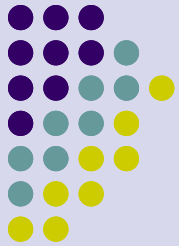
Application of nonlinear time-lapse AVO to the Pouce Coupe data set



Presented by

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Supervisor

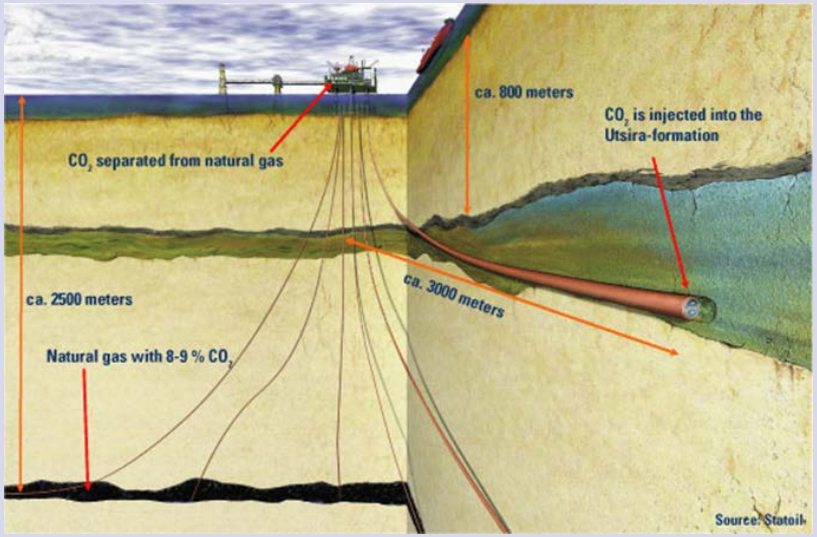
Kris Innanen

Outline

- Motivation and review
- Geology
- Seismic surveys
- Well tie and interpretation
- Time-lapse modeling
- Future work
- Acknowledgements

Time-lapse

- Monitoring changes in reservoir: production, EOR
- Repeated seismic surveys over calendar time
- The baseline and monitor survey
- Changes in seismic parameters



