The promise of 3D 3C seismic data for improved imaging and reservoir characterization in the Alberta oil sands

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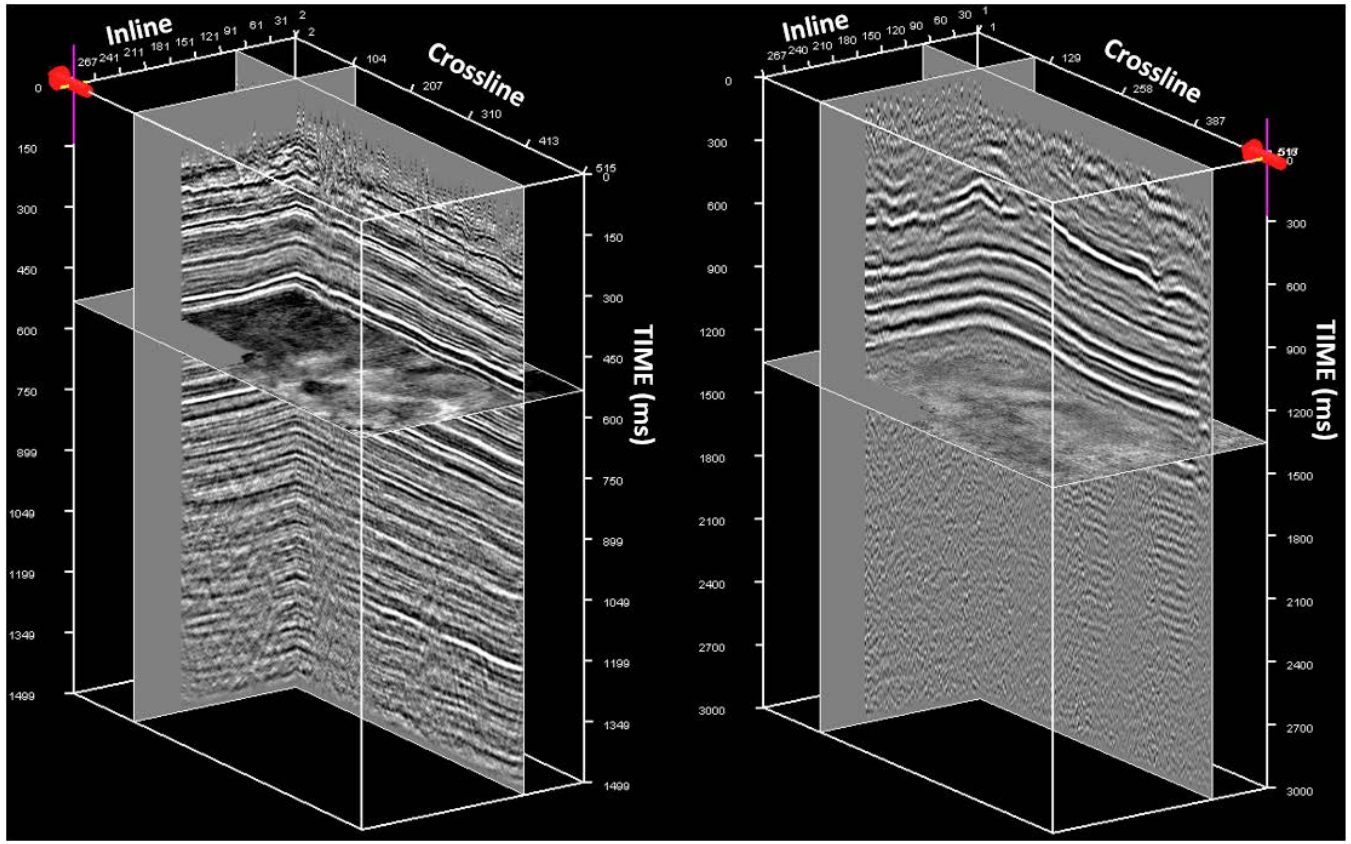
Project objectives

- Objectives
  - Characterize and understand key geological intervals through joint PP-PS interpretation and inversion
  - Demonstrate the value of acquiring and processing converted wave seismic data in in-situ oil sands type operational scenario

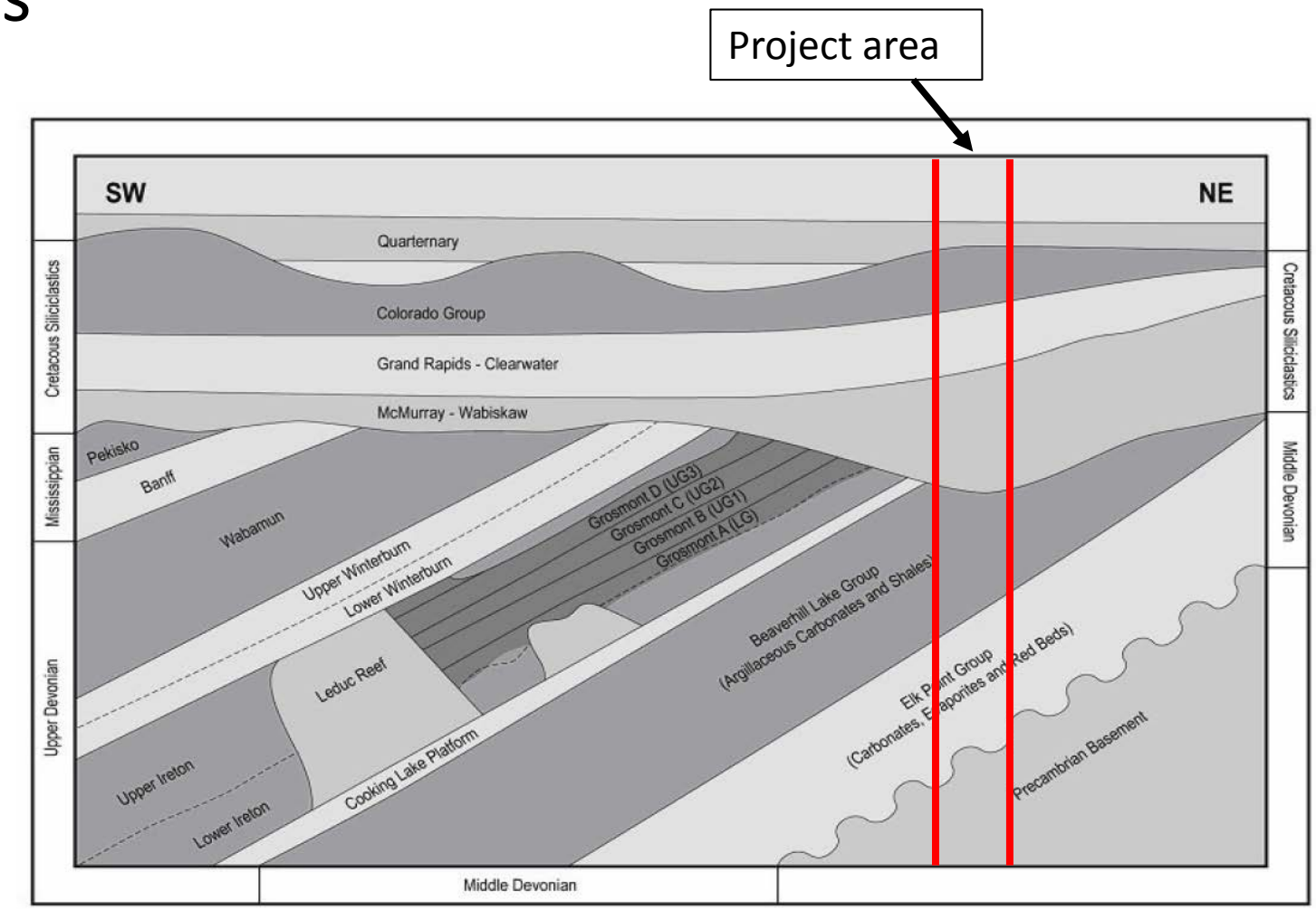


PP and PS stacked seismic data

Geological setting

- Southern Athabasca oil sands

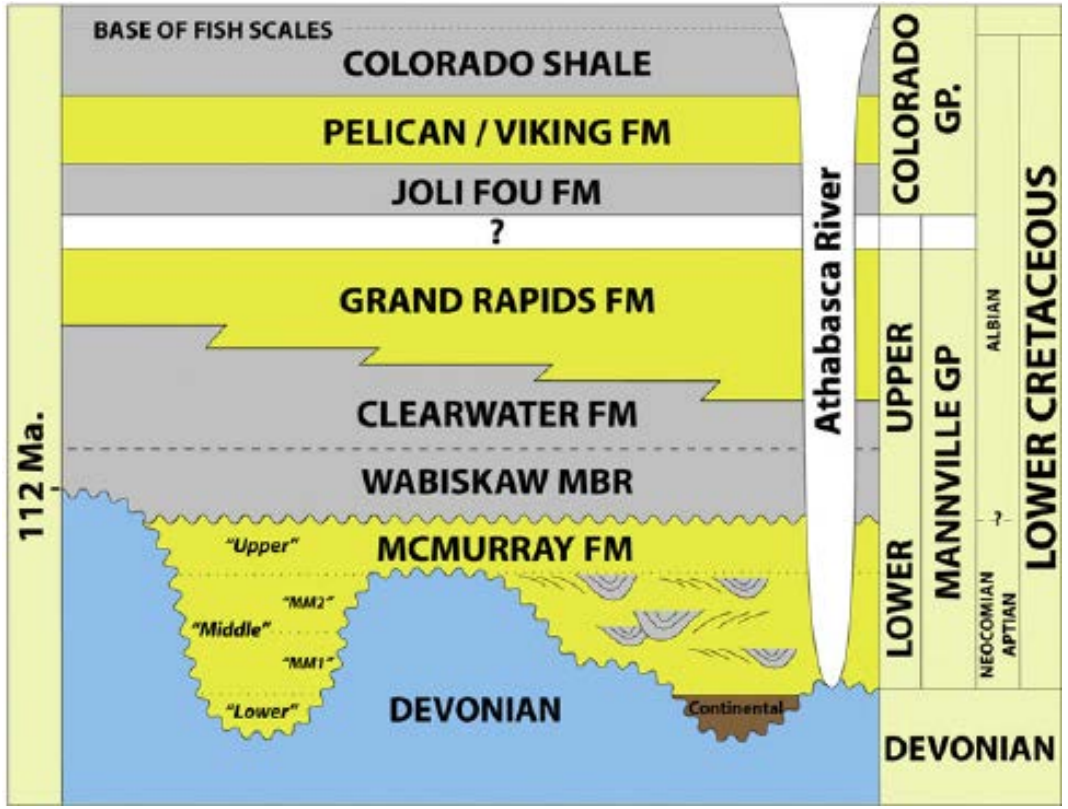
Modified from Hien et al., 2001



Modified from Hien et al., 2008

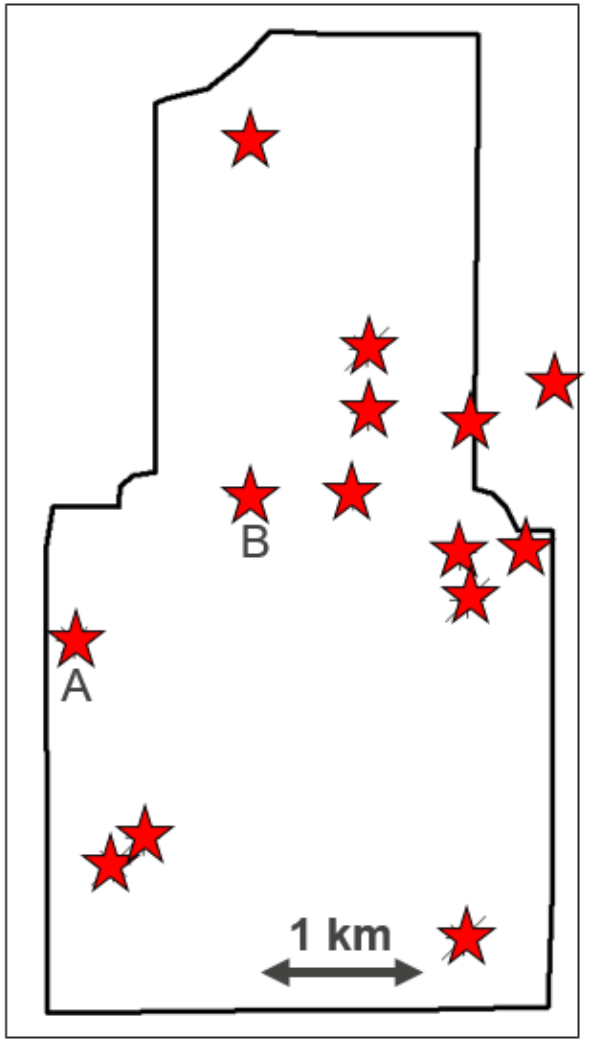
Geological and operational setting

- Reservoir
  - McMurray formation
    - Unconsolidated fluvial to marginal marine sands and mudstones
    - Inclined heterolithic stratification (IHS)
- Trap and seal
  - Upper Clearwater Formation and Colorado Group
    - Mostly marine shales
- Secondary hydrocarbon recovery method
  - Steam assisted gravity drainage (SAGD)

