Multicomponent interpretation: examples from the Marcellus Shale and Athabasca oil sands

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Project objectives

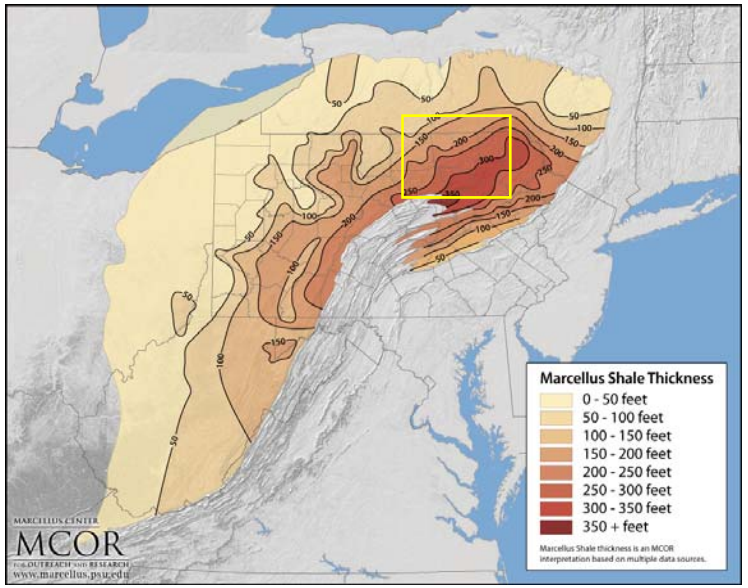
- Marcellus project
  - General interpretation of PP, PS1 and PS2 seismic volumes
  - Interval V_p/V_s map analysis
  - Anisotropic analysis utilizing PS1 and PS2 volumes
  - Identification of potential hydrocarbon and hydraulic fracturing sweet spots

- Oil sands project
  - General interpretation of PP stack including impedance inversion
  - Shear log estimation and analysis
  - Begin processing of PS data
  - Ultimate goal is to characterize and understand the reservoir, caprock, and near surface intervals

Marcellus geological setting

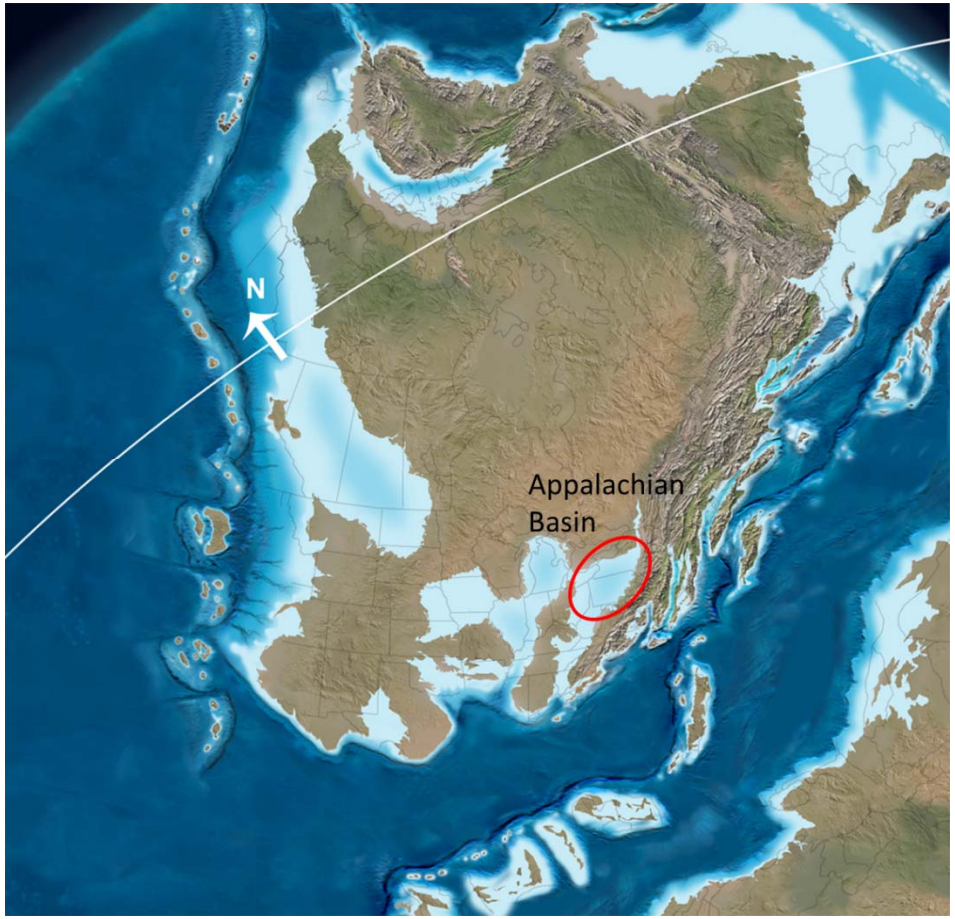
- Middle Devonian deposition
- Relatively deep marine, anoxic
  - Dominantly black shale
- Erosive clastic genetic origin
  - Appalachian orogeny
- 1% - 11% TOC range

Marcellus Shale Isopach



(modified from Marcellus Center for Outreach and Research)

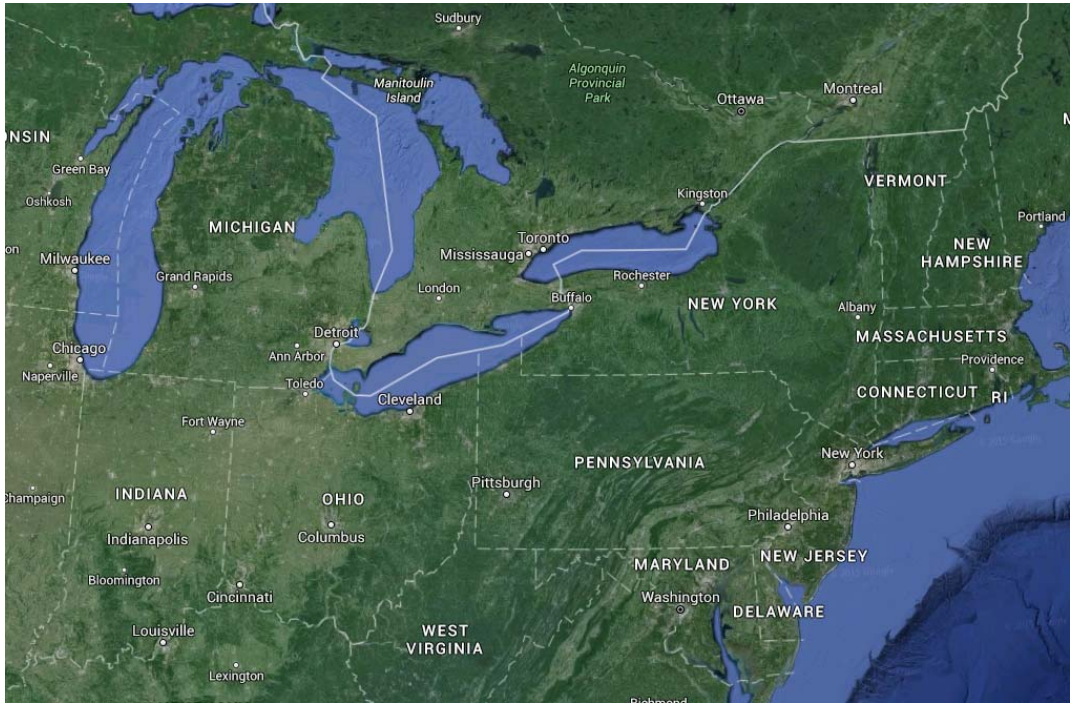
North America Devonian Paleogeography



(modified from Blakey 2011)

Marcellus seismic data

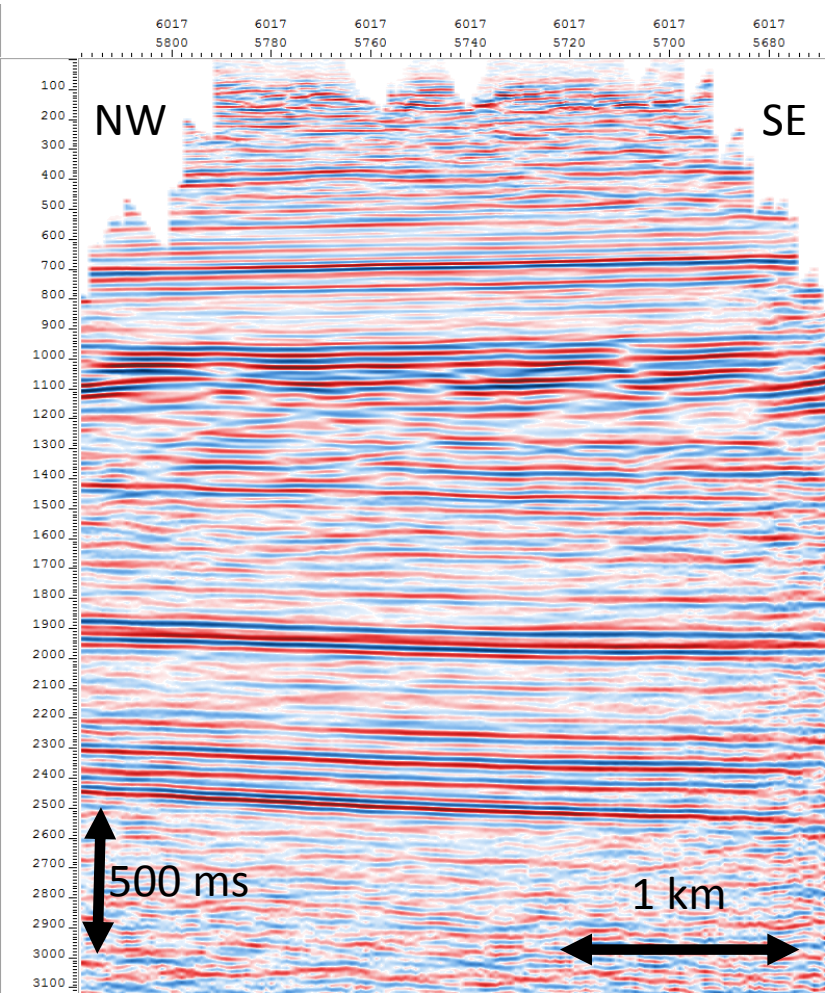
- ~24 km^2
- 2 ms sampling
- 34 m line and trace spacing
  - Inlines and xlines oriented parallel and perpendicular to Appalachian Mtns
- Freq. ranges:
  - PP: 5-50 Hz, PS1: 10-40 Hz, PS2: 10-35 Hz



