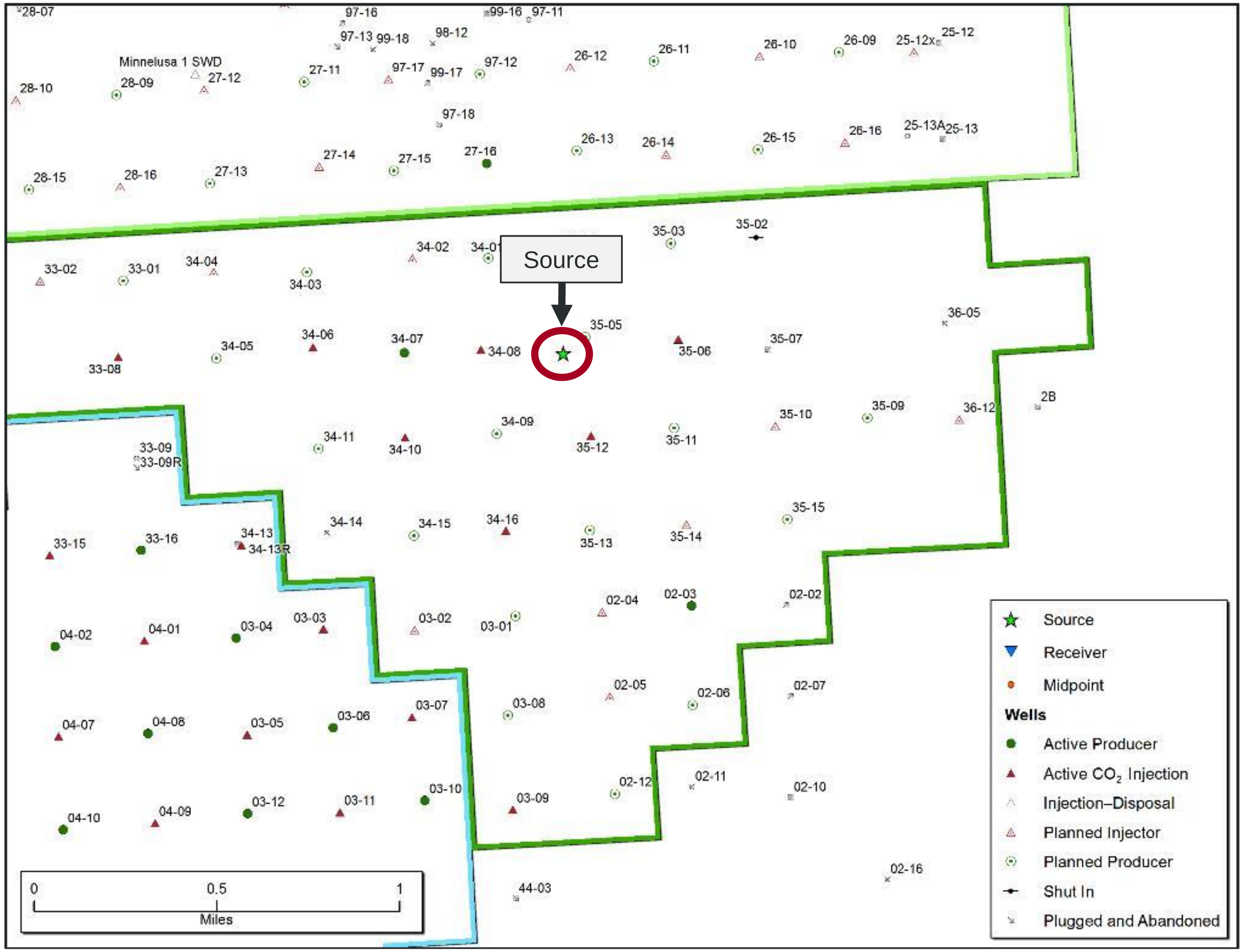


Stratigraphic Column for the Bell Creek Area with Lithology

Muddy Fm ~4500’ Deep

ARRAY LAYOUT

- Monitoring focuses on four injector–producer patterns covering about one square mile.
- The source location is indicated by the green star.

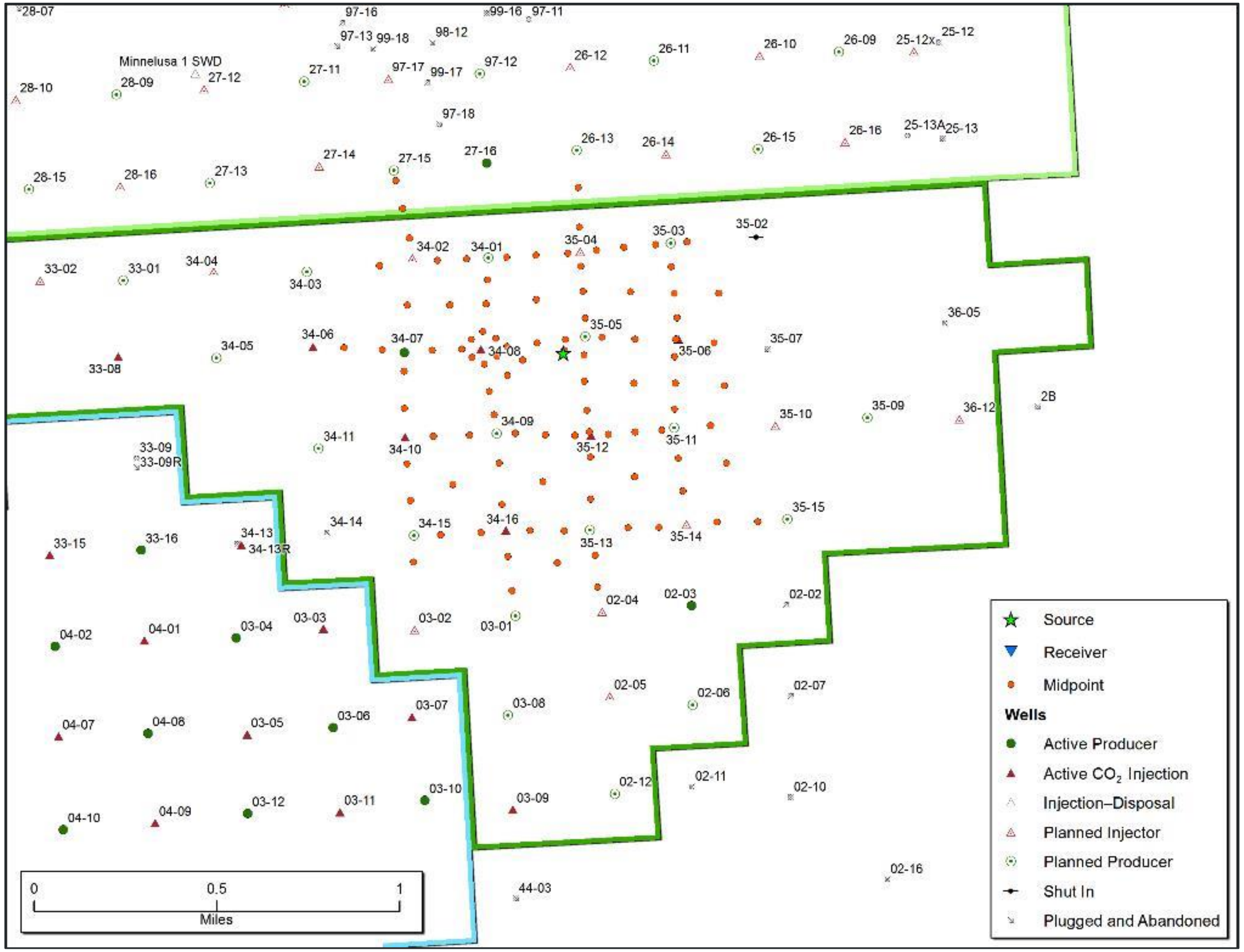


EERC

Critical Challenges. **Practical Solutions.**

ARRAY LAYOUT

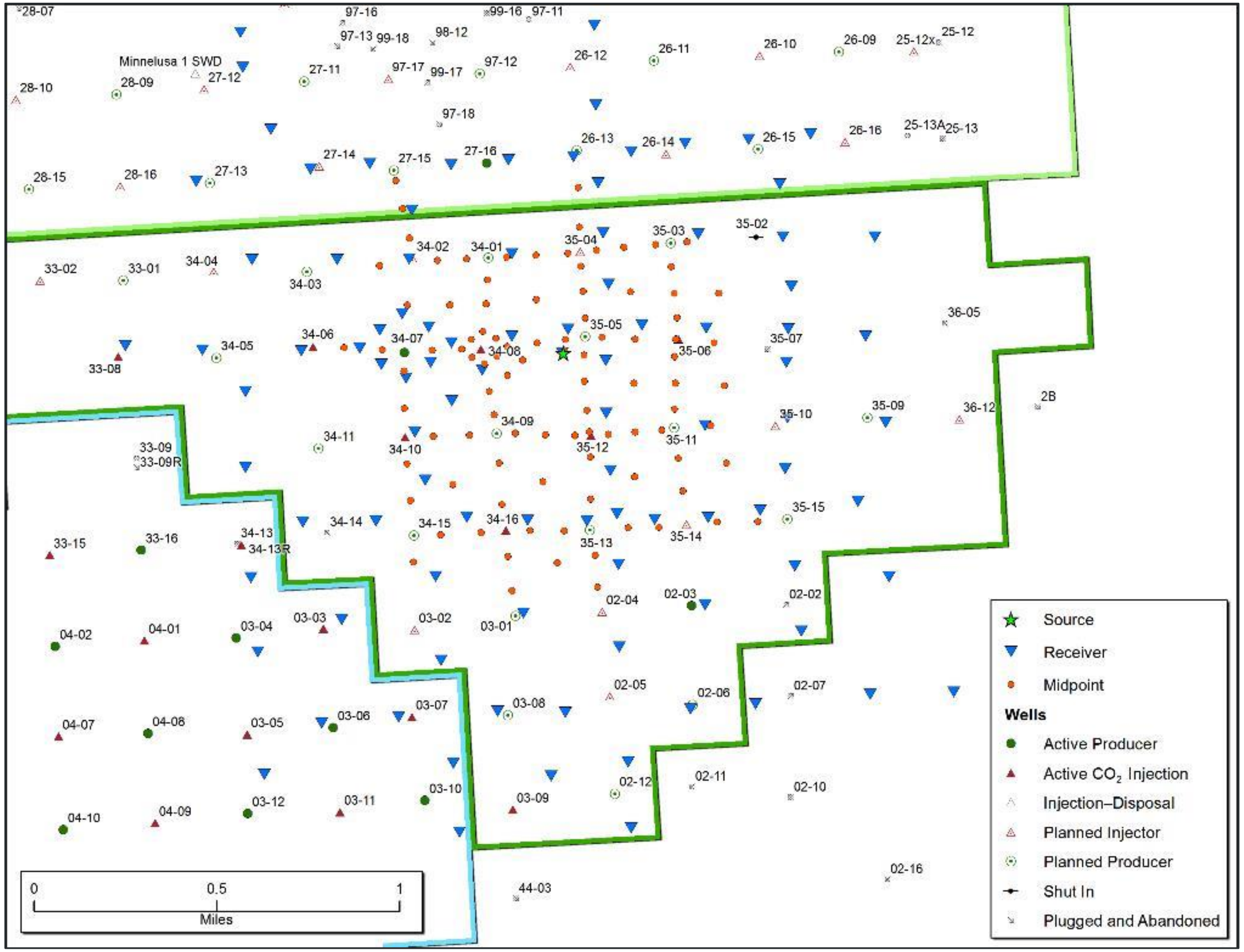
- Monitoring focuses on four injector–producer patterns covering about one square mile.
- The source location is indicated by the green star.
- Orange dots represent monitored points.



EERC

ARRAY LAYOUT

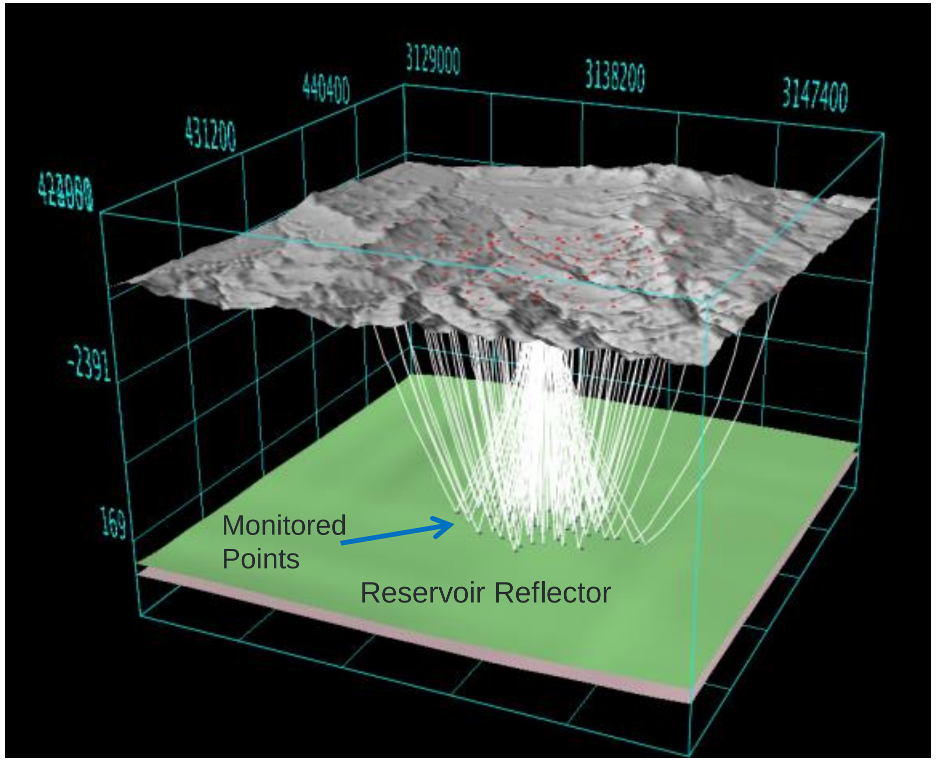
- Monitoring focuses on four injector–producer patterns covering about one square mile.
- The source location is indicated by the green star.
- Orange dots represent monitored points.
- Blue triangles are receiver locations.