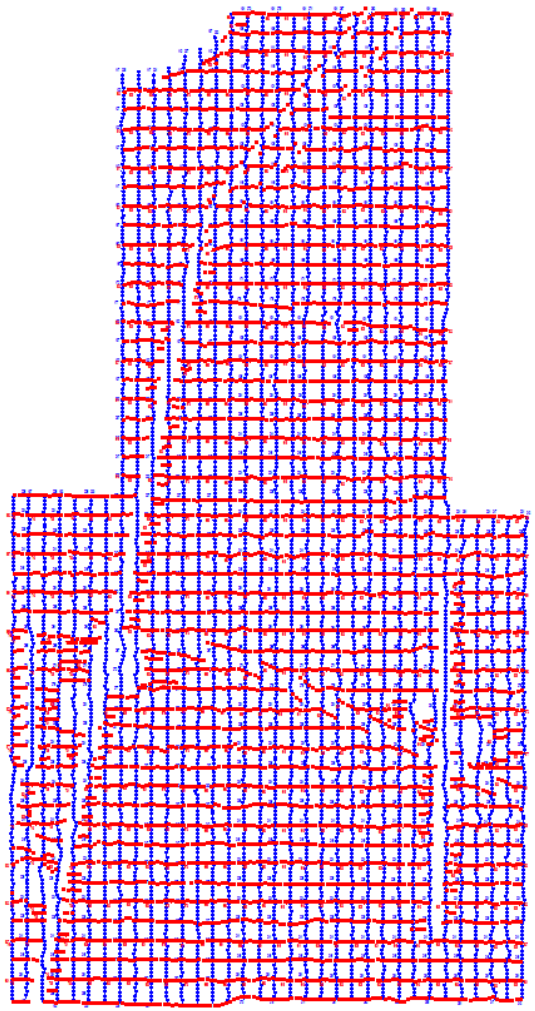


Todorovic-Marinic et al. 2015

Dataset



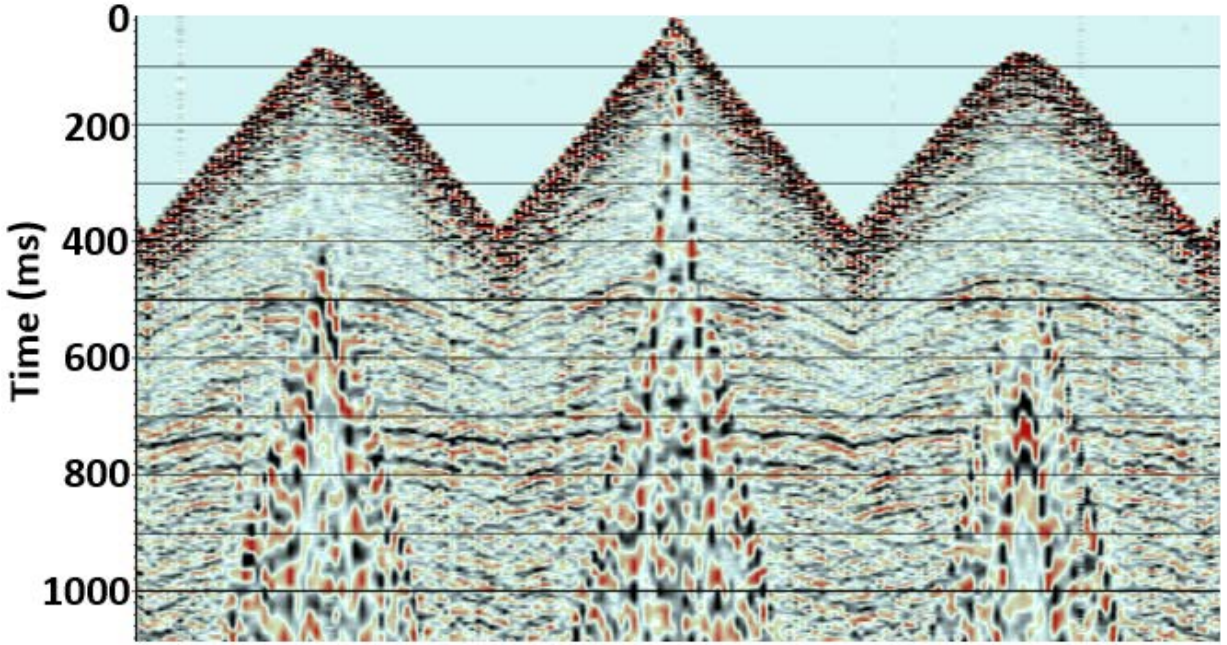
3D outline and well positions

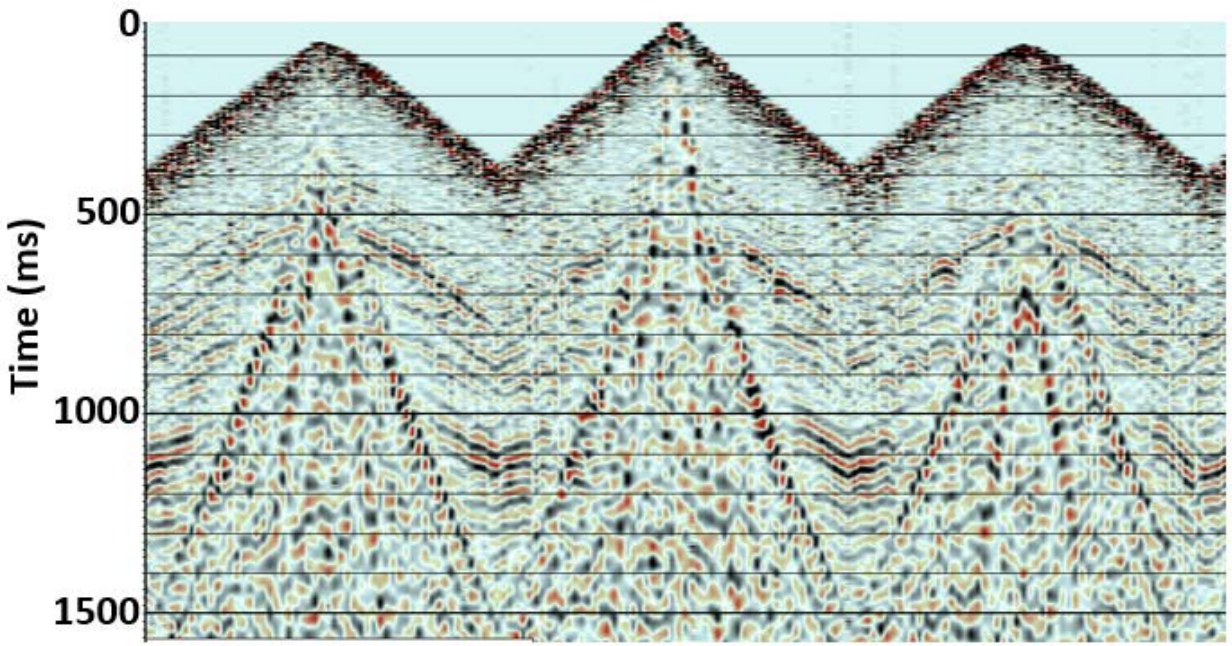


Sources (red) and receivers (blue)

- 17 km^2 3C-3D seismic data
  - Orthogonal acquisition design
  - Dynamite source
  - 125 m source and receiver line interval
  - 25 m source and receiver spacing
- 14 logged wells
  - 3 dipole sonic logs
- Polarity convention
  - Peaks blue (positive acoustic impedance contrast)
  - Troughs red (negative acoustic impedance contrast)

Raw records





- Vertical component (left)
  - PP reflection energy

- Radial component (right)
  - P-SV reflection energy
  - Rotated from inline and crossline components into radial and transverse

PP and PS Processing

- PP and PS data are processed jointly

- Several of the PP processing outputs are used in PS processing
  - Source statics, PP stacking velocities, CMP bin locations for instance

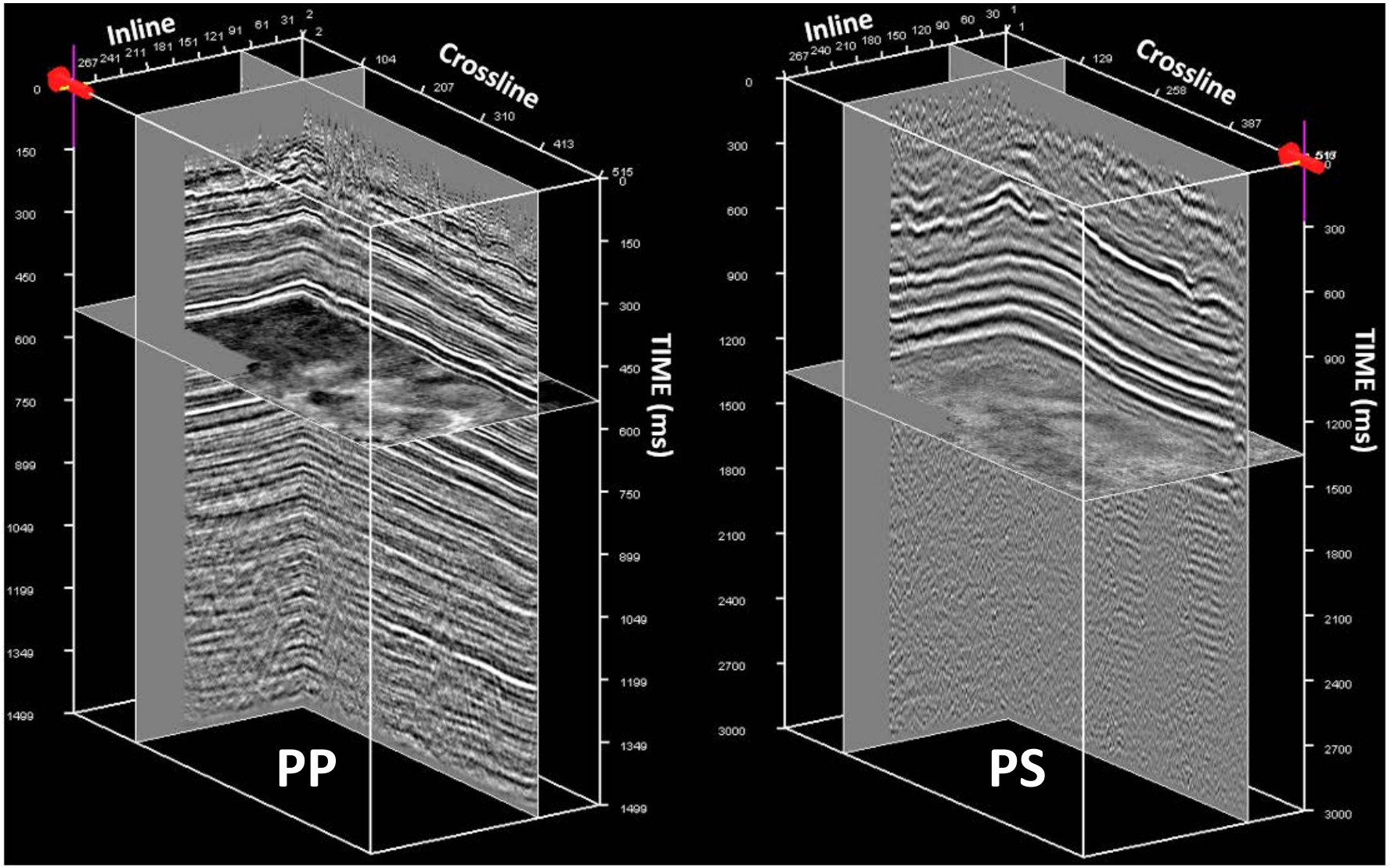
- Many PP processing tools are implemented in PS processing