AVO : Amplitude Versus Offset

Baseline and time-lapse changes

Baseline

$$\Delta V_{Pb} = V_{Pb} - V_{P_0}$$

$$\Delta V_{Sb} = V_{Sb} - V_{S_0}$$

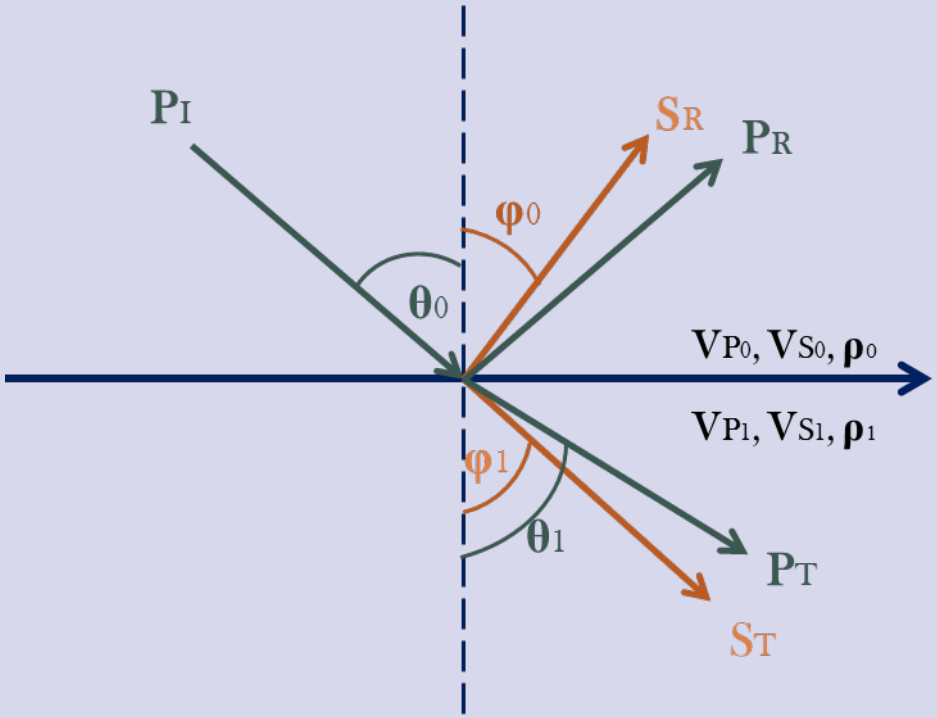
$$\Delta \rho_b = \rho_b - \rho_0$$

Time-lapse

$$\delta V_P = V_{Pm} - V_{P_b}$$

$$\delta V_S = V_{Sm} - V_{S_b}$$

$$\delta \rho = \rho_m - \rho_b$$

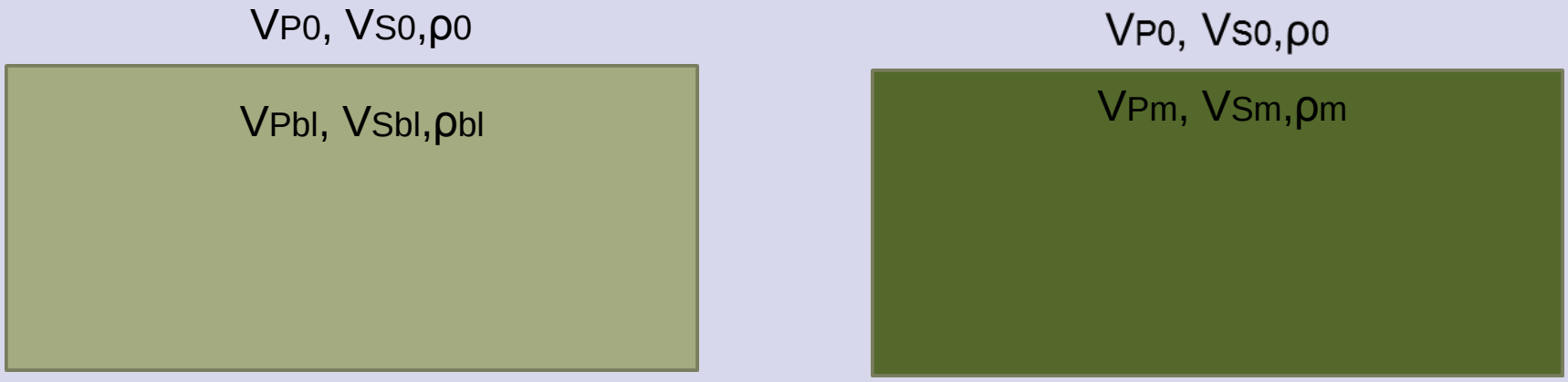


A general framework for time-lapse AVO

- Deriving $\Delta R_{PP}(\theta)$ from Zoeppritz equations
  - Linear or Aki-Richards approximation
  - Nonlinear correction

- Examine linear and nonlinear terms for:
  - Agreement with Landrø at small contrast
  - Behaviour of approximations at large contrast