DETERMINING RECEIVER LOCATIONS

- 3-D velocity modeling:
  - Layered velocity model based on 3-D seismic depth volume
  - Lidar elevation data

- Iterative ray-tracing is used to locate geophone positions that would illuminate the desired reflection point locations.

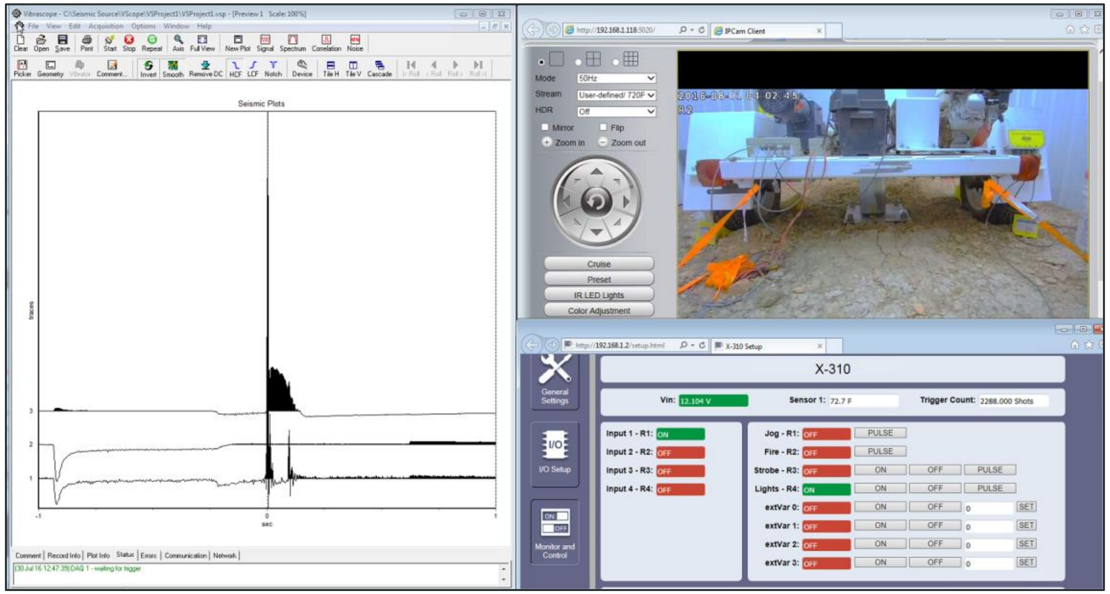


SOURCE AND RECEIVER REPEATIBILITY

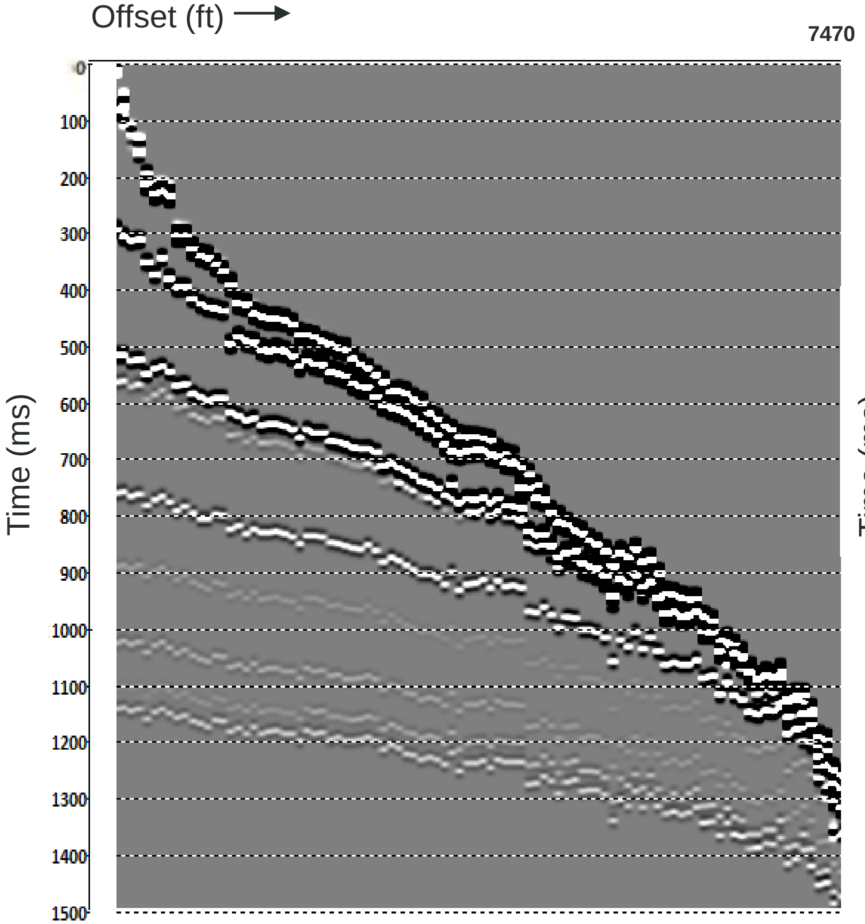
- Source
  - GISCO ESS850 850-lb elastomer-accelerated weight drop.
  - 1500-lb source footing and strike plate to help ensure consistent source signature over course of project. 3-ft x 3-ft base.
- Fairfield Zland nodes make up the semipermanent array.
  - 96 autonomous, 3-C nodes with 5-Hz geophones.
  - Node installation is semipermanent, “dug-in,” and protected by a section of PVC pipe and a cover.

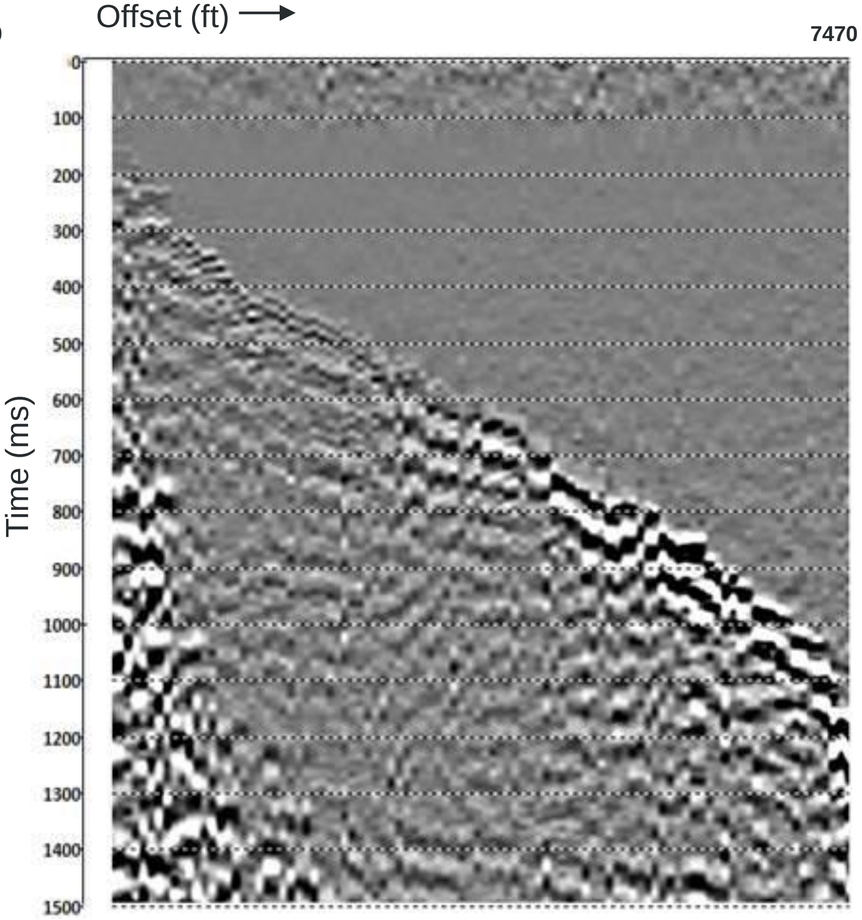
DATA ACQUISITION

- Nodes wake and receive data only on weekend days and a short time on Mondays to save battery life.
- Source remote control:
  - Via commercial satellite Internet link.
  - Web server-controlled relay box sends “fire” signal.
  - Outputs from sensors, Internet camera, and source signature recorder allow remote assessment of shot quality.
  - Safe operation: locked facility, visual confirmation of nonoccupancy, warning lights.



MODEL DATA VS. SASSA DATA



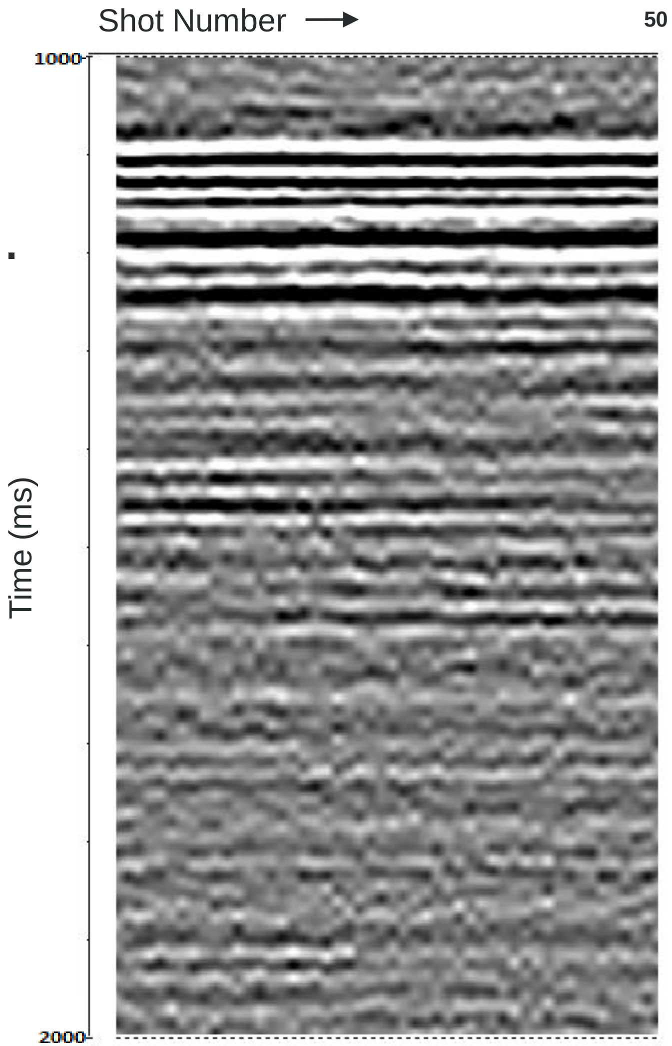


Left panel: Modeled data of the vertical component ordered by offset from the source.
Right panel: Actual data.

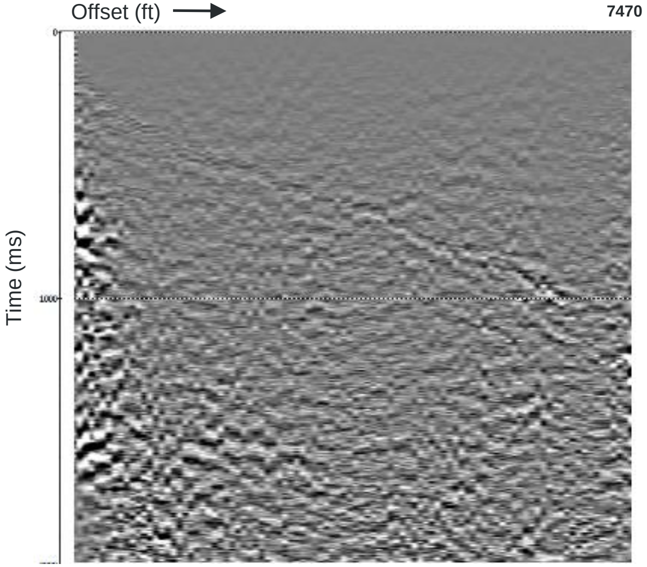
DATA PROCESSING

- Source is remotely fired 50 times.
  - Increased signal-to-noise through vertical stacking.
  - Allows for receiver domain processing prior to stacking.