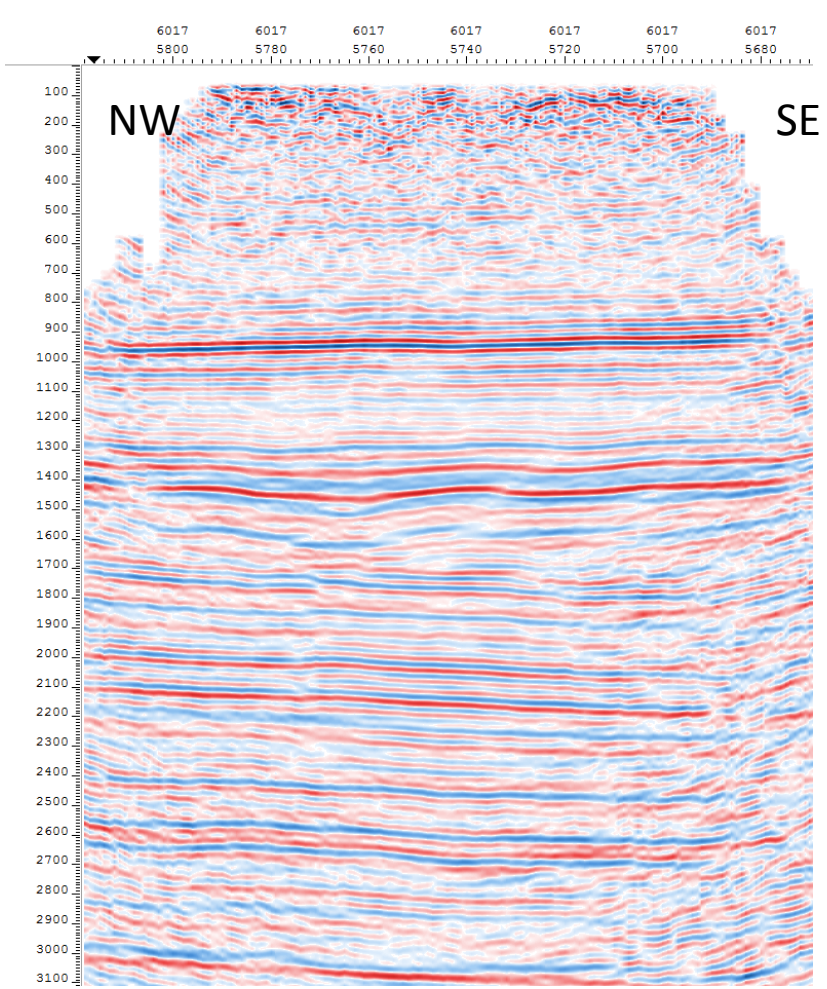
Geokinetics™

The Bradford County 3D 3C seismic dataset

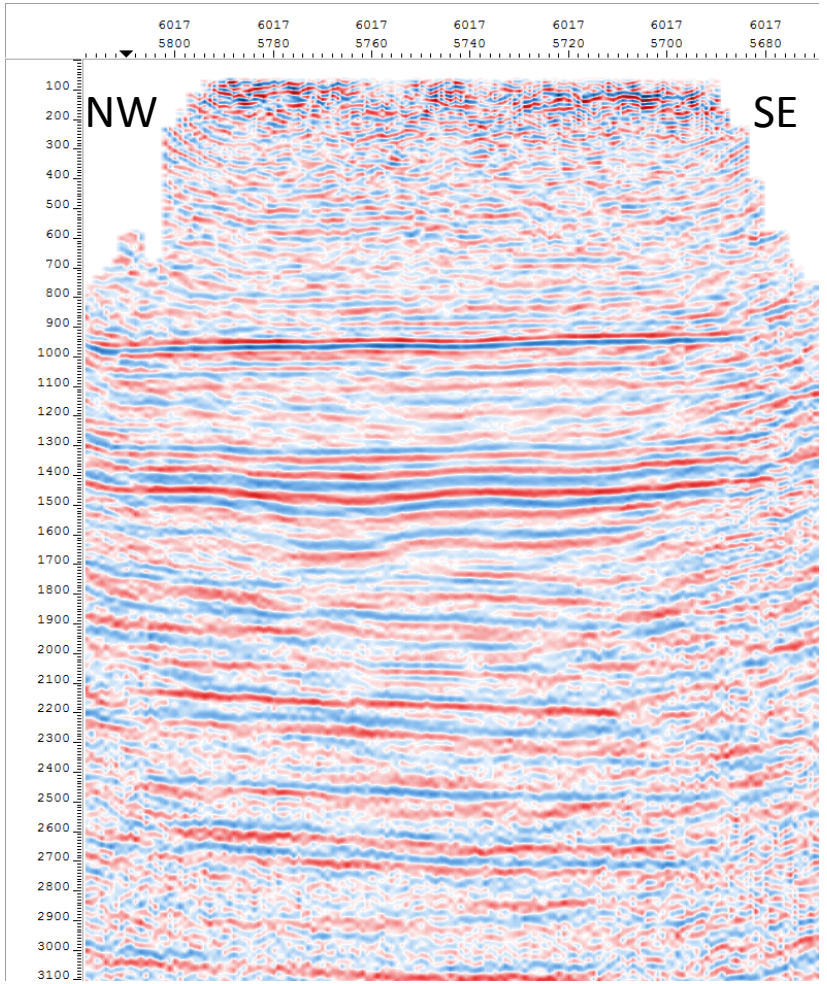
PP seismic data



PS1 seismic data

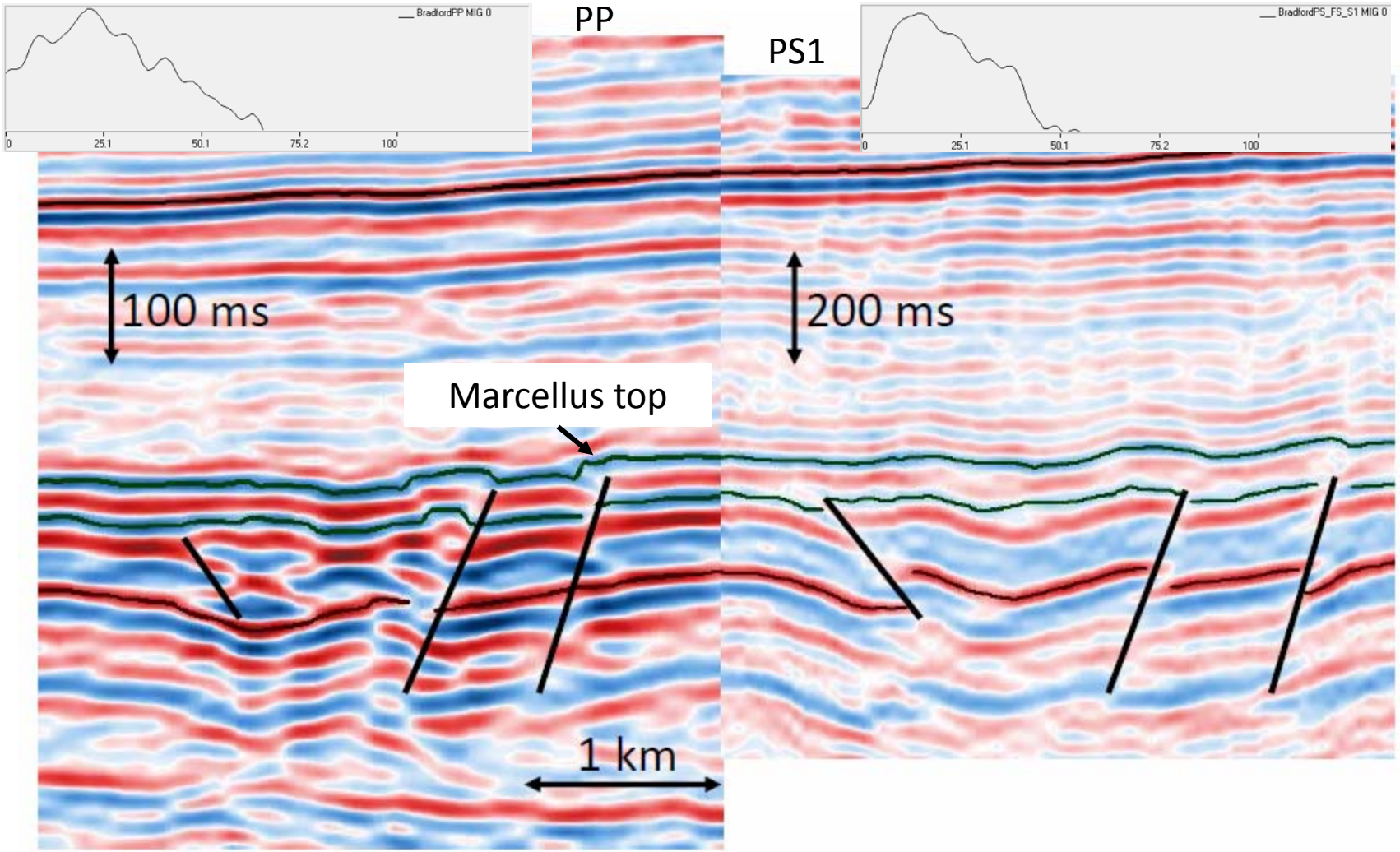


PS2 seismic data

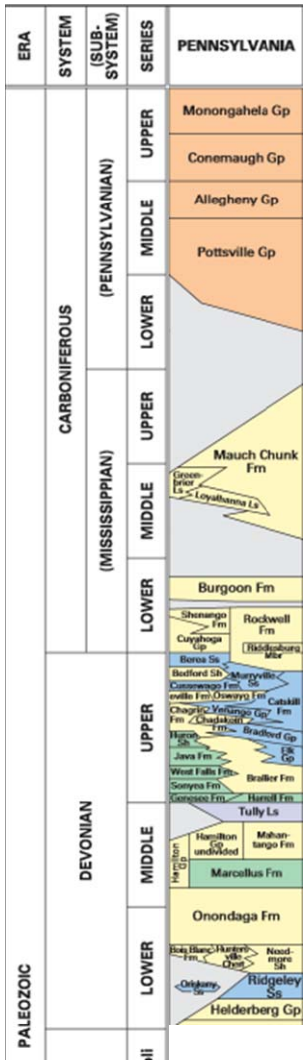


PP – PS1 registration

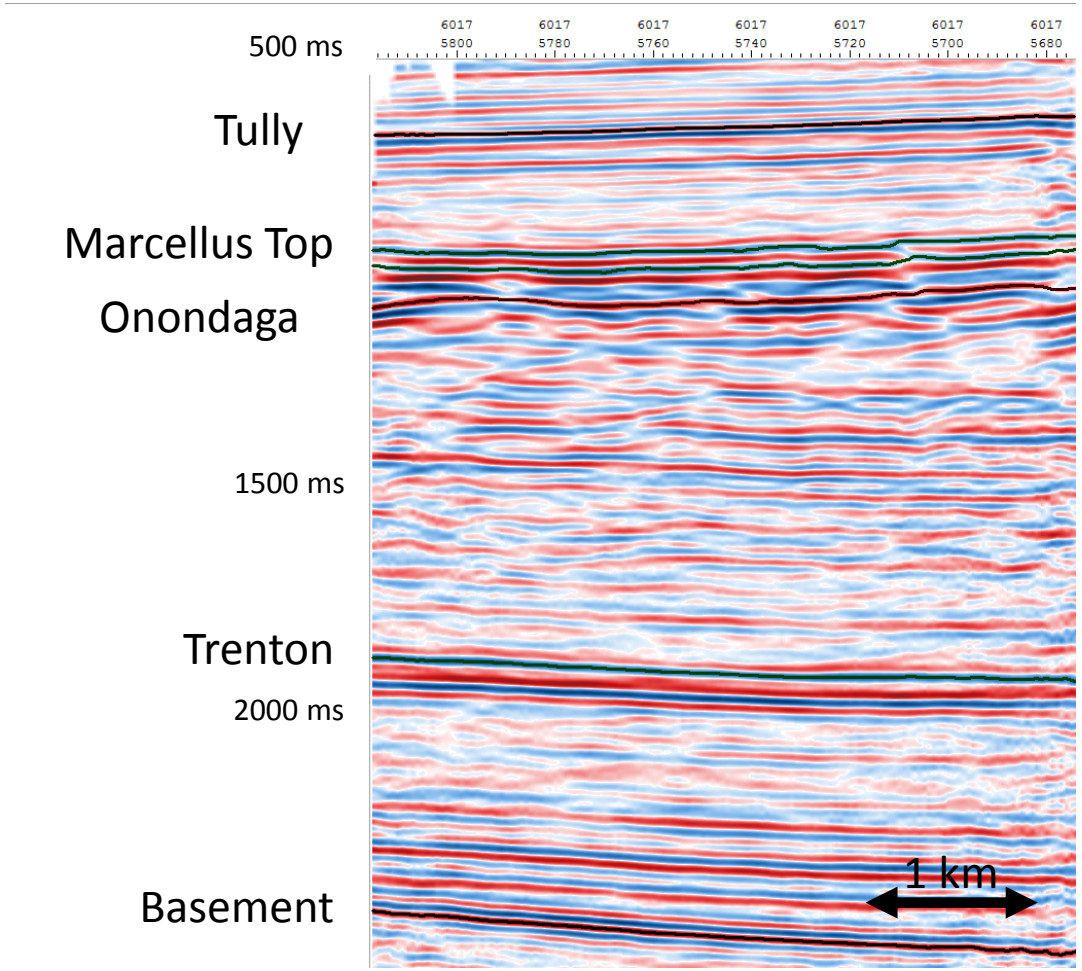
- Linear stretch/squeeze
  - Vp/Vs is near 2
- Polarity and phase appears fairly consistent between PP and PS1
- PS1 highlights faults better than PP



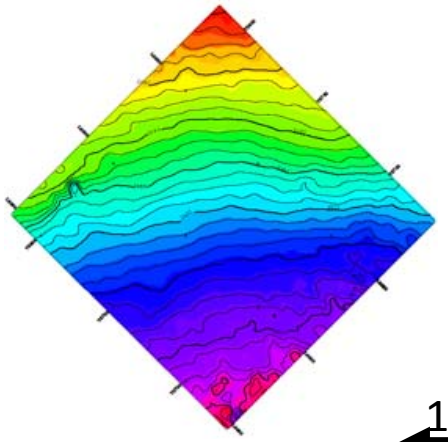
General interpretation



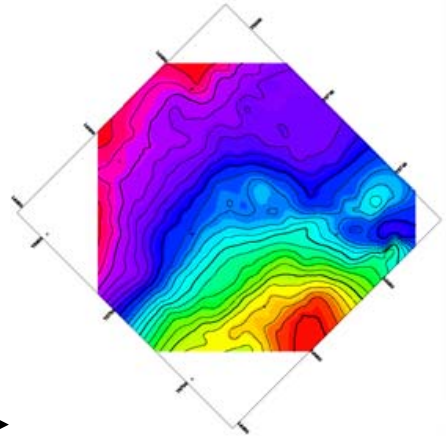
(Wickstrom et al 2005)