A time-lapse problem



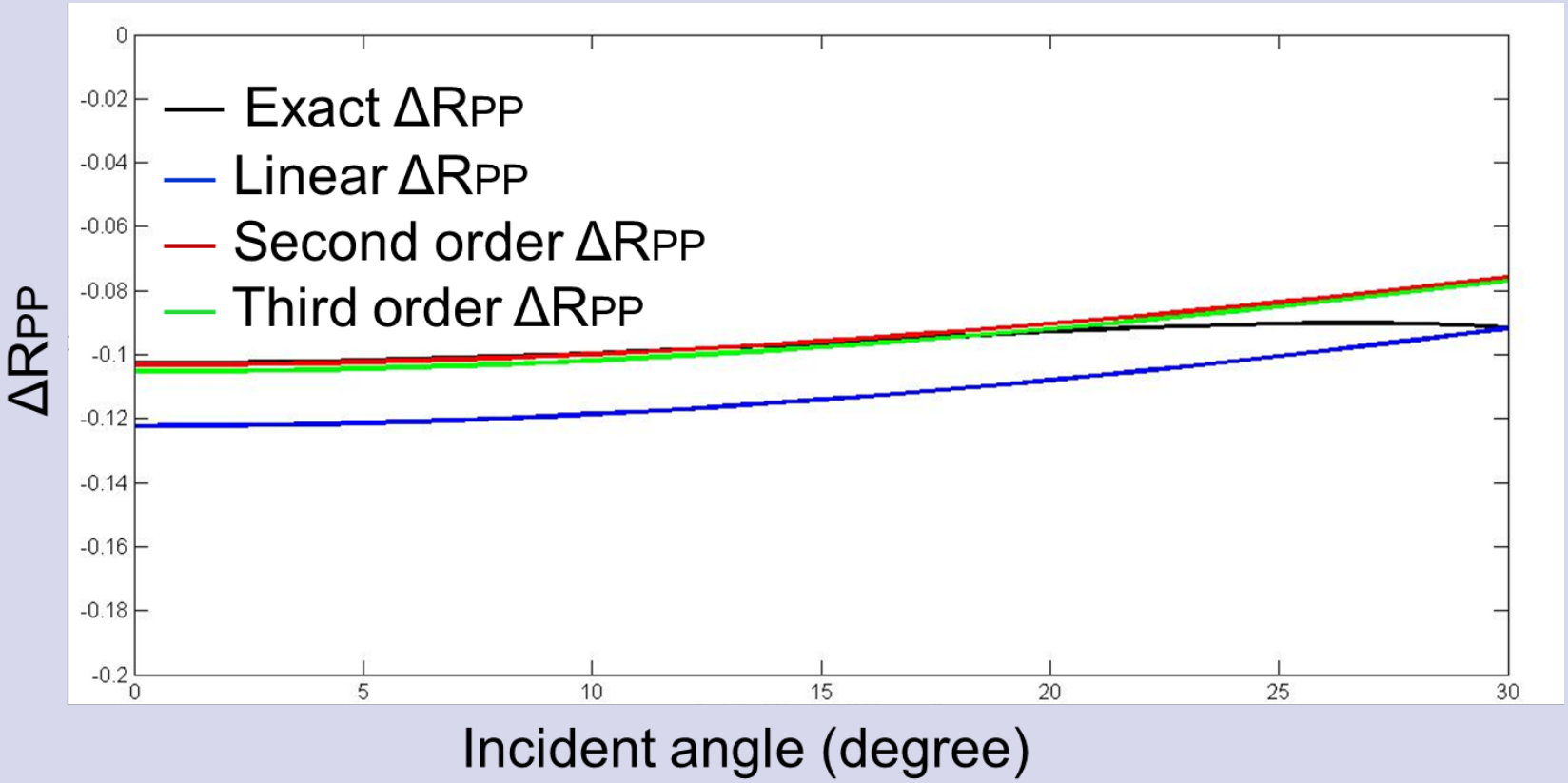
Baseline Survey

Monitor Survey

Baseline perturbation $\frac{\Delta V_P}{V_P}=2\frac{V_{Pb}-V_{P0}}{V_{Pb}+V_{P0}}$, $\frac{\Delta V_S}{V_S}=2\frac{V_{Sb}-V_{S0}}{V_{Sb}+V_{S0}}$, $\frac{\Delta\rho}{\rho}=2\frac{\rho_b-\rho_0}{\rho_b+\rho_0}$