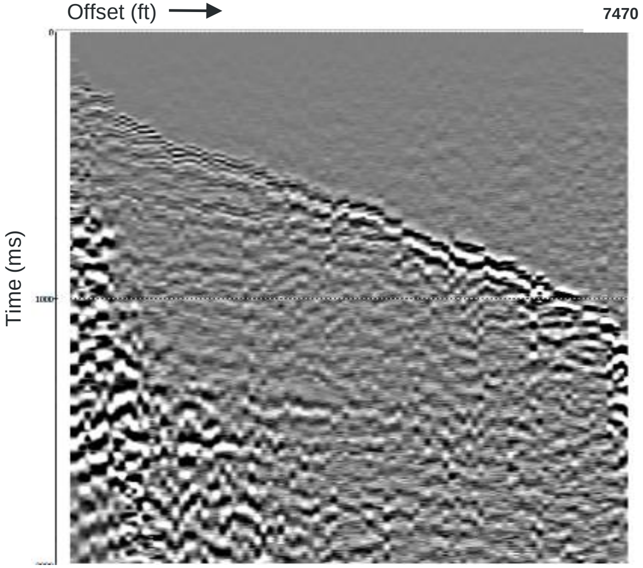
Receiver Gather



One Shot

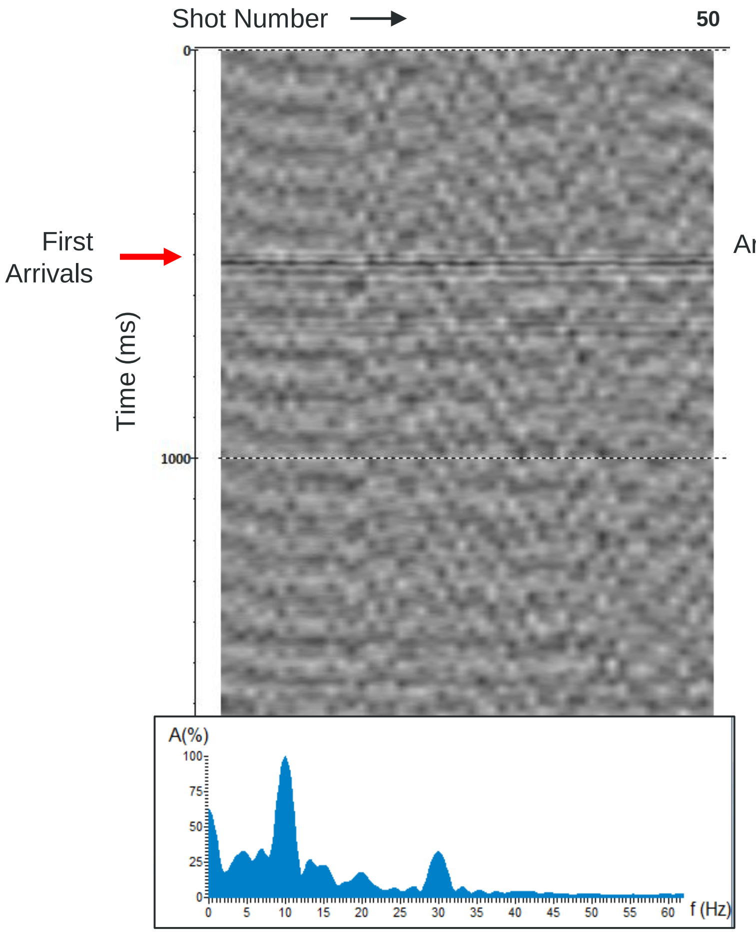


50 Shots
Vertically Stacked

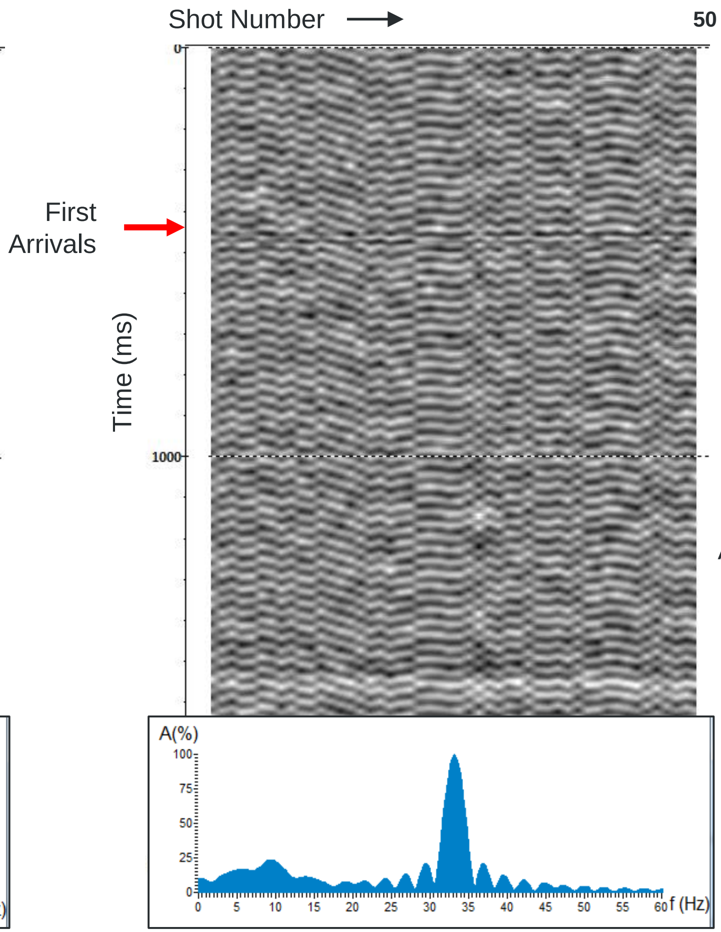


INDIVIDUALIZED RECEIVER PROCESSING

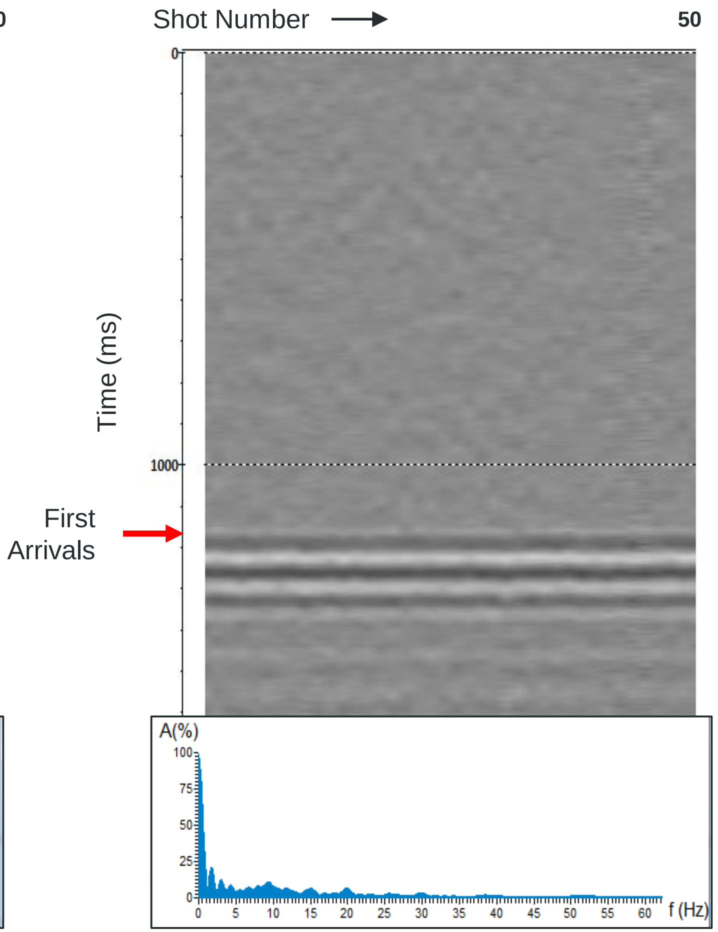
Receiver Station: 278 Line: 274
Offset: 2890 ft



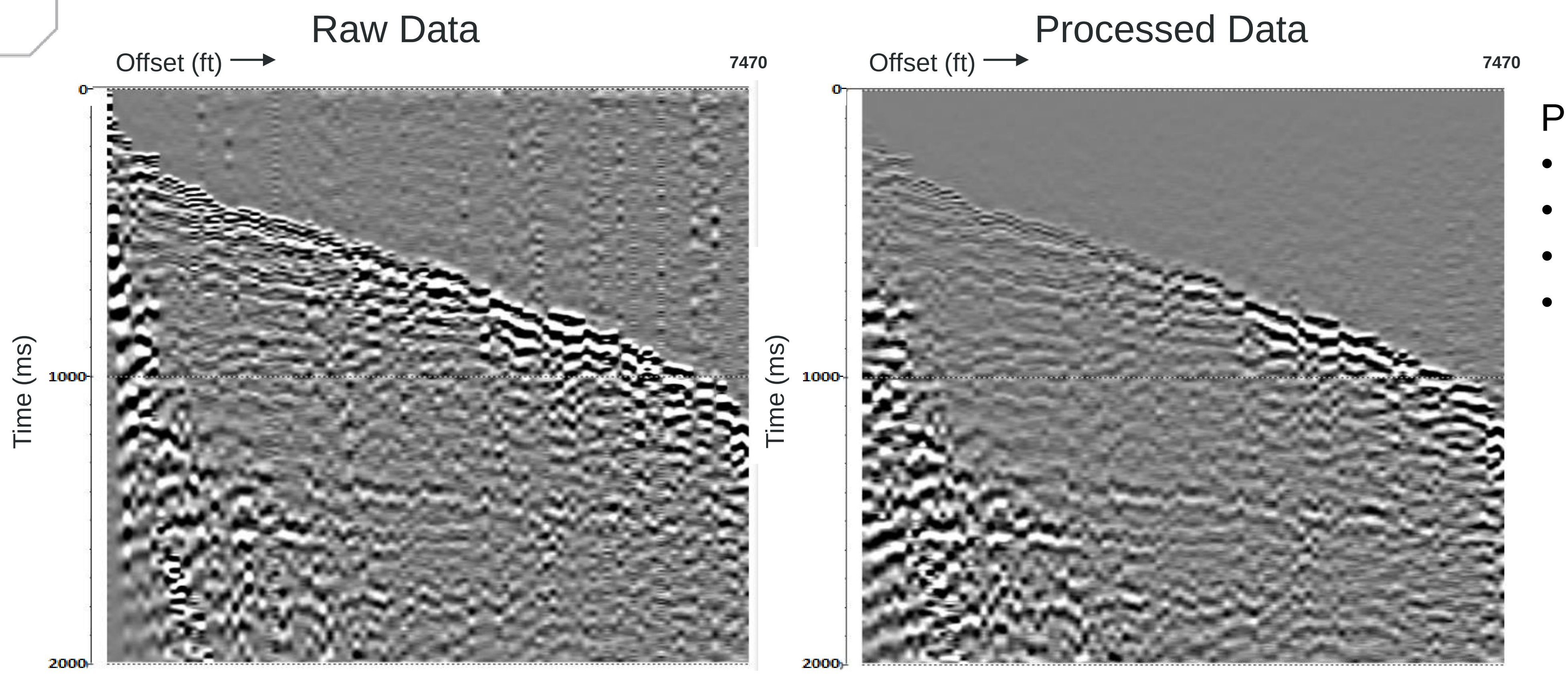
Receiver Station: 346 Line: 341
Offset: 2600 ft



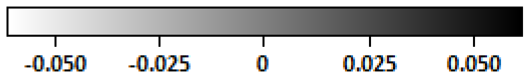
Receiver Station: 11 Line: 11
Offset: 7470 ft



SHOT DOMAIN NOISE ATTENUATION



Vertical stack and Bandpass (5-10-100-125) for display purposes.

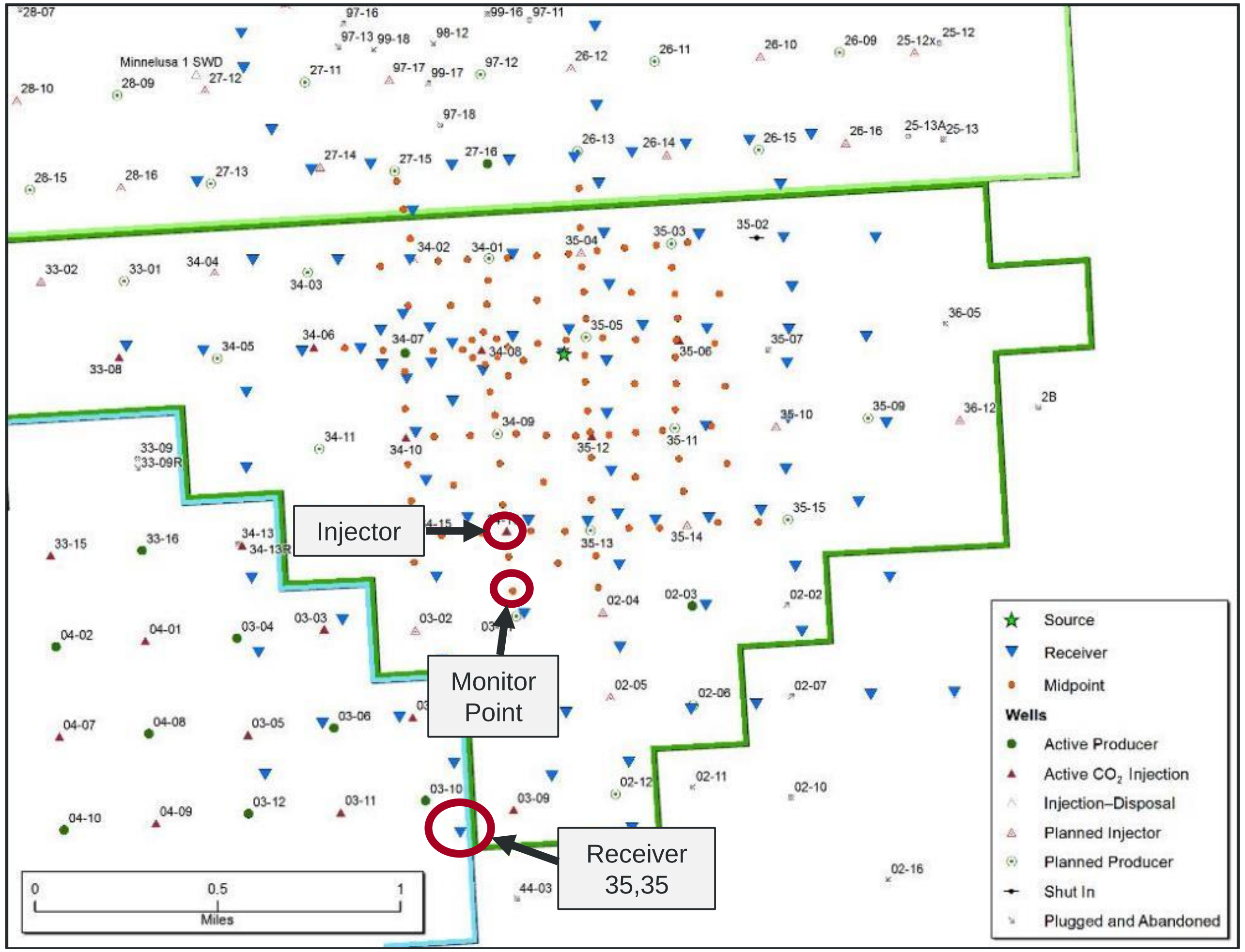


Processing Flow:

- Spherical divergence
- Burst noise removal
- High cut filter (125 Hz)
- Time and frequency domain (TFD) noise removal

RECEIVER DOMAIN PROCESSING

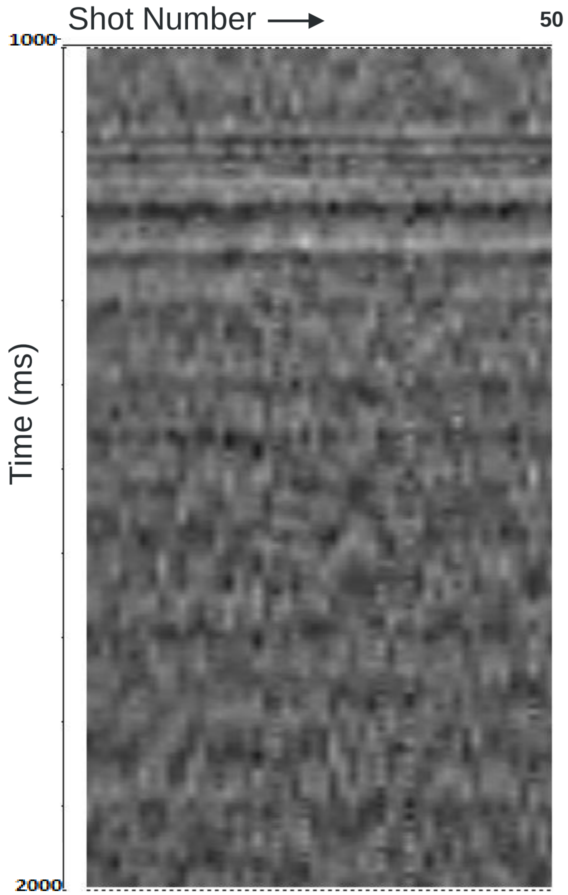
Receiver Line 35, Station 35 (Offset: 7076 ft)



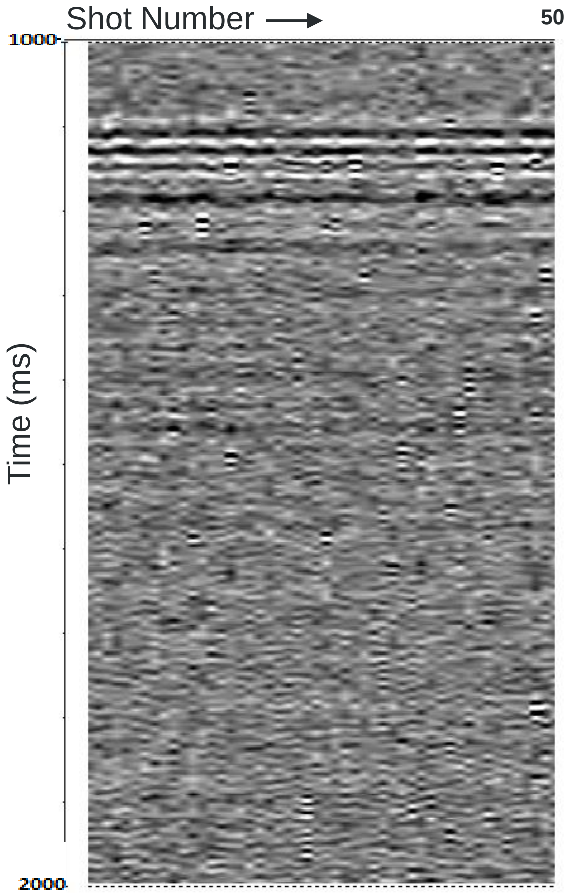
RECEIVER DOMAIN PROCESSING

Receiver Line 35, Station 35 (Offset: 7076 ft)

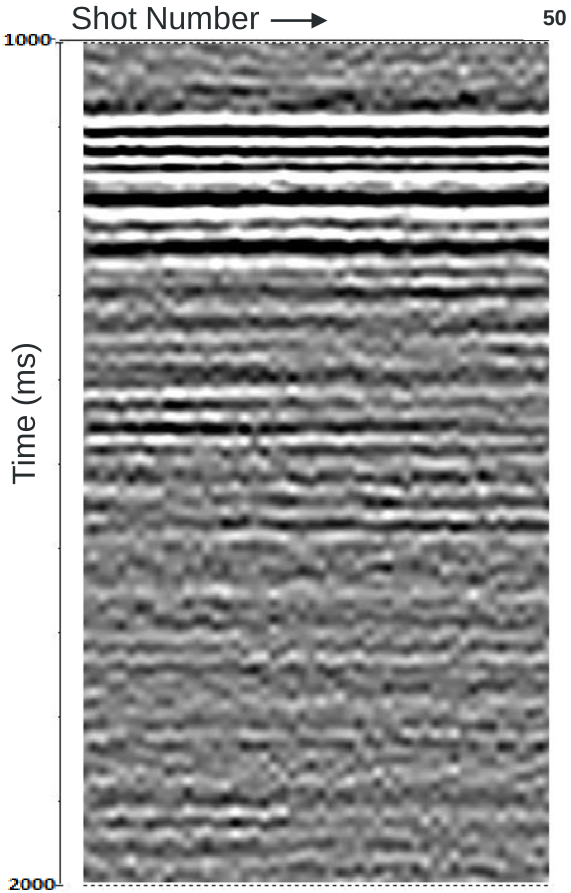
Sort to Receiver Domain



Gap Deconvolution (64 ms)
Spiking Deconvolution

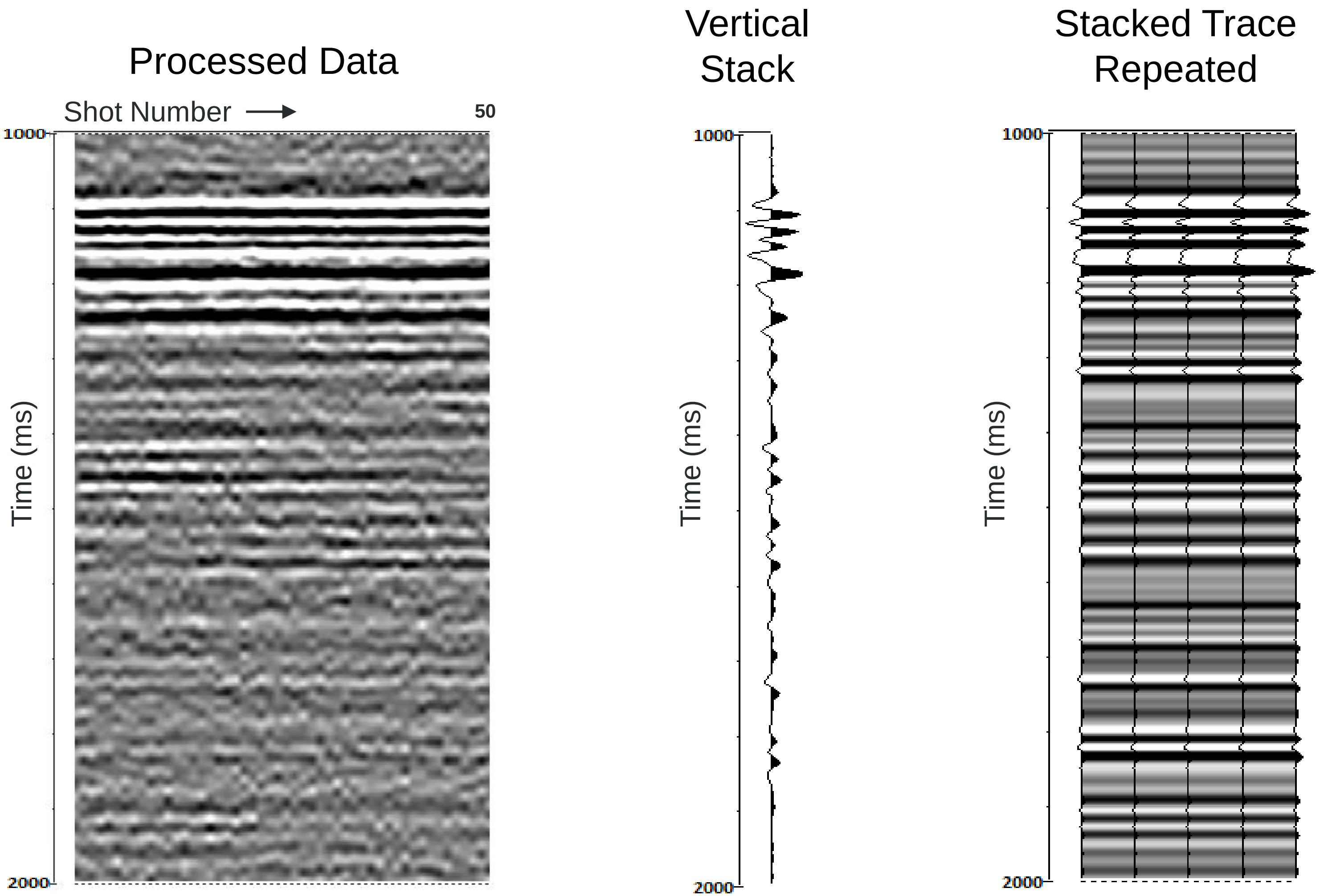


F-X Predictive Filtering
Bandpass (10-15-55-60)



RECEIVER DOMAIN PROCESSING

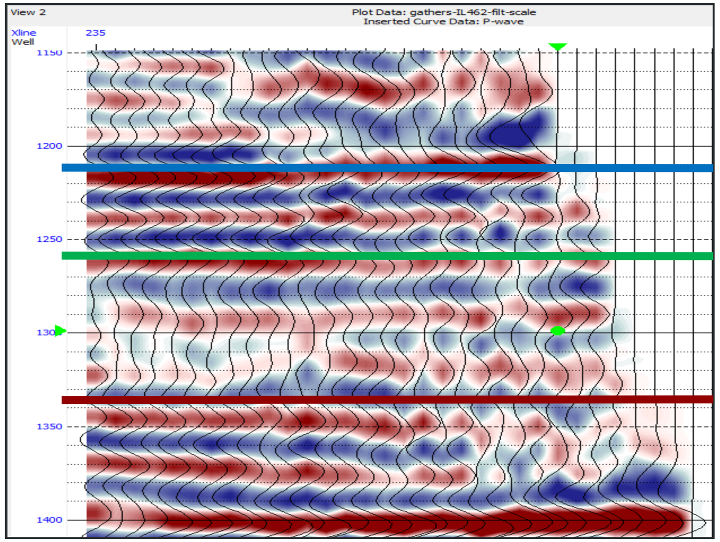
Receiver Line 35, Station 35 (Offset: 7076 ft)



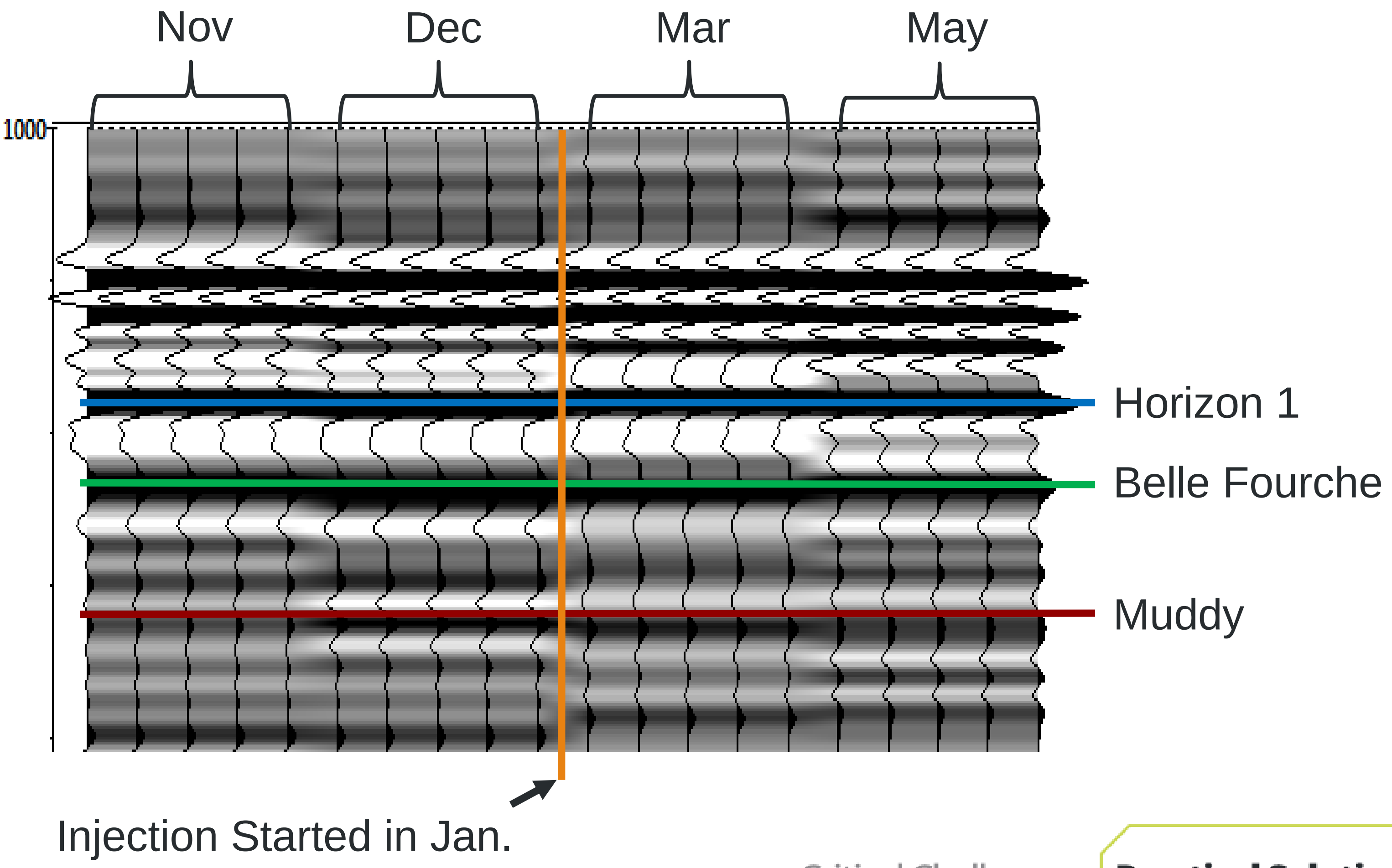
SASSA DATA VS. 3-D DATA

Receiver Line 35, Station 35 (Offset: 7076 ft)

