Interpretation of Time-Lapse Seismic Data from a Heavy Oil Field, Alberta, Canada

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Overview

Thesis Objectives

- Identical Processing of the Baseline and Monitor P-wave volumes
- Challenges Associated with Imaging Shallow Reflections
- Calibration of Monitor P-wave data to match the baseline; Amplitude, Phase, Statics
- Detailed Interpretation of Reservoir Isochrons, Amplitude Anomalies
- Projection of Amplitude Anomalies into Spatial Display
- Integration of Geological Well Logs

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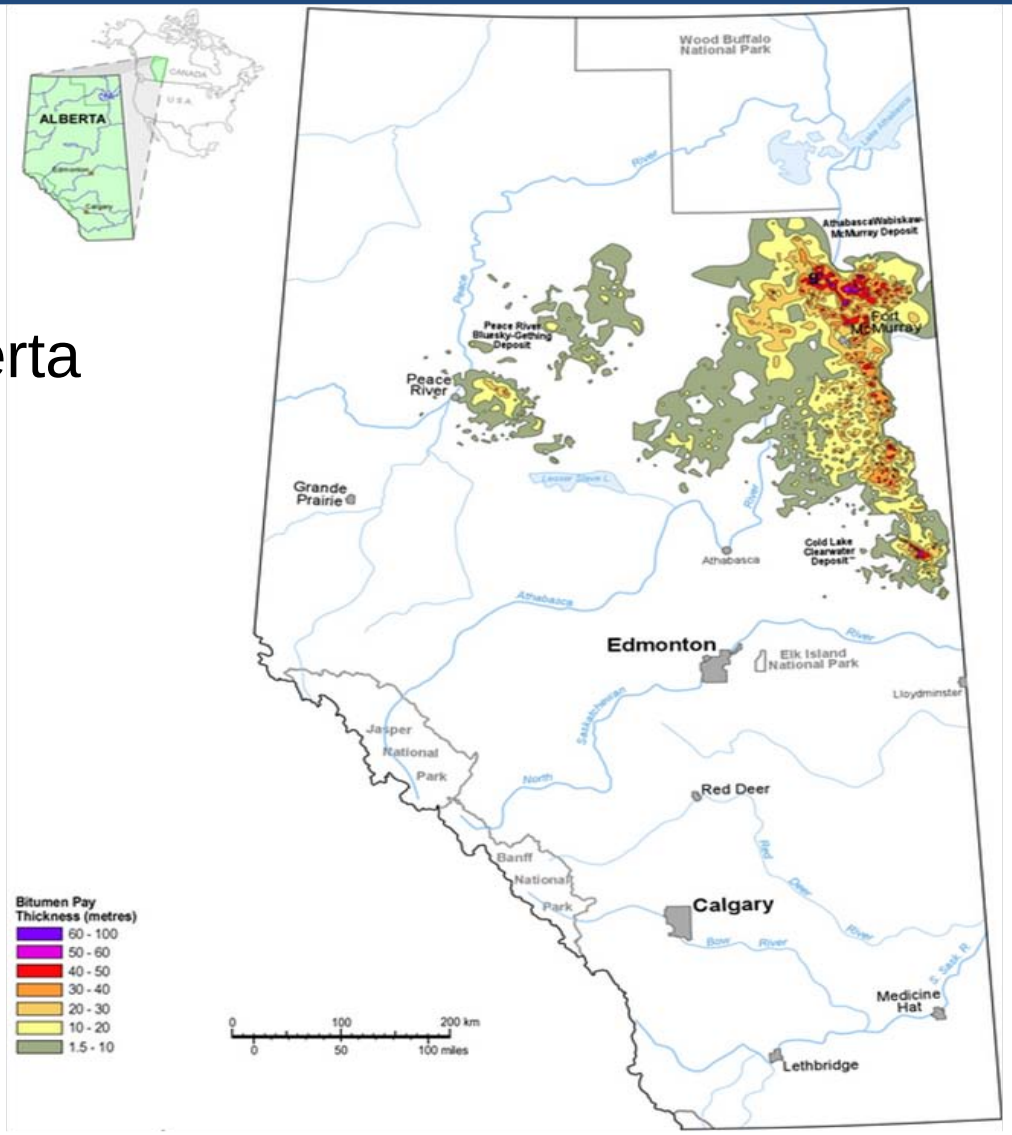
Outline

- Study Area and Reservoir Geology
- 4D Initial Interpretations
- 4D Calibration
- 4D Interpretations
  - Isochron Analysis
  - Amplitude Anomalies
  - Geological Integration
- Conclusions

Study Area

- Athabasca Oil Field, NE Alberta
- Heavy Oil Deposit
- SAGD Reservoir Production



Steam Assisted Gravity Drainage

Previous Work

- Reduction of P-wave velocity – elevated temperature, change in elastic constraints

- Porosity, pore fluid, temperature and effective pressure (*Hicks and Berry, 1956*)

- Tosaya et al. (1984) and Nur (1984) → 125 - 250◦ C: up to 50% decrease in P-wave Velocity (typically 30% for bitumen saturated rocks)
  - Increase compressibility of heavy oil (bulk modulus)

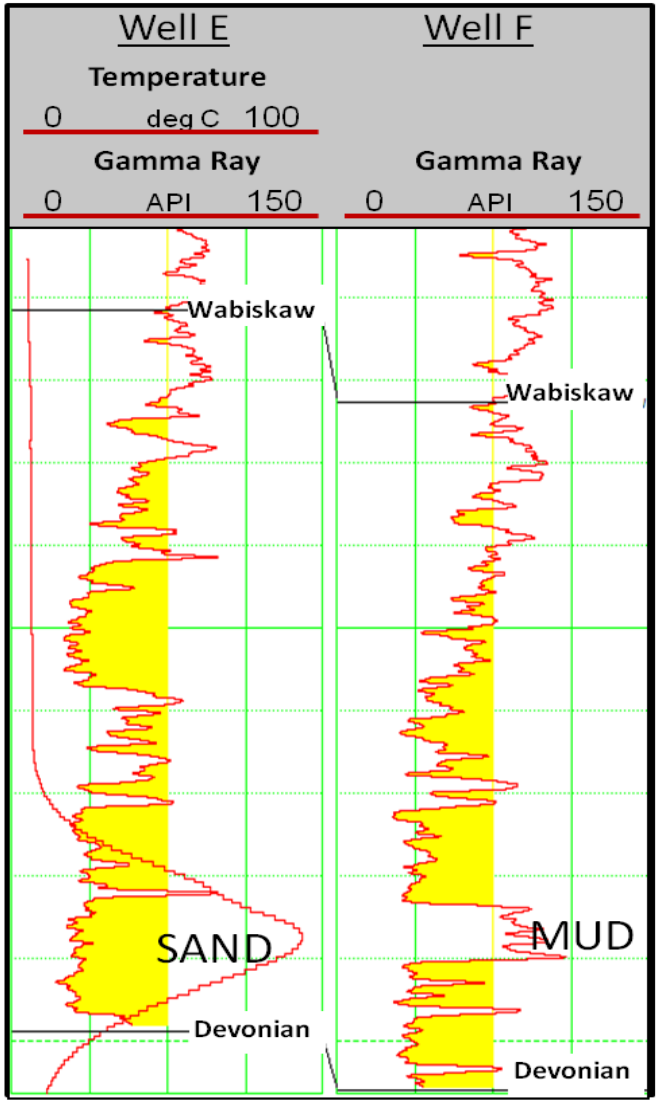
•Changes in seismic velocity observable in a time-lapse sense

- Time-Lapse monitoring of heavy oil
  - Pikes Peak Field (Watson, 2004)
  - Cold Lake Field (Smith & Perpelecta, 2002)
  - Peace River Field (McGillivray, 2005)
  - Athabasca Filed (Kendall, 2010)

Data Set

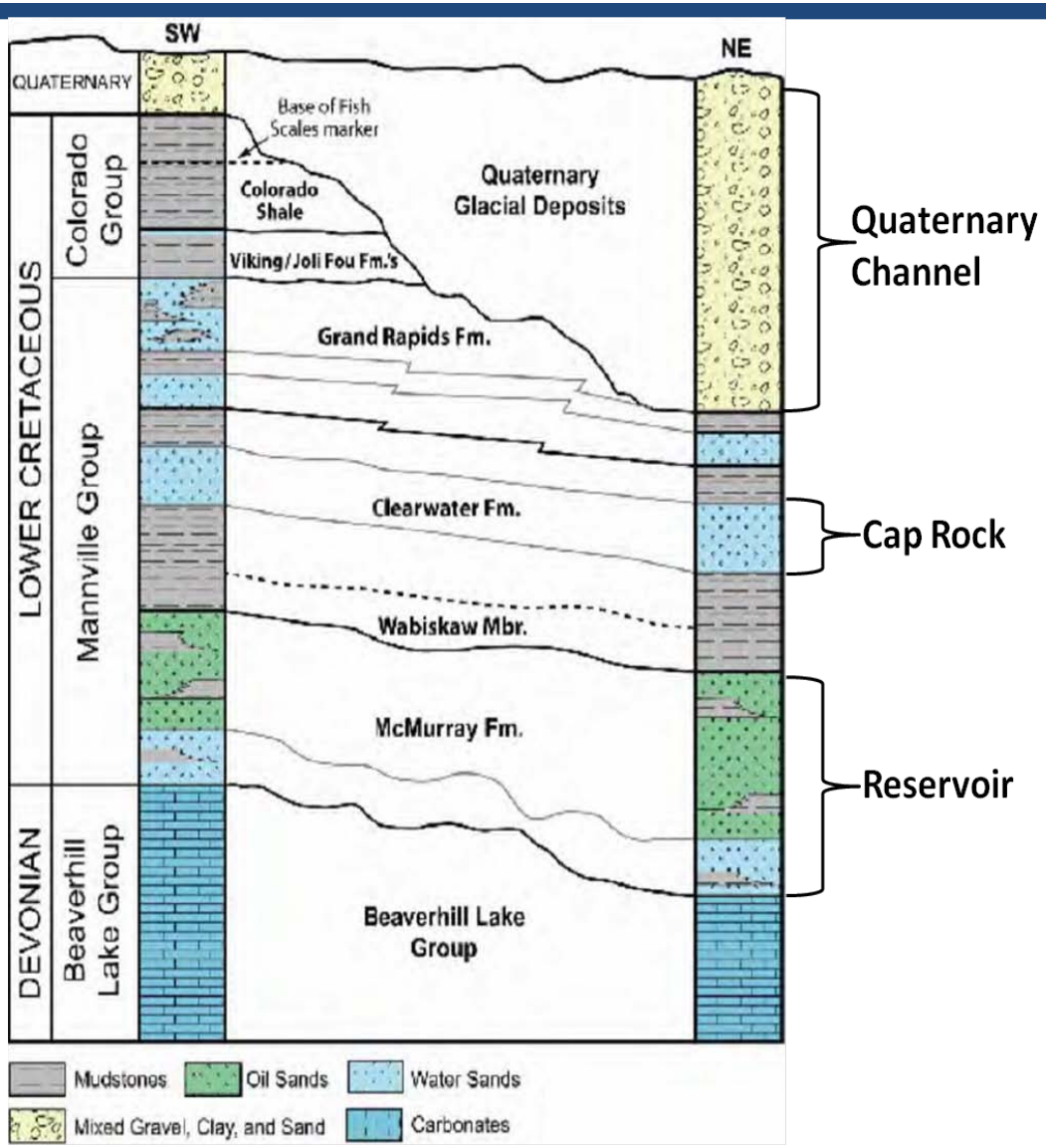
Data Set is Comprised of:

- 4D - 3C seismic data
- Petrophysical well logs
  - Gamma Ray
  - Sonic
  - Density
  - Temperature



Reservoir Geology

- Beaverhill Lake Group (Devonian)
  - Seismic: High Amplitude Peak
- McMurray Formation
  - Reservoir
- Clearwater Formation
  - Clearwater C
  - Cap Rock



4D Initial Interpretation: Data Comparison *Inline B*

Data Comparison of the Processed Data

- Differences exist between the baseline and monitor data
  - Resolution and Coherency of Shallow Reflections
  - Phase and Static Differences (34deg; ~8.0ms)
- Compare Two Inlines (N – S) through the baseline and monitor volumes
  - Identify Amplitude Anomalies
- Compare one Arbitrary line running perpendicular to SAGD Well pairs (NW – SE)
  - Identify Anomalies intersecting channel sands

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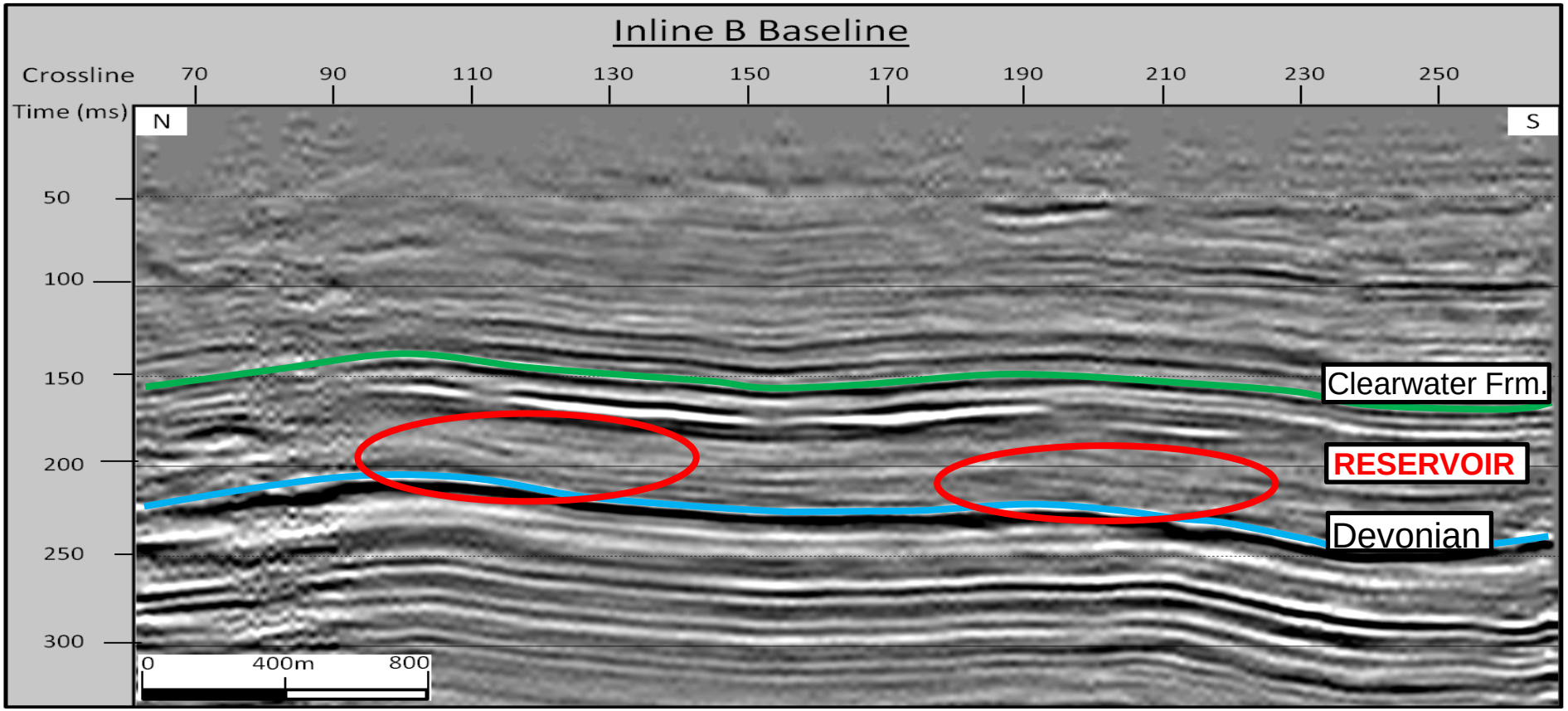

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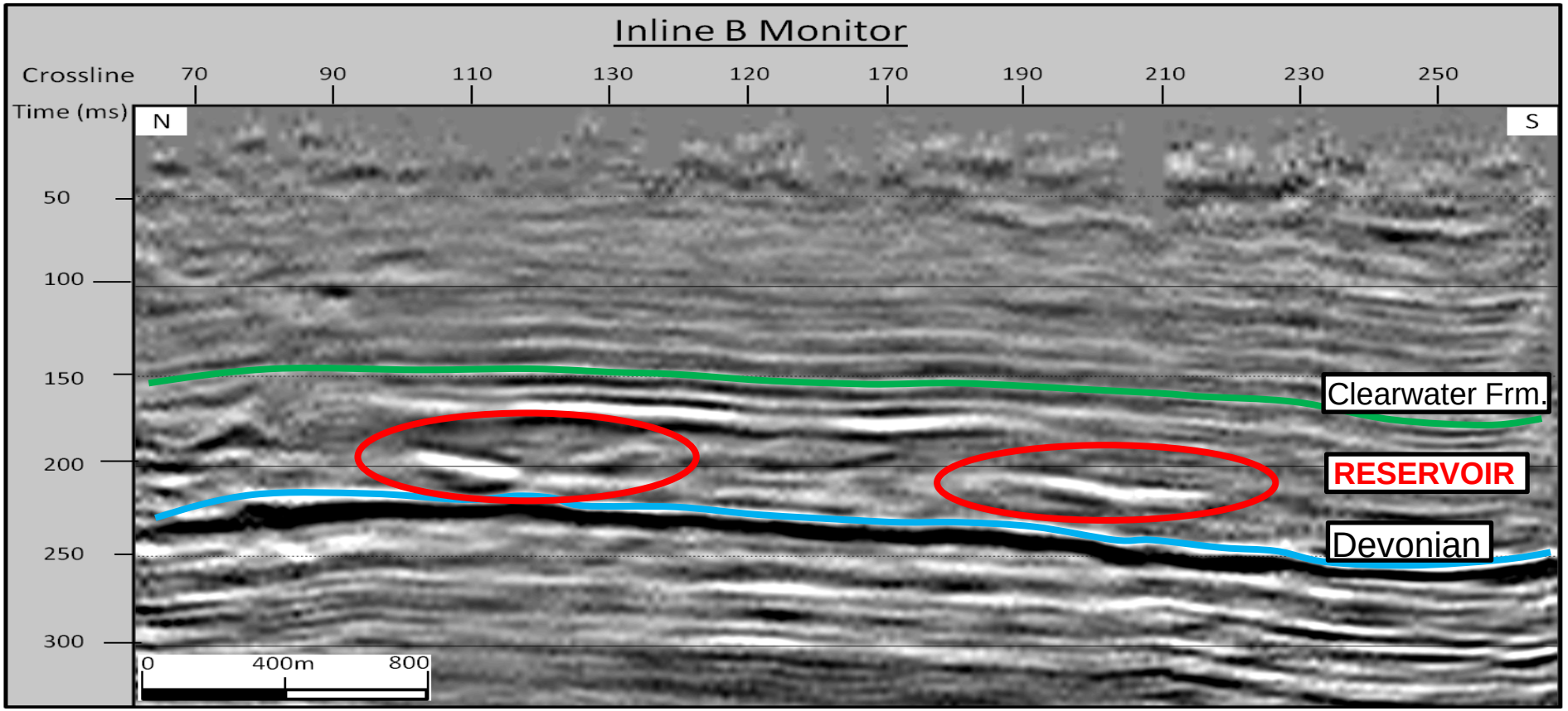

4D Initial Interpretation: Data Comparison *Inline C*

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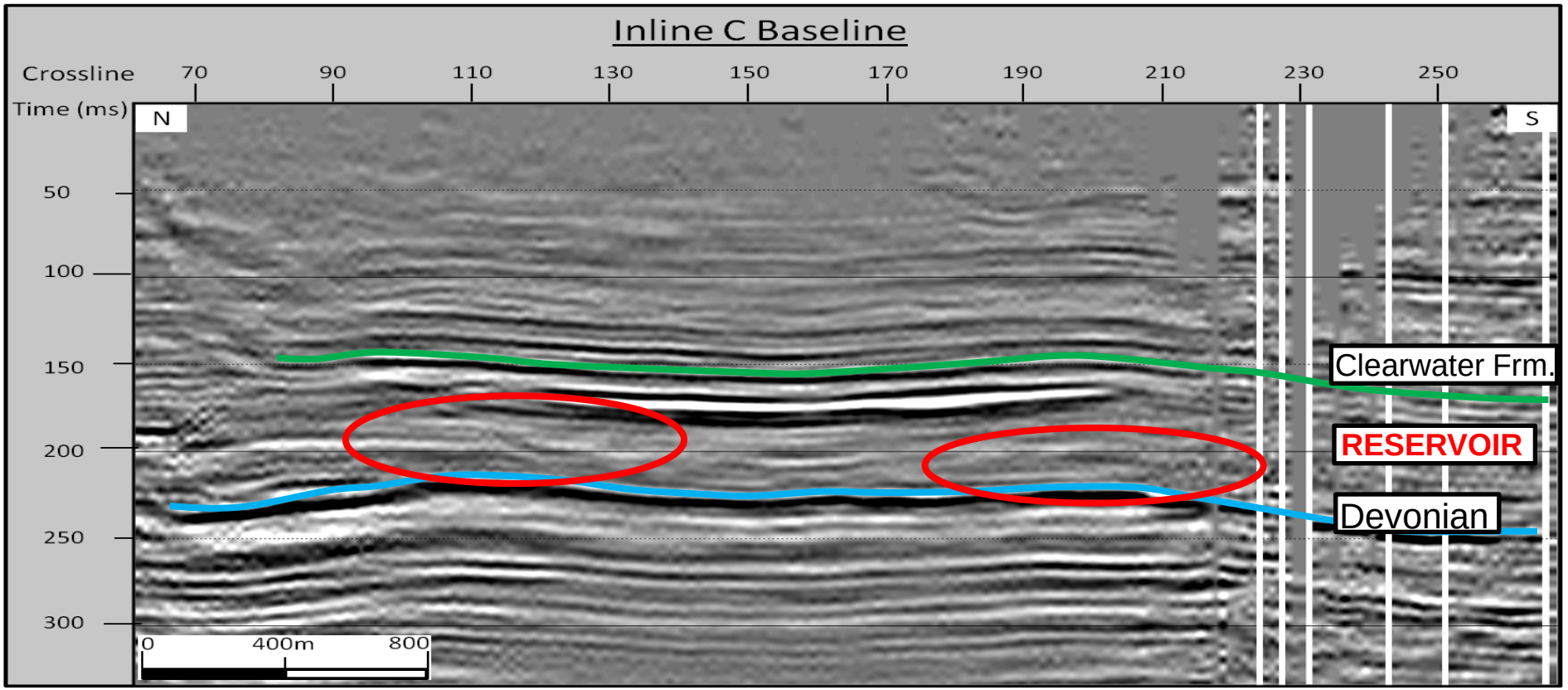