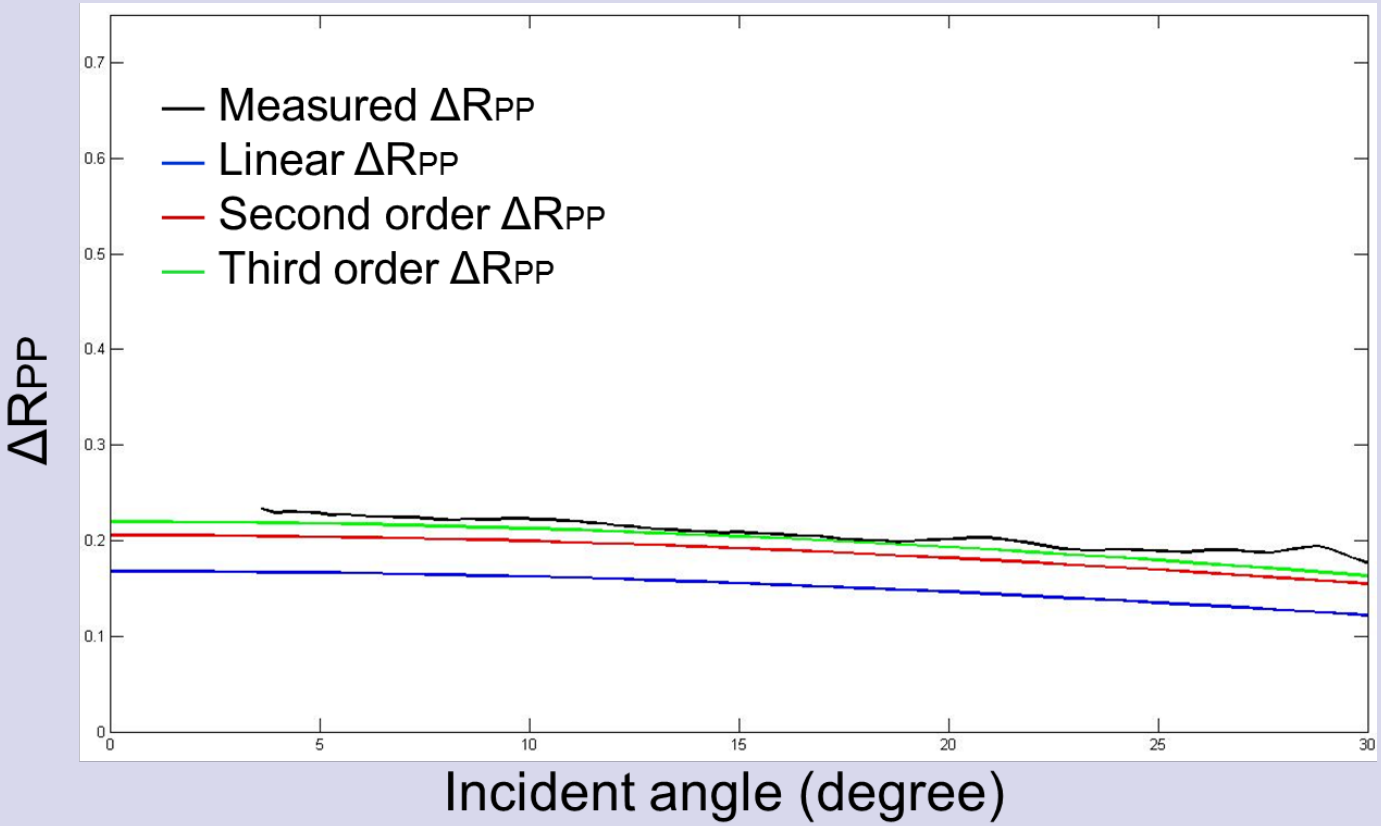
Time-lapse perturbation $\frac{\delta V_P}{V_P}=2\frac{V_{Pm}-V_{Pb}}{V_{Pm}+V_{Pb}}$, $\frac{\delta V_S}{V_S}=2\frac{V_{Sm}-V_{Sb}}{V_{Sm}+V_{Sb}}$, $\frac{\delta\rho}{\rho}=2\frac{\rho_m-\rho_b}{\rho_m+\rho_b}$