PP basement

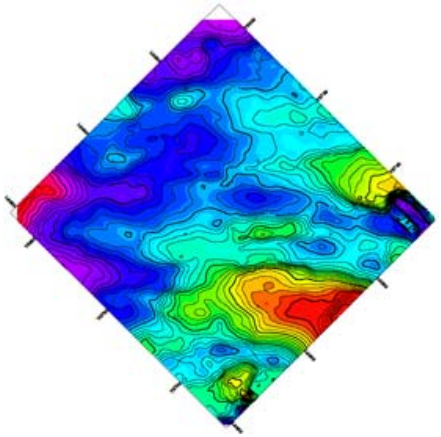


PP Tully Limestone

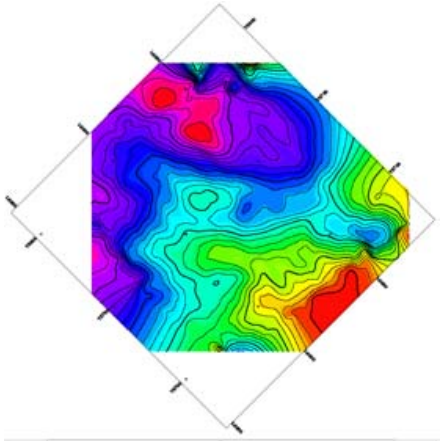


1 km

PP Marcellus Top

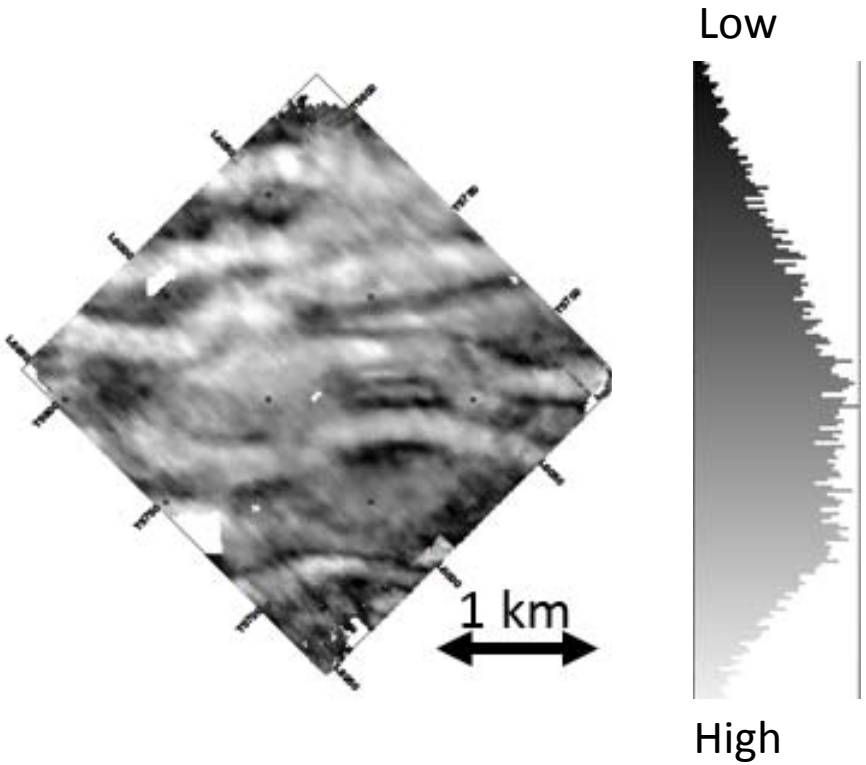


PS1 Tully Limestone

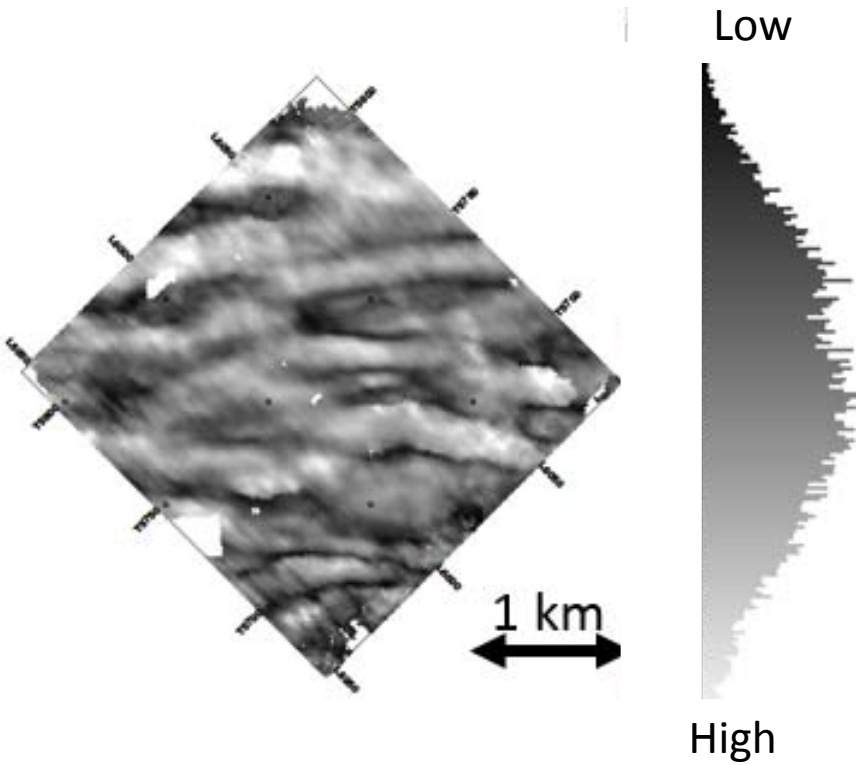


General interpretation

Upper Marcellus PP RMS amplitude

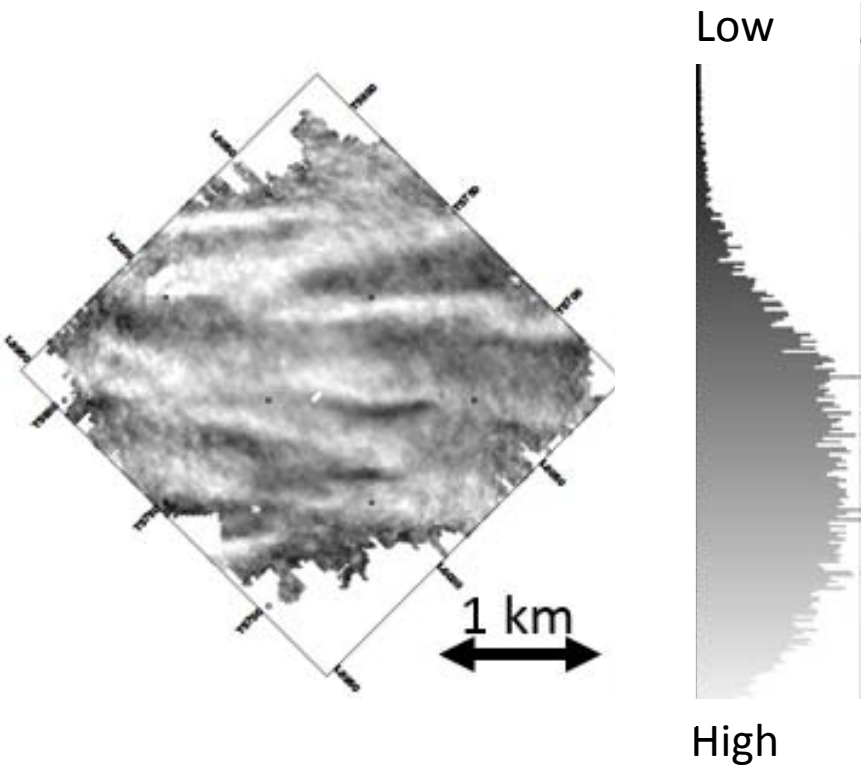


Lower Marcellus PP RMS amplitude

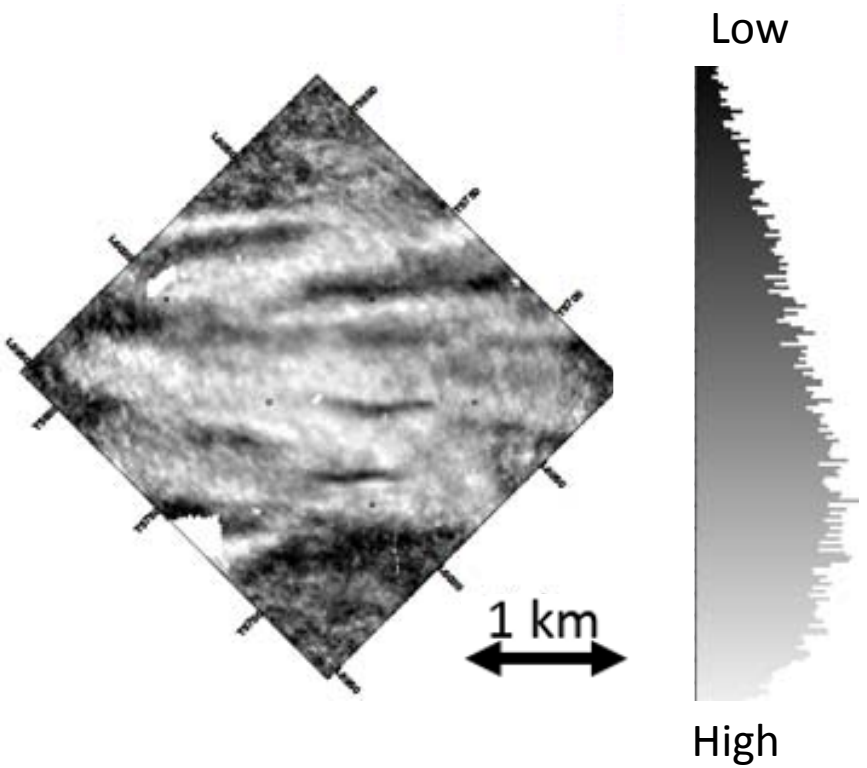


General interpretation

Upper Marcellus PS1 RMS amplitude

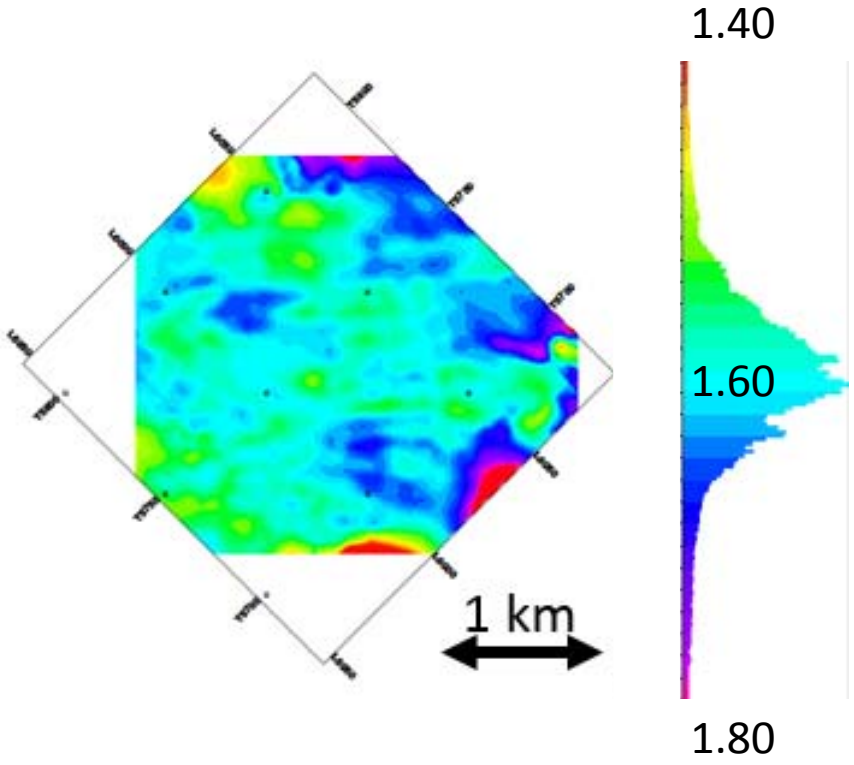


Lower Marcellus PS1 RMS amplitude

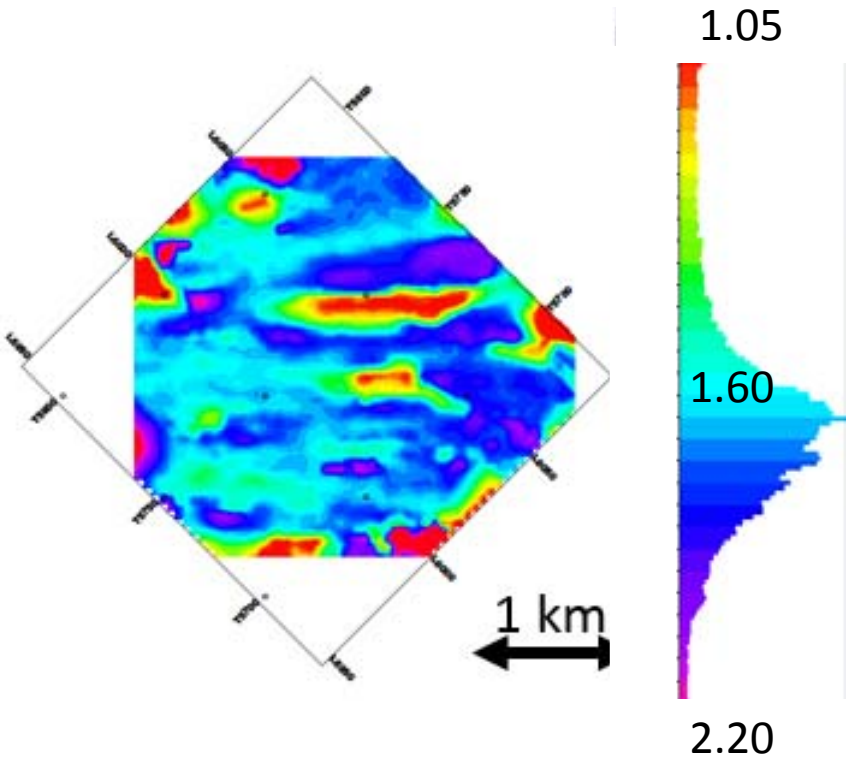


Interval V_p/V_s

Tully-Marcellus interval V_p/V_s

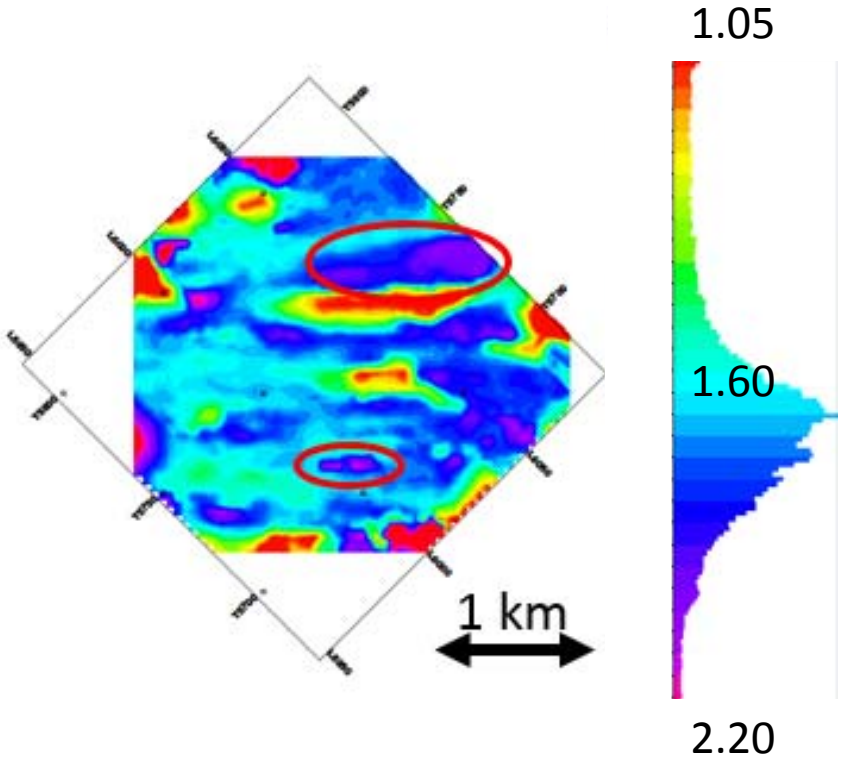


Marcellus-Onondaga interval V_p/V_s

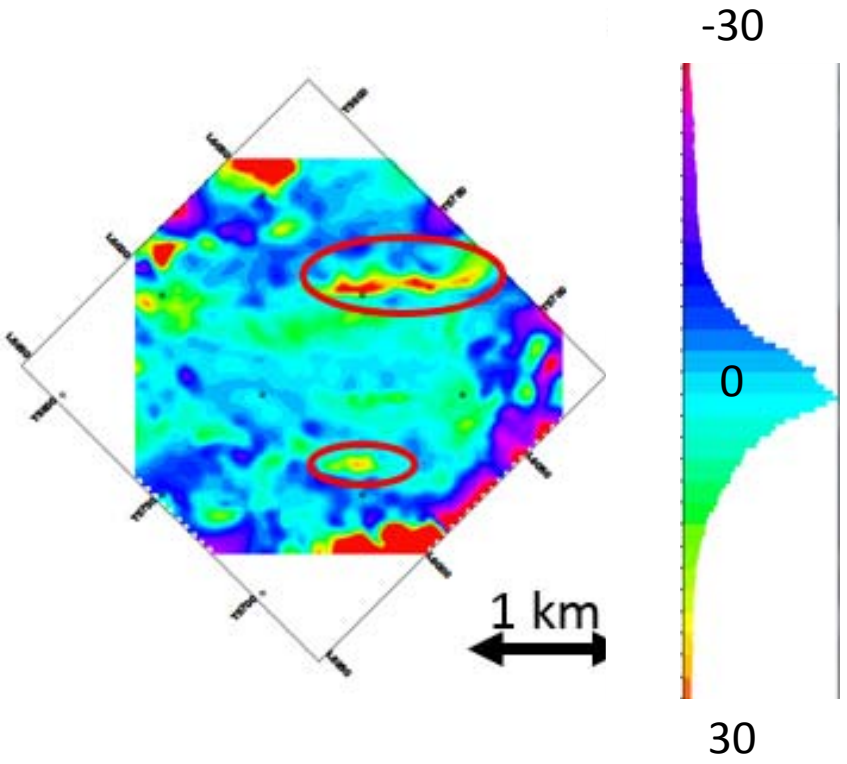


PS1 to PS2 traveltime anomalies

Marcellus-Onondaga interval V_p/V_s ratio



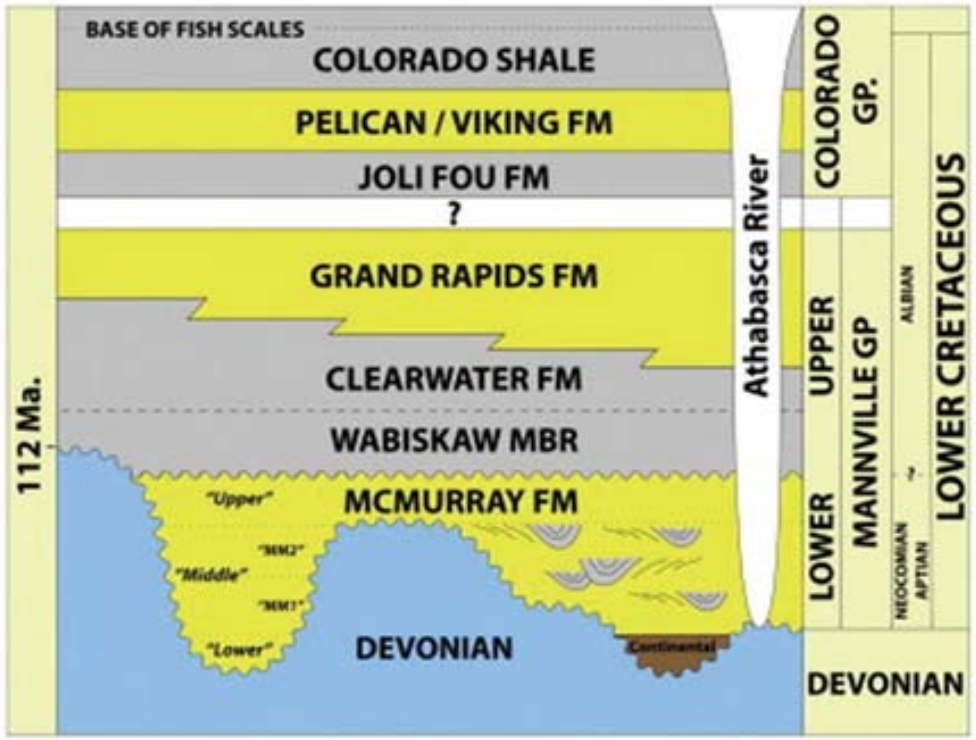
Marcellus-Onondaga PS1 to PS2 isochron difference

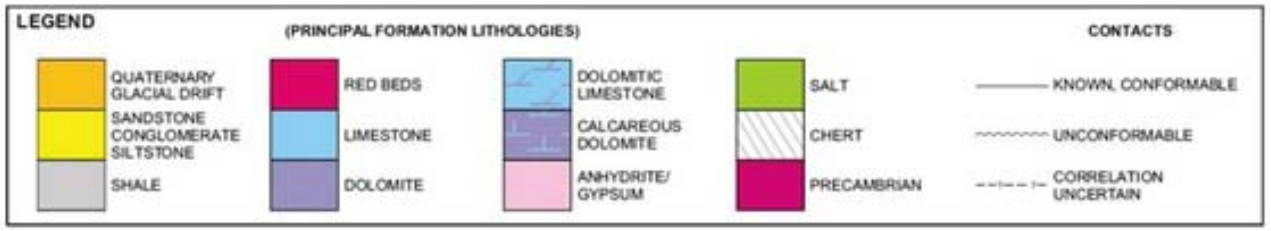


Marcellus project conclusions

- The Appalachian Basin in the project area is a wedge shape thickening towards the orogeny (southeast)
- The target interval, the Marcellus Shale, is mildly dipping with complex, but well-imaged fault structure
- Interval V_p/V_s maps are highly variable in the Marcellus Fm, and may indicate sweet spots conducive to hydraulic fracturing
- High V_p/V_s values tend to correlate with anisotropic zones and along faults