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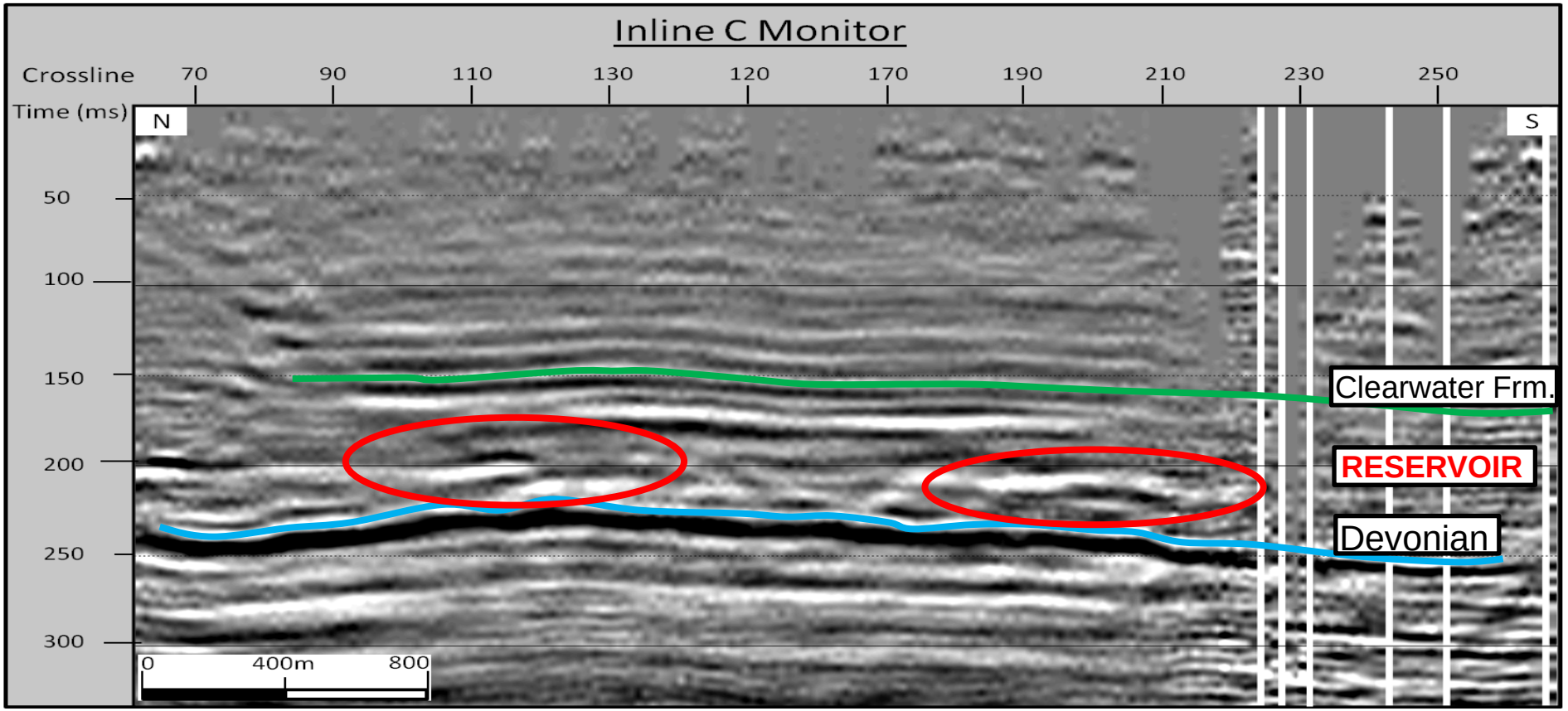

4D Initial Interpretation: Data Comparison *Channel Identification*

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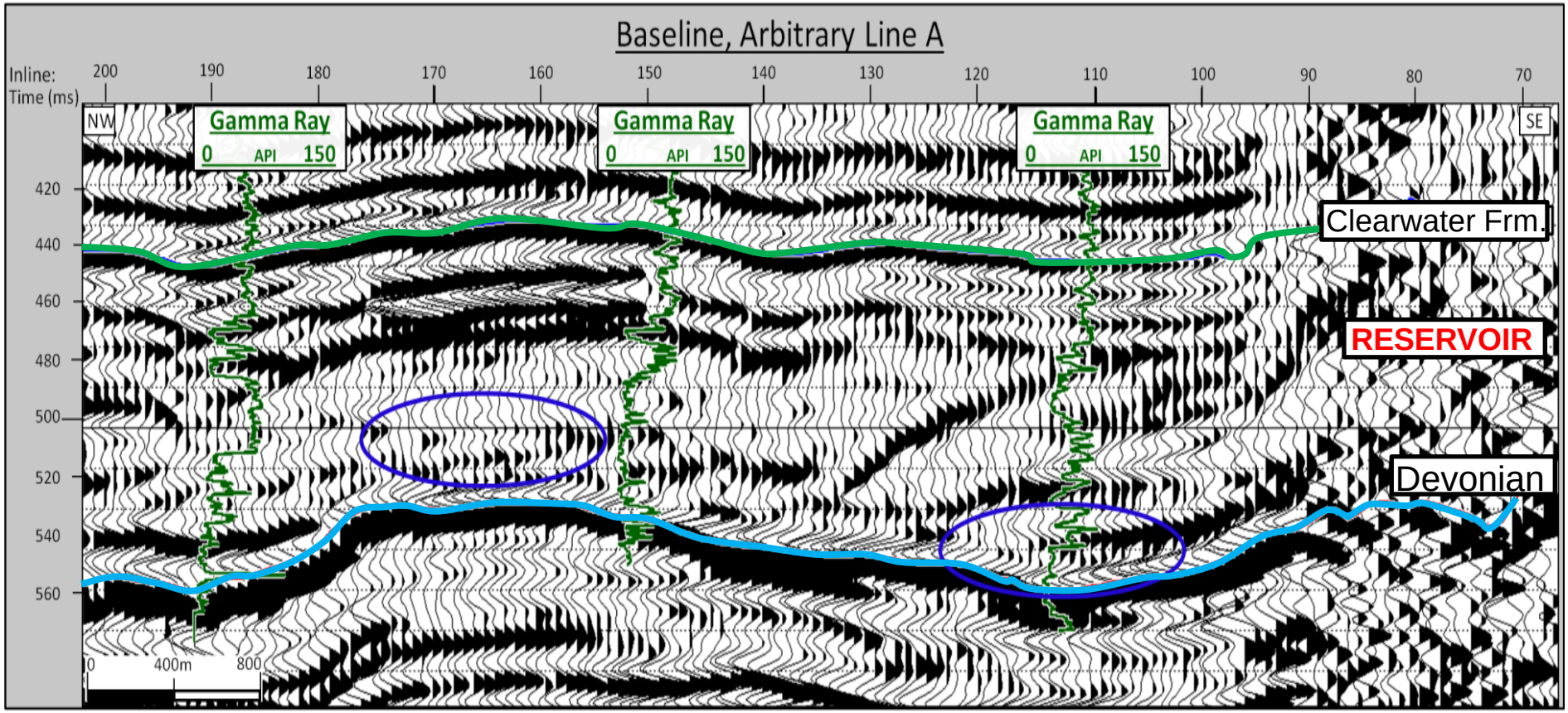

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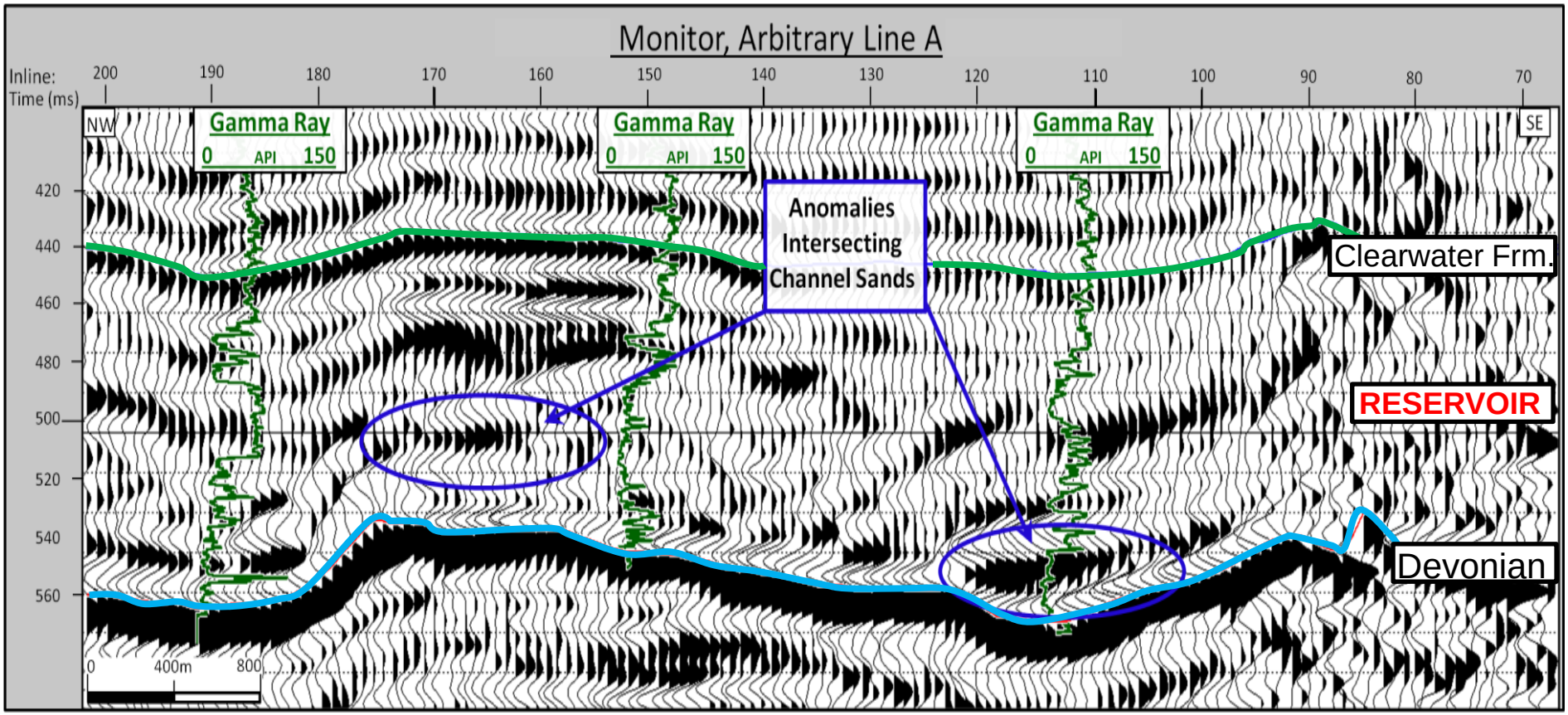