CDP Gather from
3-D Baseline Survey

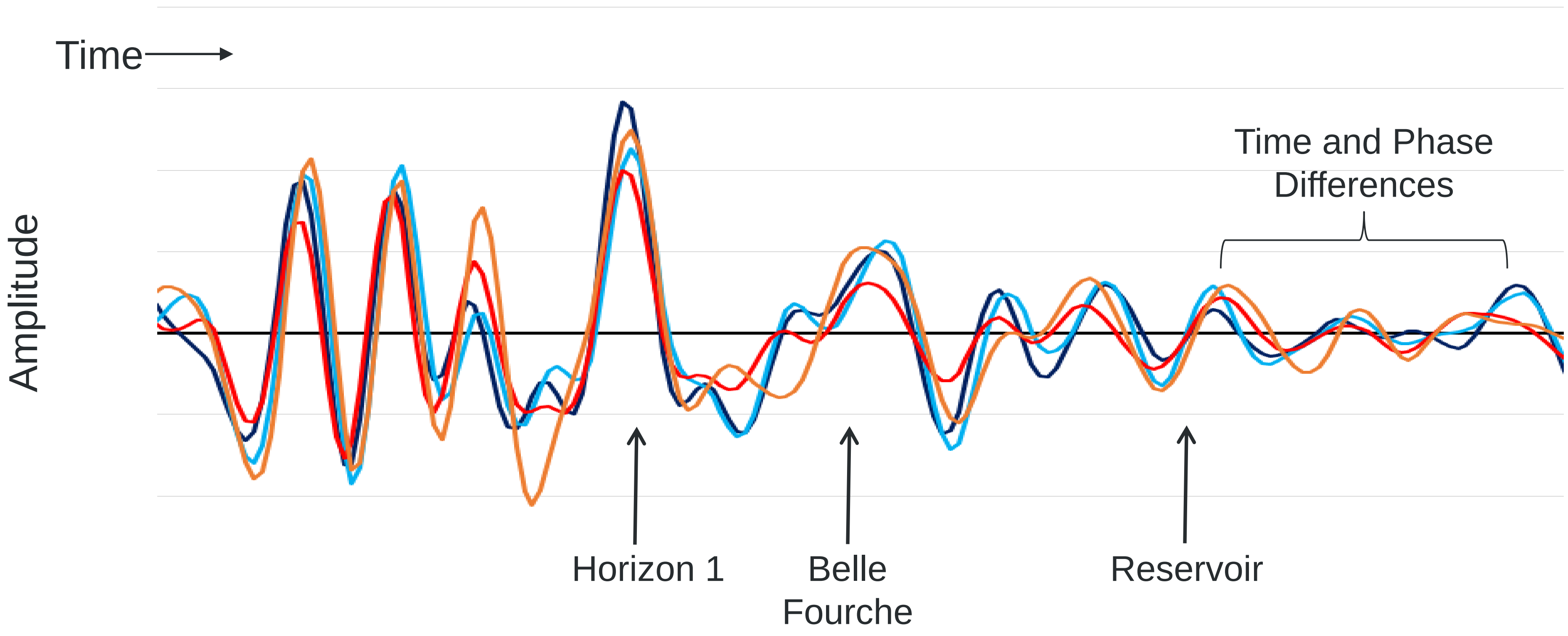


SASSA Time-Lapse Panels



ANALYZING STACKED TRACES

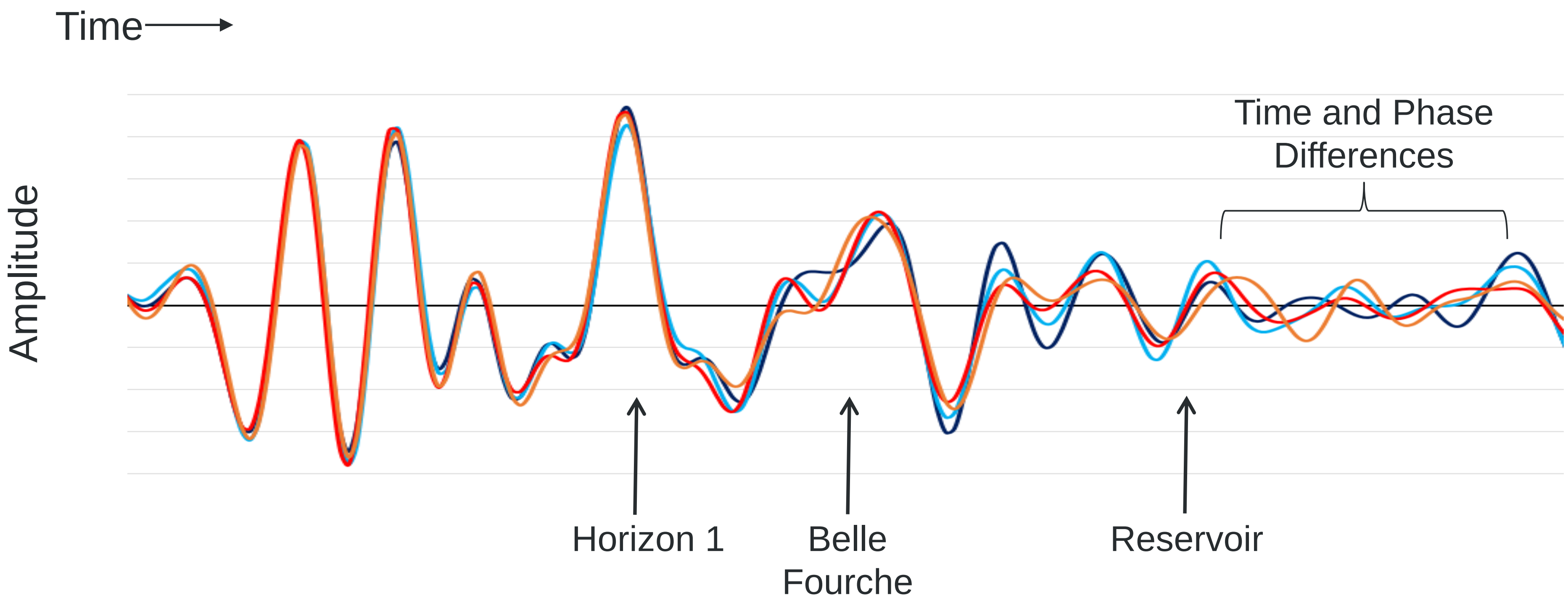
Receiver Line 35, Station 35 (Offset: 7076 ft)



Lt. and Dark Blue: Preinjection
Red and Orange: Postinjection

ANALYZING STACKED TRACES

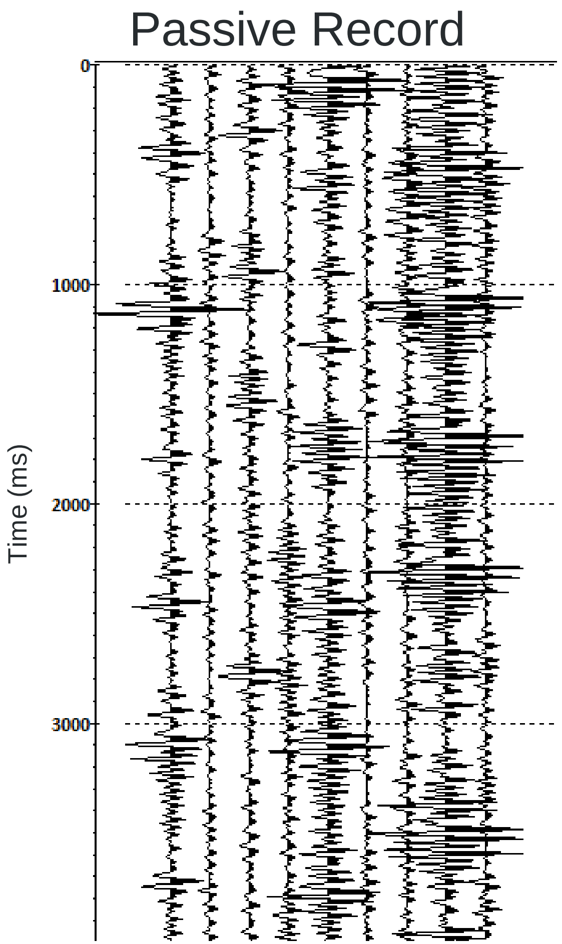
Receiver Line 35, Station 35 (Offset: 7076 ft)

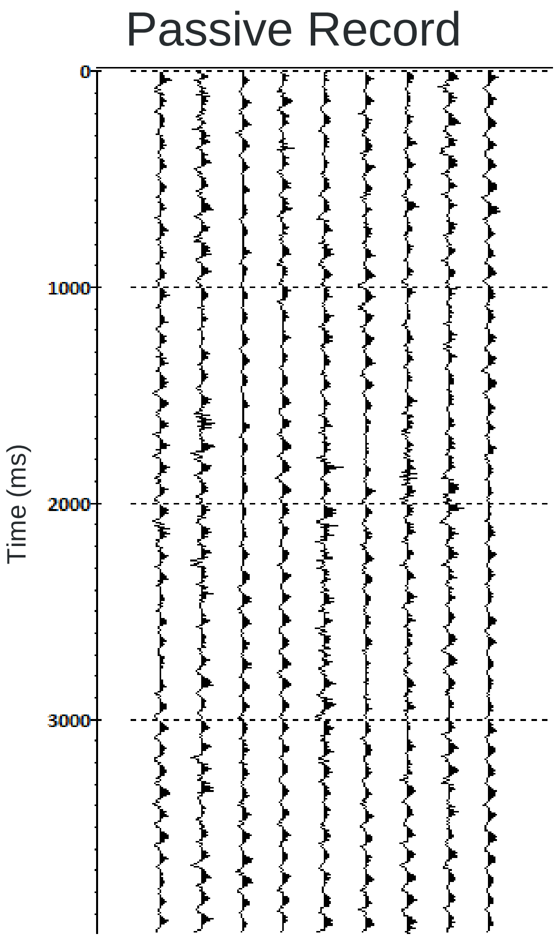


Lt. and Dark Blue: Preinjection
Red and Orange: Postinjection

NOISE ANALYSIS FOR IMPROVED PROCESSING

- Noise analysis
  - Utilizing passive seismic data to assess noise
  - Weather history data
  - Near-surface condition and seasonal changes