PP and PS Processing

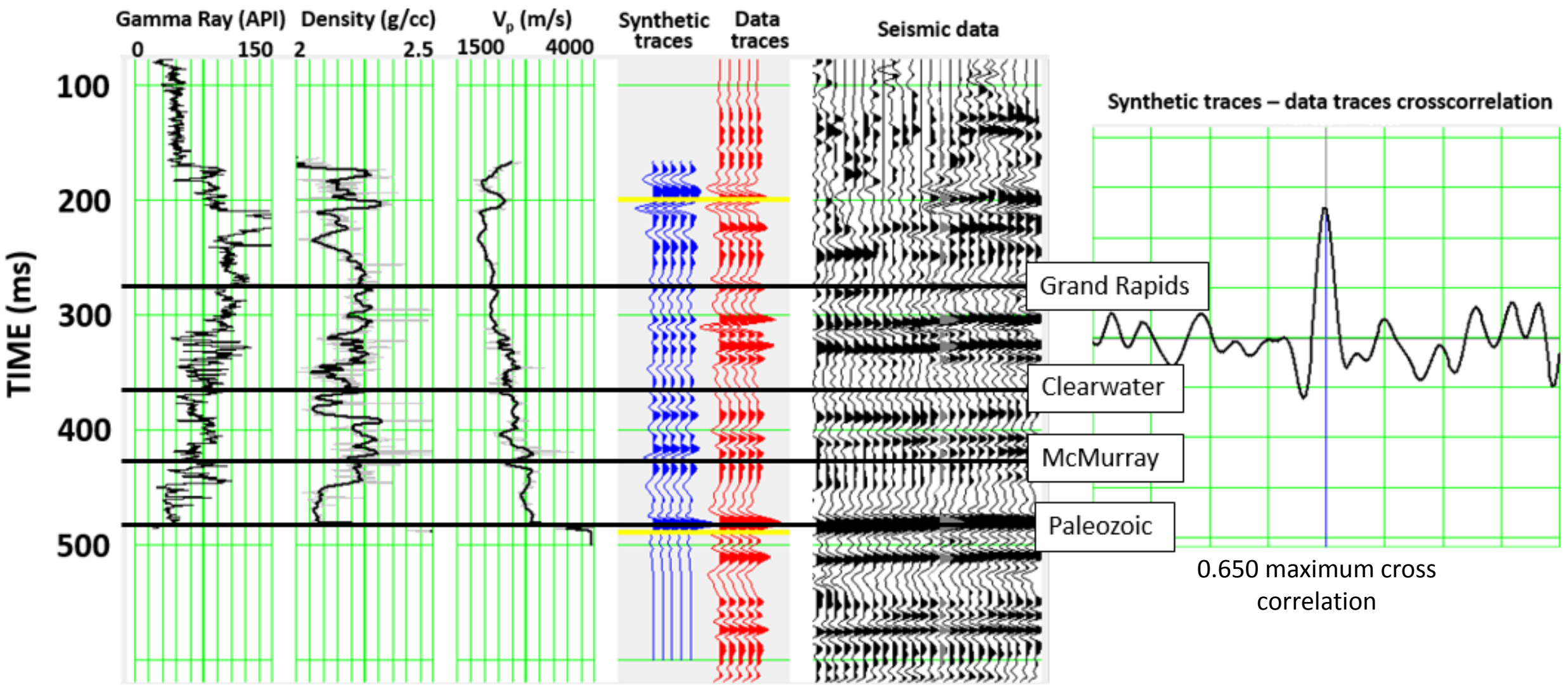
- Geometry and bin grid assignment
- Refraction and elevation statics
- Radial transform denoise
- Amplitude corrections
- Gabor deconvolution
- Spectral balancing
- P wave velocity analysis and normal moveout correction
- Residual statics
- Repeated velocity analysis and residual statics (x4)
- CMP stack
- PSPI migration
- FXY signal enhancement

- Geometry assignment and bin grid assignment
- **Trace rotation into radial and transverse components**
- **P wave shot statics** and elevation statics application
- Radial transform denoise
- Gabor deconvolution
- Spectral balancing
- **Converted** wave velocity analysis
- **Common receiver stack**
- **S wave receiver statics**
- **Asymptotic common conversion point binning and stacking**
- Residual statics
- Repeated velocity analysis, **receiver statics** and residual statics (x4)
- **Common conversion point (CCP) stack**
- PSPI migration
- FXY signal enhancement