Data Calibration

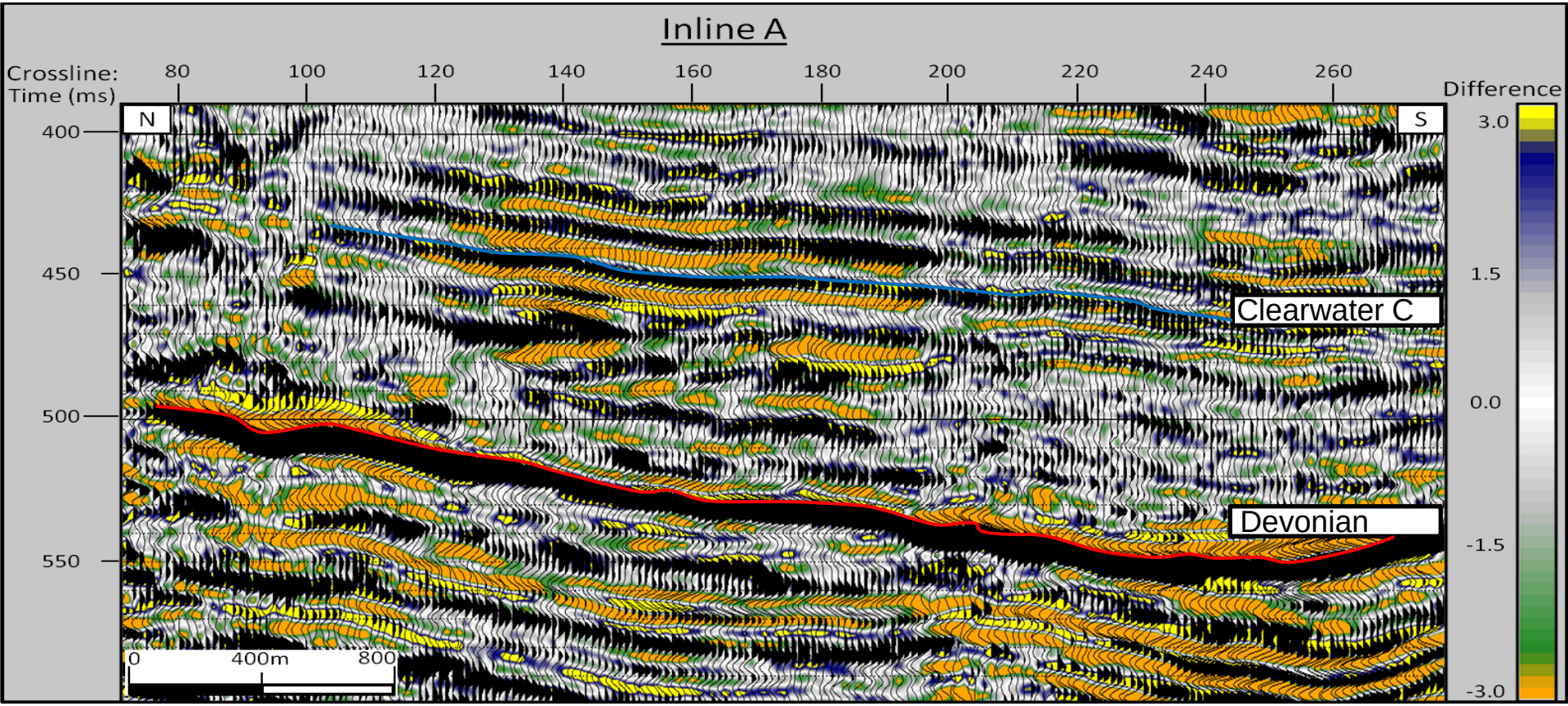
Data Calibration

- Differences exist between the baseline and monitor data: Phase, Statics, and Amplitudes
- Removed differences not due to production
- Calibration is windowed on data not influenced by production
  - Typically, on shallow data; low S:N, low event coherency
  - Windowed on the Devonian event and underlying reflections
- Calibration performed in 4 steps
  [1] Phase Matching to match global phase and align events in time (34 degrees; ~8.0ms)
  [2] Shaping Filter to match the wavelet of the monitor to the baseline in a least-squares sense (Zero Phase)
  [3] Static Correction: Trace-by-trace alignment of the Devonian events in time. Propagated time-delays upward (instead of downward)
  [4] Amplitude Matching: Scaled monitor amplitudes via cross-normalization

Data Calibration: Comparison *Monitor Before and After*

- Monitor data was altered to match the phase, amplitude and static solution of the baseline data → reduction of differences NOT due to production

Monitor Data before Calibration



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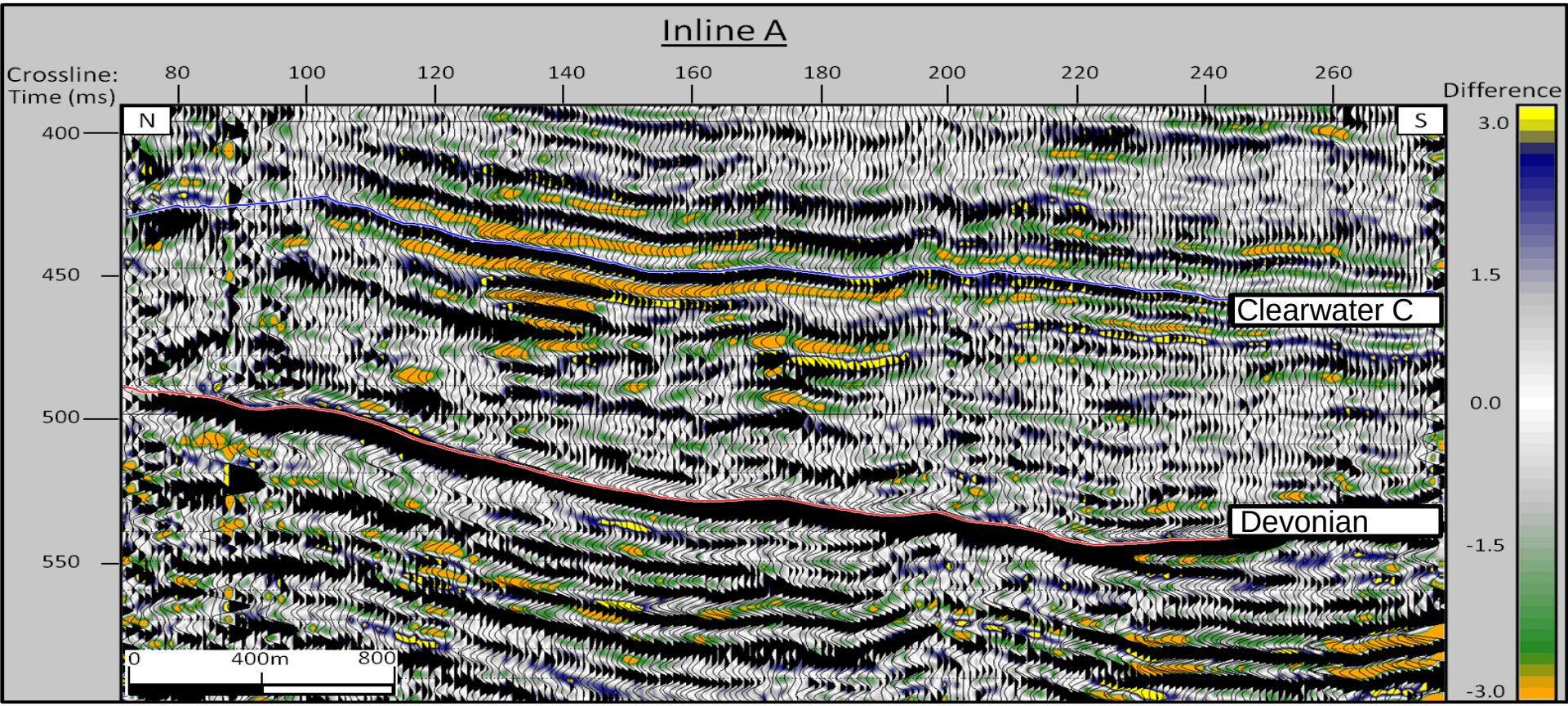

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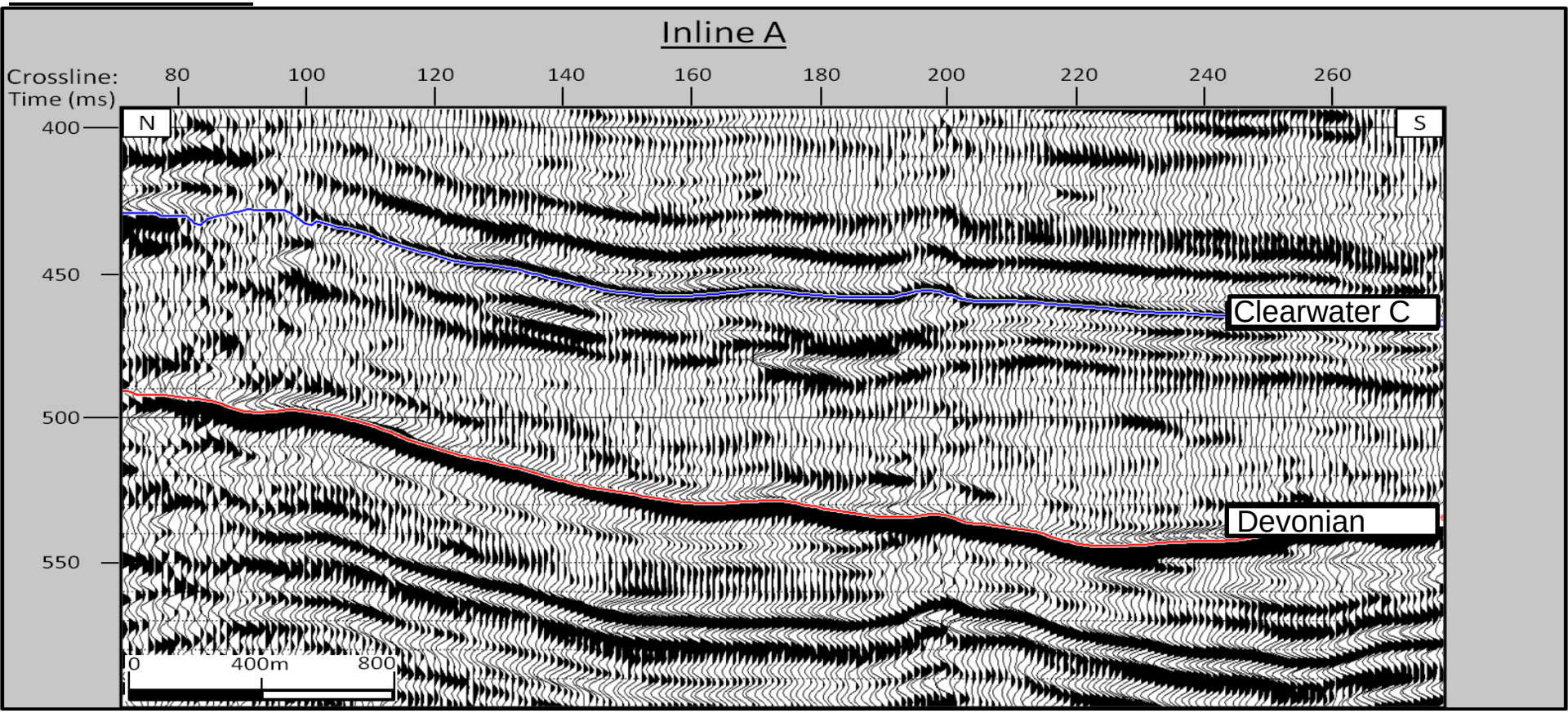
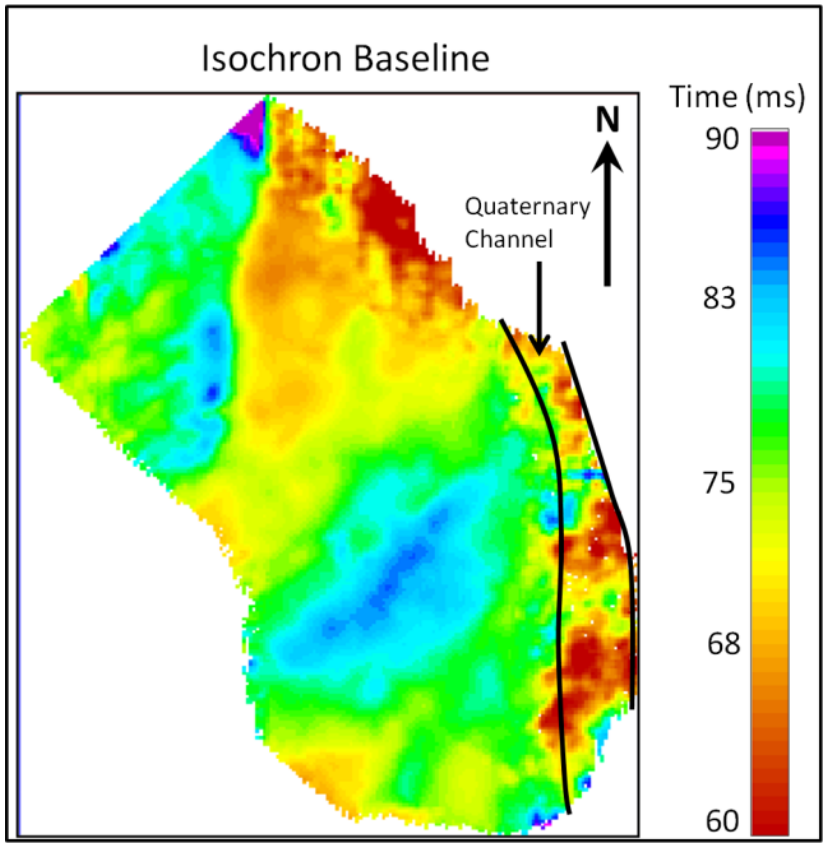
Baseline Data