ΔR_{PP} for the exact, linear, second and third order approximation



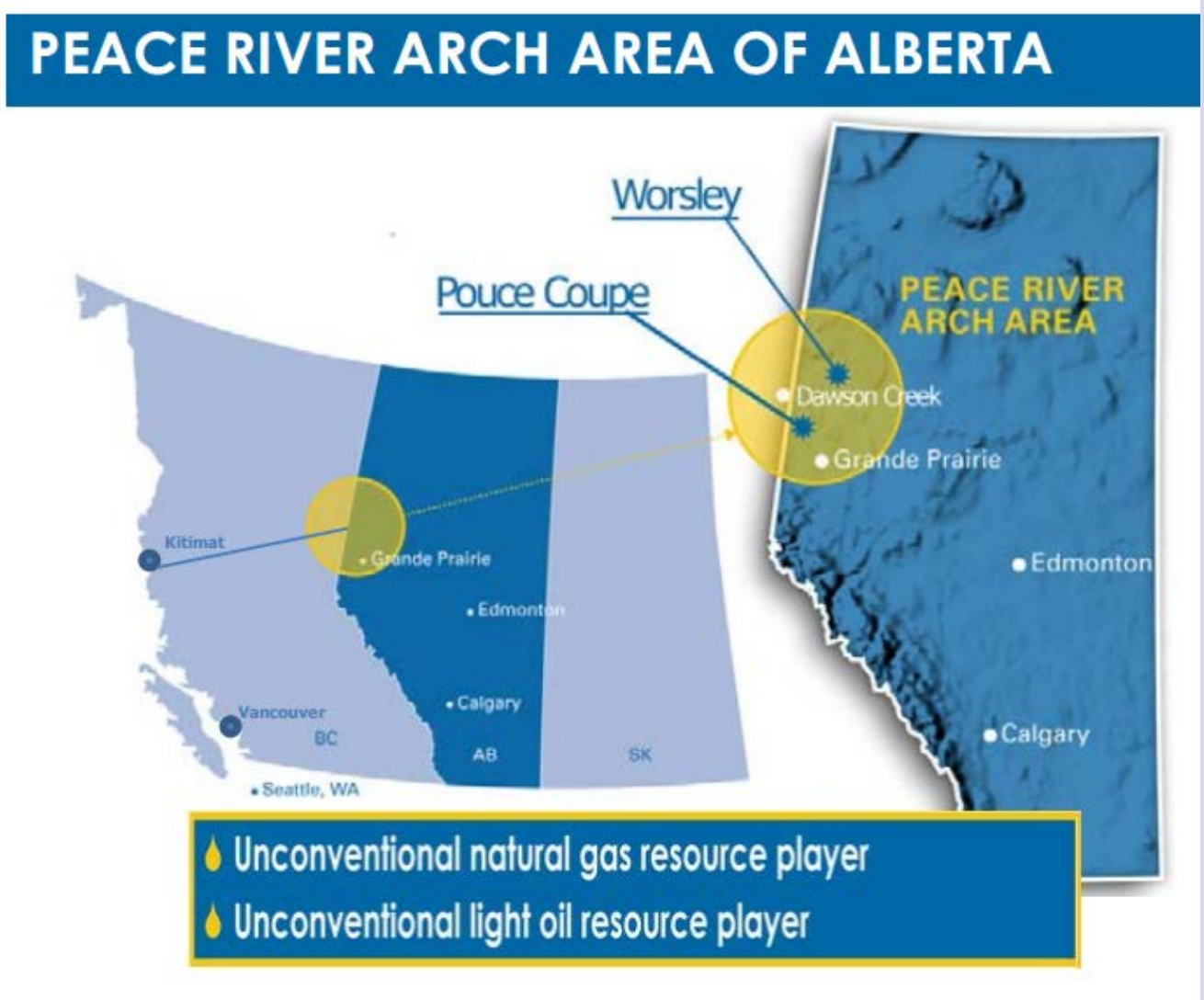
Numerical example is taken from Greaves and Fulp (1987)
Elastic incidence parameters: V_{P0} = 3000m/s, V_{S0} = 1500m/s and ρ_0 = 2.0gm/cc ;
Baseline parameters: V_{Pb} = 4000m/s, V_{Sb} =2000m/s and ρ_b = 2.5 gm/cc ;
Monitor parameters: V_{Pm} = 3400m/s, V_{Sm} = 1700m/s and ρ_m = 2.4 gm/cc.