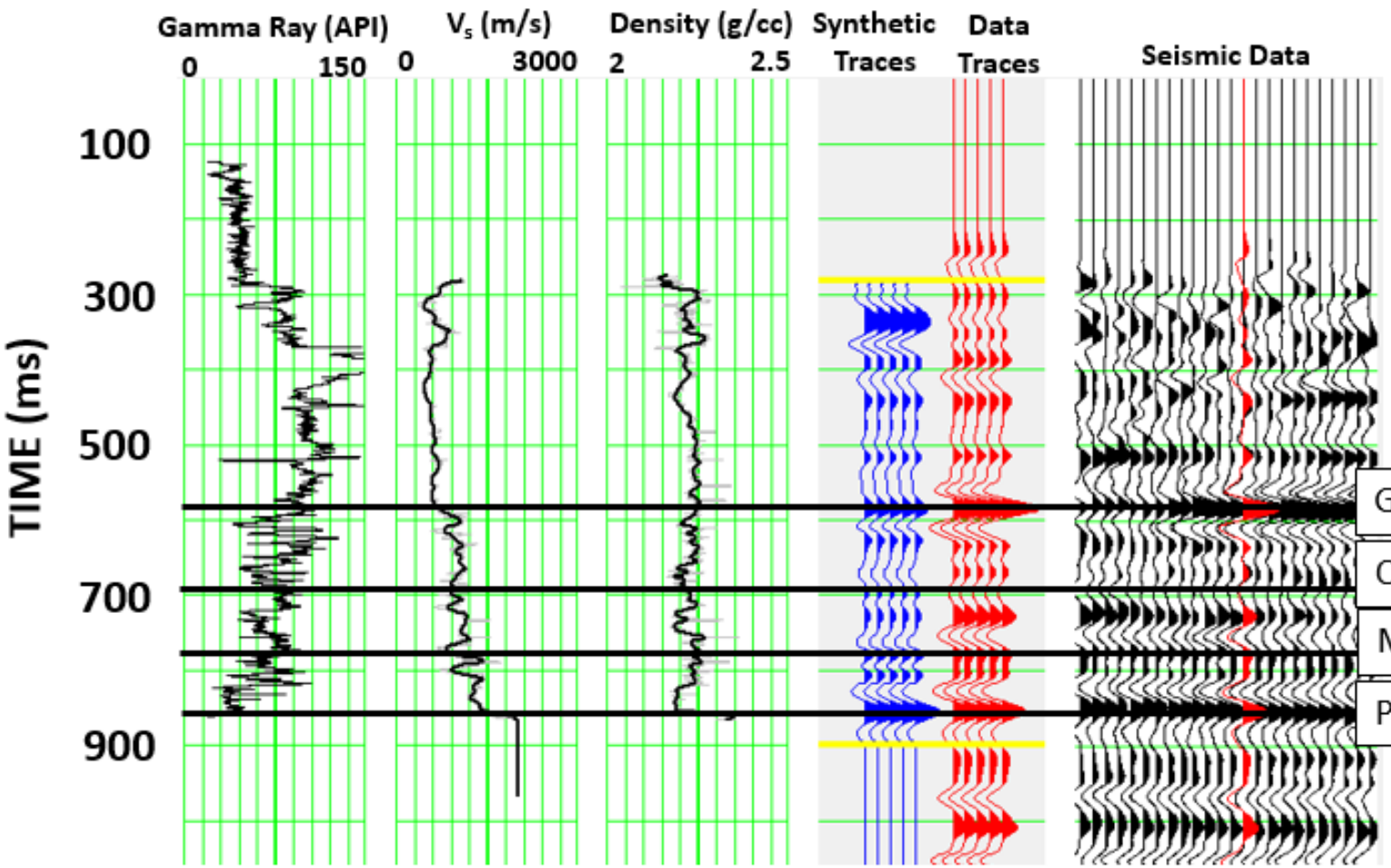
Fully processed stack data examples

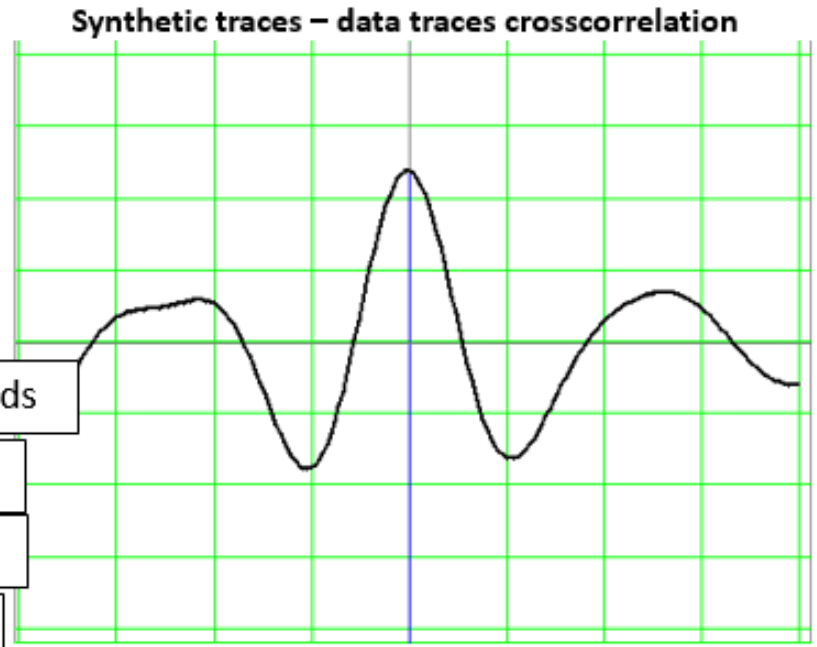


PP synthetic seismogram



PS synthetic seismogram

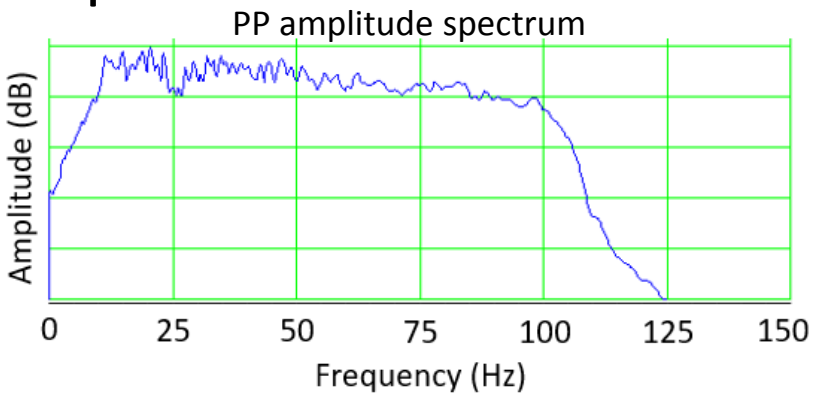


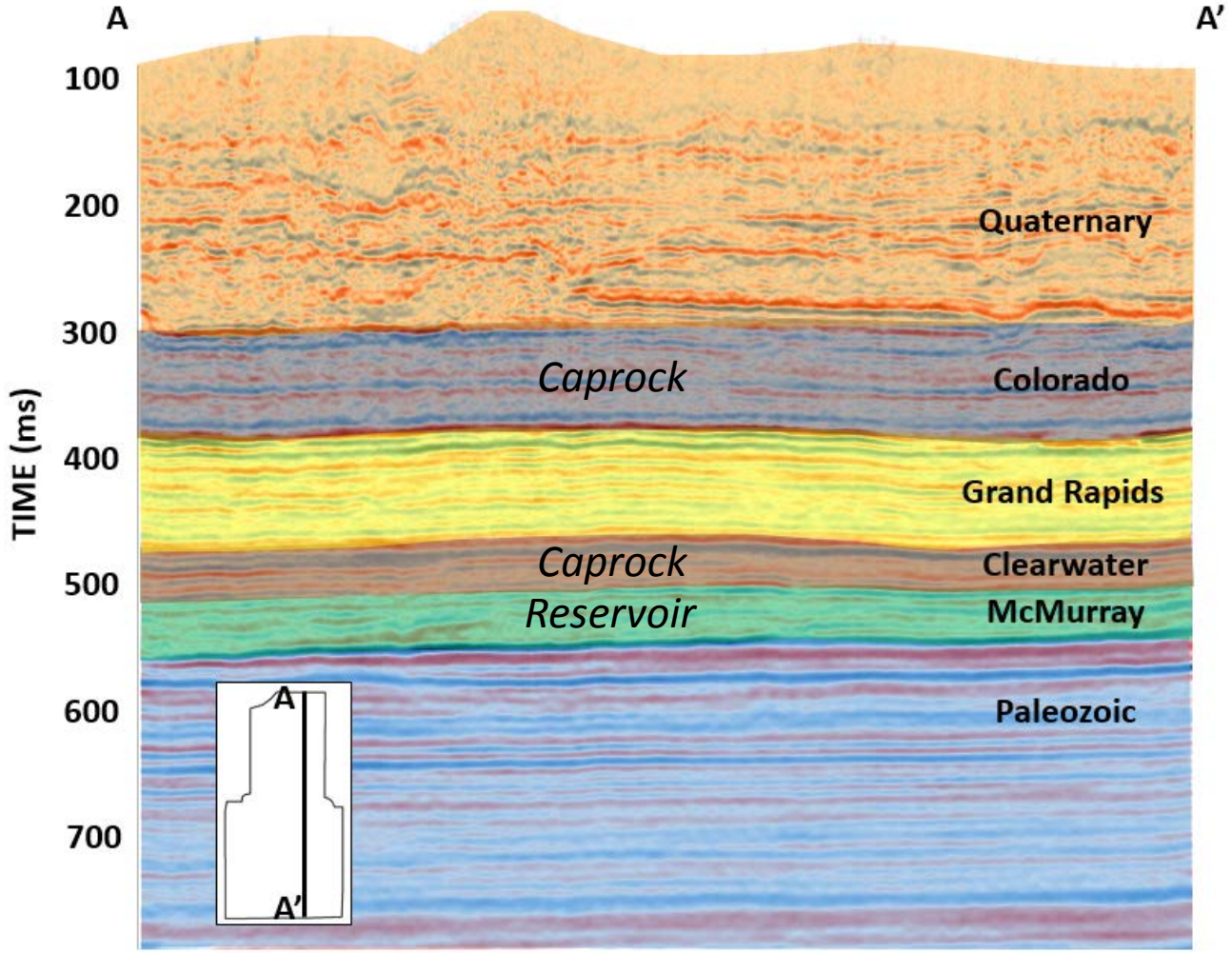


0.667 maximum cross correlation

PP seismic stratigraphy

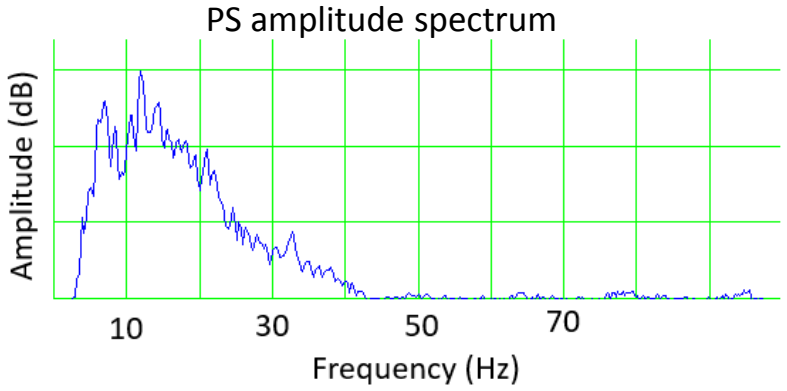
- Good reflection continuity
  - Paleozoic unconformity
  - Clearwater Fm
  - Grand Rapids Fm
- Marginal reflection continuity
  - McMurray Fm
  - Colorado Gp