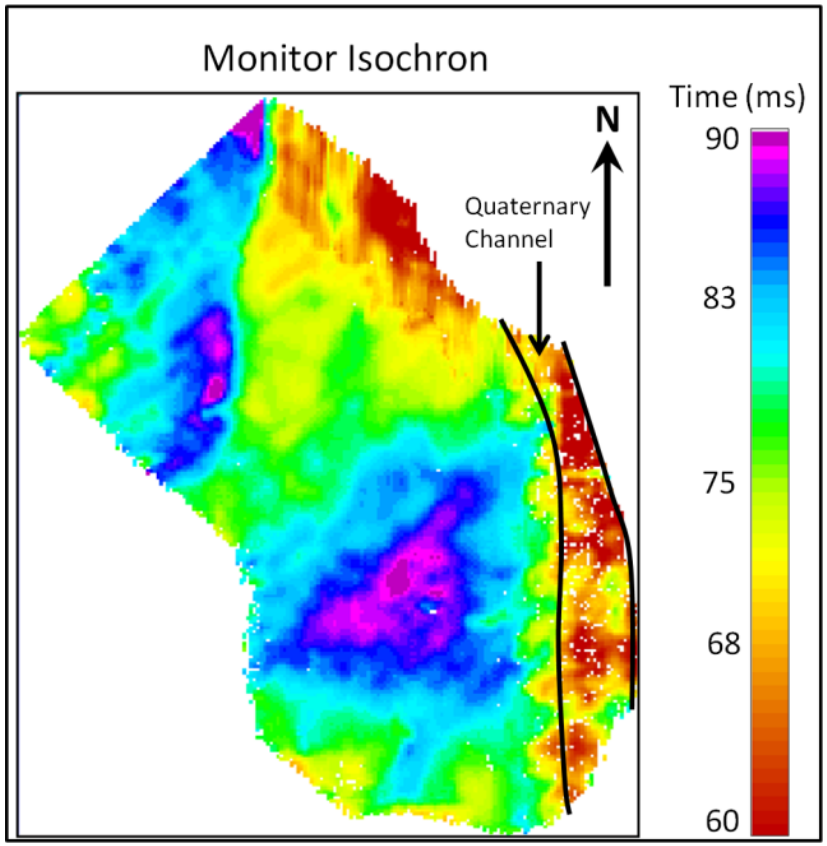


Interpretation: Isochron Analysis

Isochrons

- Time-thickening due to velocity reduction (Steam Injection)
- Velocity Reduction ~30%
- Isochrons: Clearwater C (Cap Rock) to Devonian Reflections





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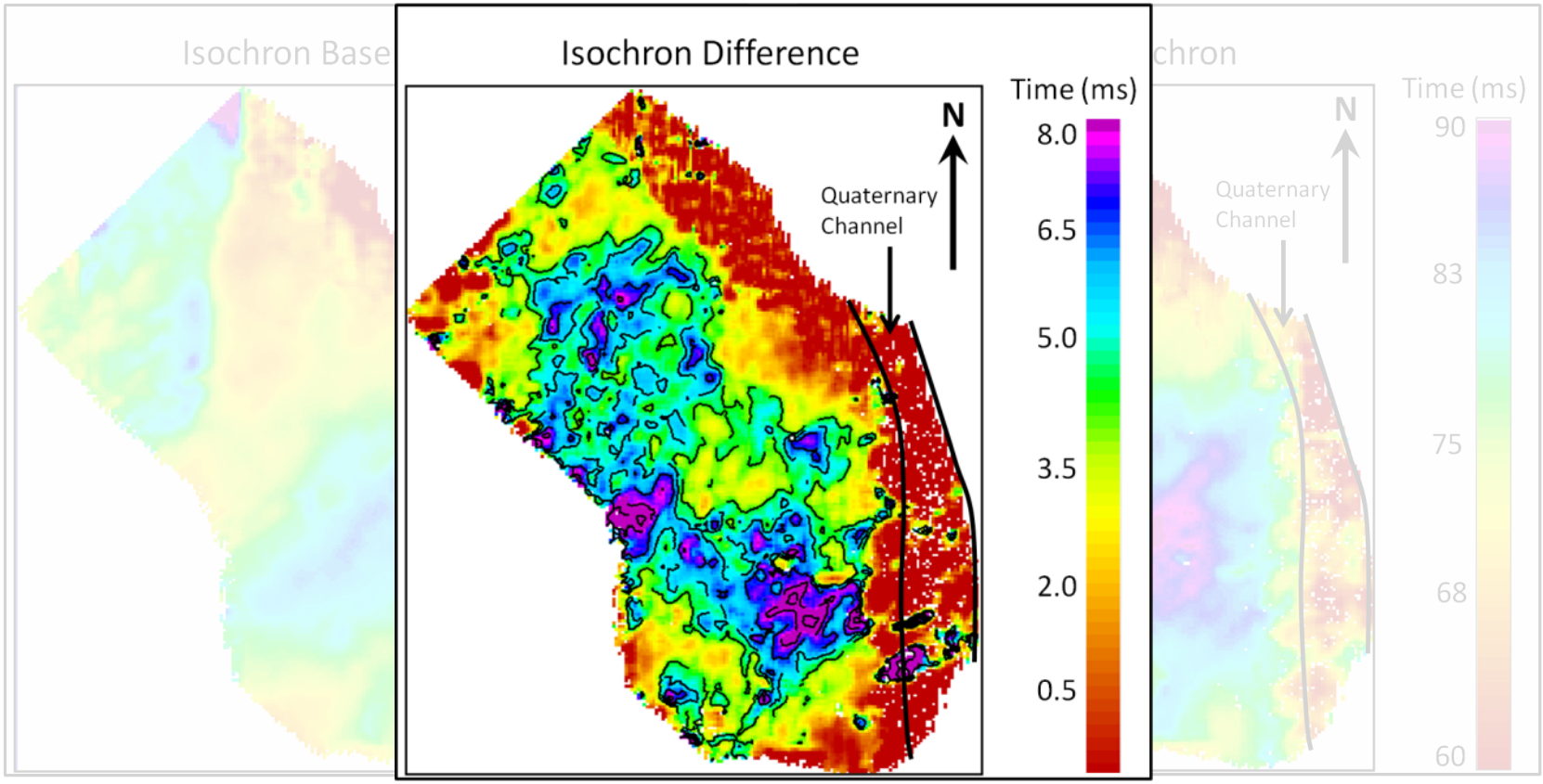

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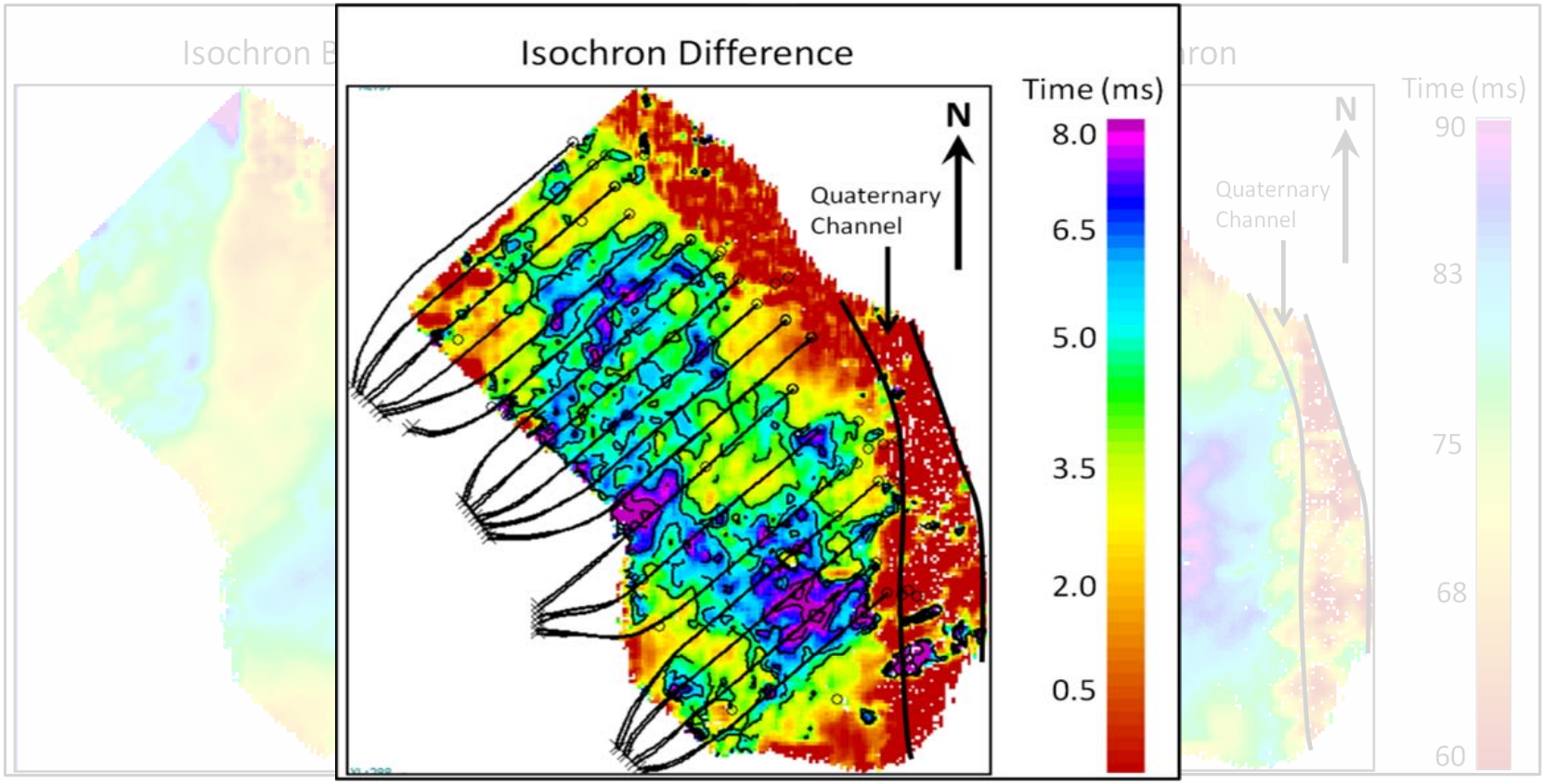