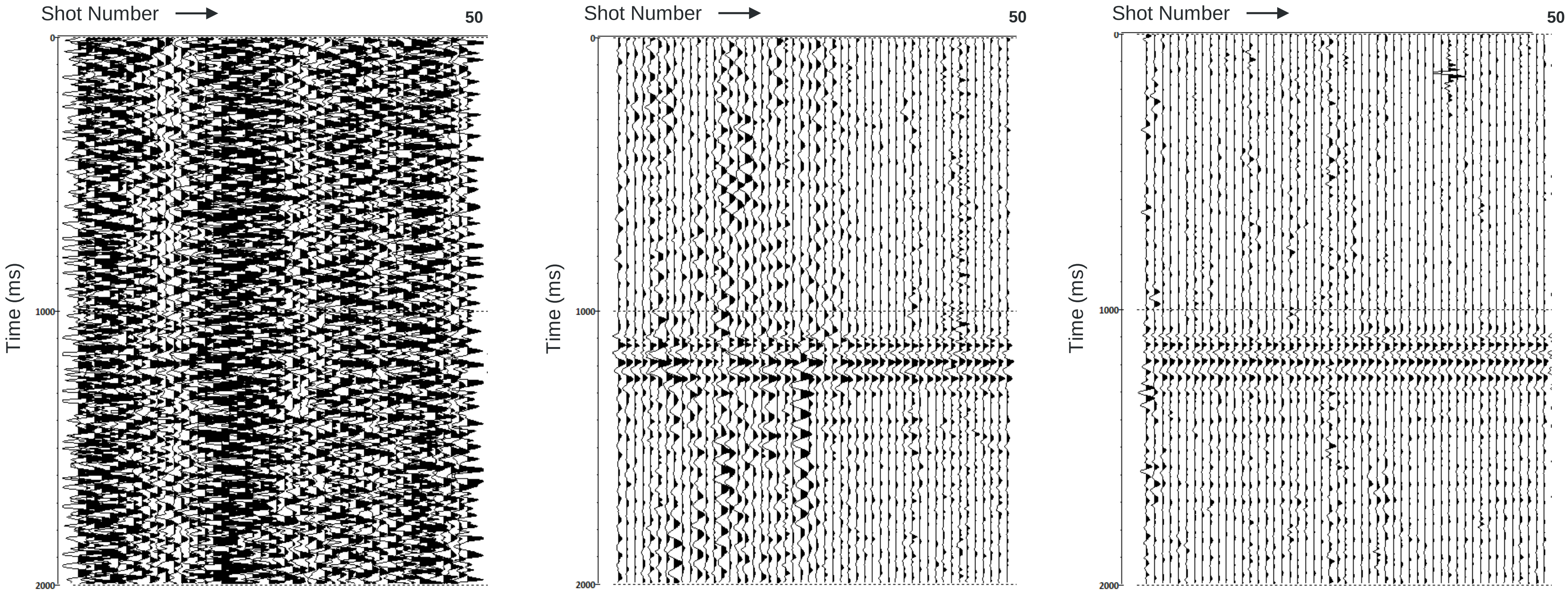




NOISE VARIATION DUE TO WEATHER CONDITIONS

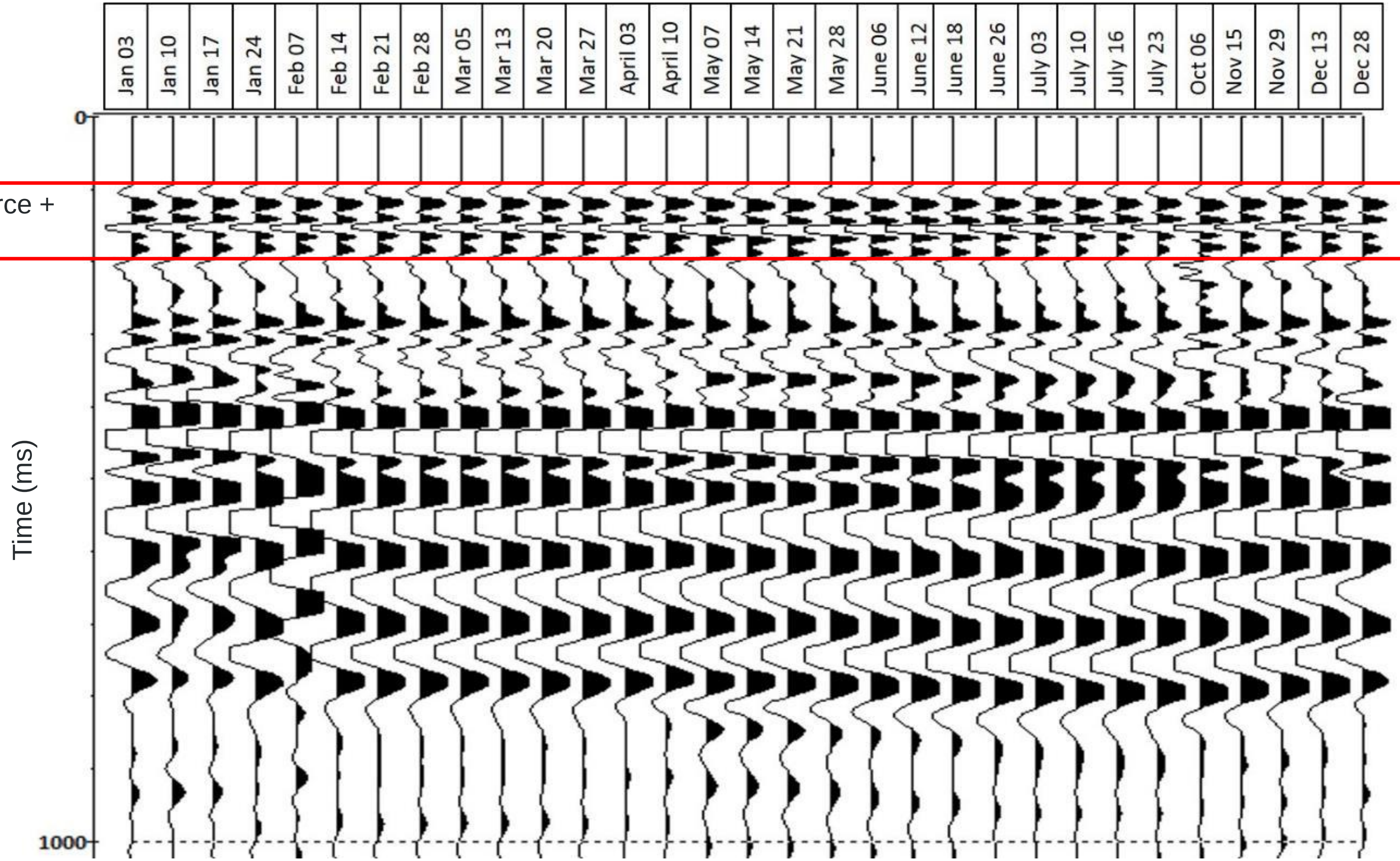
Receiver Line 35, Station 35 (Offset: 7076 ft)

02-07-16	02-28-16	07-03-16
15-30 mph wind	9-12 mph wind	0-5 mph wind



SASSA NEAR-FIELD SOURCE SIGNATURE

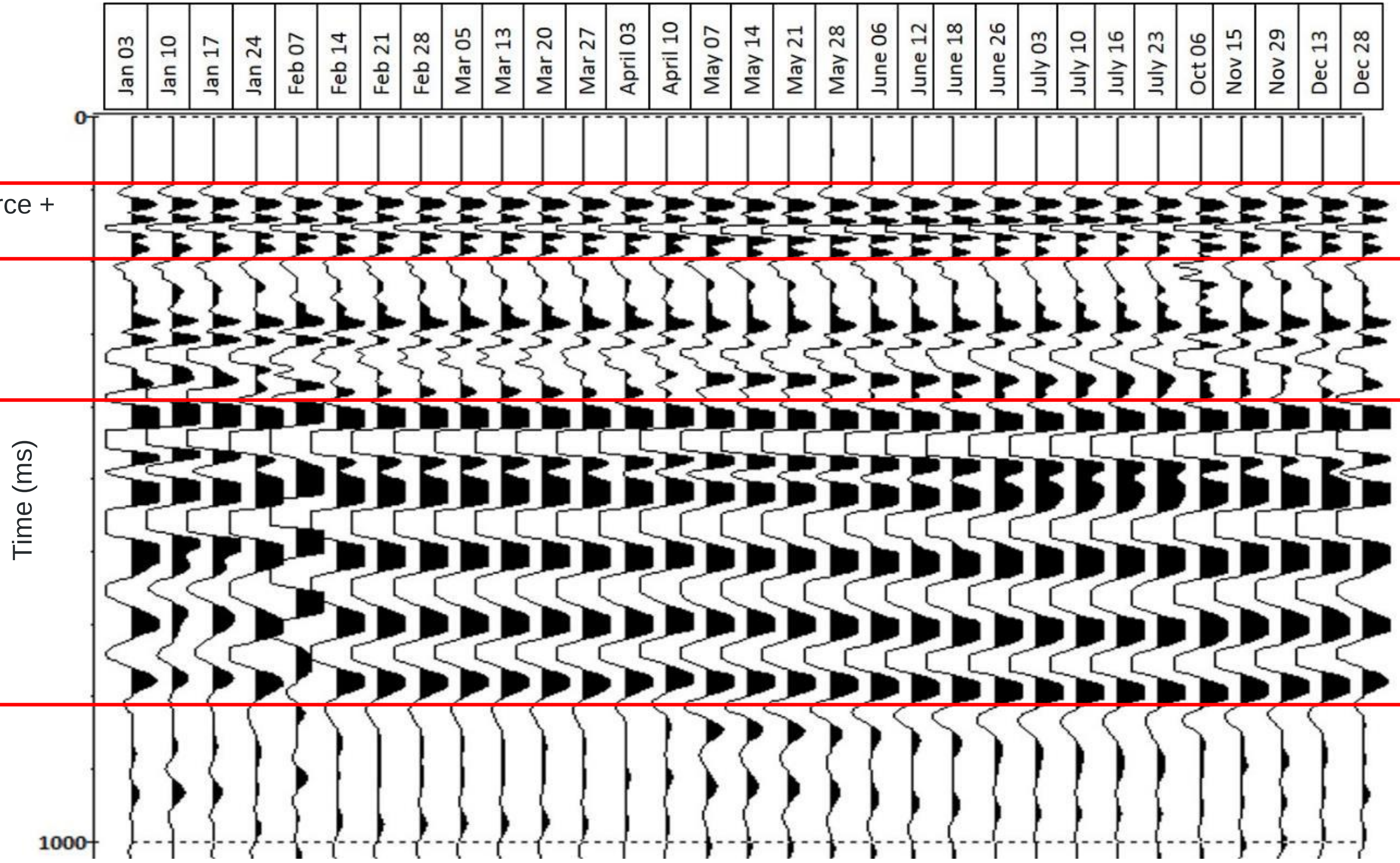
First arrival character (source + bounce) is very consistent.



SASSA NEAR-FIELD SOURCE SIGNATURE

First arrival character (source + bounce) is very consistent.