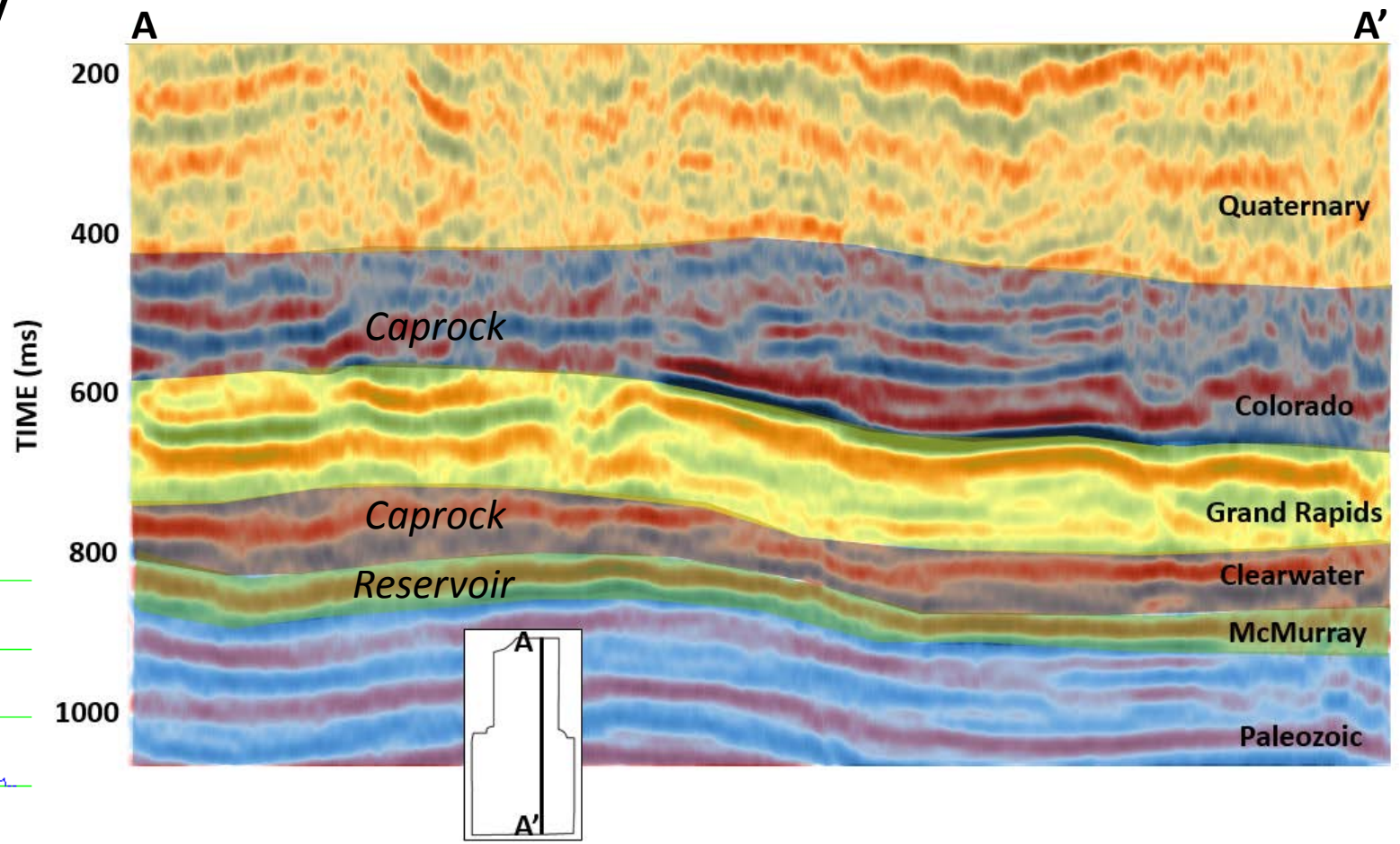




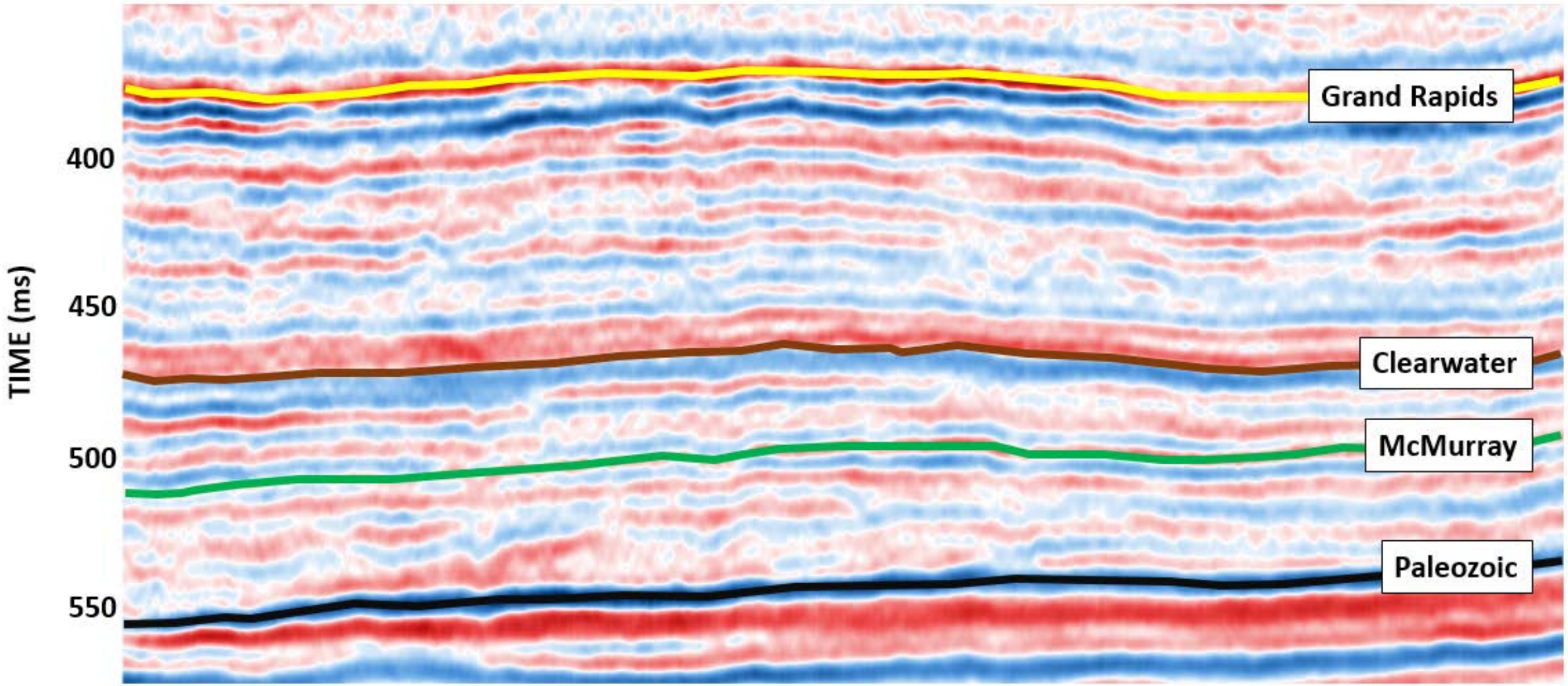
PS seismic stratigraphy

- Good reflection continuity
  - All major events besides Quaternary

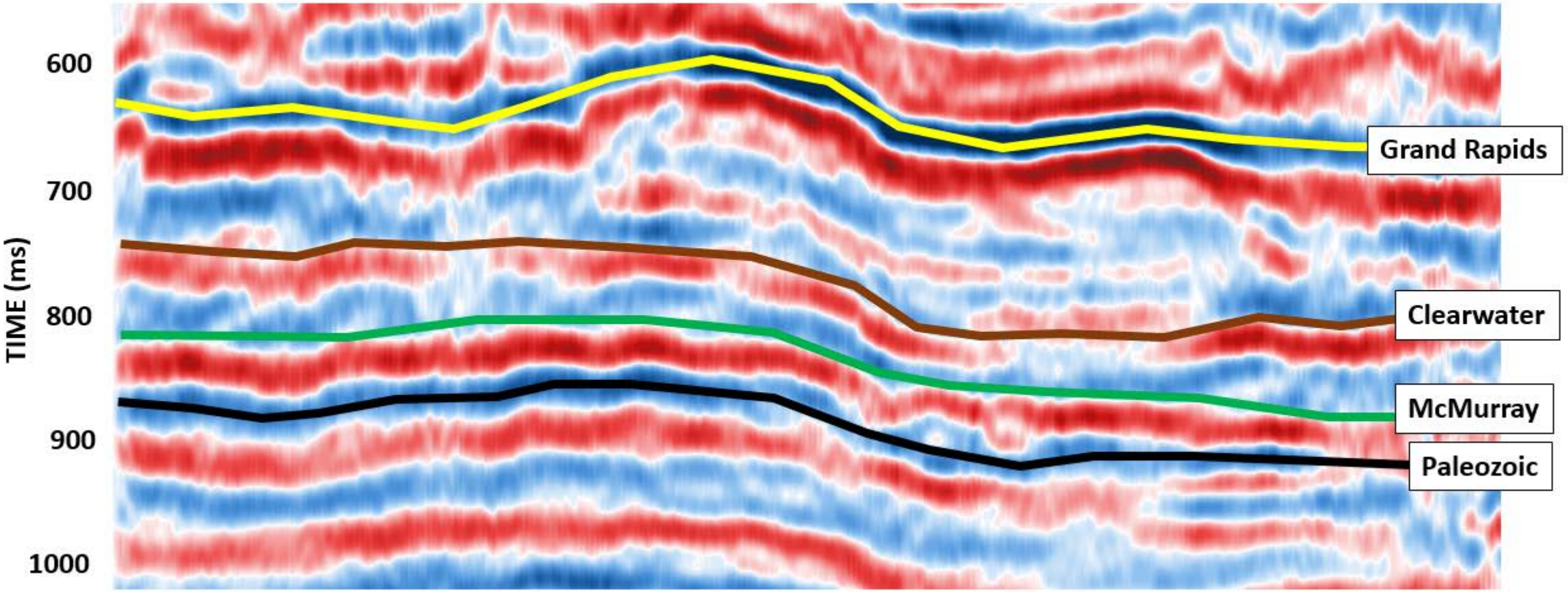




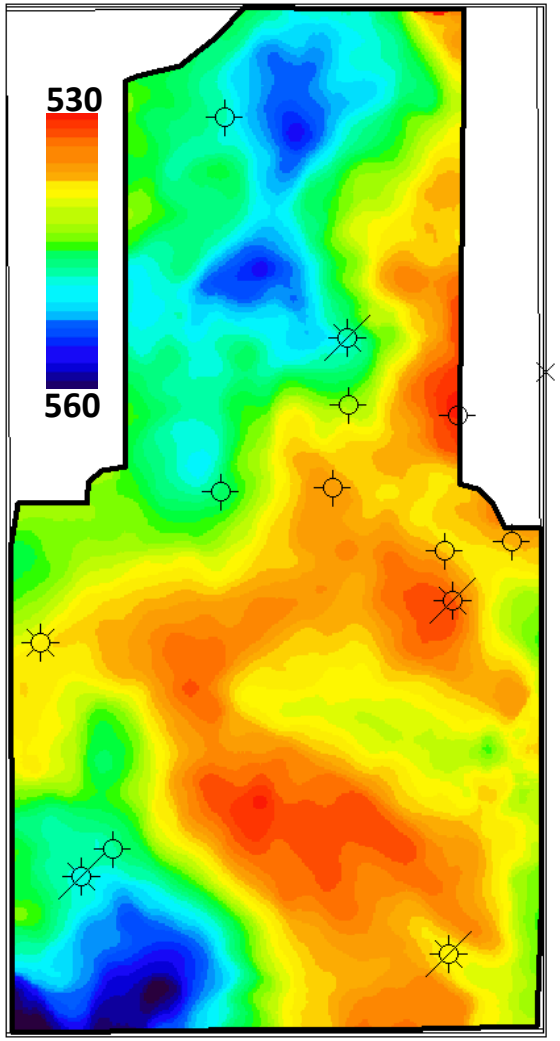
Interval of interest – PP



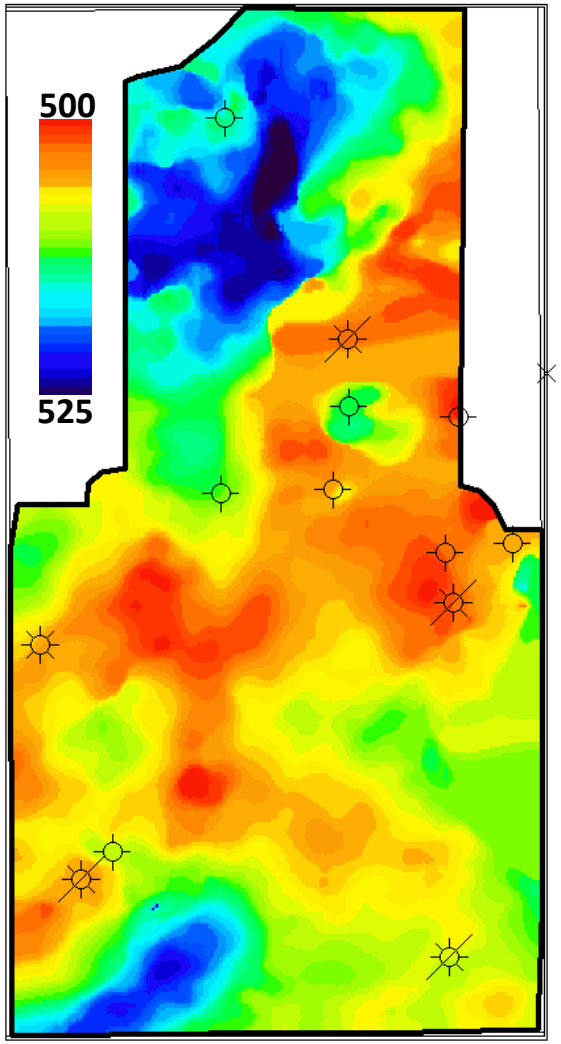
Interval of interest – PS



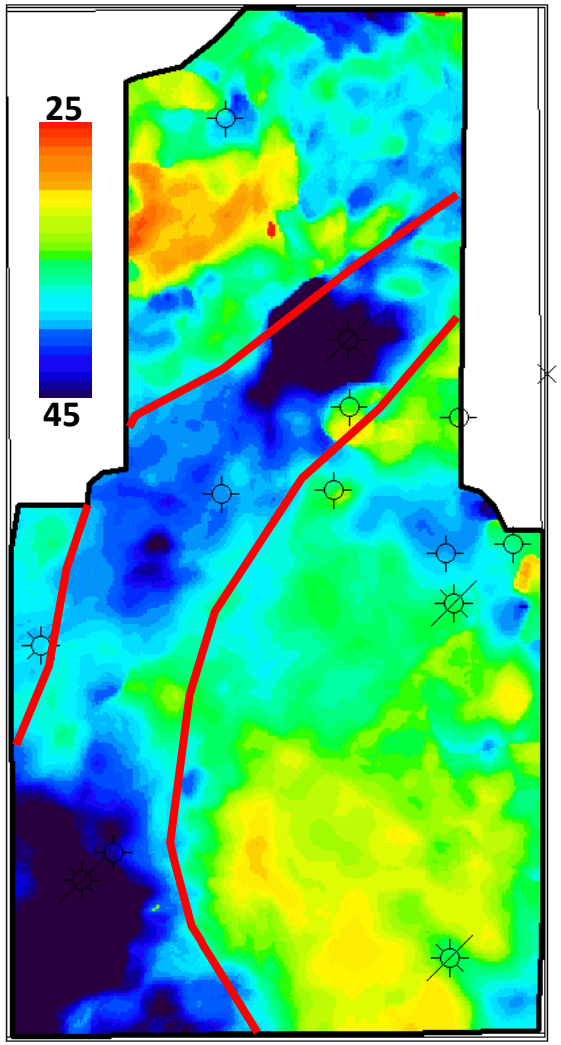
McMurray time structure and isochron



Paleozoic time structure



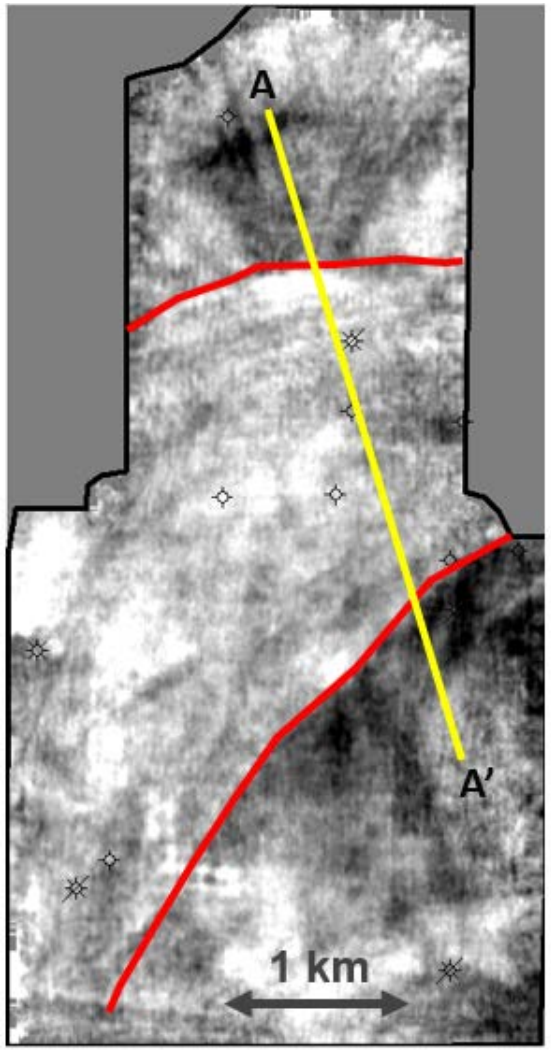
McMurray time structure



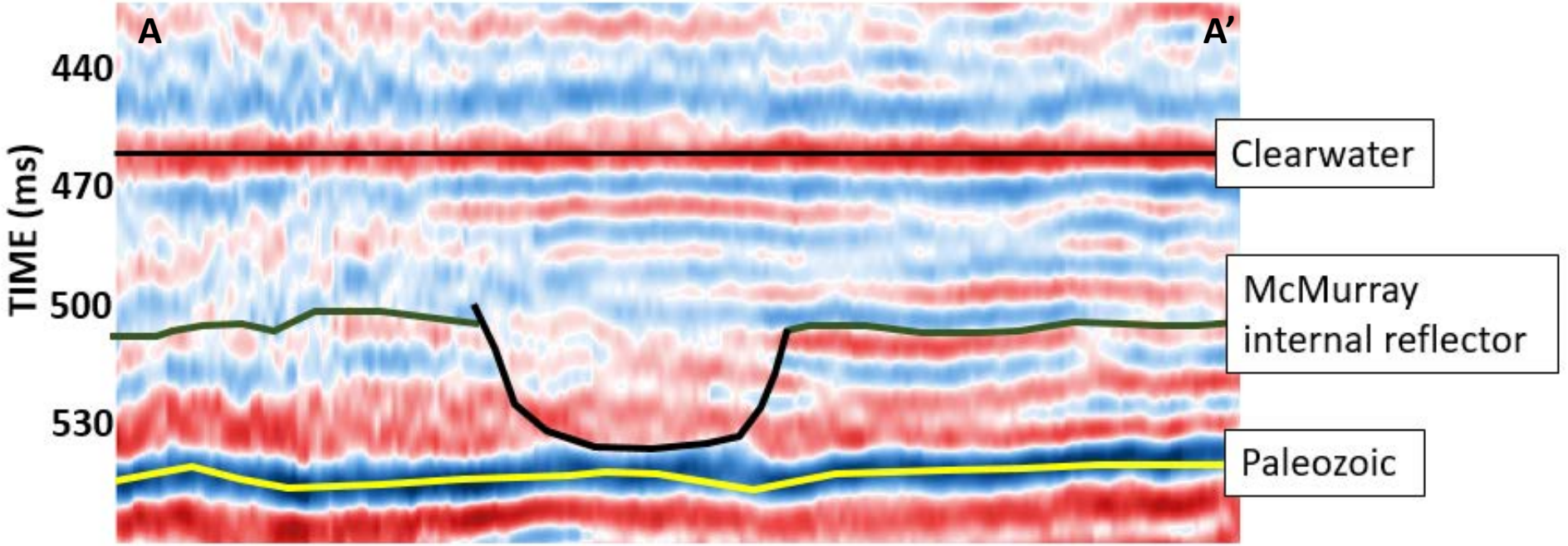
McMurray – Paleozoic isochron

- McMurray structure follows regional Paleozoic topography
- High structure, thick isochron trend from NE to SW
  - McMurray channel fill

McMurray channel – PP

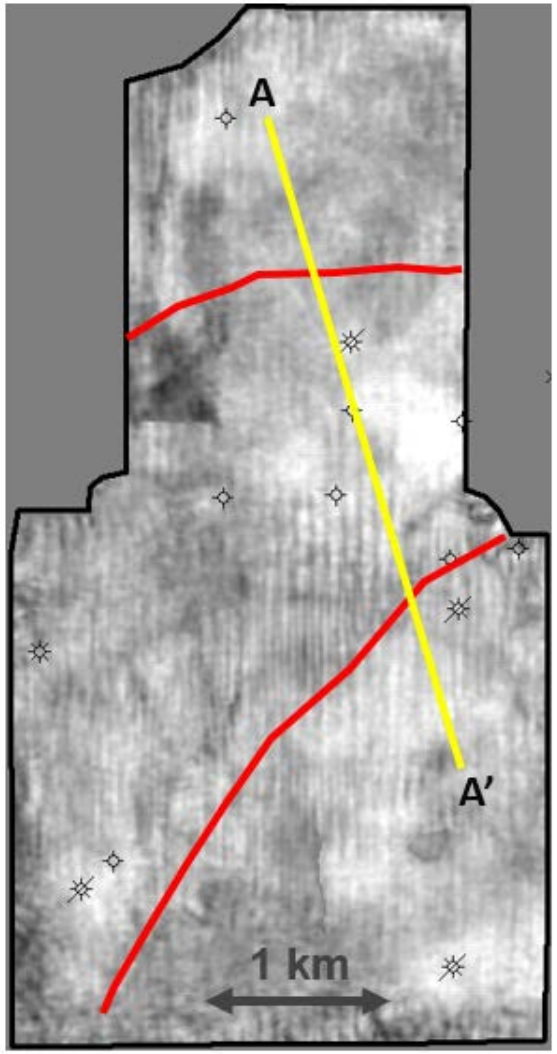


Middle McMurray stratal slide (amplitude)