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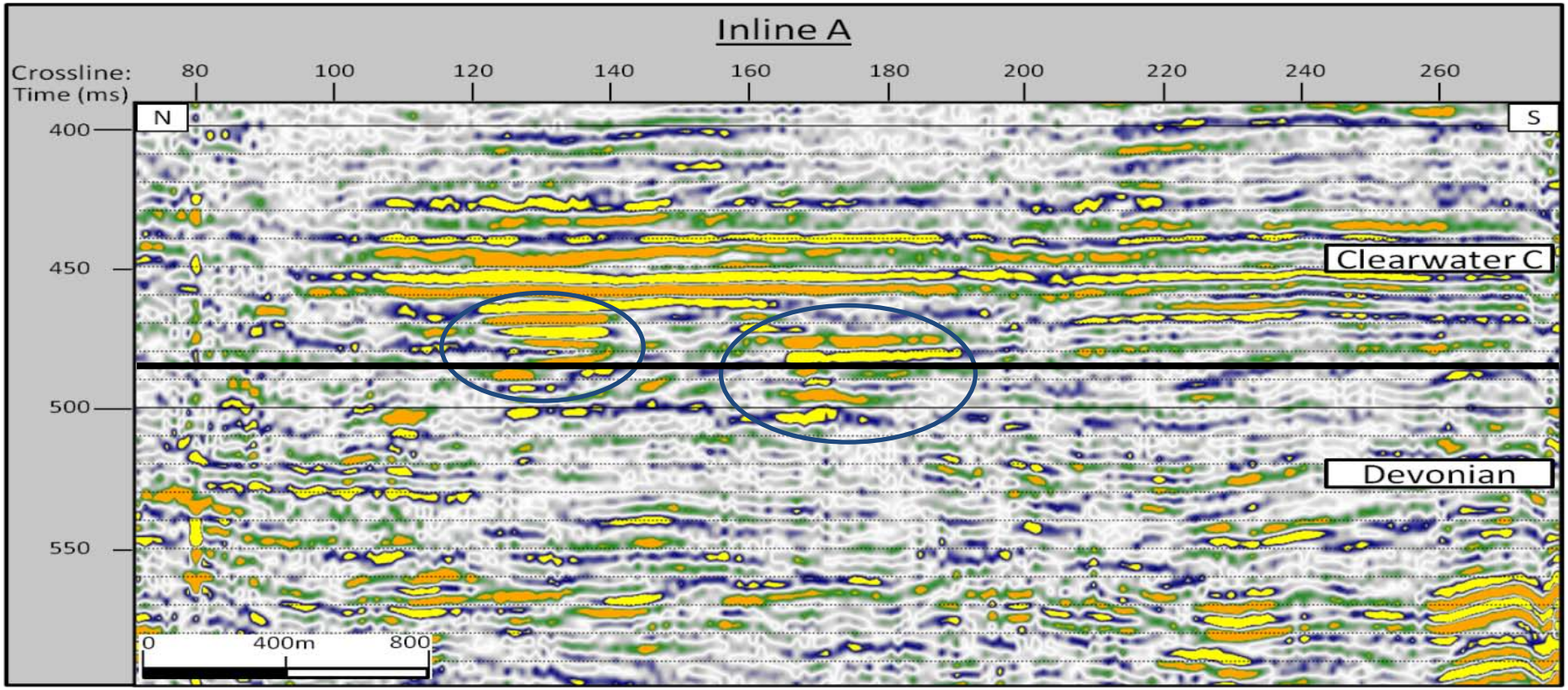

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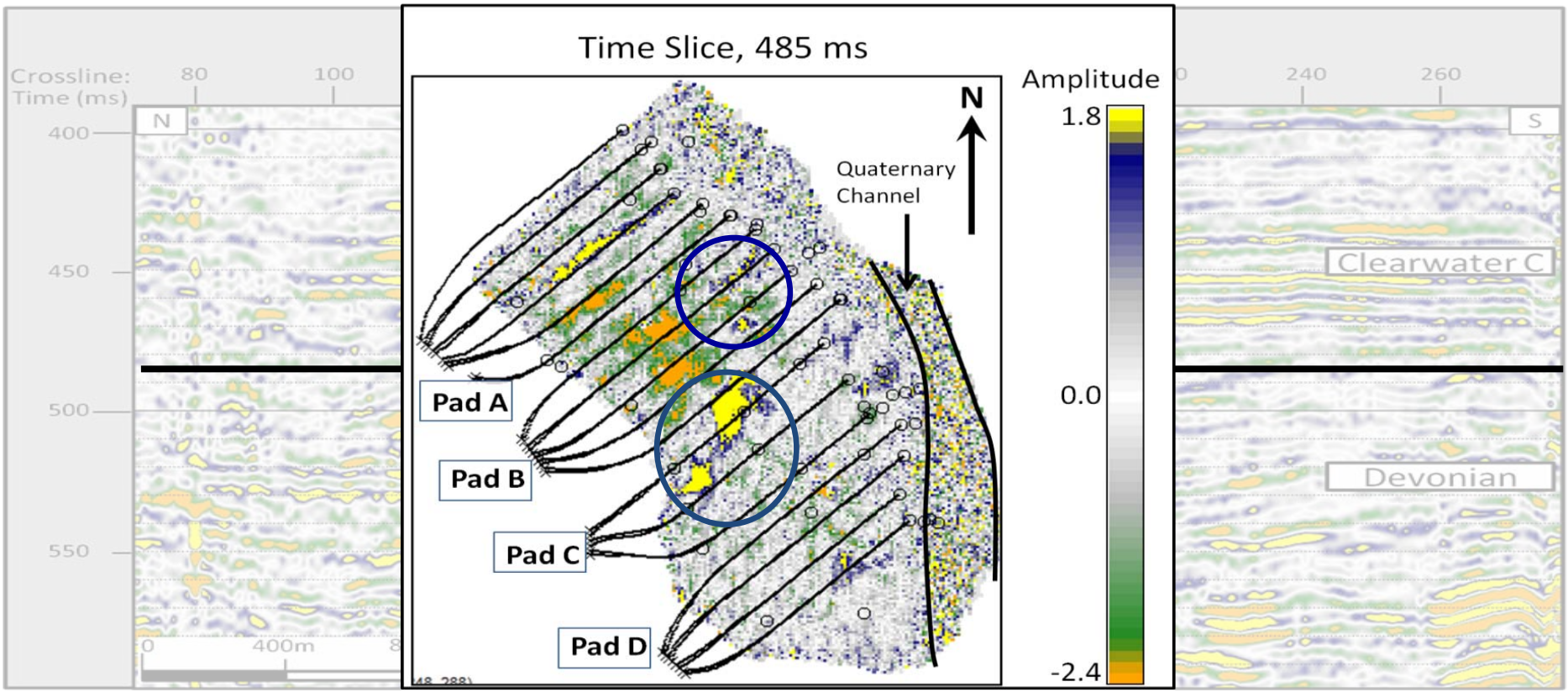
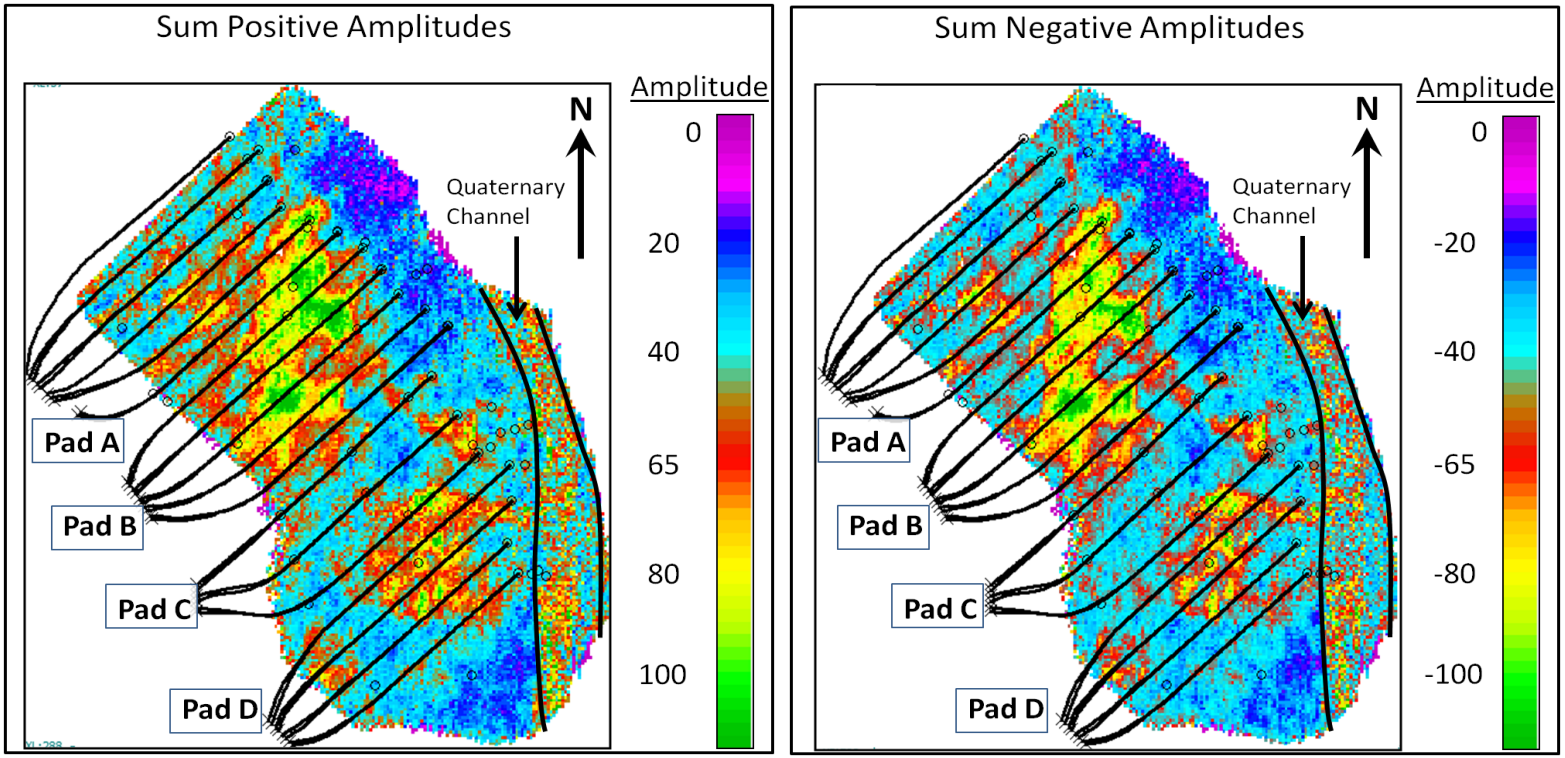