ΔR_{PP} for the physical model, linear, second and third order approximation



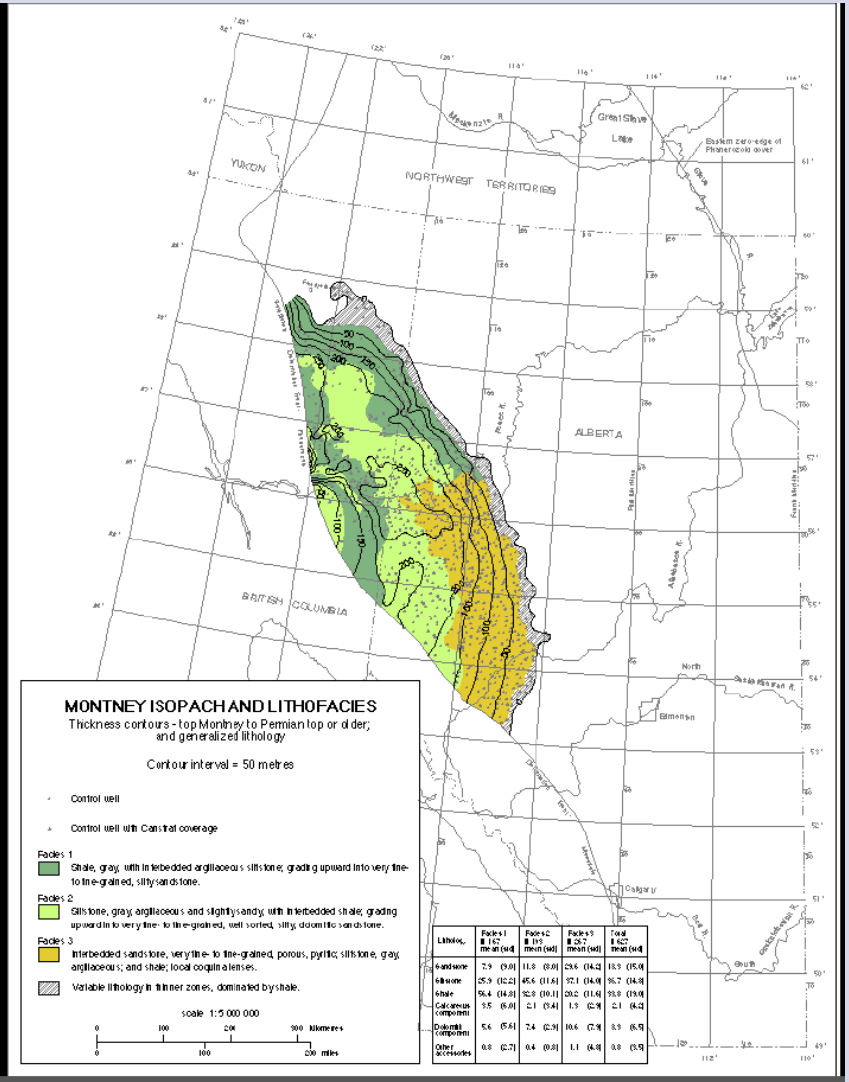
Physical Model: Acrylic as caprock, PVC and Phenolic as reservoir
Elastic incidence parameters: V_{P0} = 2745m/s, V_{S0} = 11380m/s and ρ_0 = 1.19gm/cc ;
Baseline parameters: V_{Pb} = 2370m/s, V_{Sb} =1122m/s and ρ_b = 1.13 gm/cc ;
Monitor parameters: V_{Pm} = 3500m/s, V_{Sm} = 1700m/s and ρ_m = 1.39 gm/cc.

Pouce Coupe Field Source: Birchcliff Energy November 2013.