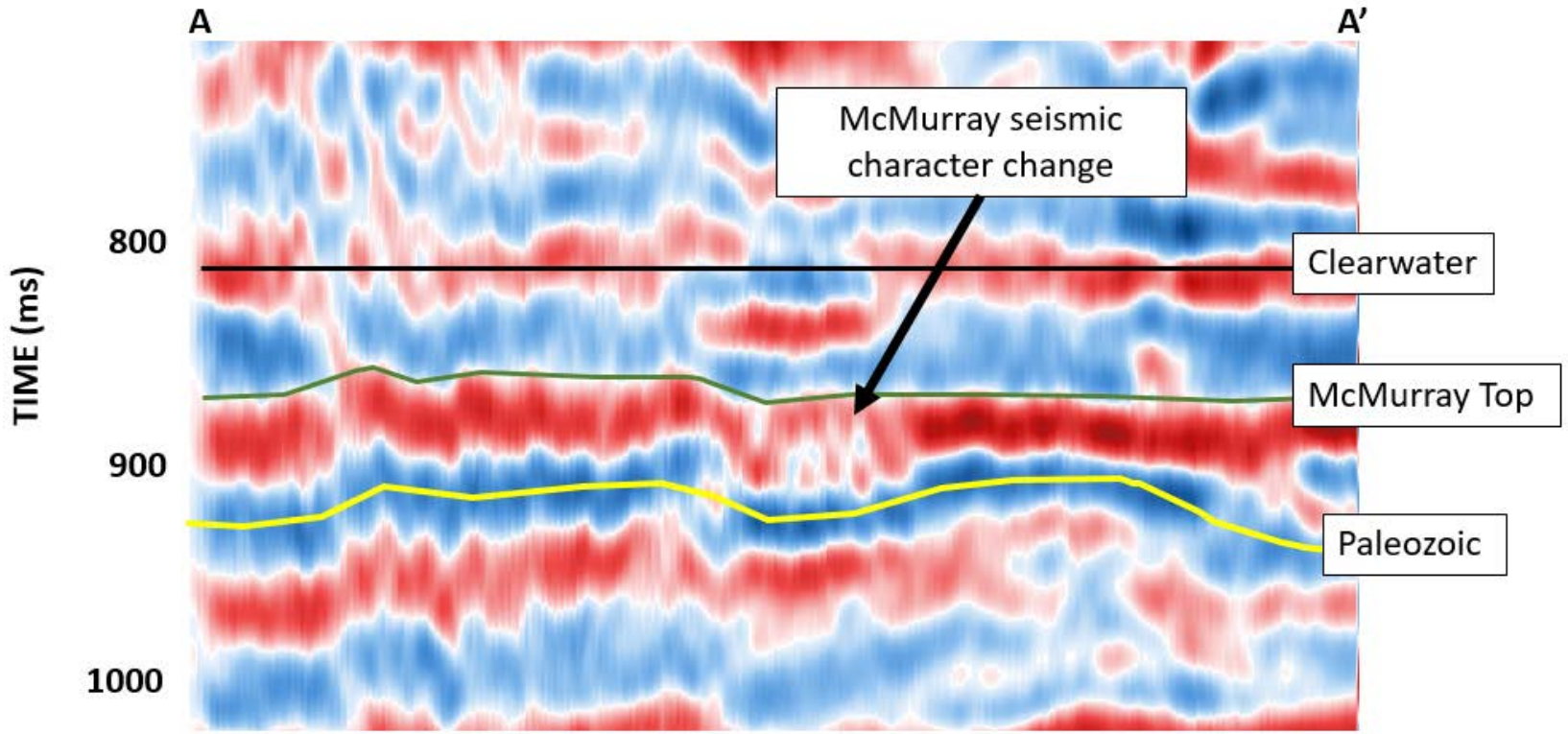


PP seismic cross section – flattened on Clearwater Fm

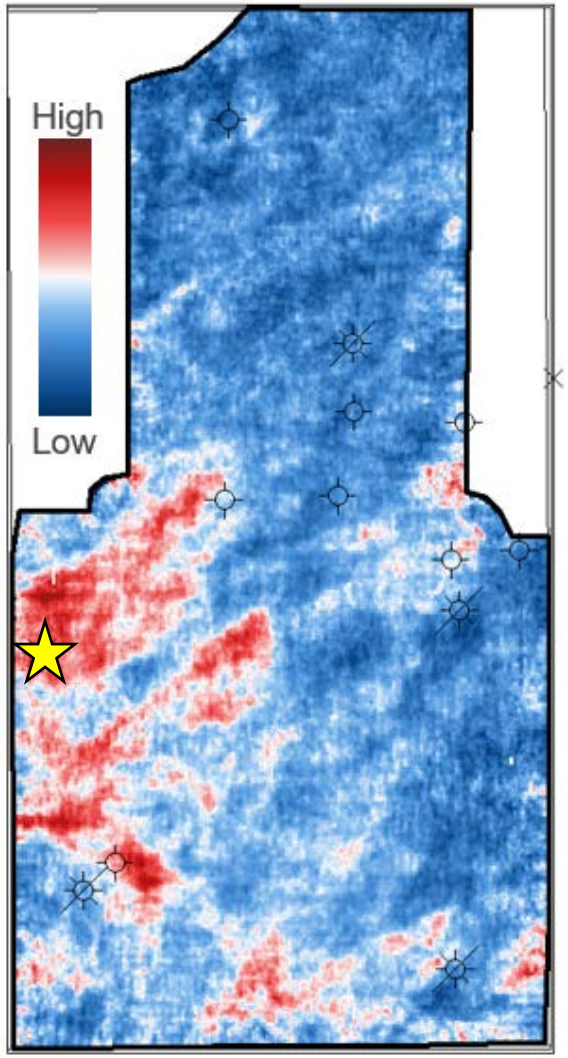
McMurray channel – PS



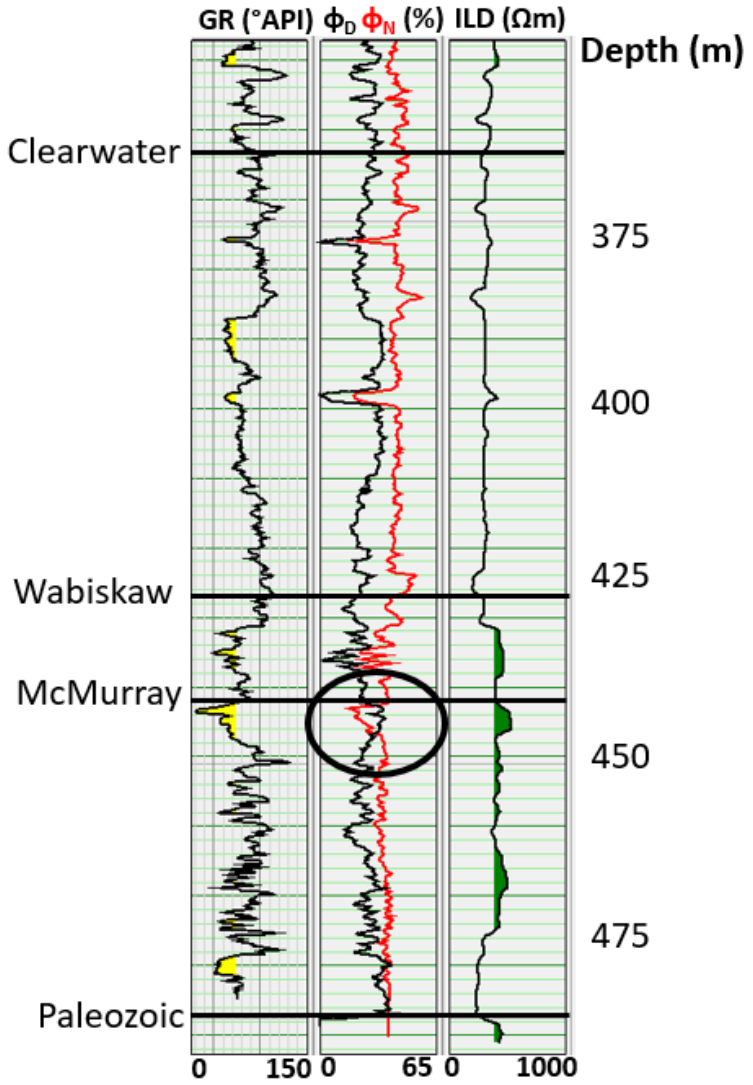
Middle McMurray time slide (amplitude)



McMurray natural gas

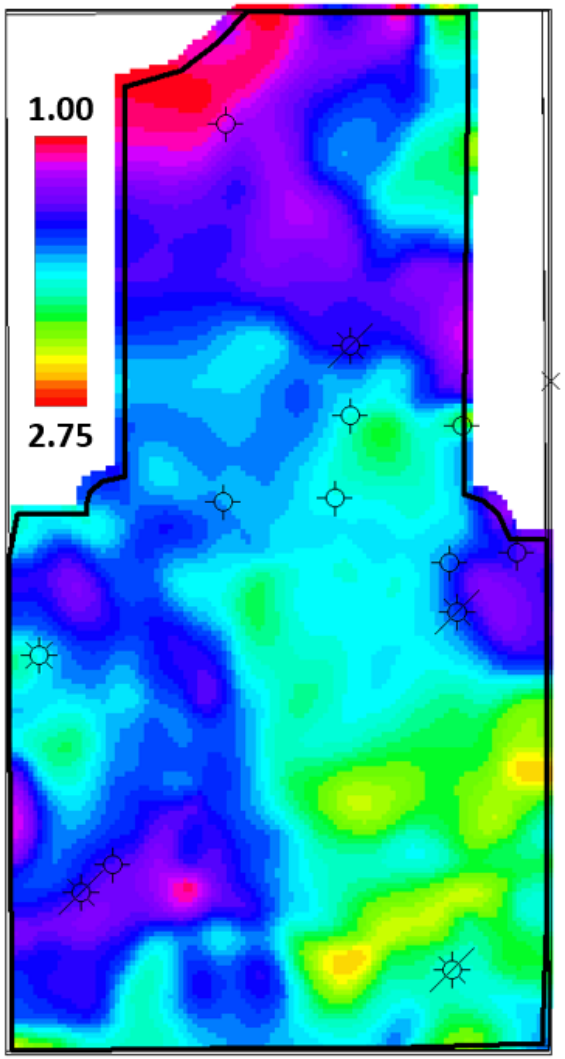


Upper McMurray RMS amplitude



- High RMS amplitude in the Upper McMurray correlated to in situ natural gas
  - Based off of porosity logs