Interpretation: Amplitude Anomalies

Projection of Anomalies into Map View

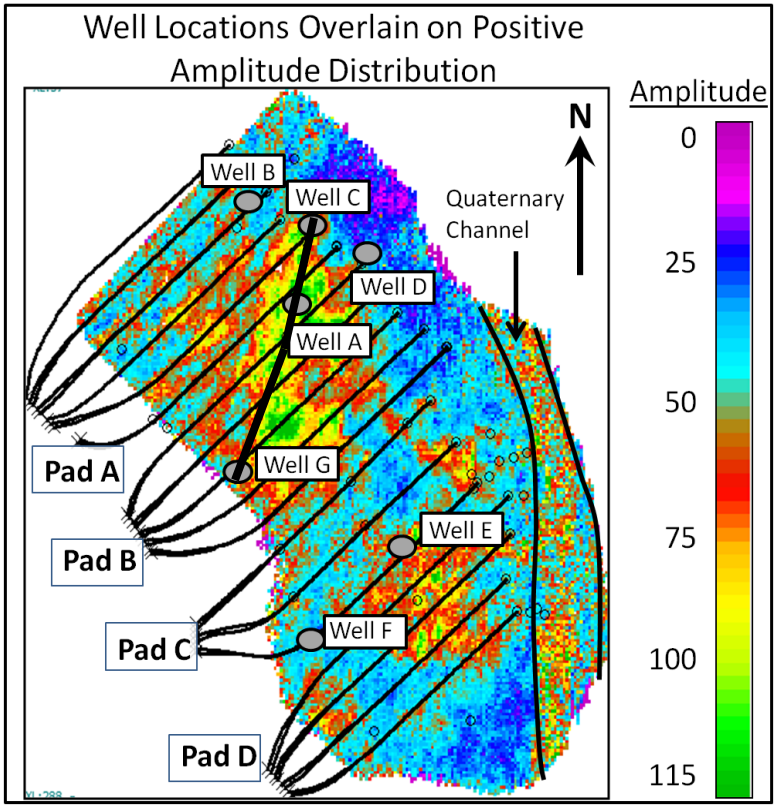
- Summation of Positive (and Negative) amplitudes through reservoir interval (McGillivray, 2005)
- Two large amplitude anomalies (1) Northern Anomaly & (2) Southern Anomaly

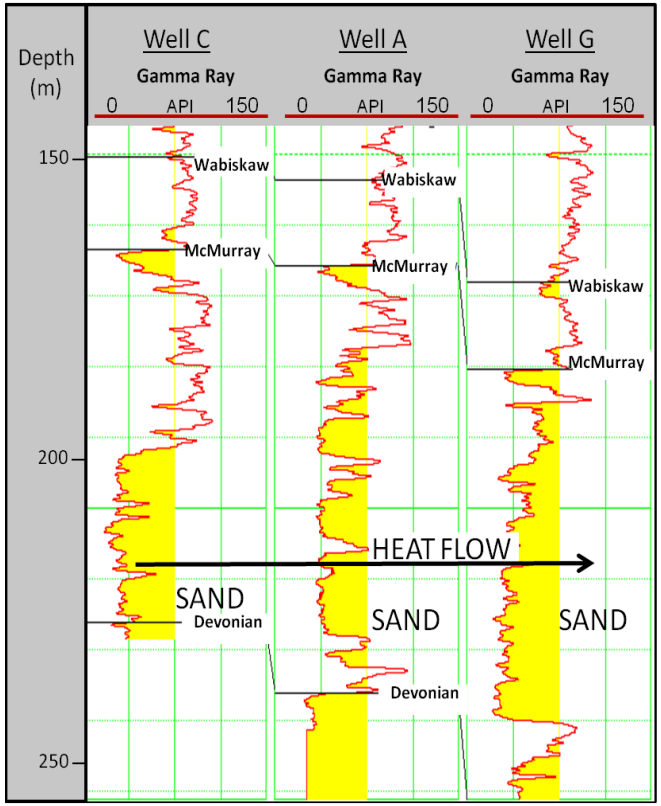


Interpretation: Geological Integration

Well Log Cross-Sections

- Three well-log cross sections constructed through the amplitude anomalies using Gamma Ray logs
- Displaying the intersection of amplitude anomalies with McMurray Formation sands





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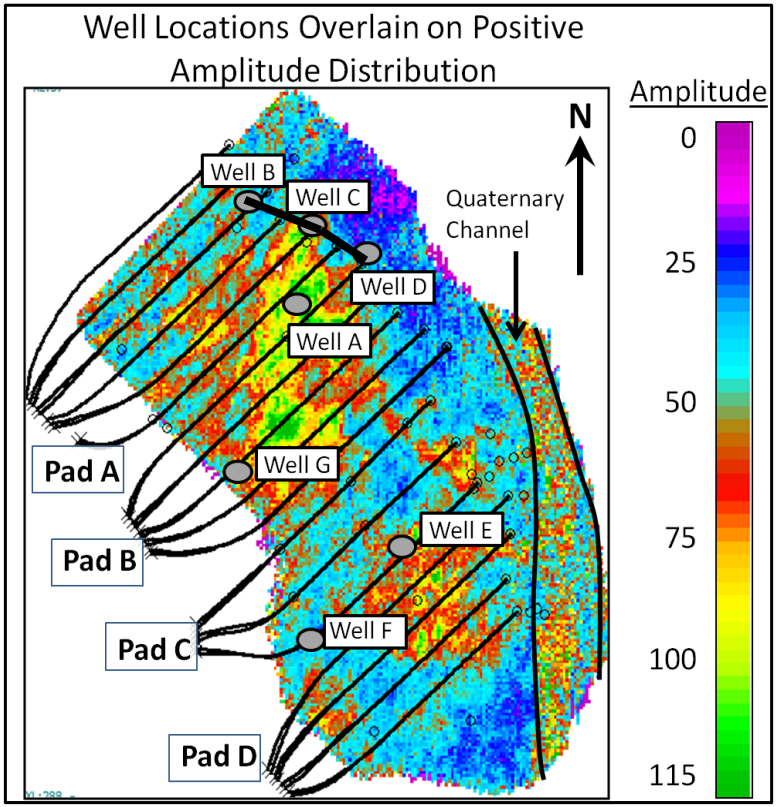