Ground Roll

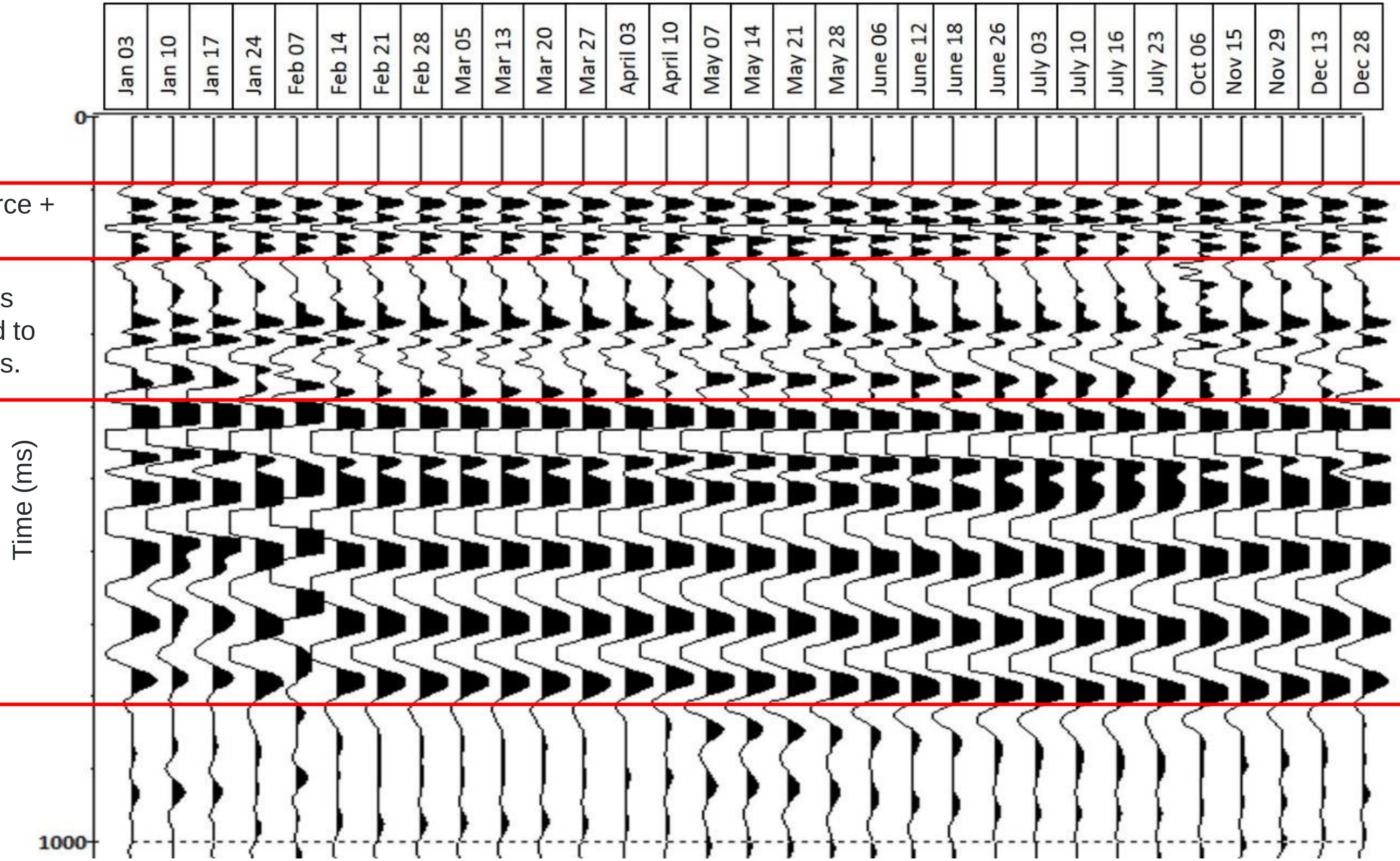


SASSA NEAR-FIELD SOURCE SIGNATURE

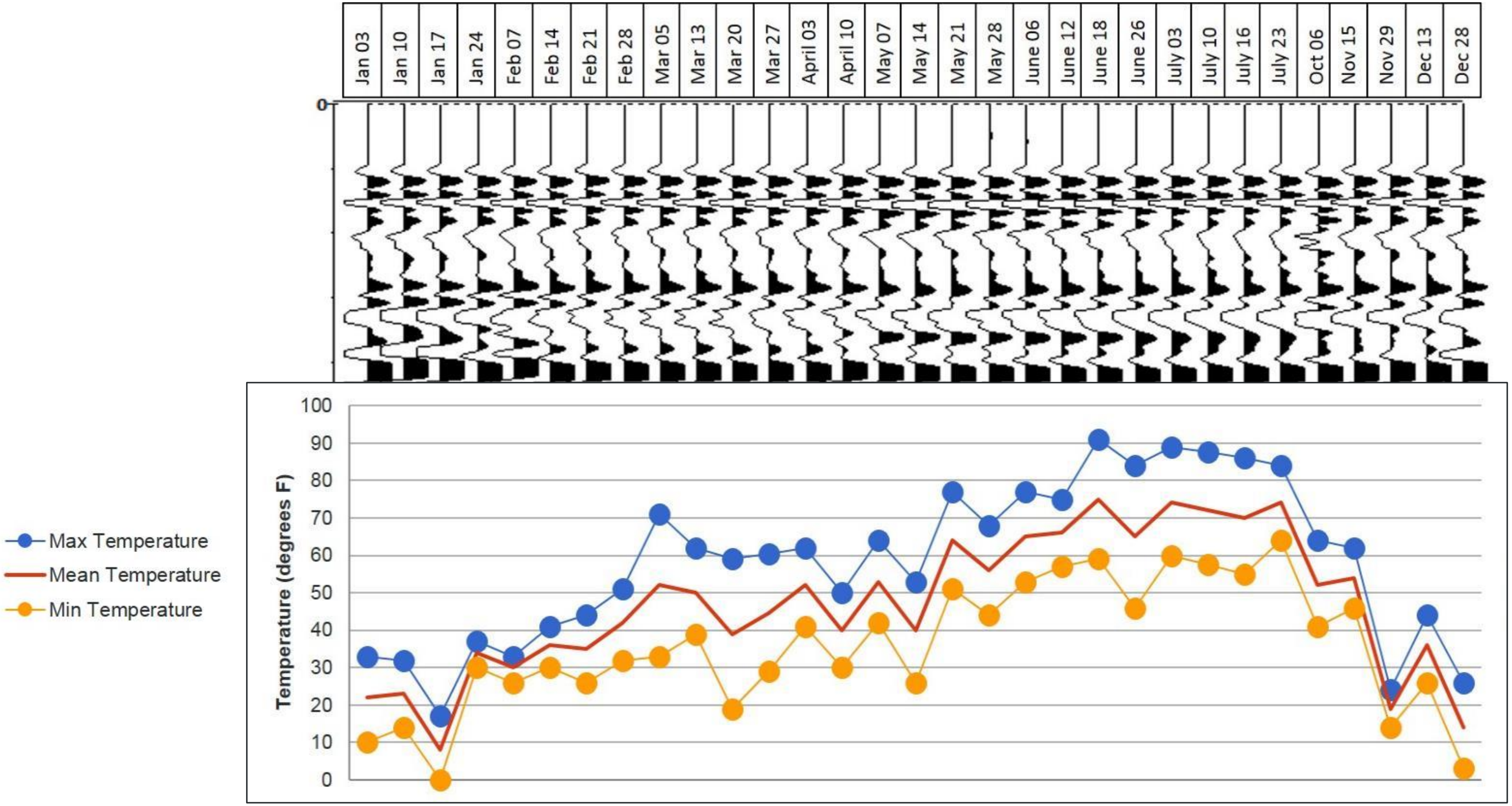
First arrival character (source + bounce) is very consistent.

Most variation occurs in this interval and may be related to seasonal surface conditions.

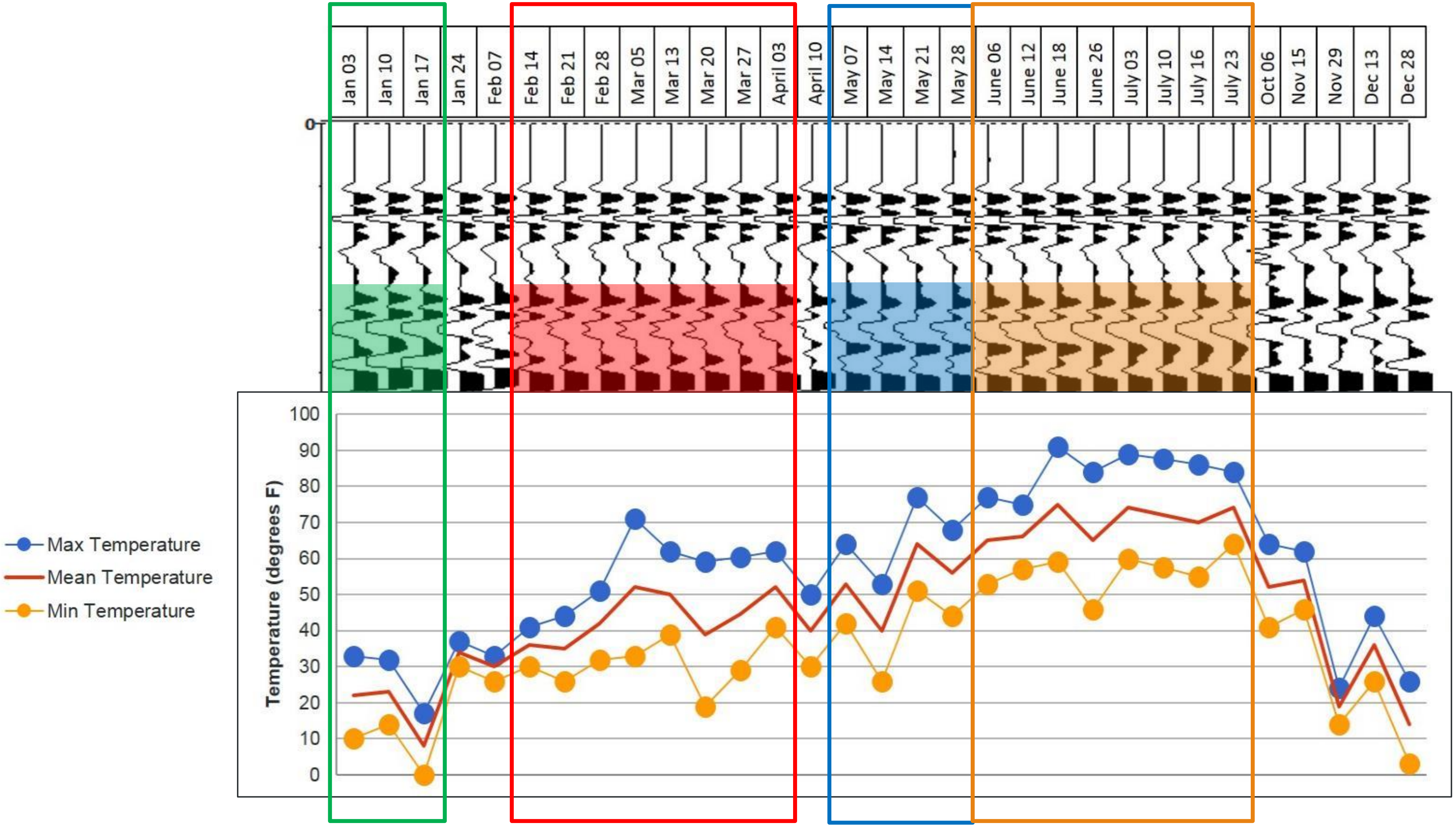
Ground Roll



NOISE VARIATION DUE TO SEASONAL CHANGES



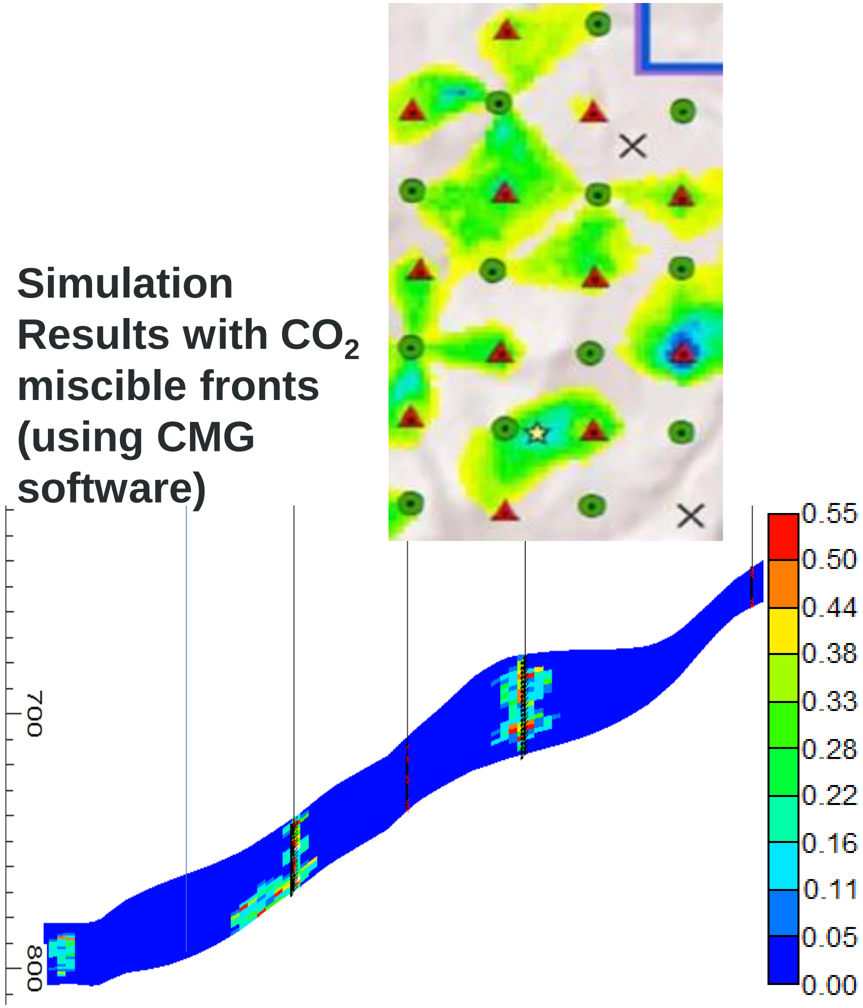
NOISE VARIATION DUE TO SEASONAL CHANGES



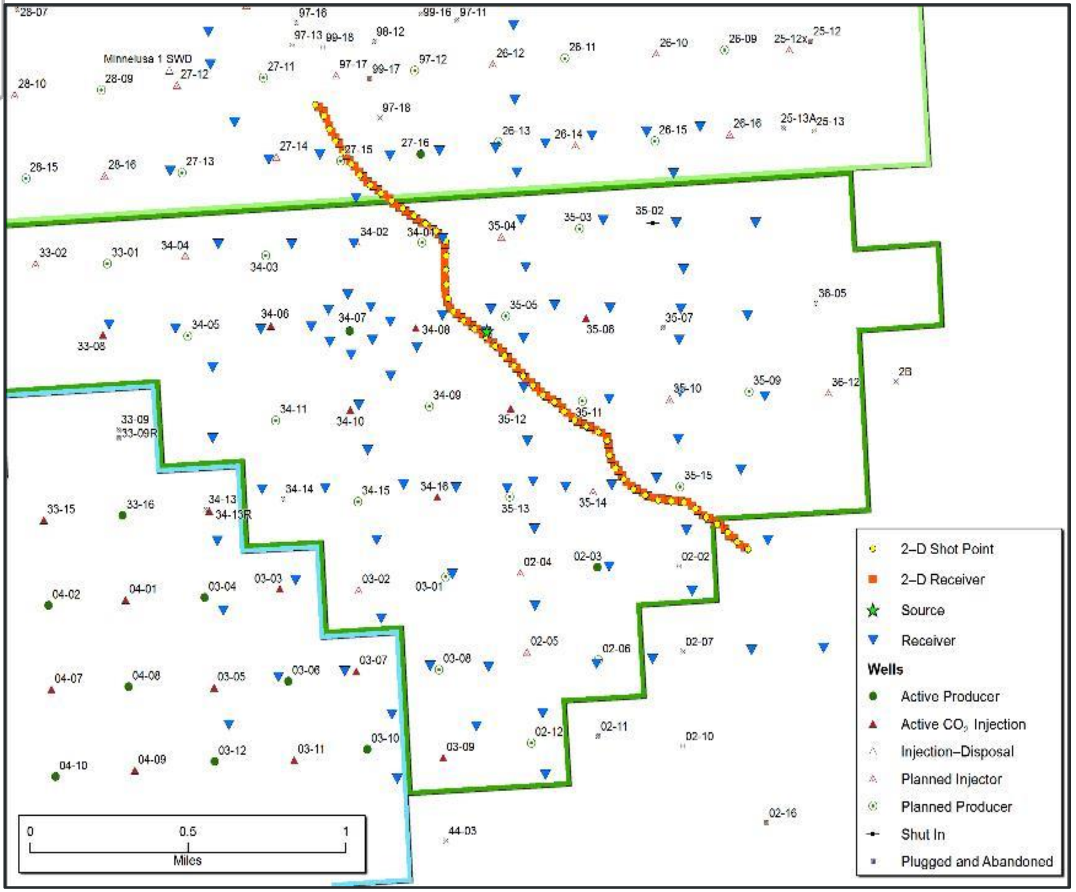
NEXT STEPS – DYNAMIC RESERVOIR SIMULATION

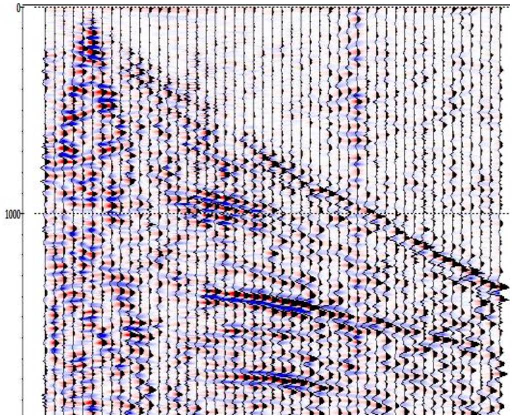
- Predictive simulations of CO_2 miscible front development using Computer Modelling Group (CMG) software to corroborate and help evaluate SASSA results.
  - A subset of the current Bell Creek static geologic model covering the SASSA area will be the input.
  - After SASSA results are available, they may be used to recalibrate the simulation.
  - A time-lapse 2-D line will provide validation and will allow for evaluation of the SASSA and simulation results.