Athabasca project geological setting

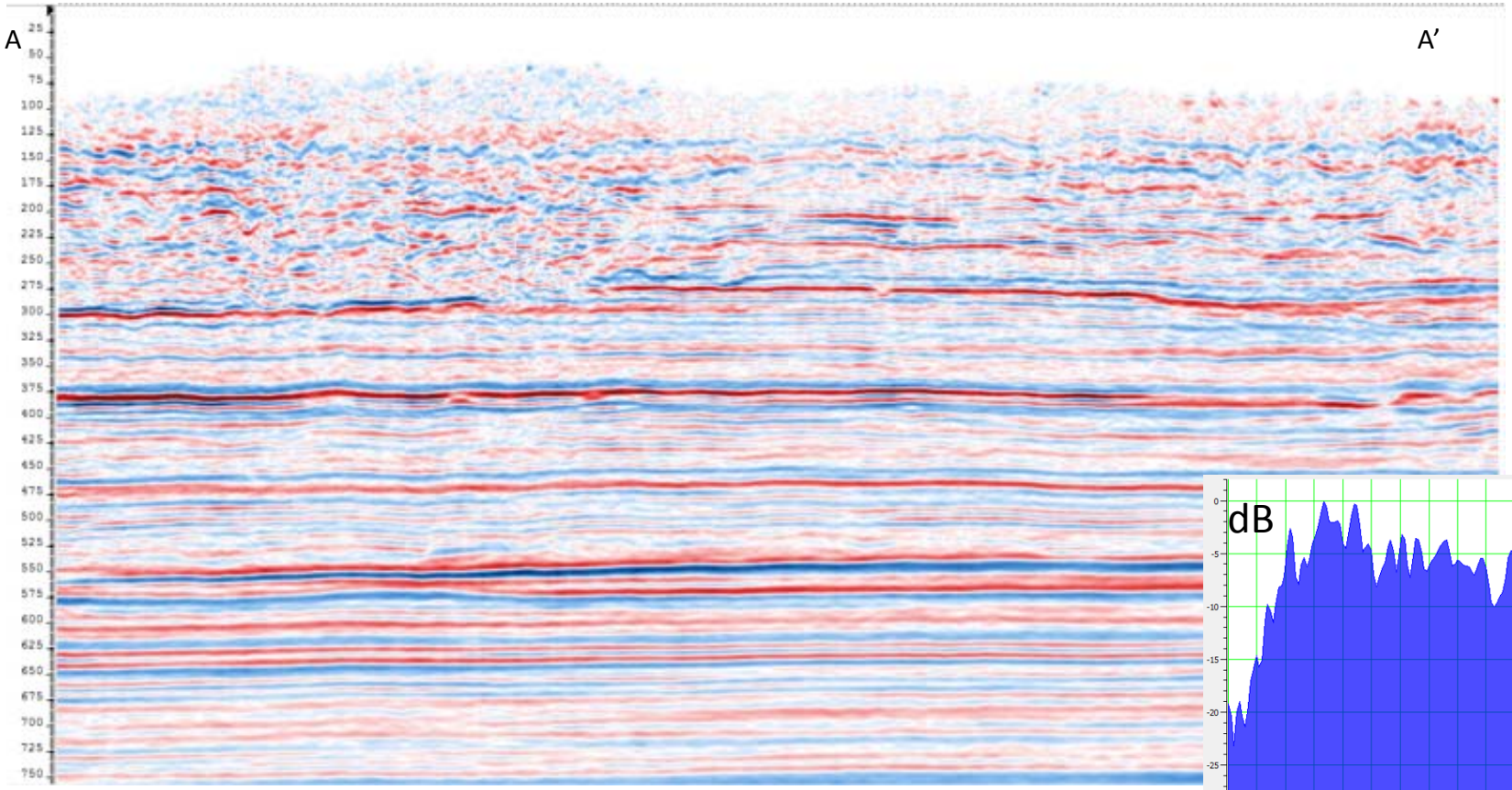


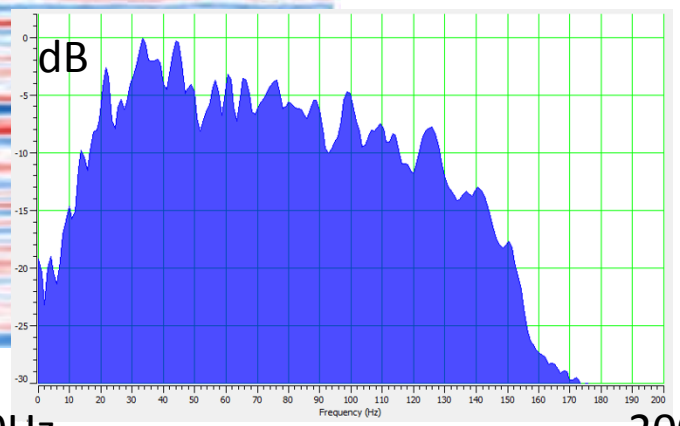


North America Cretaceous Paleogeography

(modified from Blakey 2011)