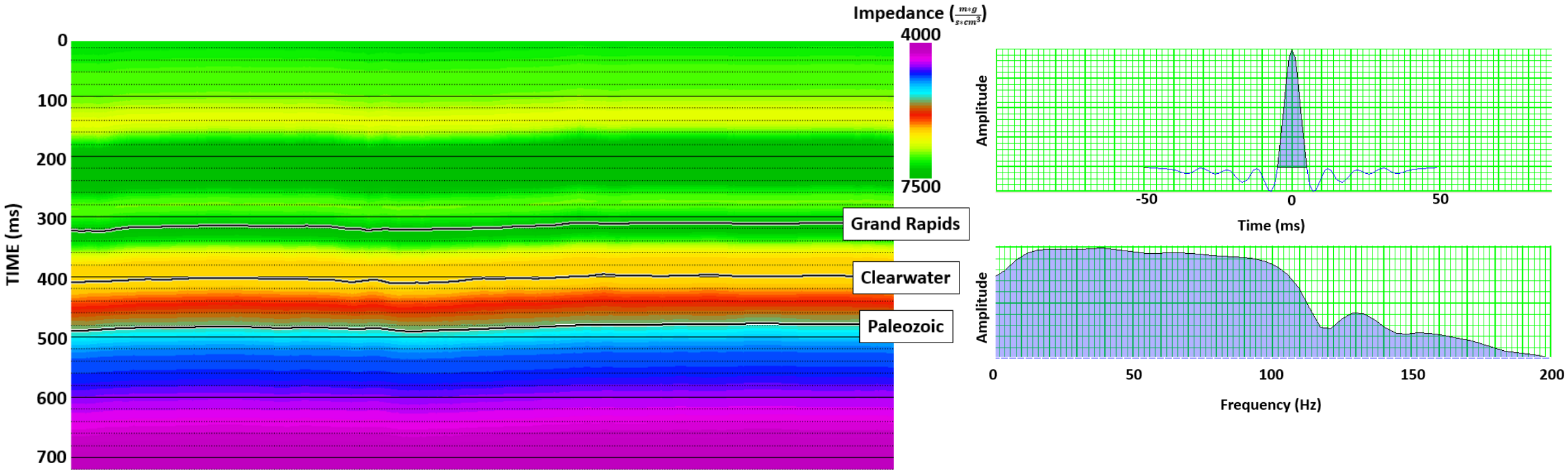
Horizon based interval V_p/V_s



Grand Rapids – Paleozoic interval V_p/V_s

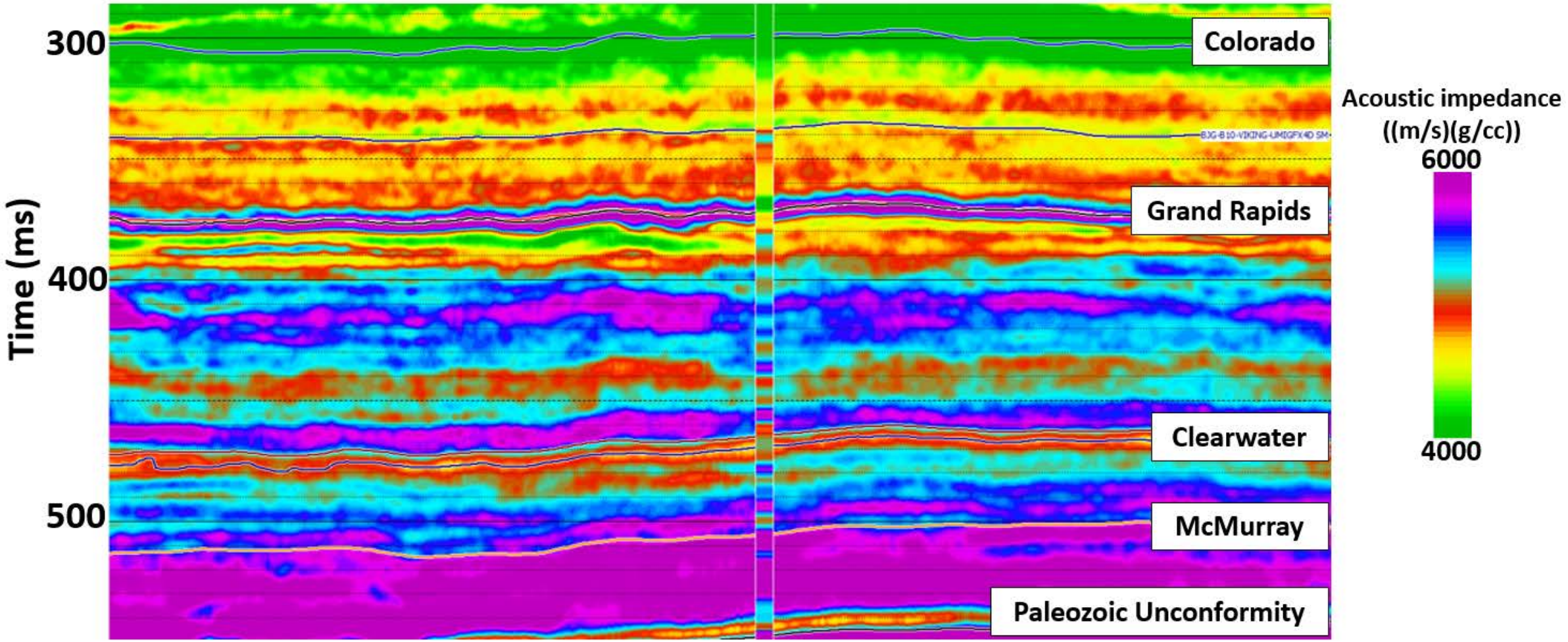
- Horizon based interval V_p/V_s maps require large intervals
  - To avoid creating large anomalies from small picking errors
- Bad picks are amplified in interval V_p/V_s maps
  - NW corner of survey for example
- Well log average V_p/V_s is 2.25 in the interval

Inversion

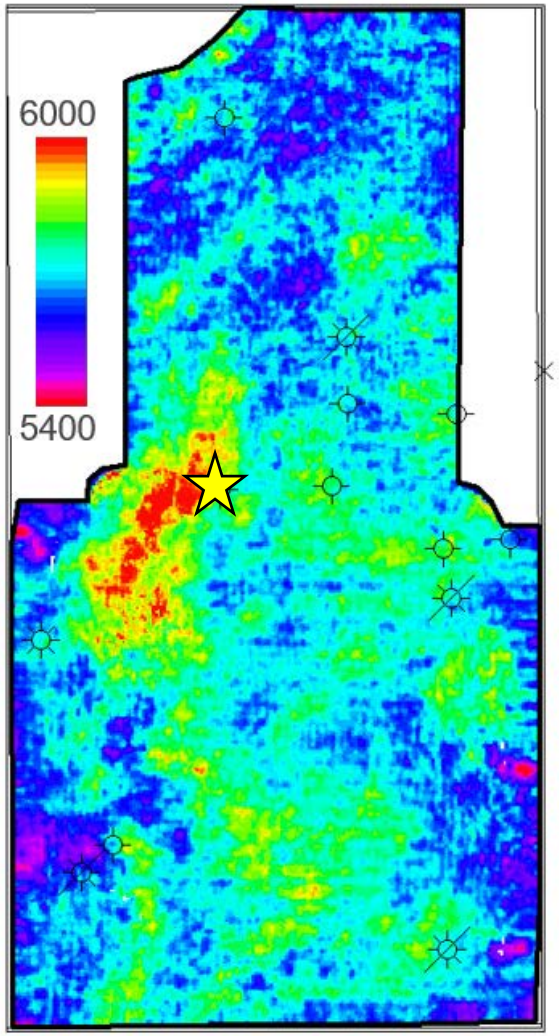


- Inversion P-impedance input model, created from three pervasive reflection horizons and a single well
- Inversion wavelet, extracted from the zone of interest in the PP seismic data

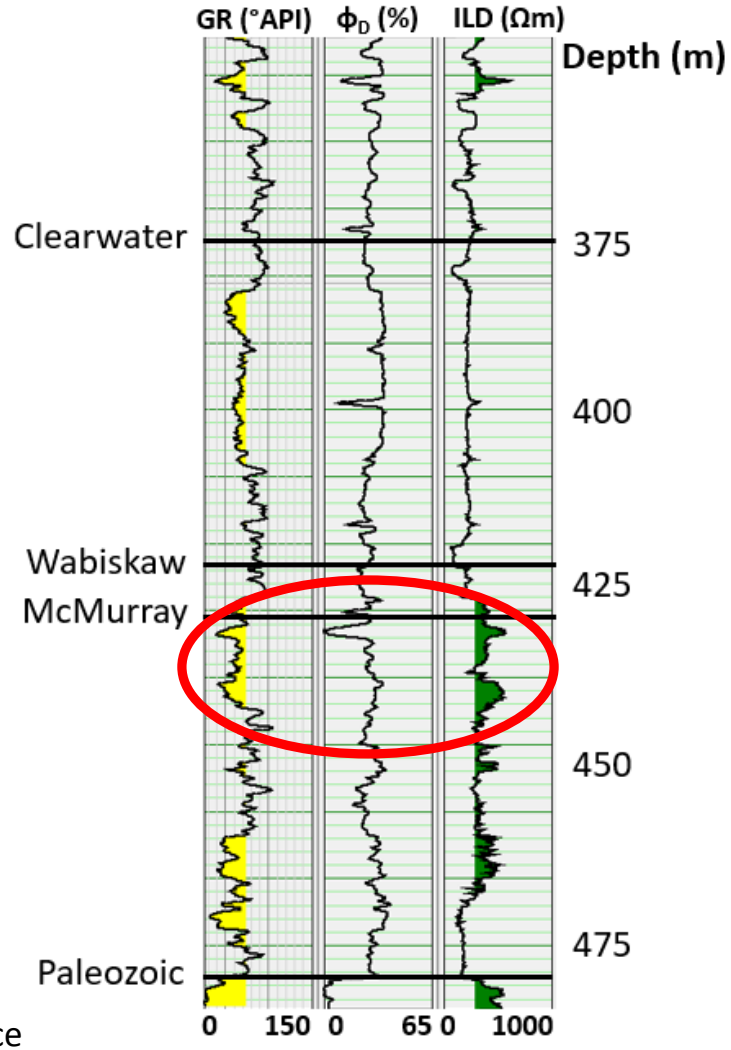
Post-stack inversion results



Interval RMS impedance

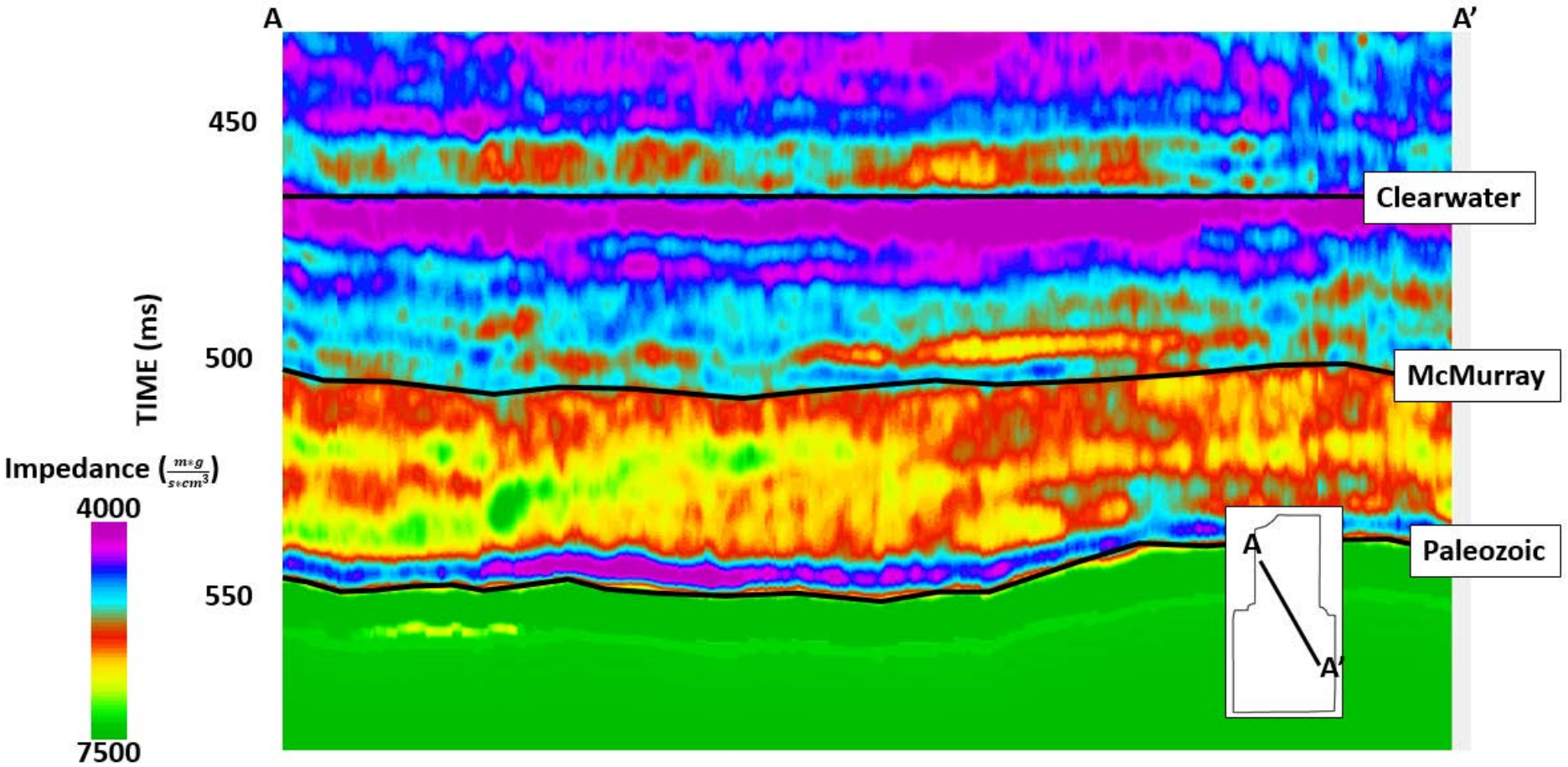


Upper McMurray interval RMS impedance

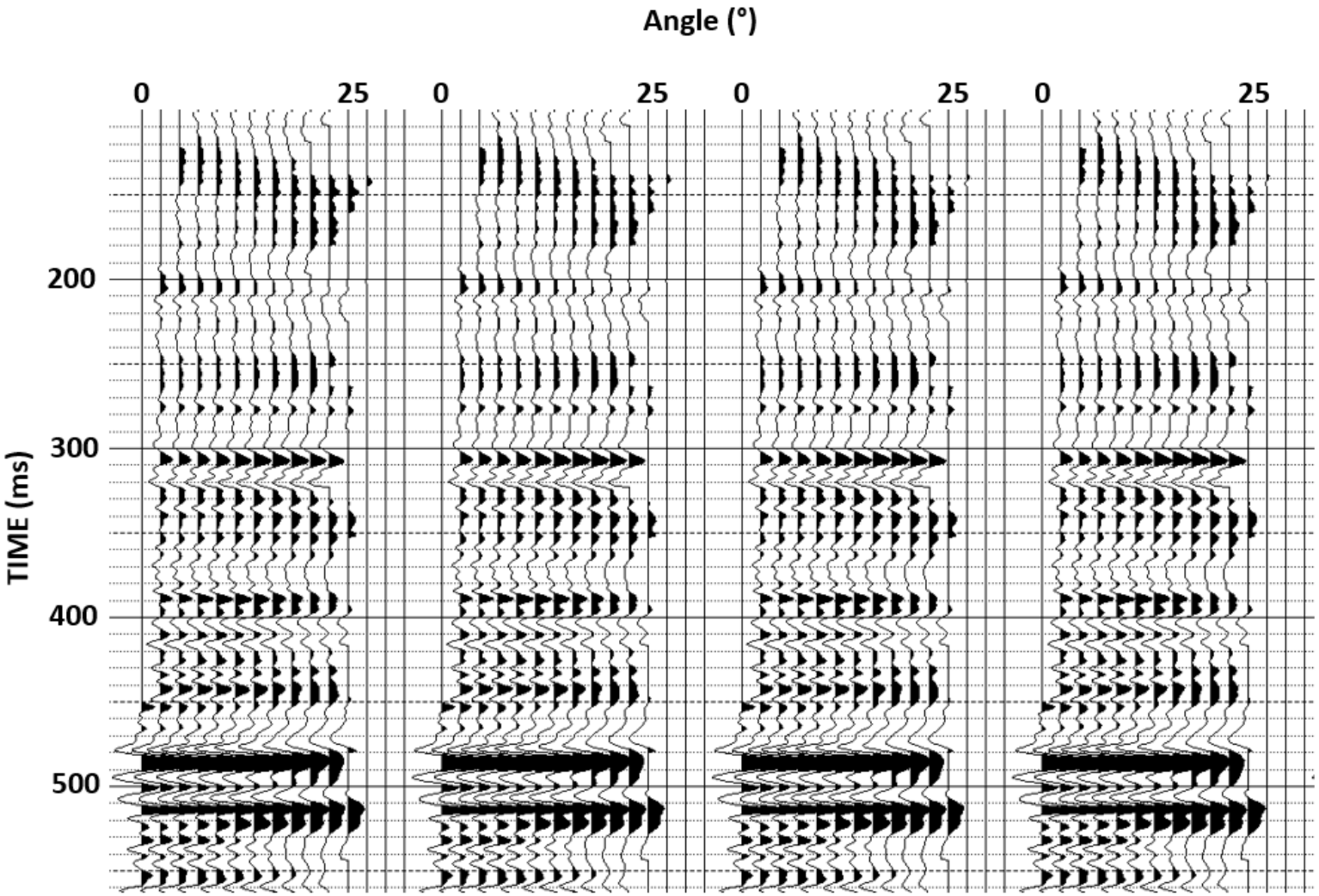


- High RMS impedance correlates to better quality reservoir
  - Based on GR and porosity logs