Simulation Results with CO_2 miscible fronts (using CMG software)

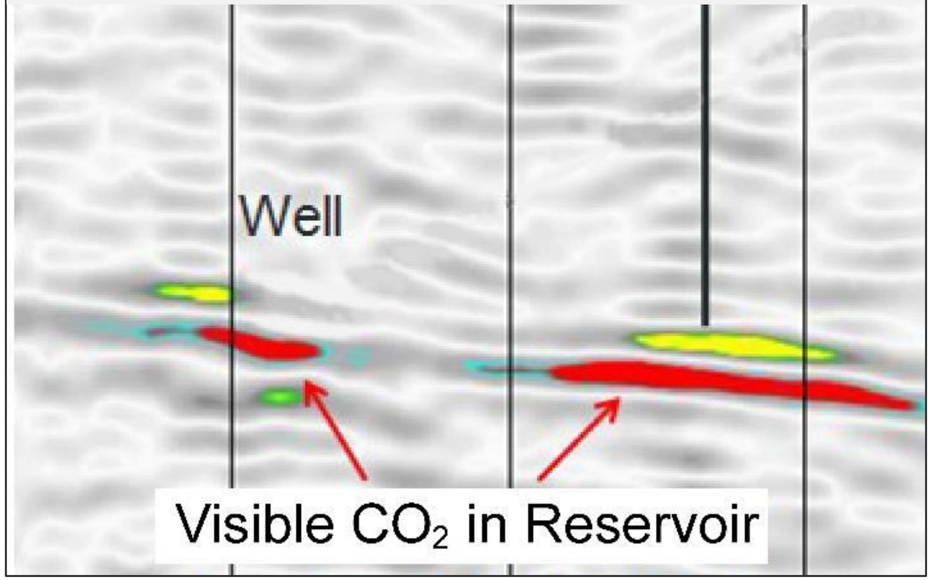


2-D TIME-LAPSE ANALYSIS FOR VALIDATION





2-D Seismic Difference Display Example



2-D line shot point and receiver locations were along a road going through the study area. Time-lapse difference images from the line will help validate the SASSA results.

ACCOMPLISHMENTS TO DATE

- Equipment procured – source, recording system, remote control, structure.
- Source location selected; source structure and strike plate installed.
- Monitored midpoints chosen, geophysical modeling to determine receiver positions completed, semipermanent array designed and installed.
- Recording system and source remote control system installed, tested, and in use.
- 2-D baseline seismic data acquired; 2-D line processing in progress.
- Data collection is ongoing – 34 weeks of data to date.
- Processing workflow development and parameter testing in process.
- Preliminary time-lapse comparison of weekly data sets started.
- Individual geologic reflectors and reservoir reflector identified.

SYNERGY OPPORTUNITIES

- Several international CO_2 storage projects are experimenting with fixed sources and permanent or semipermanent receiver arrays.
  - Aquistore (Canada)
  - Otway (Australia)
  - Tomakomai (Japan)
- They may be able to apply the SASSA time-lapse seismic trace analysis process.
- A task in the Intelligent Monitoring project is to apply the SASSA time-lapse trace analysis work to Aquistore data.

SUMMARY

- Project Goal 1 met: Equipment procured, installed, and operational.
  - Several baseline data sets were collected prior to start of injection.
- Project Goal 2 is in process:
  - 10 months of successful data collection to date, continuing until the end of October.
  - Data-processing workflow development is active, and processed data are interpretable.
- Key findings
  - Noise levels vary from week to week, with frequent cultural noise. Data from individual nodes require individual attention.
  - Near-surface conditions change with the seasons and affect the source signature. Corrections for these effects are in process.
- Lessons learned
  - Ground roll presents a data-processing challenge for nodes at certain offsets.
  - A way to gauge current weather conditions before shooting would be an advantage.
- Future plans
  - Complete data collection, acquire the postinjection 2-D line, compute predictive simulations, and perform in-depth analysis and validation of the results.

ACKNOWLEDGMENTS

- Thank you to the EERC Geophysics Team of Shaughn Burnison, Dr. Olarinre Salako, and Dr. César Barajas-Olalde and the project management leadership of John Hamling and Charlie Gorecki.
- The EERC thanks Denbury Onshore LLC for providing field access, technical advice, and assistance in the Bell Creek Field.
- CGG GeoSoftware is acknowledged for the donation of HRS-10 software that was used in generating some of the results for this project and presentation.
- Thanks to the many staff members at the EERC who have contributed to the success of this project, including senior management, project management, technical staff, field teams and field support, project support, legal and contracts, procurement, travel, administration, IT, graphics, editing, and more.
- This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under Award No. FE0012665.

THANK YOU!

Critical Challenges. **Practical Solutions.**

APPENDIX

- Organization chart
- Gantt chart
- Bibliography

ORGANIZATION CHART

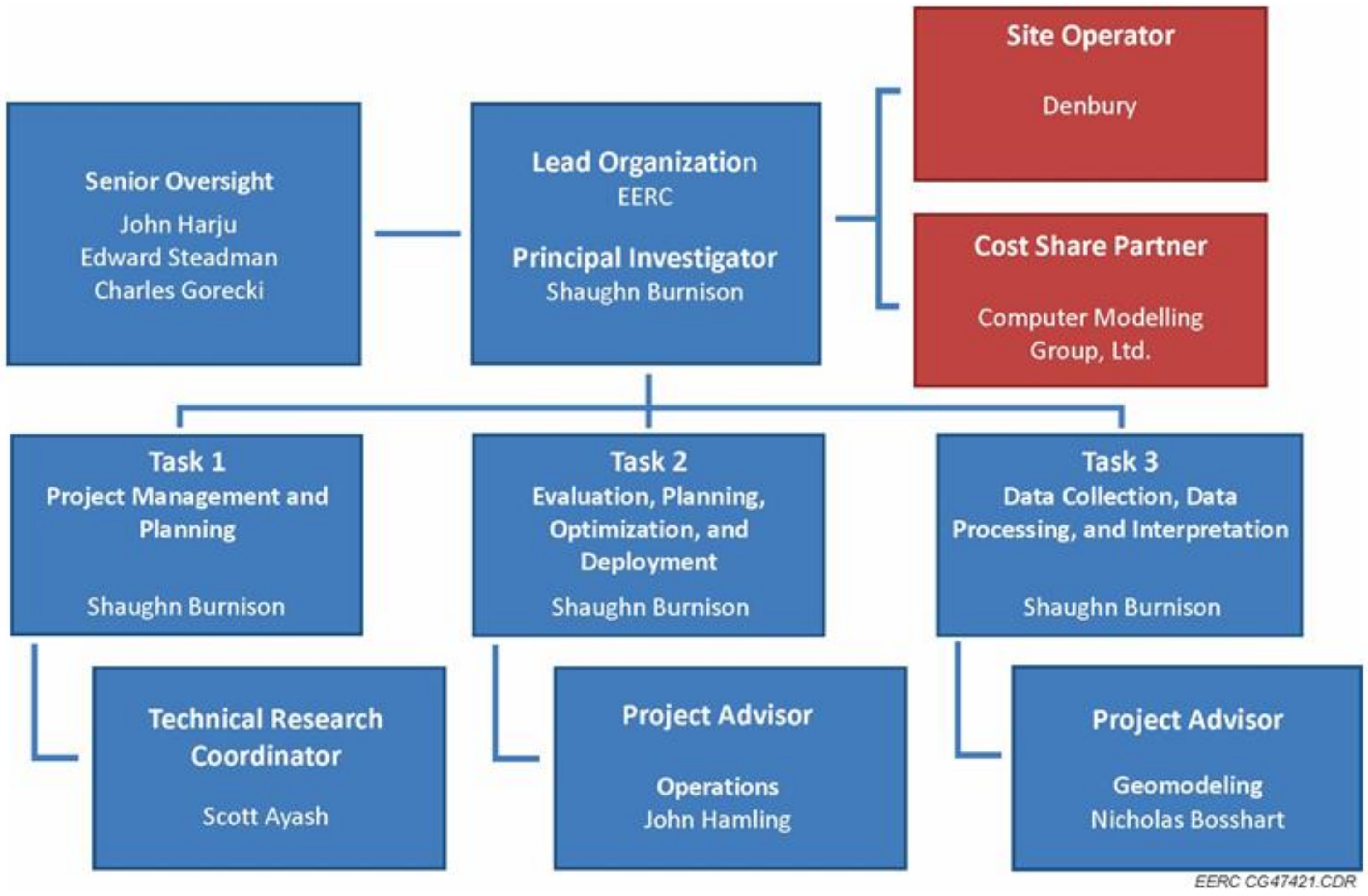
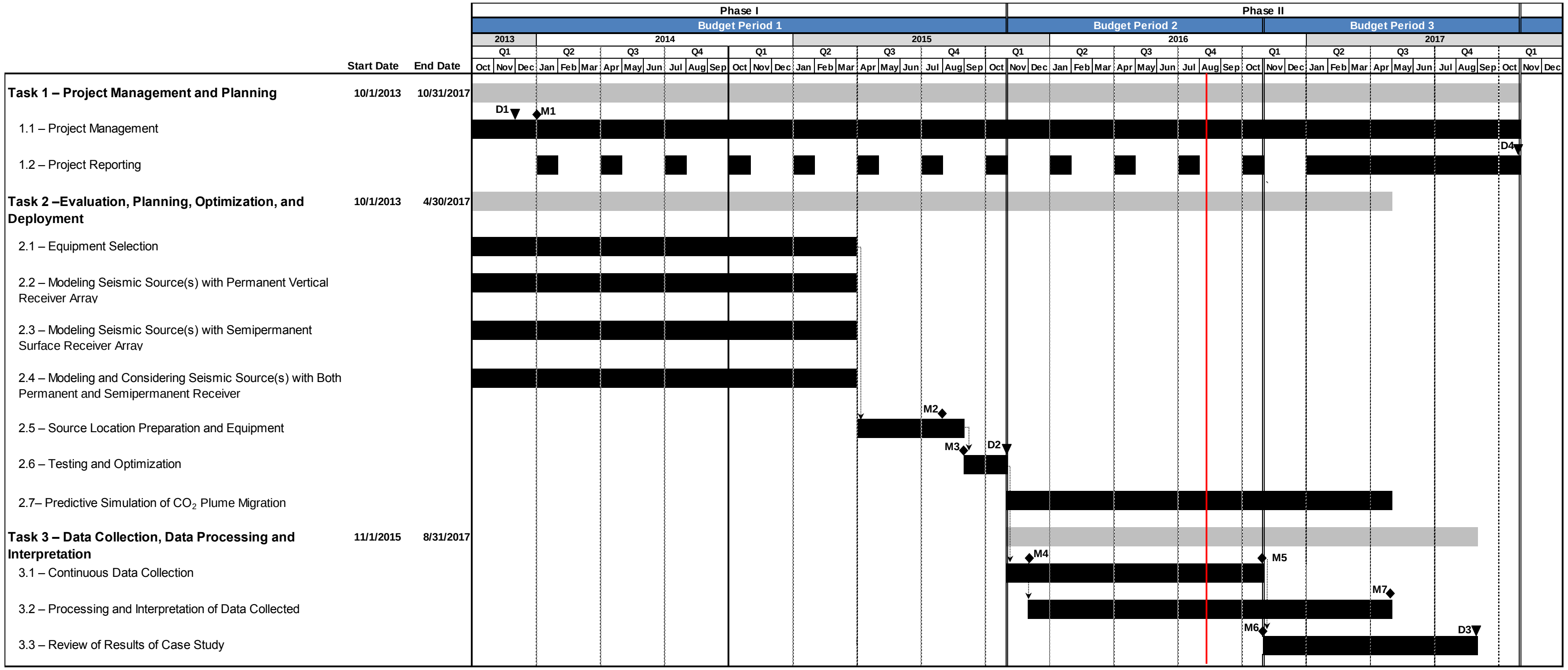


Figure 1. Project organization chart.

GANTT CHART



- Summary Task
- Activity Bar
- Milestone (M) ◆
- Deliverable (D) ▼
- Critical Path

Key for Deliverables (D) ▼	Key for Milestones (M) ◆
D1 – Updated Project Management Plan (PMP)	M1 – Project Kickoff Meeting Held
D2 – Interim Report on Completion of Technical Design	M2 – Source Location Preparation Initiated
D3 – Technical Paper or Journal Article Based on Processing and Modeling Results and Overall Recommendations	M3 – Start Optimization and Testing of Equipment
D4 – Final Report	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 – July 27, 2016

BIBLIOGRAPHY

One published deliverable:

Burnison, S.A., Beddoe, C.J., Glazewski, K.A., Salako, O., Hamling, J.A., Ayash, S.C., and Gorecki, C.D., 2015, Technical design of a scalable, automated, semipermanent seismic array (SASSA) method for detecting CO_2 extent during geologic CO_2 injection: Deliverable D2 Interim Report on Completion of Technical Design (Oct 1, 2013 – Oct 31, 2015) for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FE0012665, Grand Forks, North Dakota, Energy & Environmental Research Center, October 2015.

No peer reviewed publications to date.

CONTACT INFORMATION

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