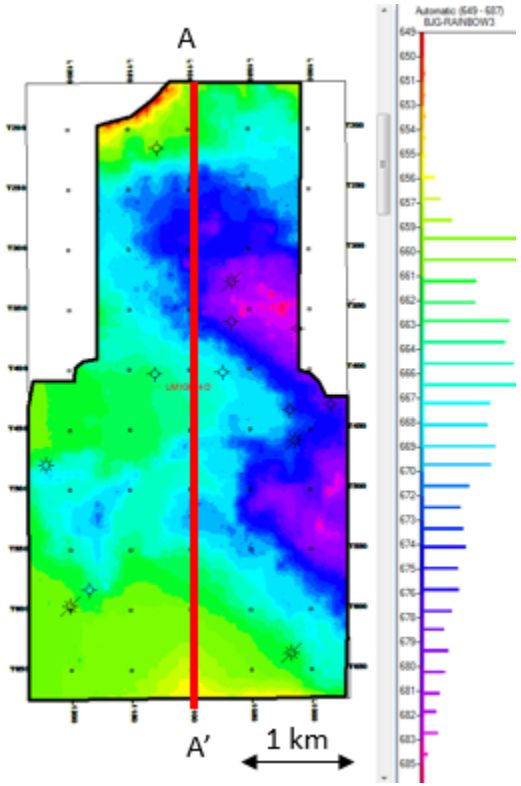
3D 3C seismic data and well log data



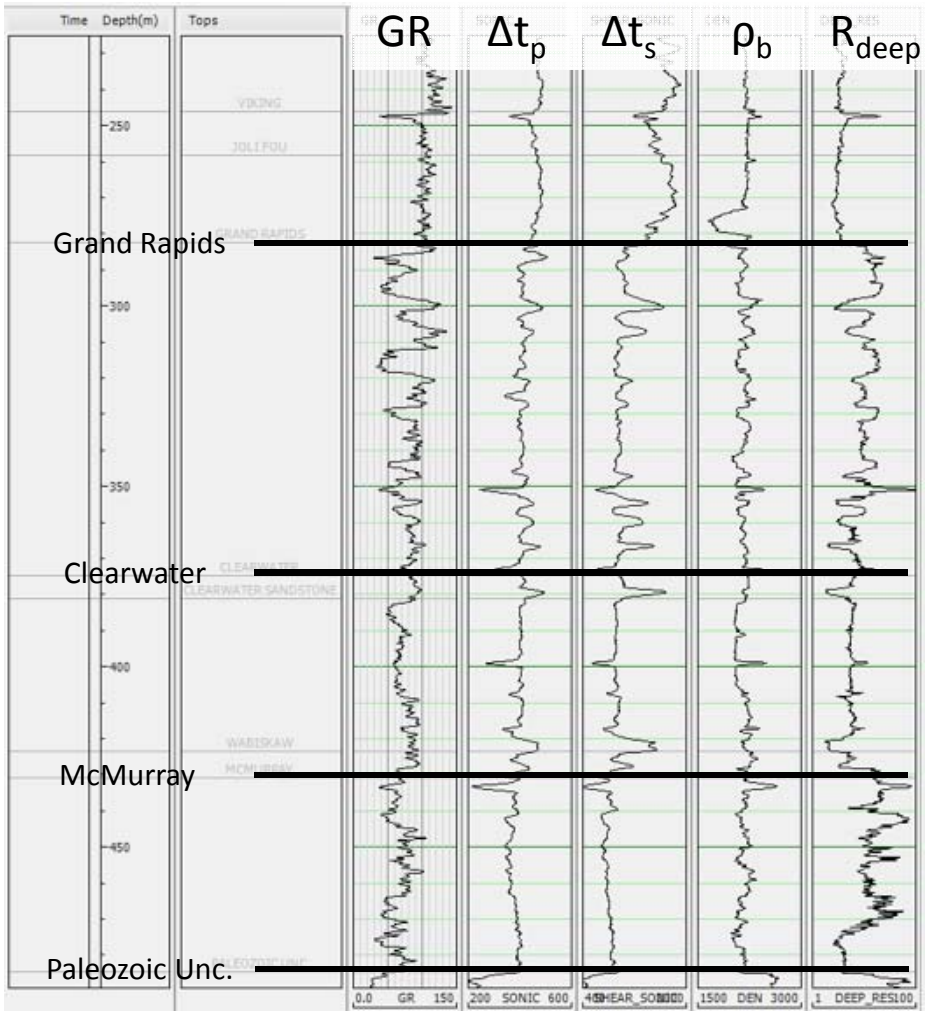


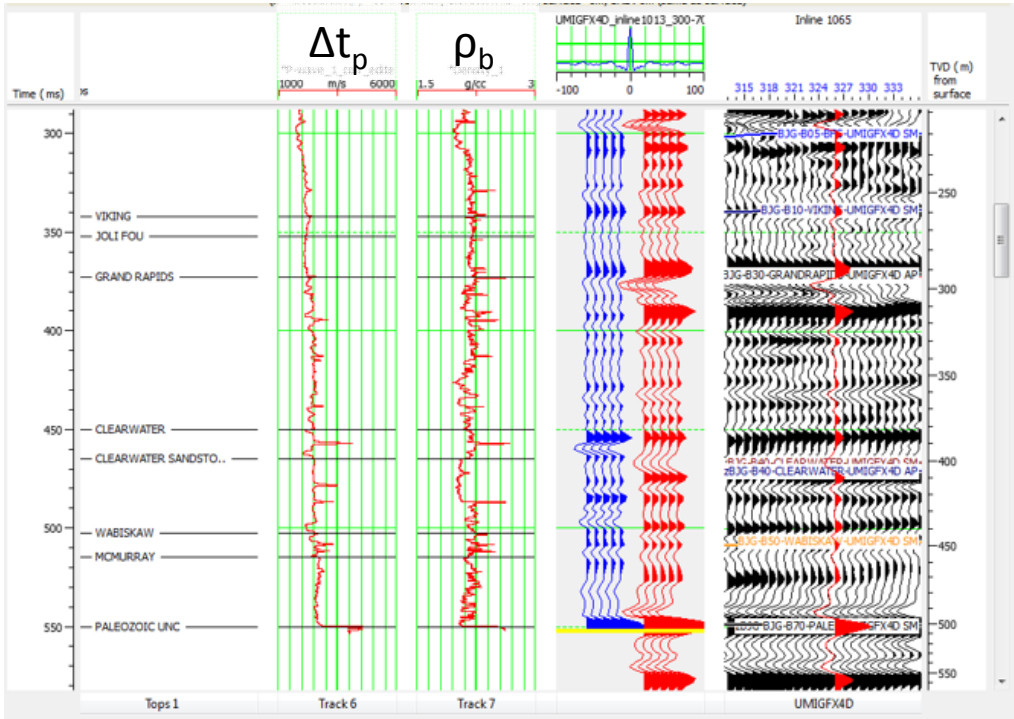
0Hz 200Hz

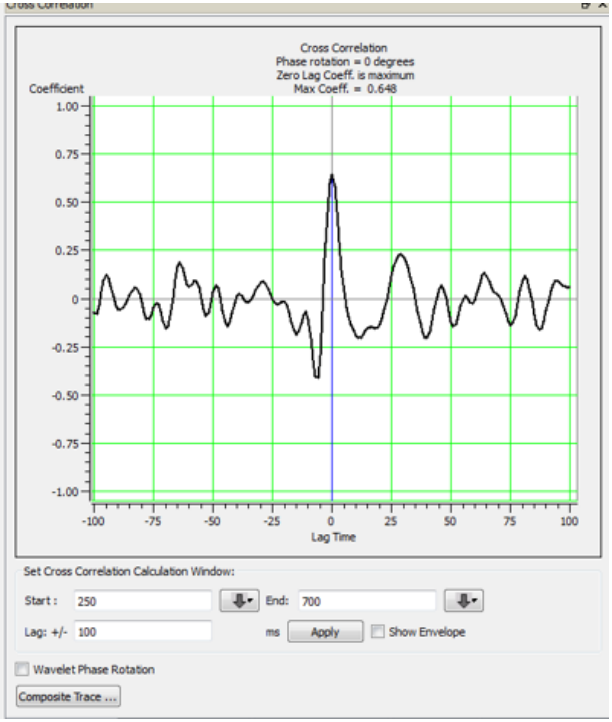
Surface elevation of seismic data



3D 3C seismic data and well log data

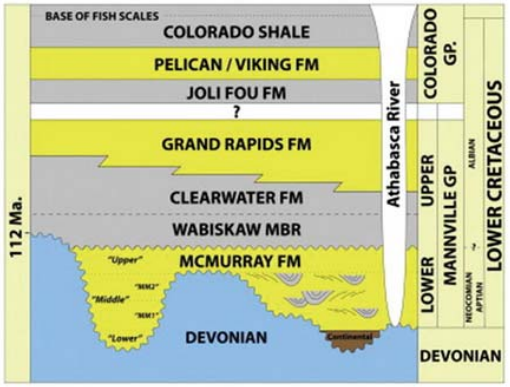


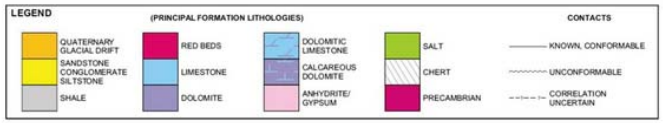




General interpretation

Canadian Natural





Base Fish Scales

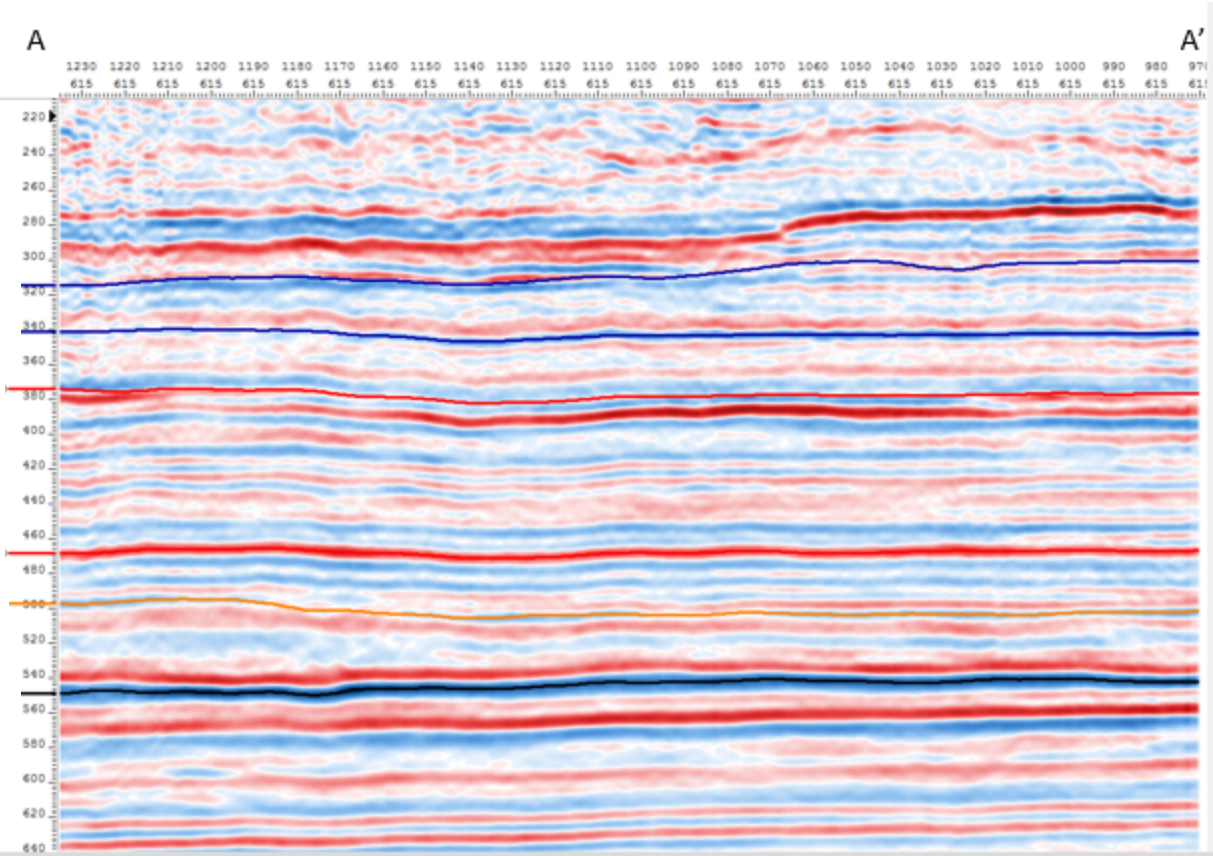
Viking

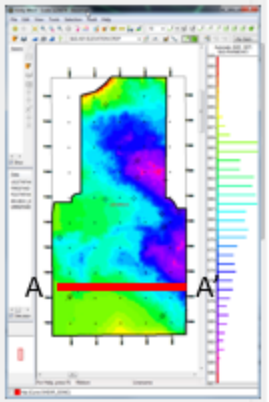
Grand Rapids

Clearwater

McMurray

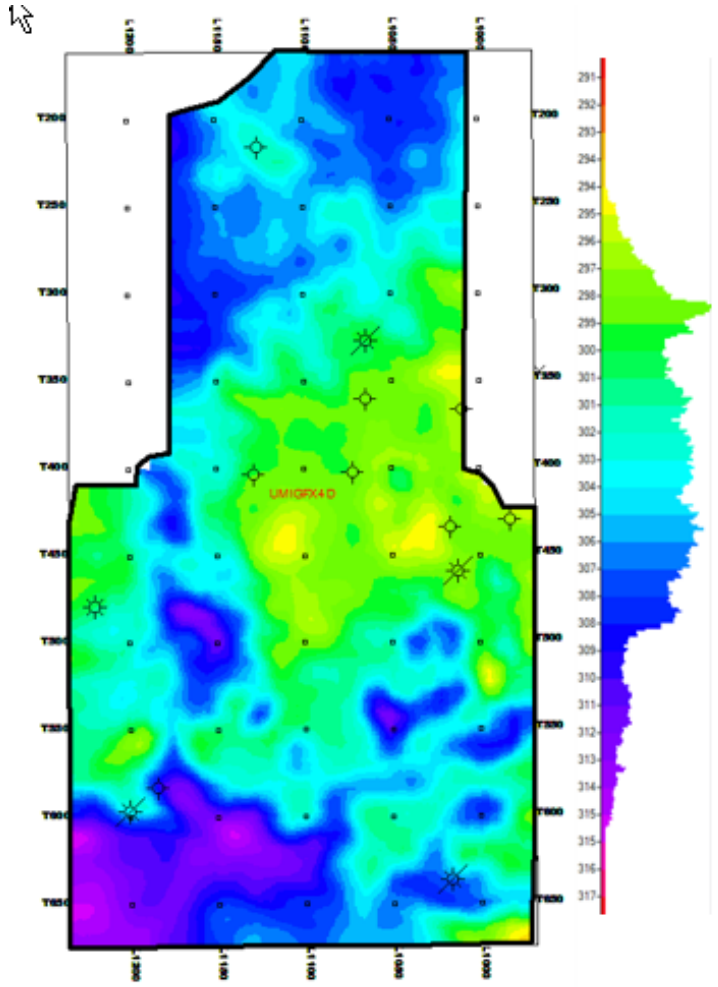
Paleozoic Unc.



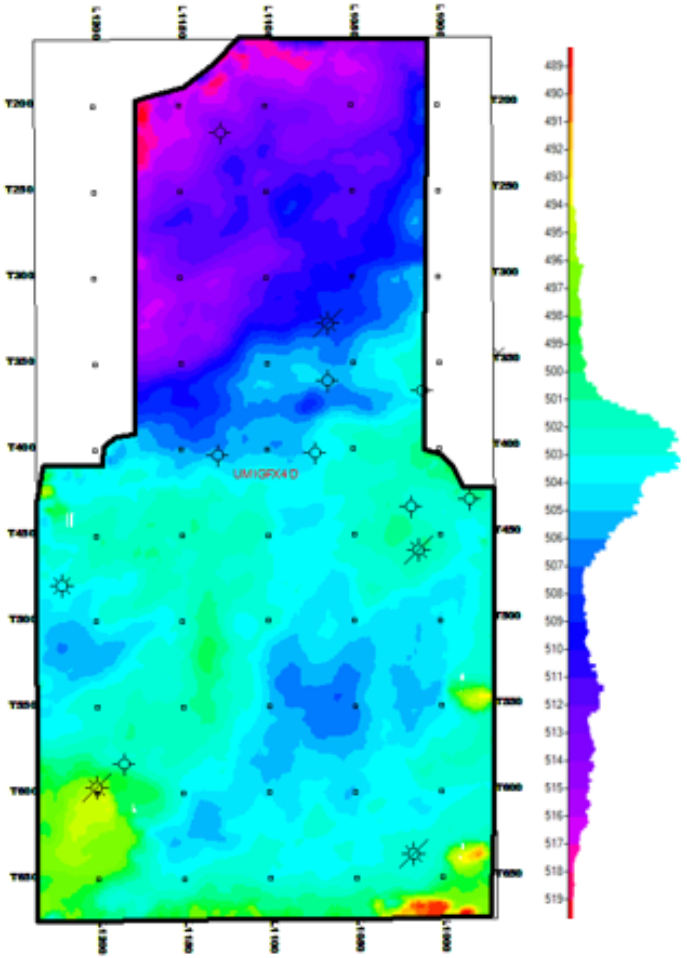


General interpretation

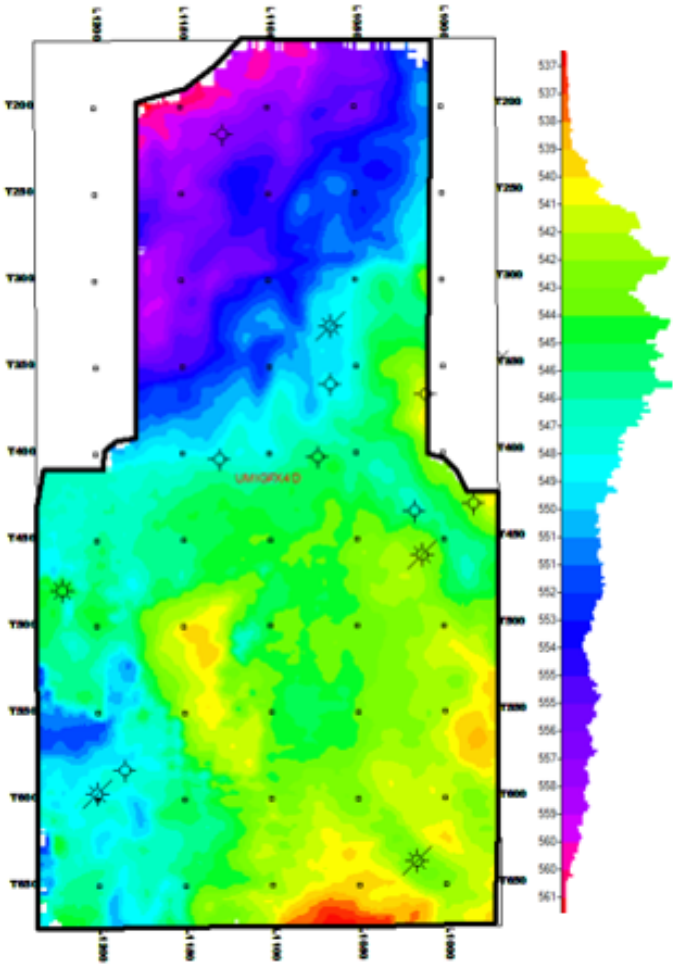
Base Fish Scales



McMurray Fm



Paleozoic Unconformity

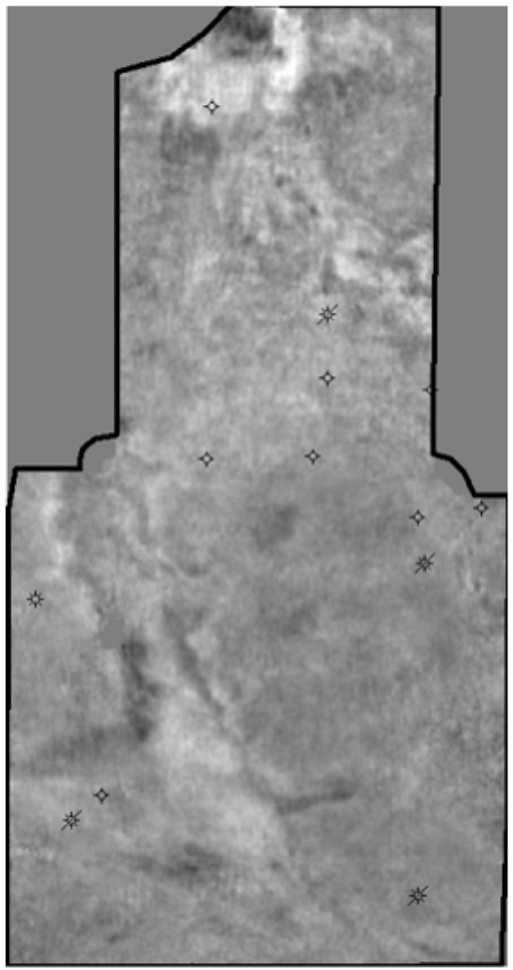


General interpretation

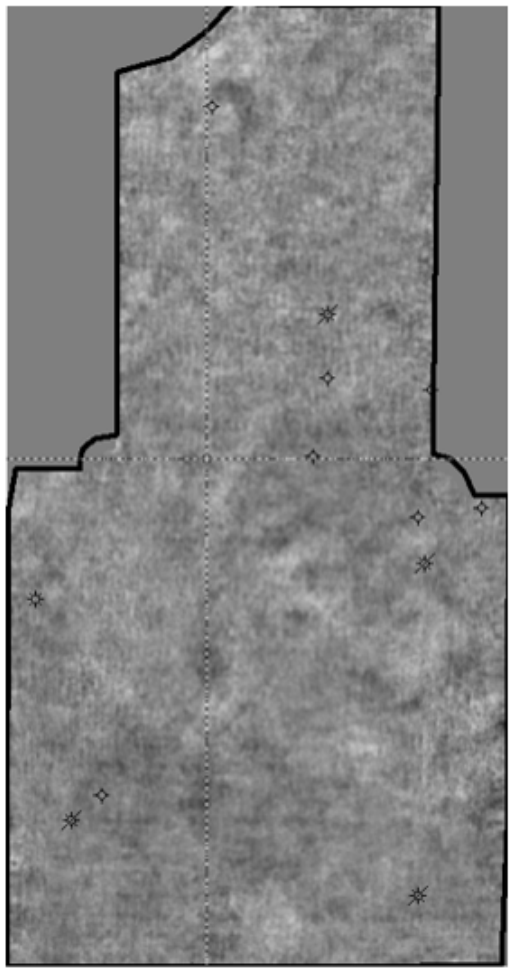
Upper Grand Rapids stratal slice

Middle McMurray stratal slice

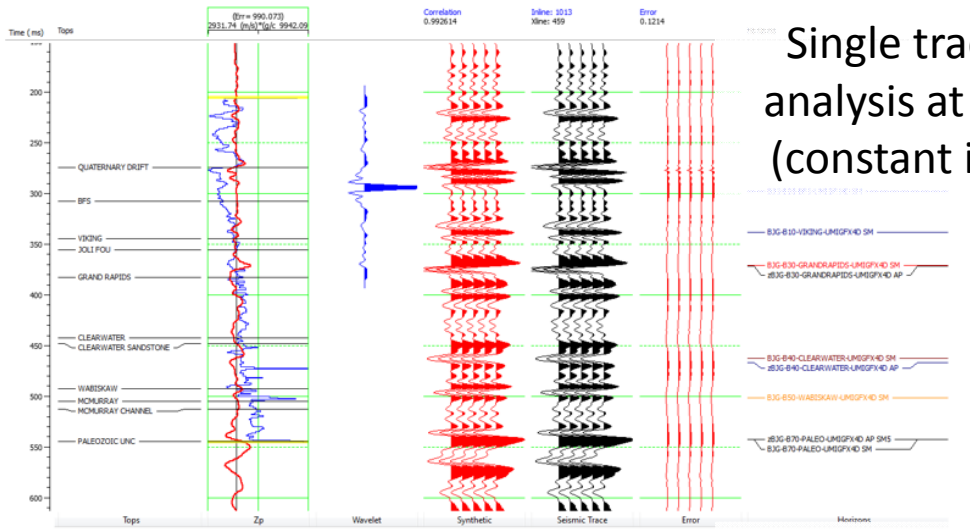
Base Fish Scales time slice



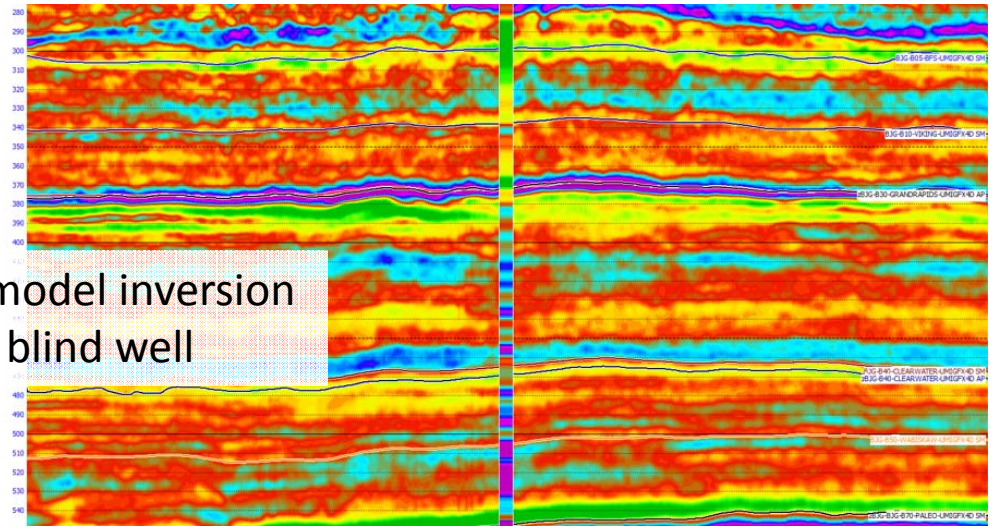
Joli Fou time slice



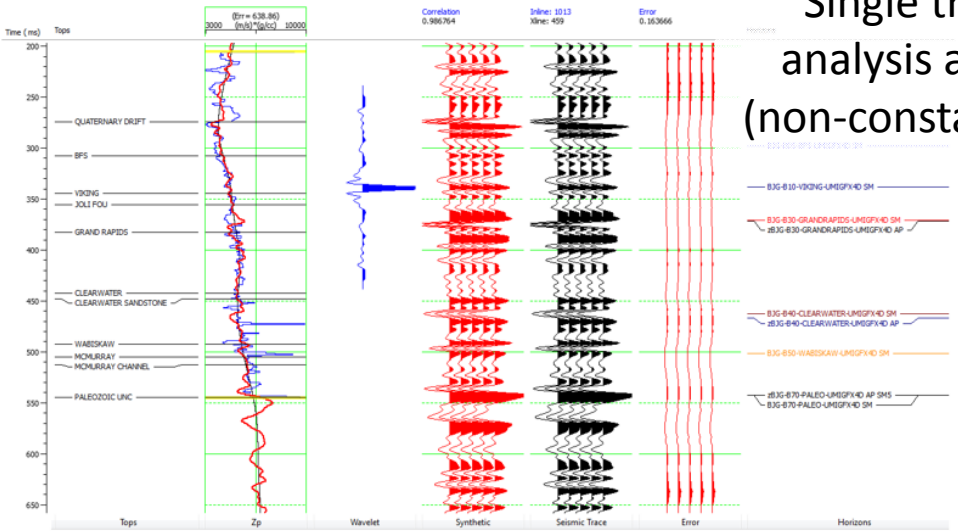
Impedance inversion



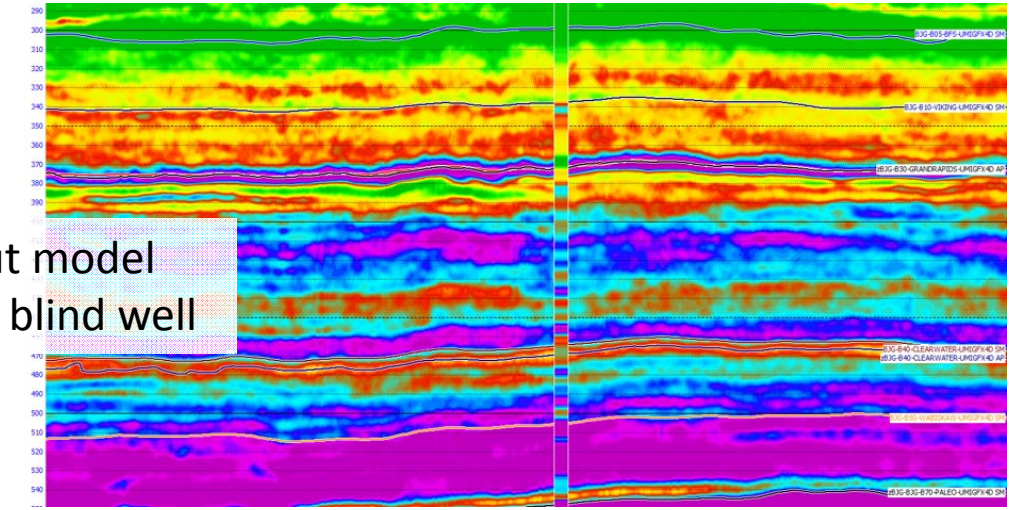
Single trace inversion analysis at well location (constant input model)