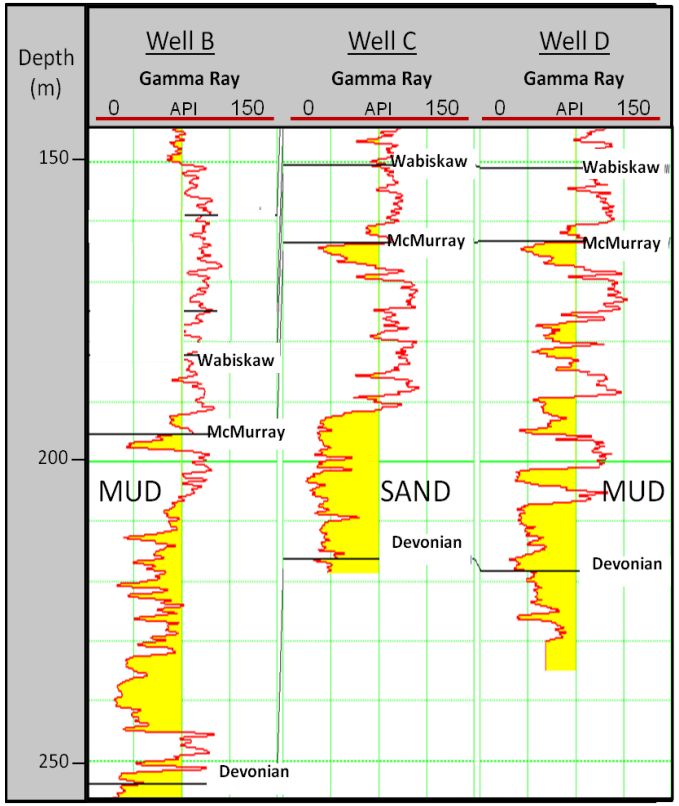

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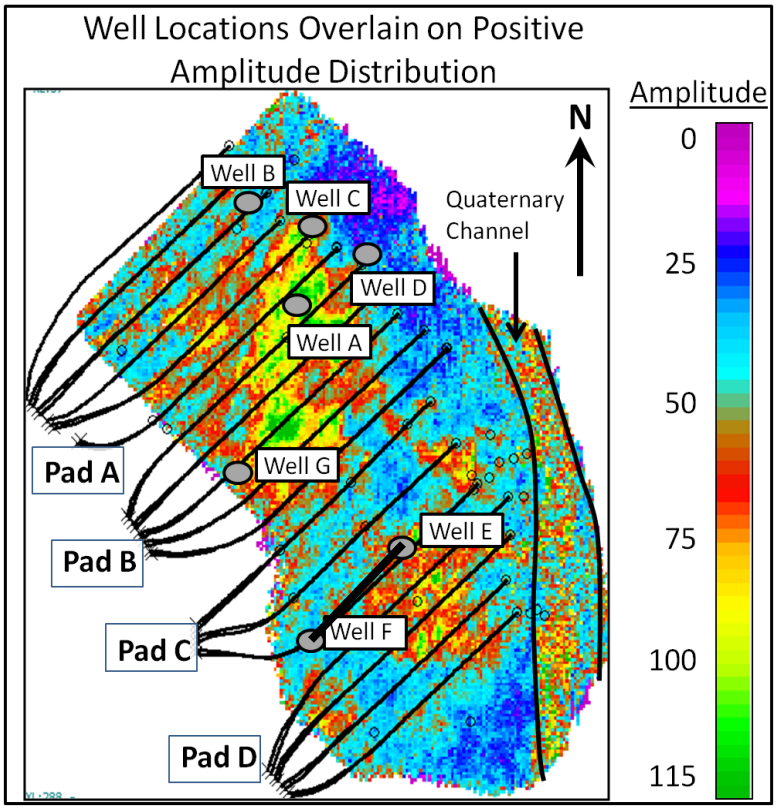
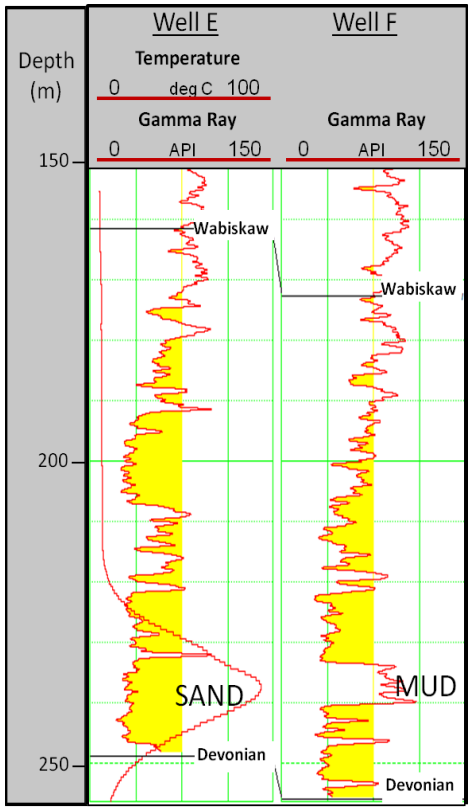
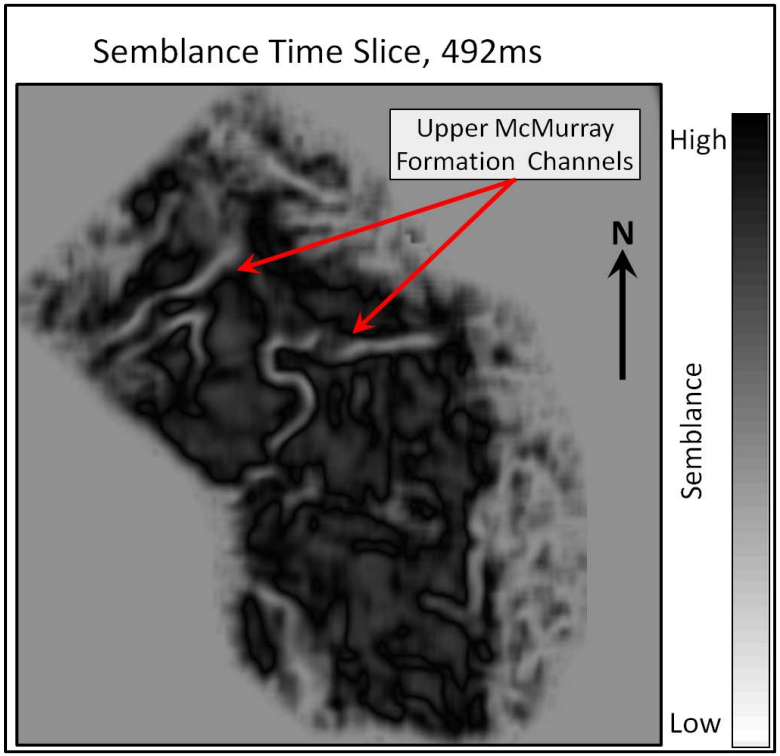


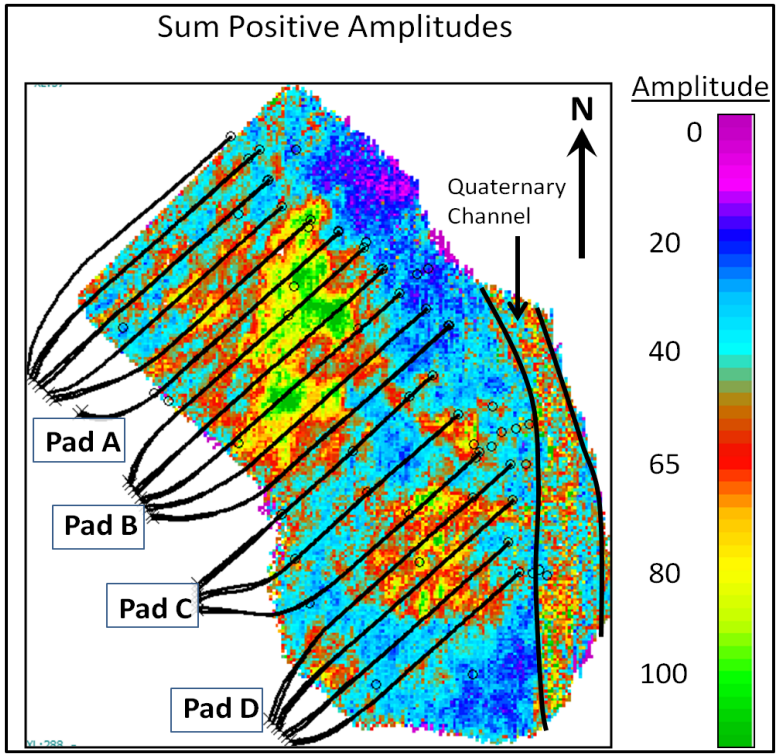


Interpretation: Semblance Attribute

Semblance

- Analysis of the changes in seismic character
- Comparison of the similarity of two adjacent traces
- Ratio of energy of the trace to the average energy of all traces
- Values 0 – 1: 1 - two traces have identical amplitudes





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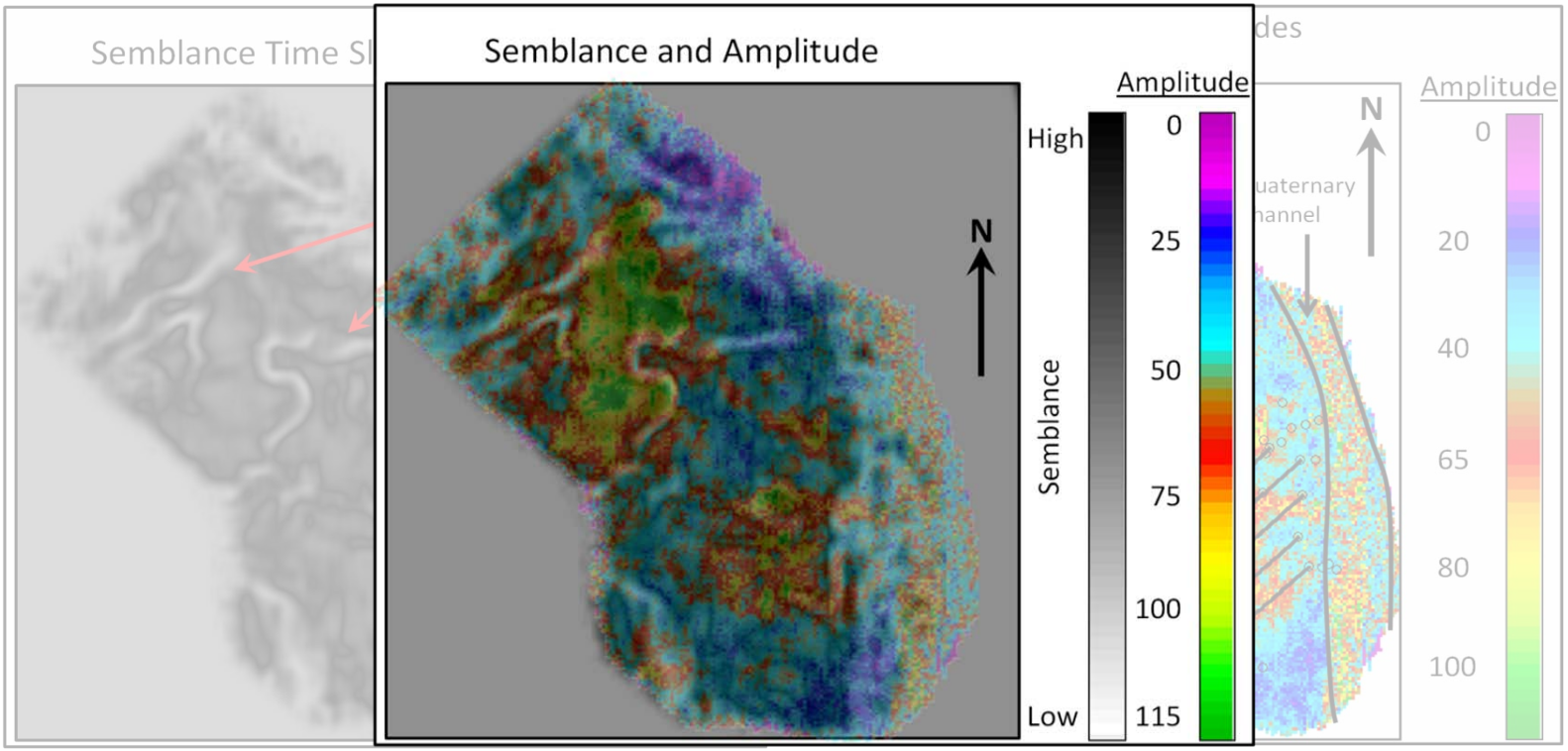
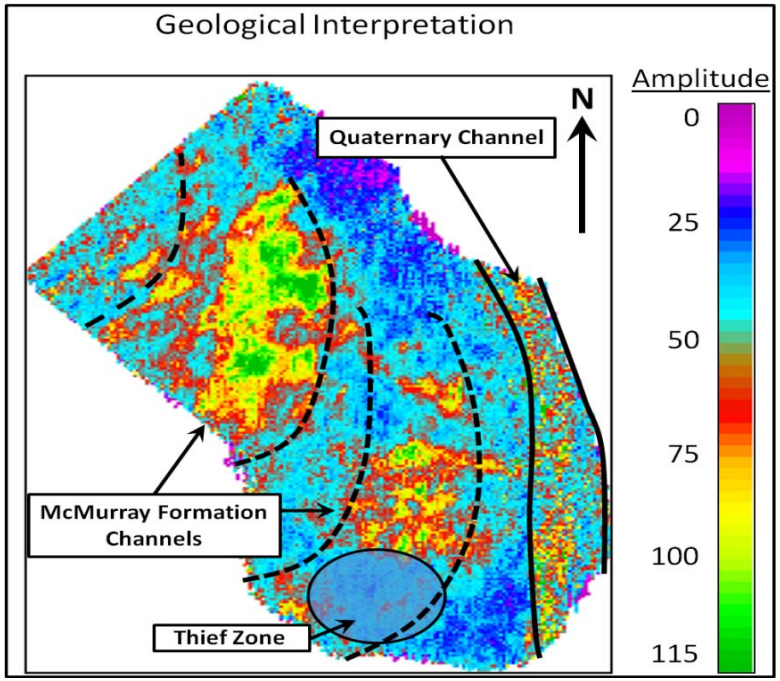


Interpretation Discussion

Summary:

- Isochrons show regions of reservoir heating (time thickening)
- Amplitude Anomalies observed within the McMurray Formation reservoir Interval (difference volume)
- Anomalies intersect McMurray Formation sands
- Anomalies correlate with channel boundaries as identified within semblance attribute time-slices



Acknowledgments

Thank You

Dr. Don Lawton

Helen Isaac

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University of Calgary

Anonymous Donor of the Data

Steam Assisted Gravity Drainage