Impedance cross section through McMurray Channel

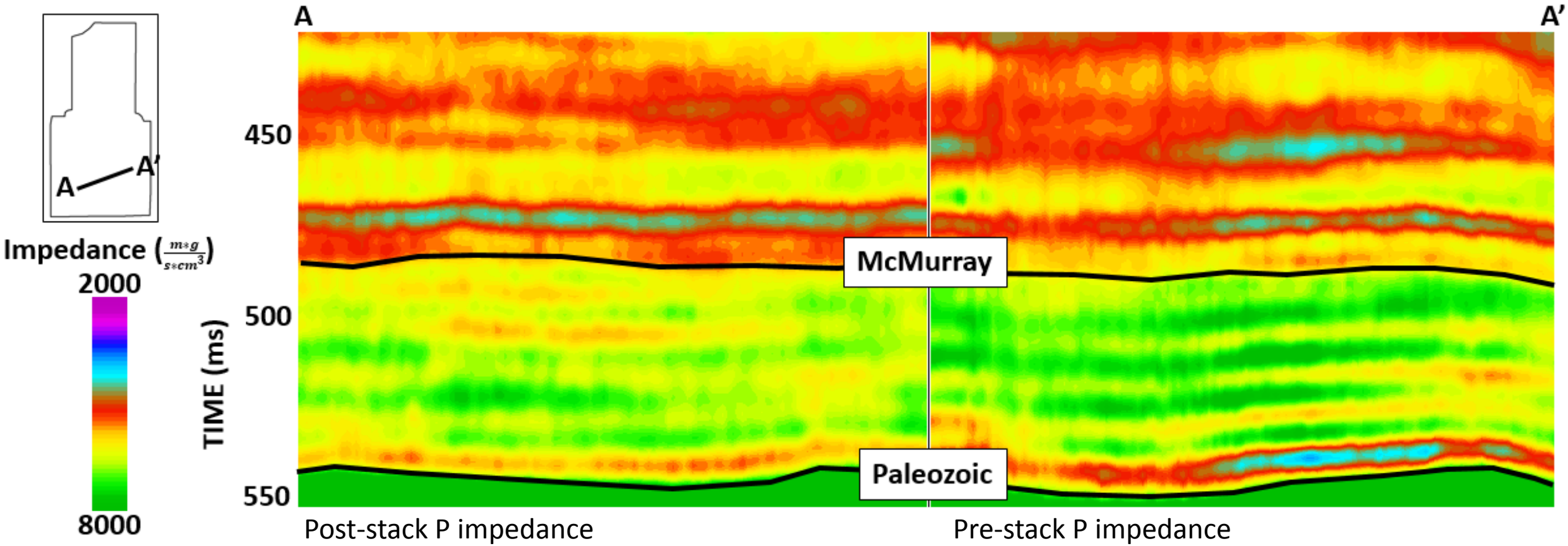


Pre-stack model based inversion – Angle gathers

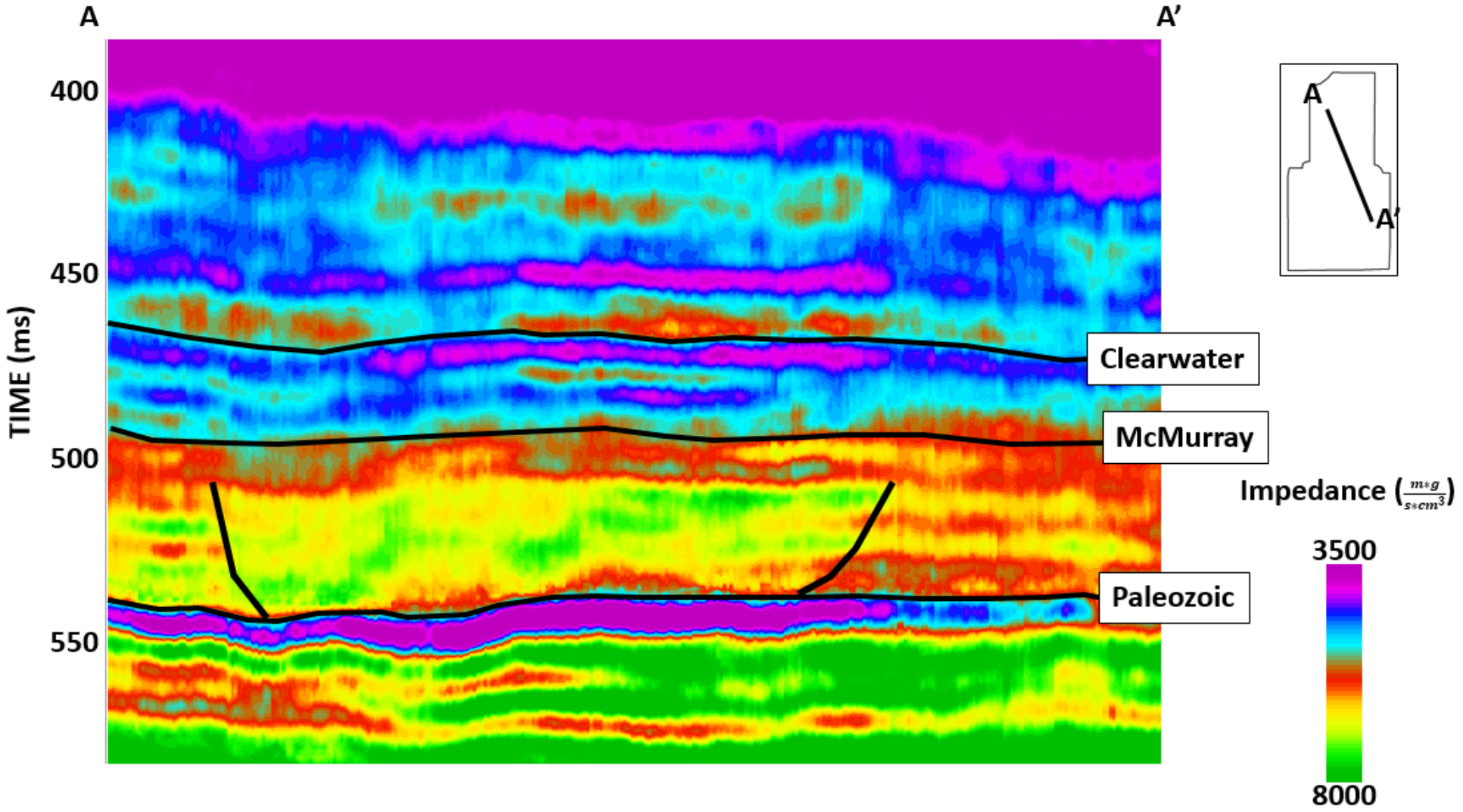


- Pre-stack data conditioning
  - Filtering
  - Super gather
  - Radon de-noise
  - Trim statics
  - Angle gather

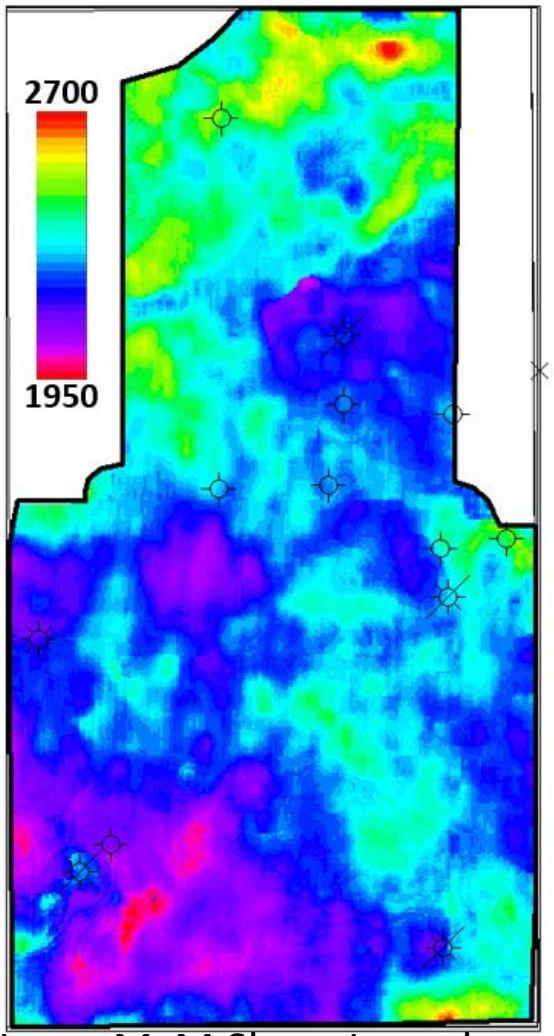
Comparing inversions



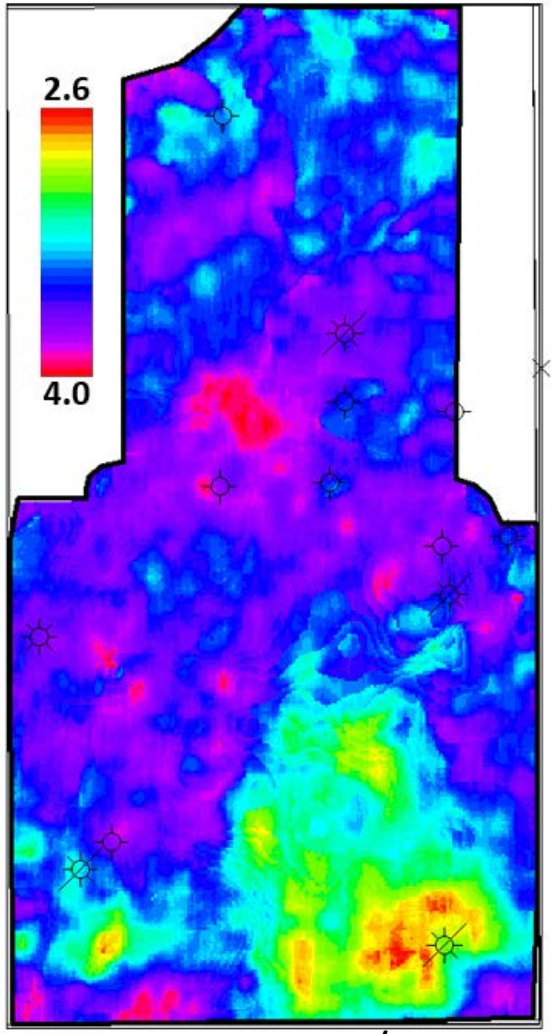
Pre-stack model based inversion



Interval RMS shear impedance and V_p/V_s



Upper McM Shear Impedance



Upper McM V_p/V_s

- Relatively low shear impedance and high V_p/V_s in the McMurray channel

Summary and future work

- Processing of 3C 3D seismic data from Athabasca Oil Sands
  - Vertical and Radial geophone components processed to PP and PS stacks
- Regional geologic interpretation
  - Pervasive reflection horizons
  - Identification of large McMurray channel from structure and isochron maps
- Inversion analysis to identify high quality reservoir zones
- Future work:
  - PP-PS joint inversion and comparison to pre-stack PP inversion
  - Linear and nonlinear multiattribute analysis

Acknowledgements

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