Constant input model inversion result with blind well

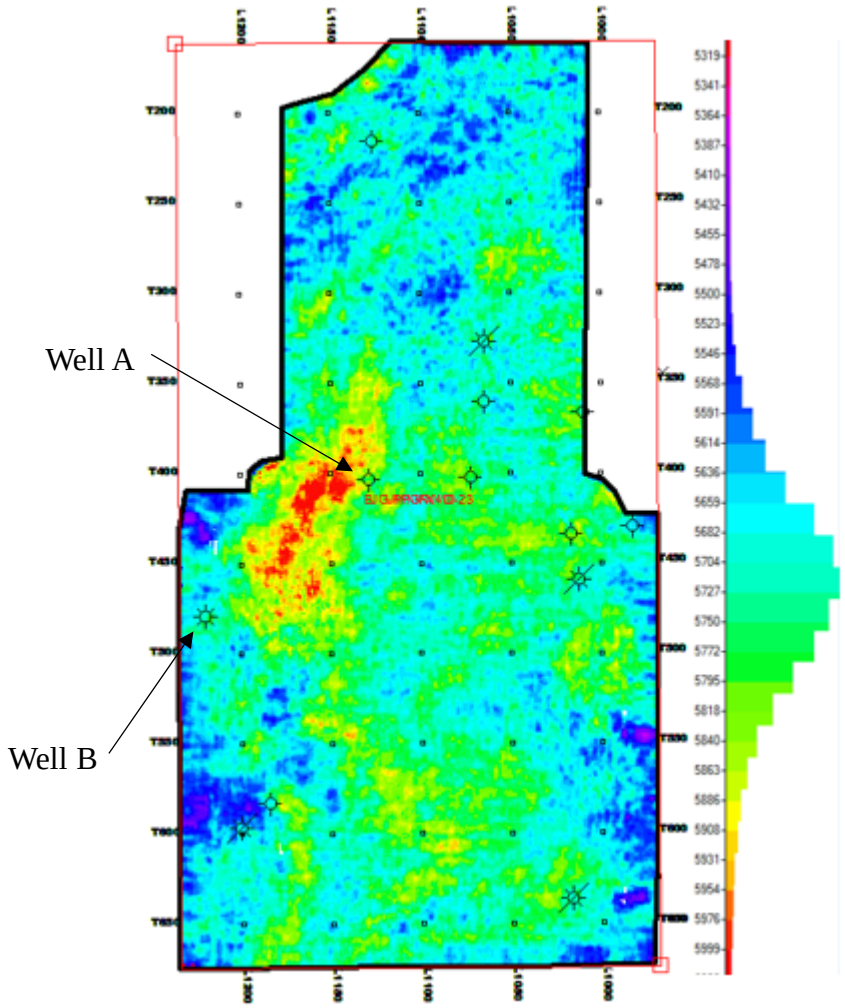


Single trace inversion analysis at well location (non-constant input model)

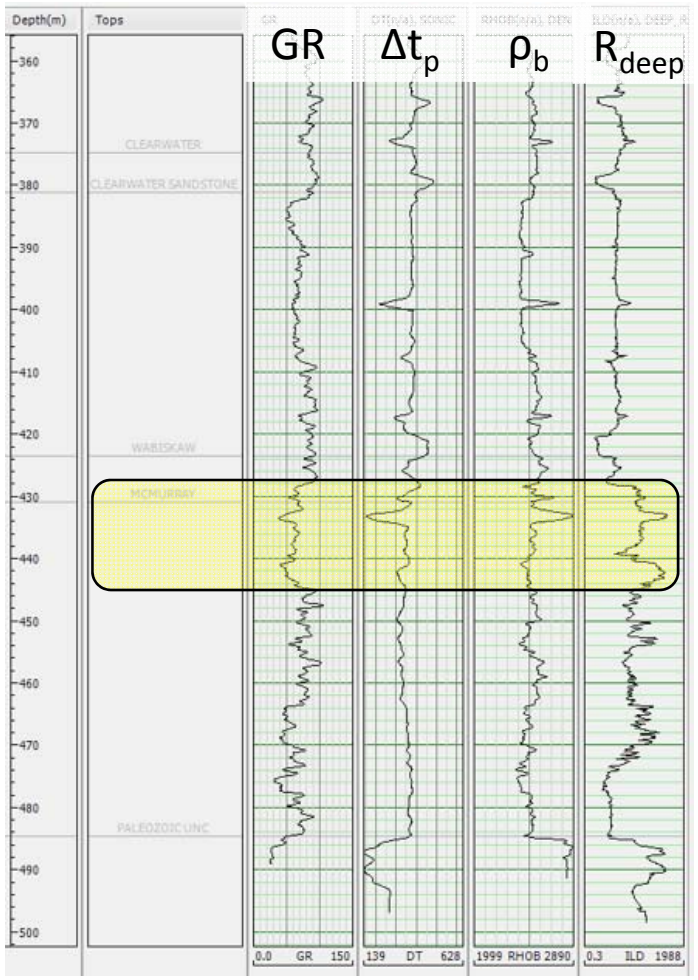


Non-constant input model inversion result with blind well

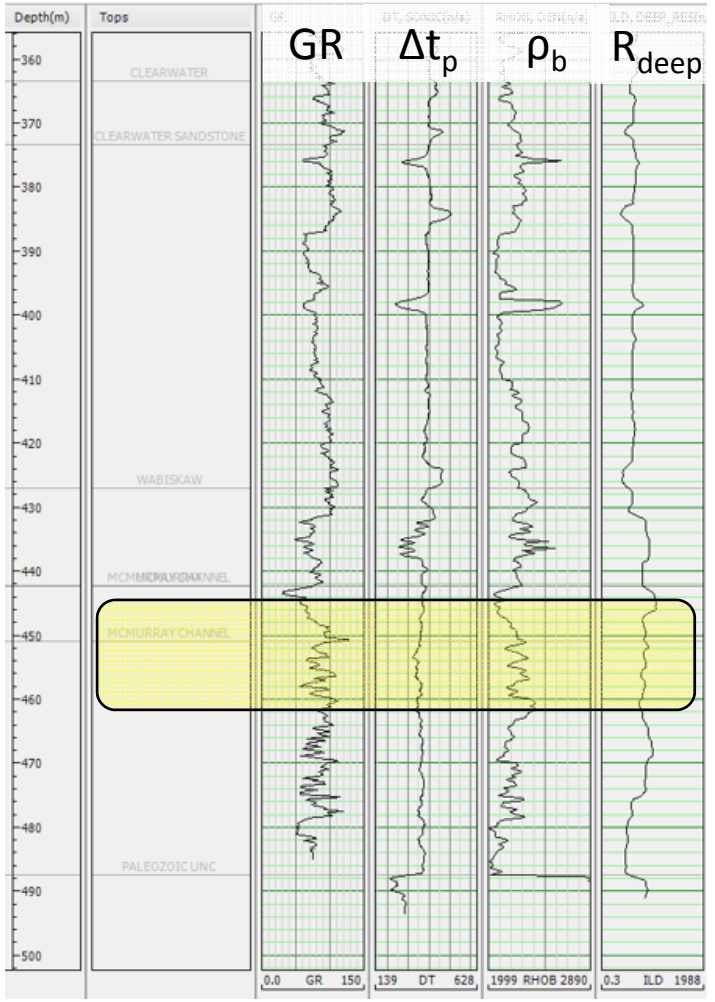
Impedance inversion



Well A

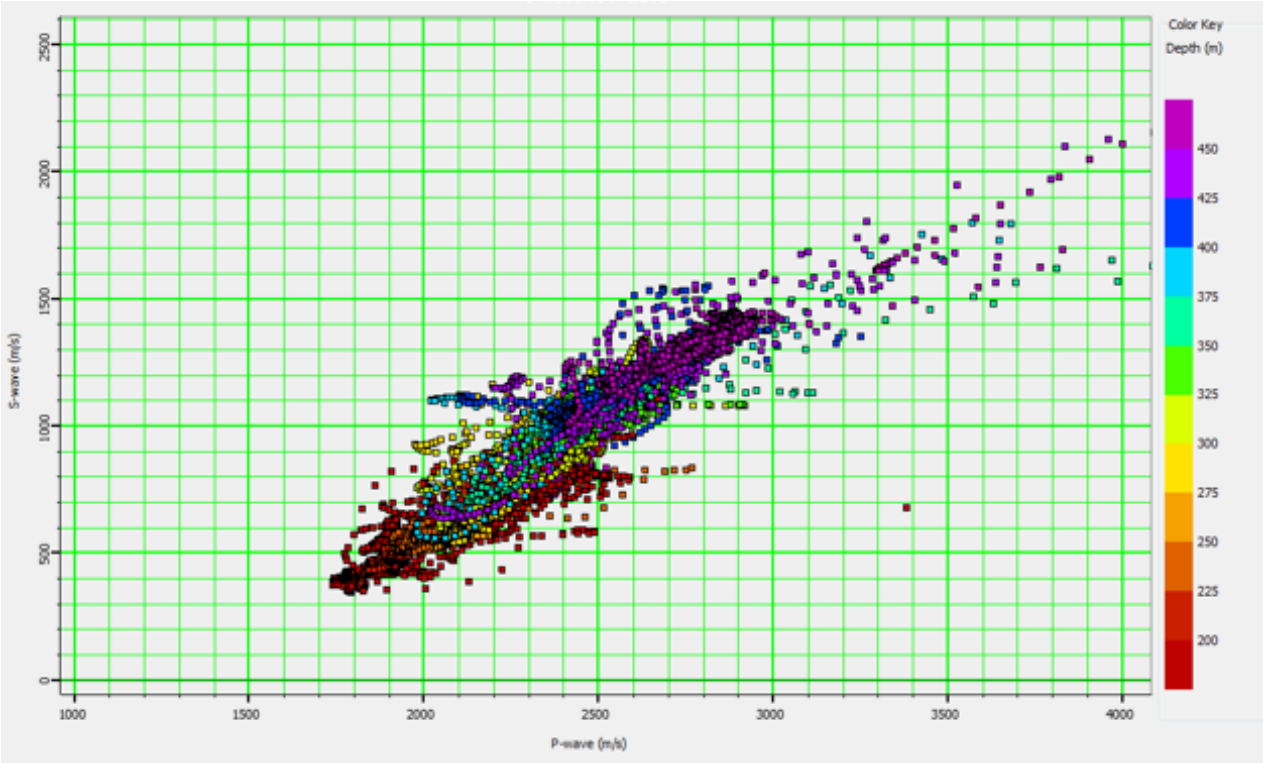


Well B

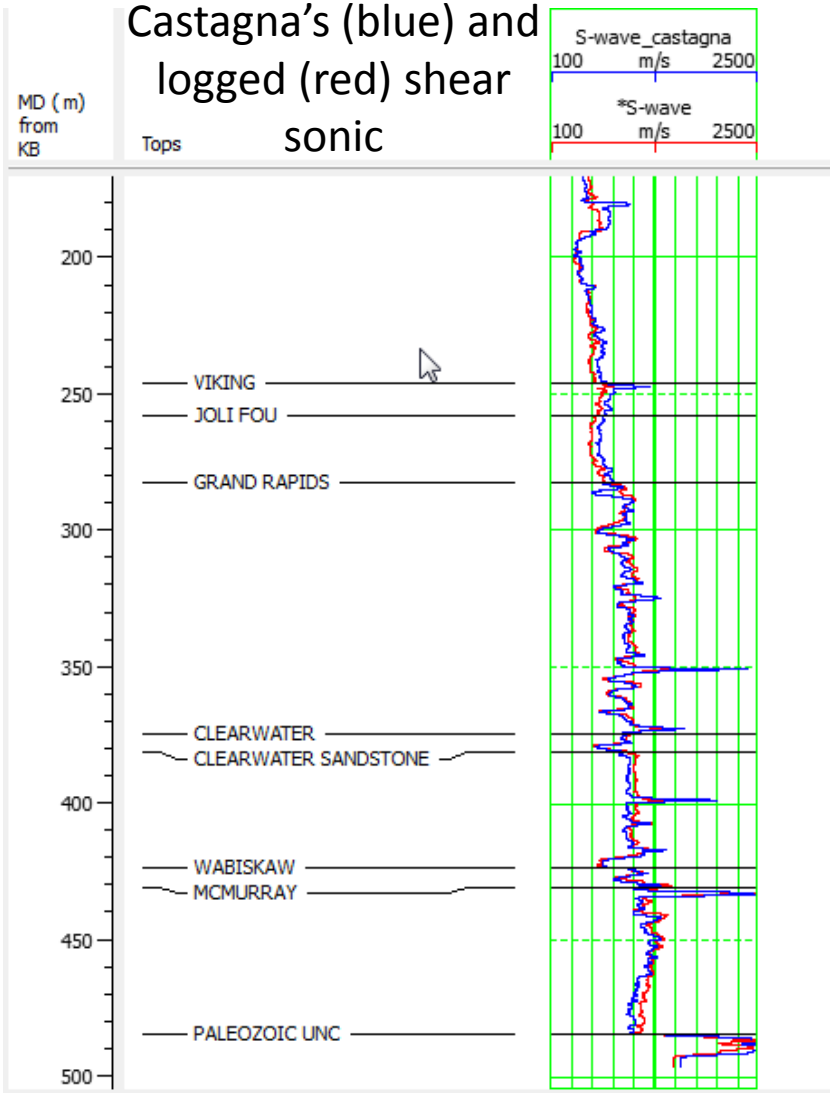


Castagna's derived shear sonic log

Vp vs. Vs crossplot

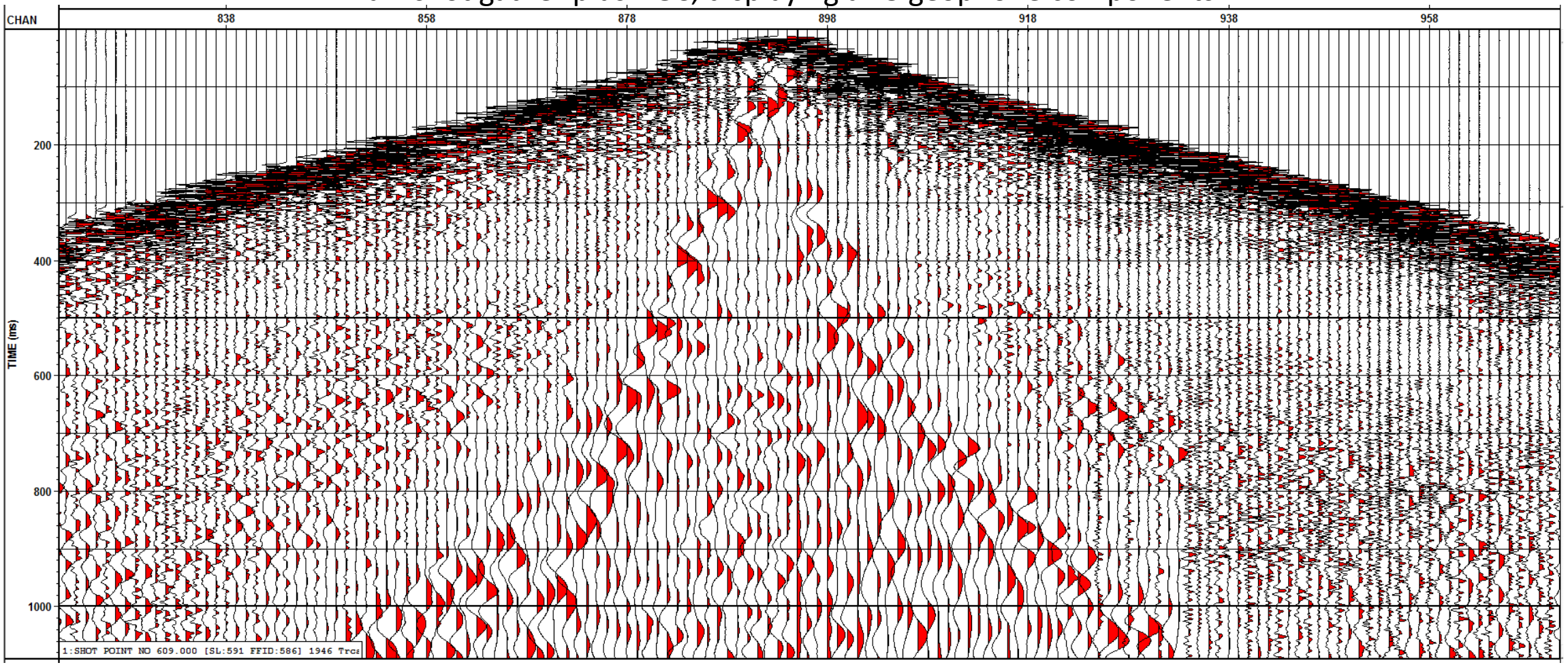


Castagna's (blue) and logged (red) shear sonic



PS data processing progress

Raw shot gather plus AGC, displaying all 3 geophone components



Oil sands project summary

- Regional seismic interpretation completed on cretaceous clastics
  - Well data integration
  - Pervasive seismic reflection horizon picking
- Post stack PP impedance inversion
  - Based on both constant and variable input models
  - High interval RMS impedance correlates with increased sand content
- Shear log estimation for wells without dipole sonic logs
- PS seismic data processing underway

Going forward

- Marcellus project
  - Well control is the most important factor deciding future work
  - Understanding production trends based on geological data
  - Proper PP-PS1 and PP-PS2 registration with variable V_p/V_s values
  - Post-stack and pre-stack individual and joint inversion could be a useful tool for understanding unconventional reservoir properties

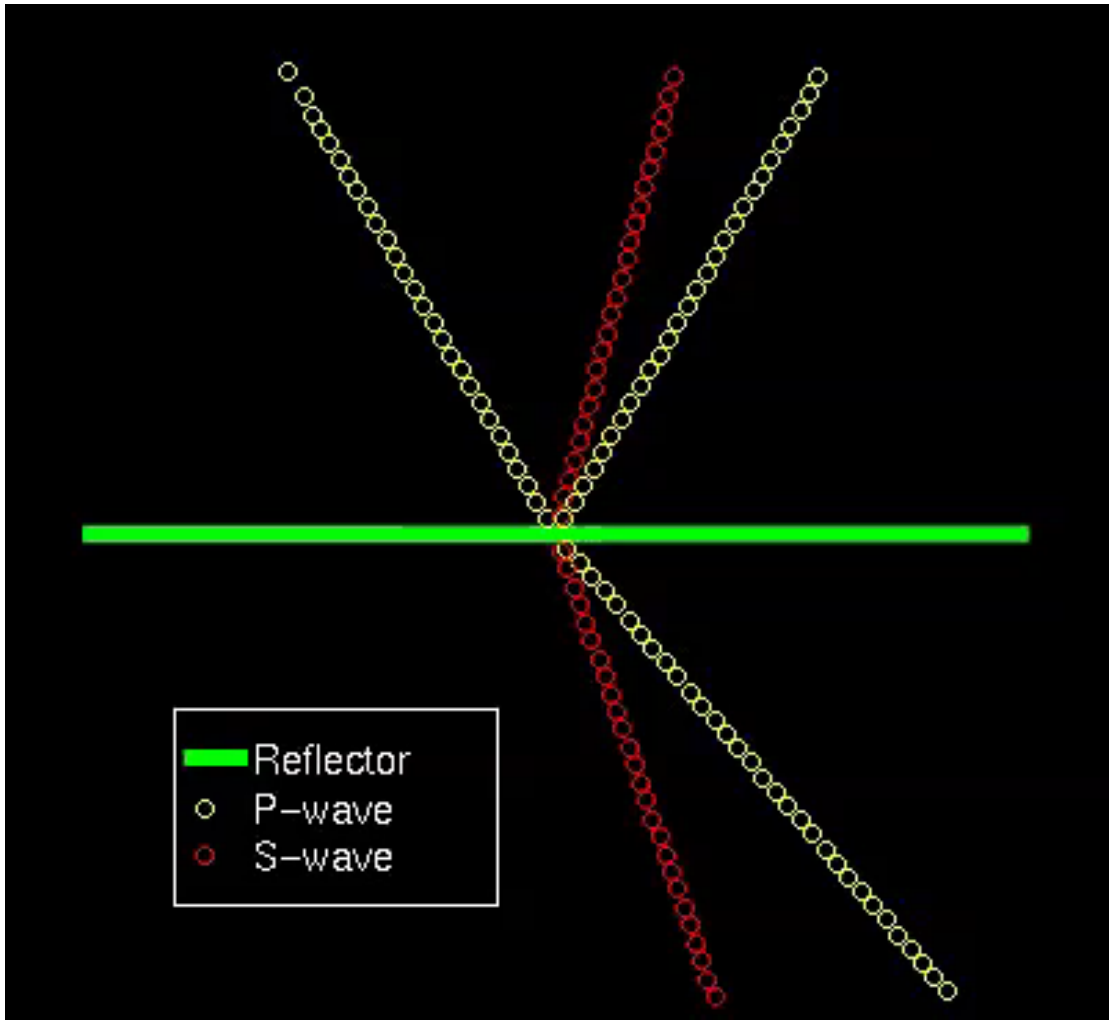
- Oil sands project
  - Joint processing of PP seismic data with converted wave seismic data
  - Joint inversion and pre-stack inversion of fully processing PP, PS1 and PS2 seismic data
  - Focus analysis on more specific intervals and geographical locations

Acknowledgements

- Canadian Natural Resources Limited and Geokinetics for providing data
- CREWES industrial sponsors
- Natural Sciences and Engineering Research Council through grant CRDPJ 461179-13

Hidden and removed slides

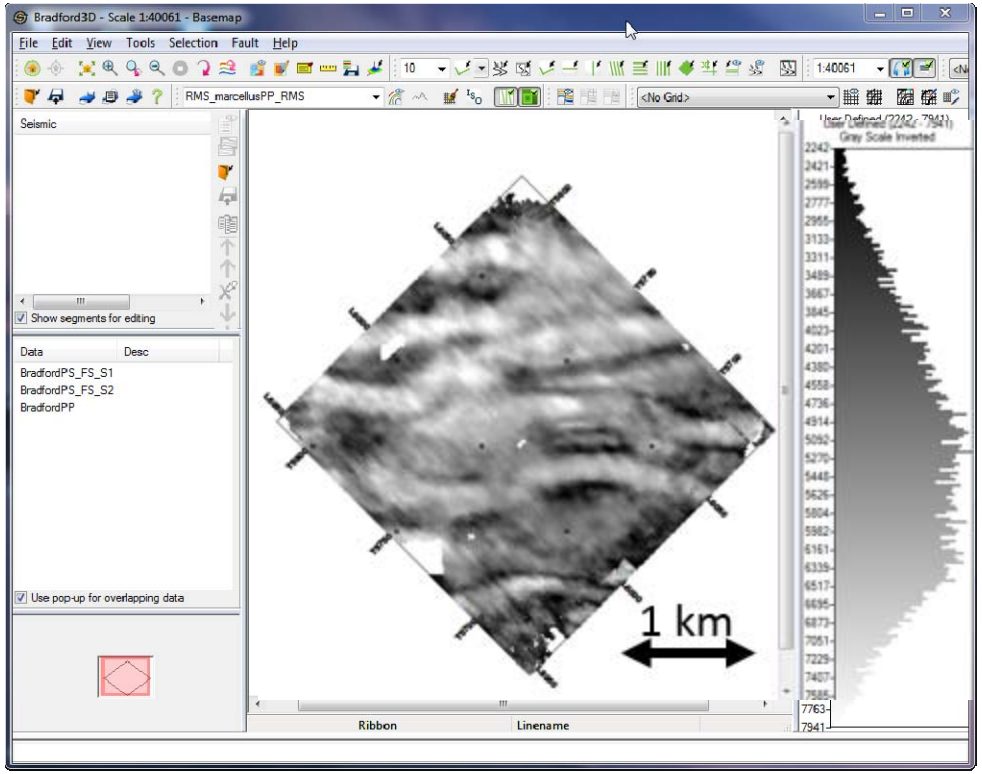
Converted waves



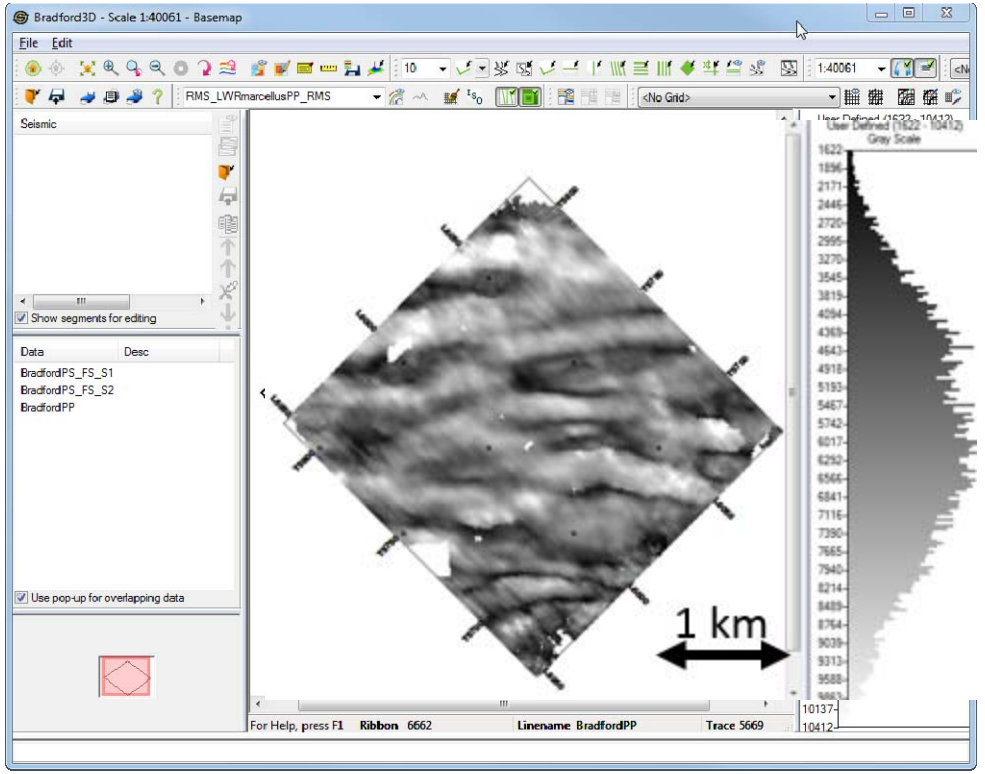
- Asymmetric ray paths
  - Common conversion versus midpoint
- Travel time difference in PP and PS
  - Shear velocities vs p velocities
- Applications of converted wave seismic:
  - Constraining interpretation
  - Imaging through variable fluids
  - Interfaces with low p-impedance contrasts
  - Near-surface imaging
  - Lithological classification and geomechanics

General interpretation

Upper Marcellus PP RMS amplitude

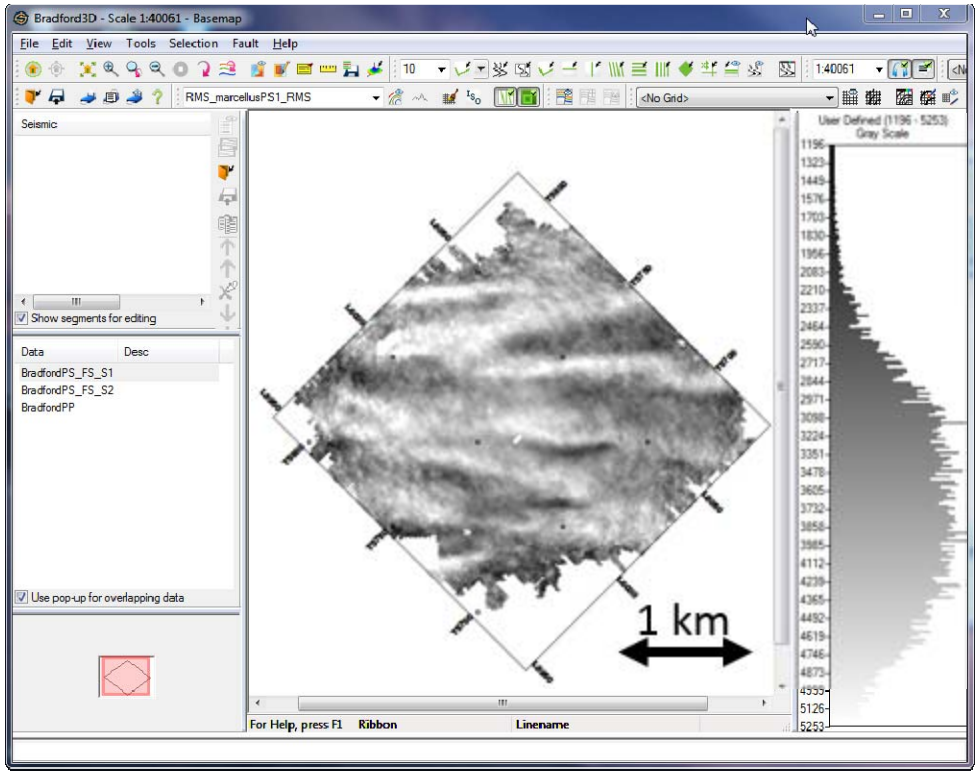


Lower Marcellus PP RMS amplitude

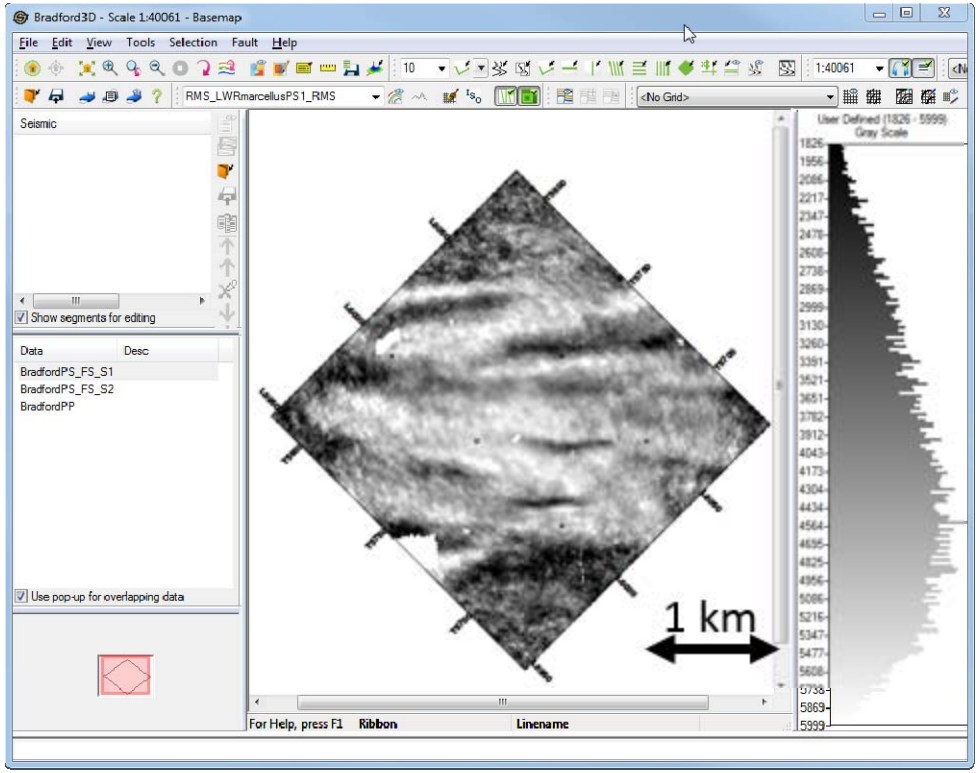


General interpretation

Upper Marcellus PS1 RMS amplitude

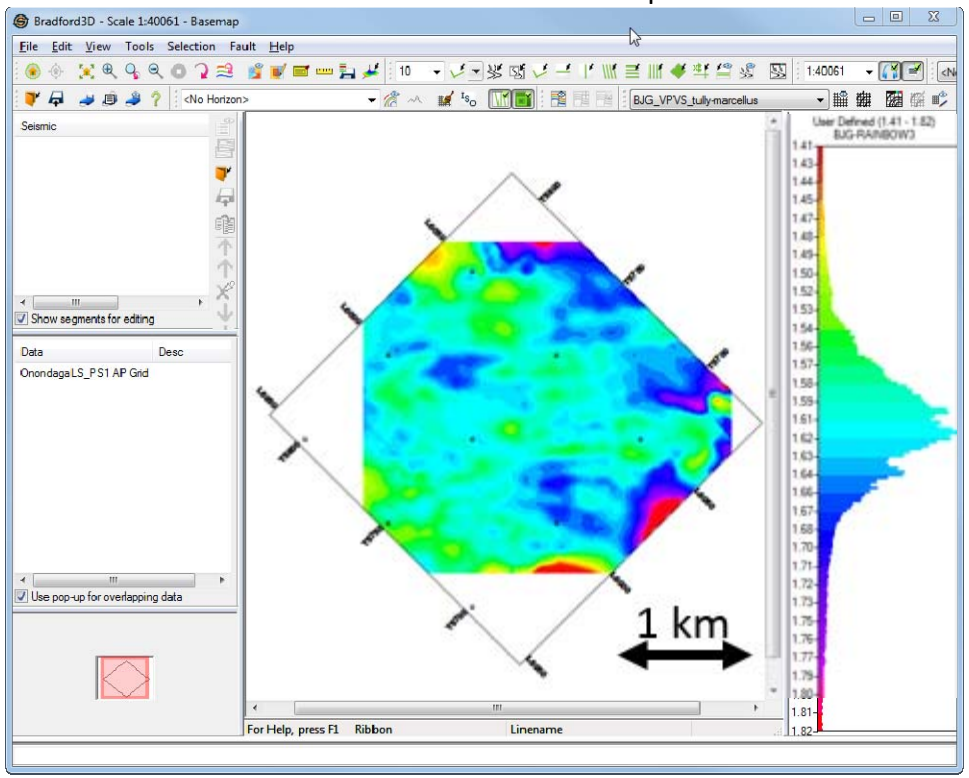


Lower Marcellus PS1 RMS amplitude

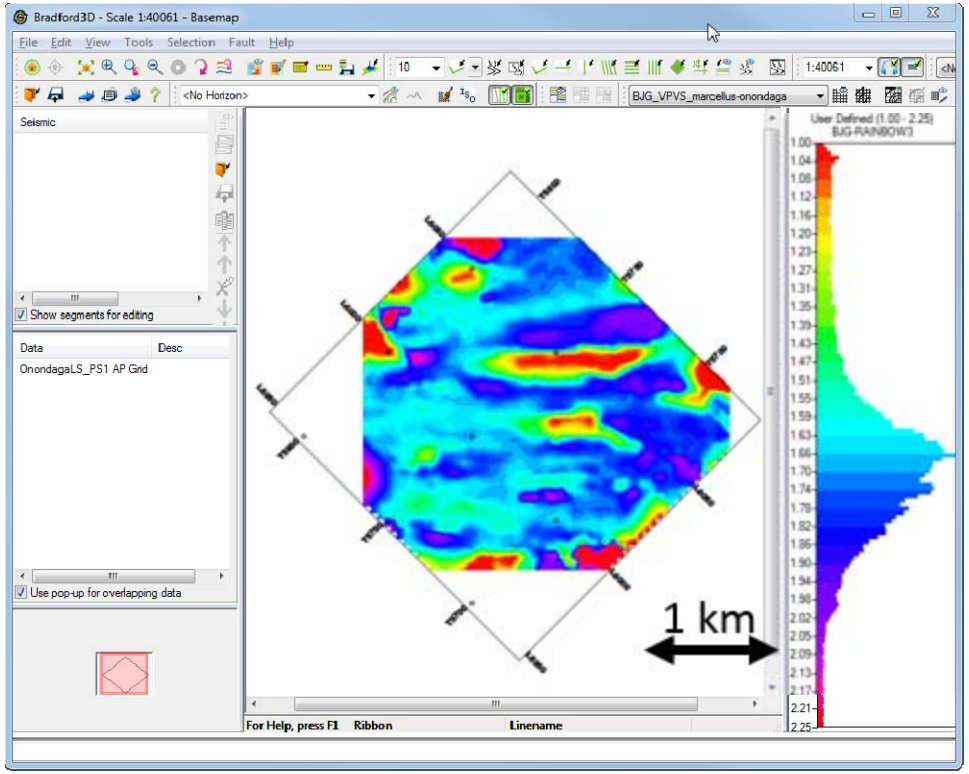


Interval V_p/V_s

Tully-Marcellus interval V_p/V_s ratio

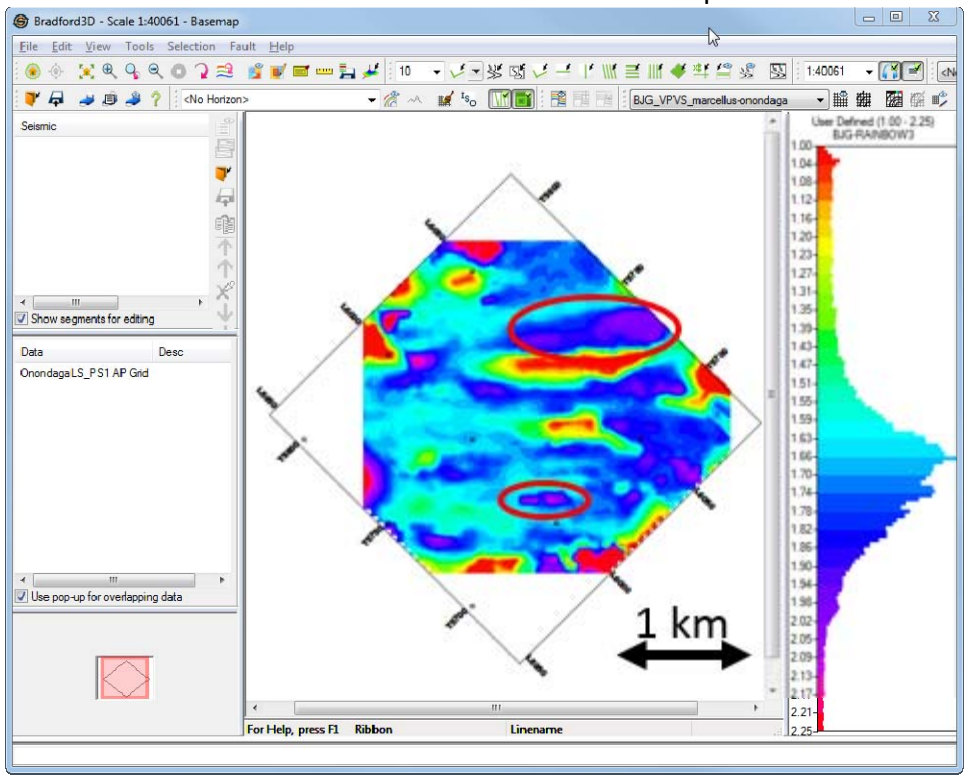


Marcellus-Onondaga interval V_p/V_s ratio

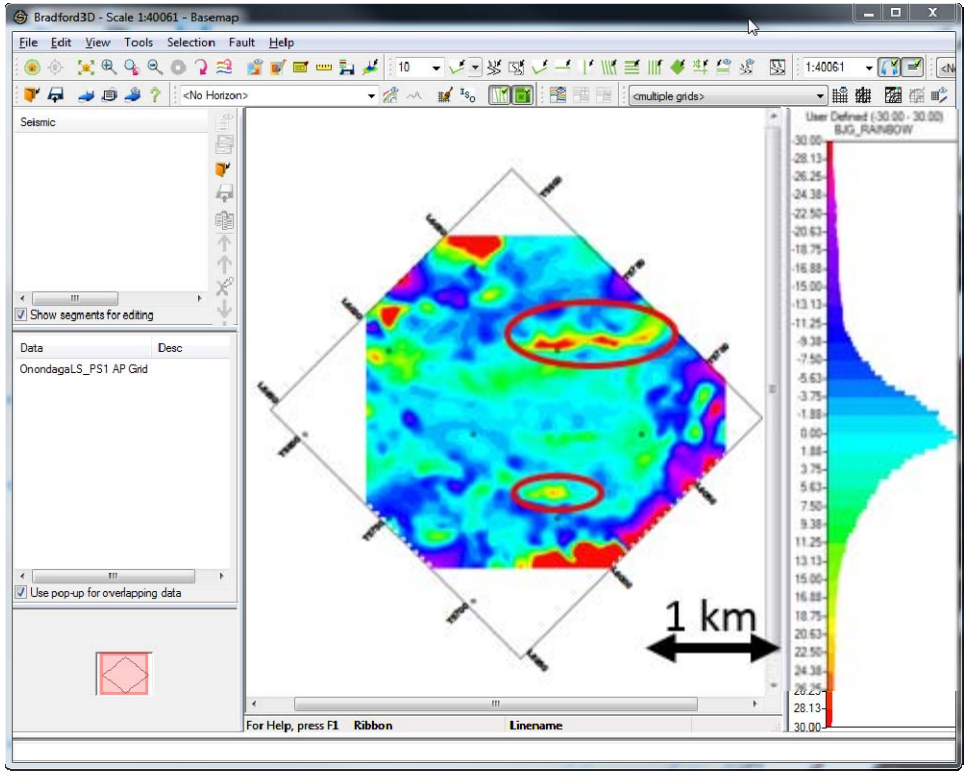


PS1 to PS2 traveltime anomalies

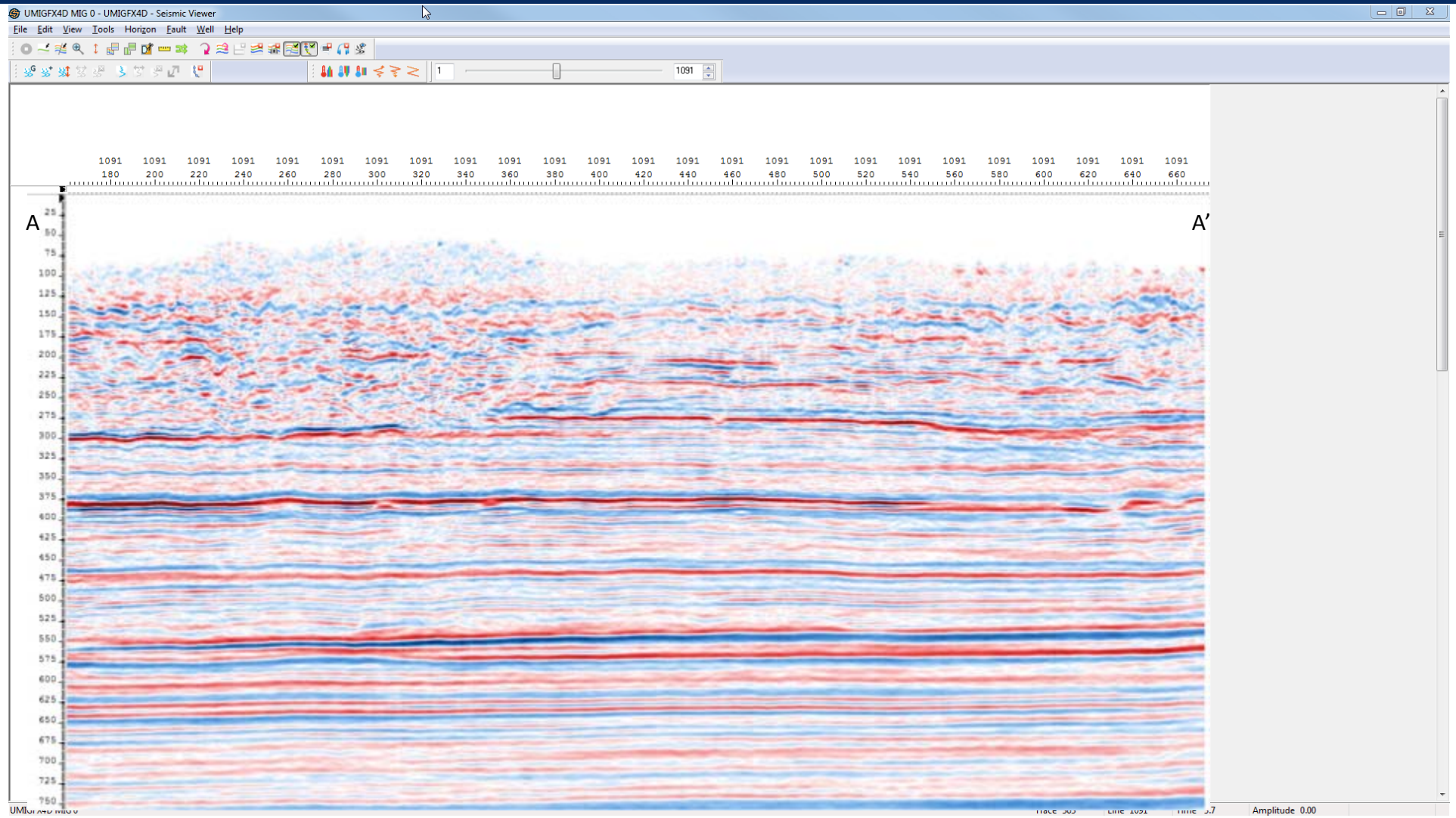
Marcellus-Onondaga interval V_p/V_s ratio



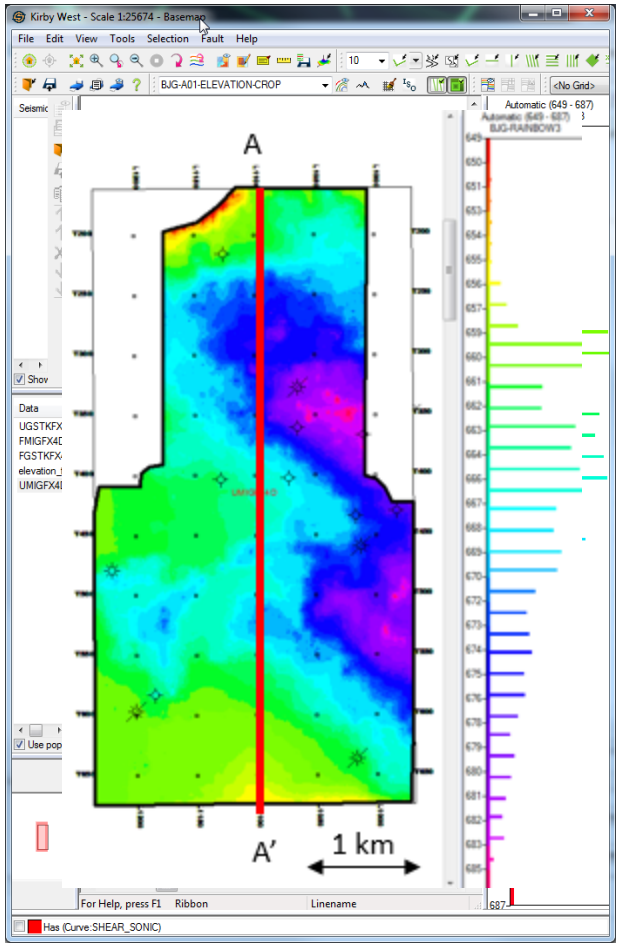
Marcellus-Onondaga PS1 to PS2 isochron difference



3D 3C seismic data and well log data



Surface elevation of seismic data



3D 3C seismic data and well log data