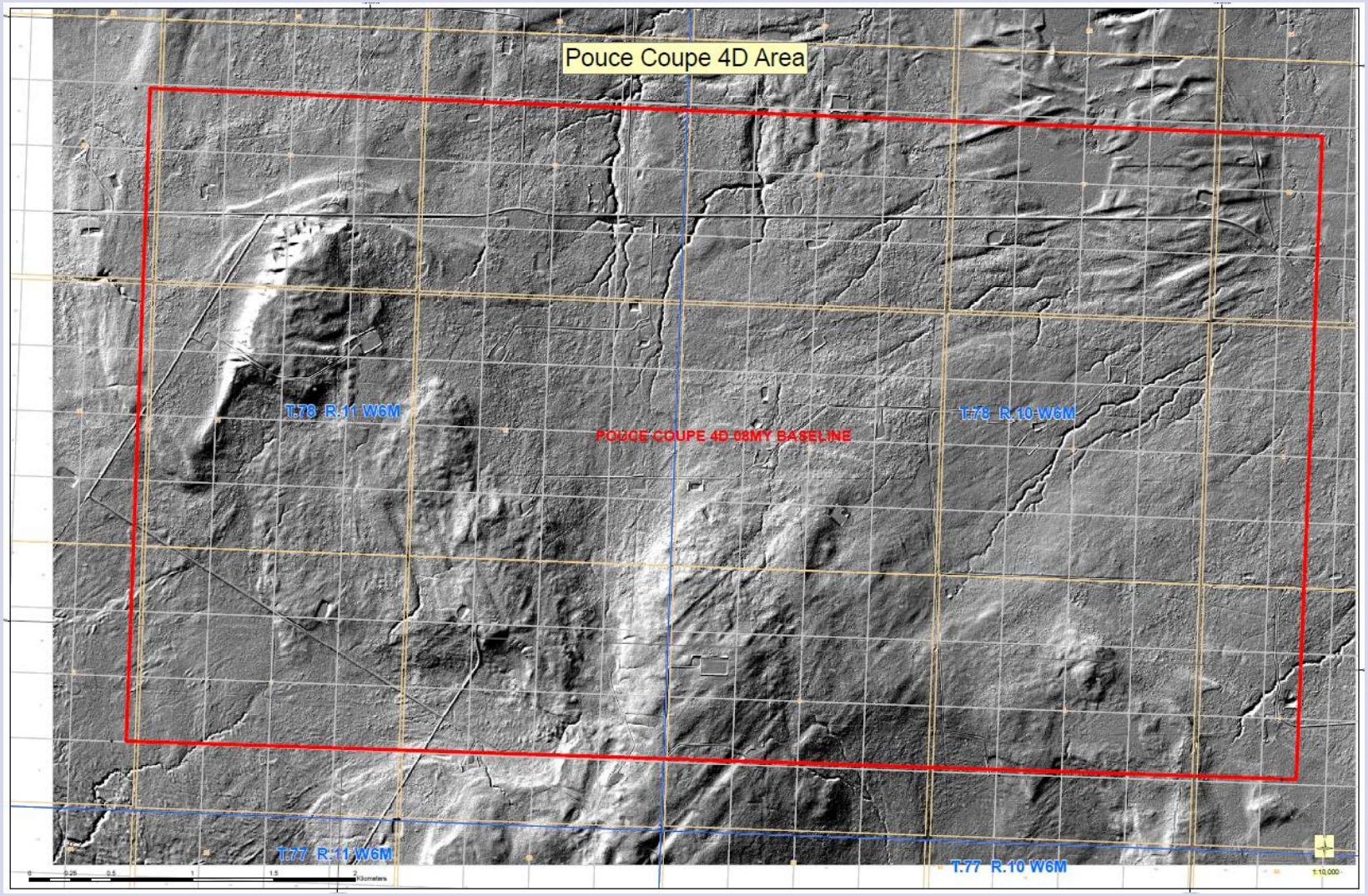
Montney Formation

Montney Formation Isopach



Mossop G.D and Shetsen, I., 1994
Geological Atlas of the WCSB

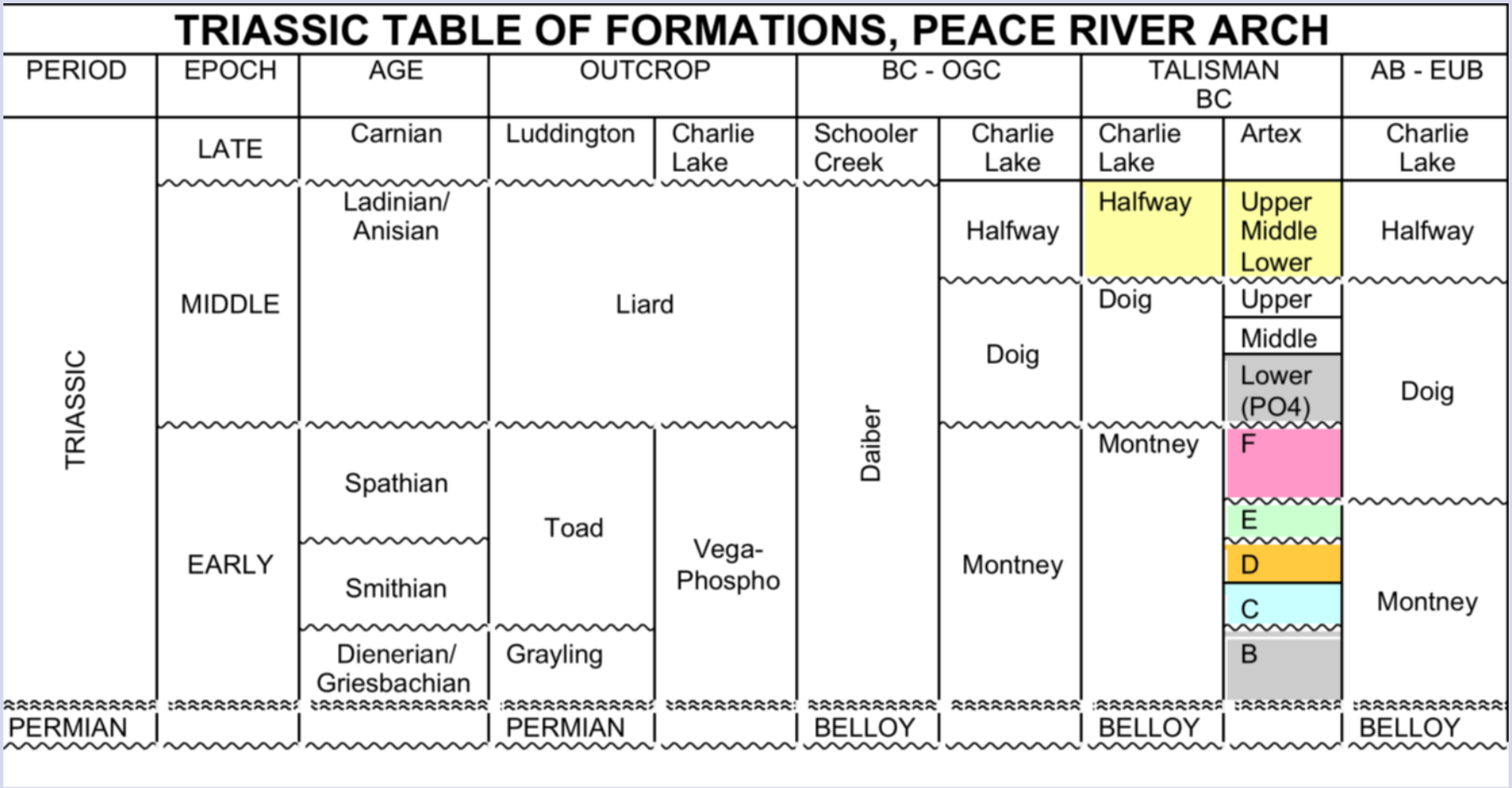
Pouce Coupe Area



Geology

- Montney deposition extends over 40,000 km^2
- Maximum thickness of 350 meters with production depths ranging 1500-2500 meters
- Sandstone, siltstone, and shale reservoir:
  - Permeability of 0.01-0.02 mD
  - Porosity of 6-10%
- The Montney is a tight gas/condensate reservoir

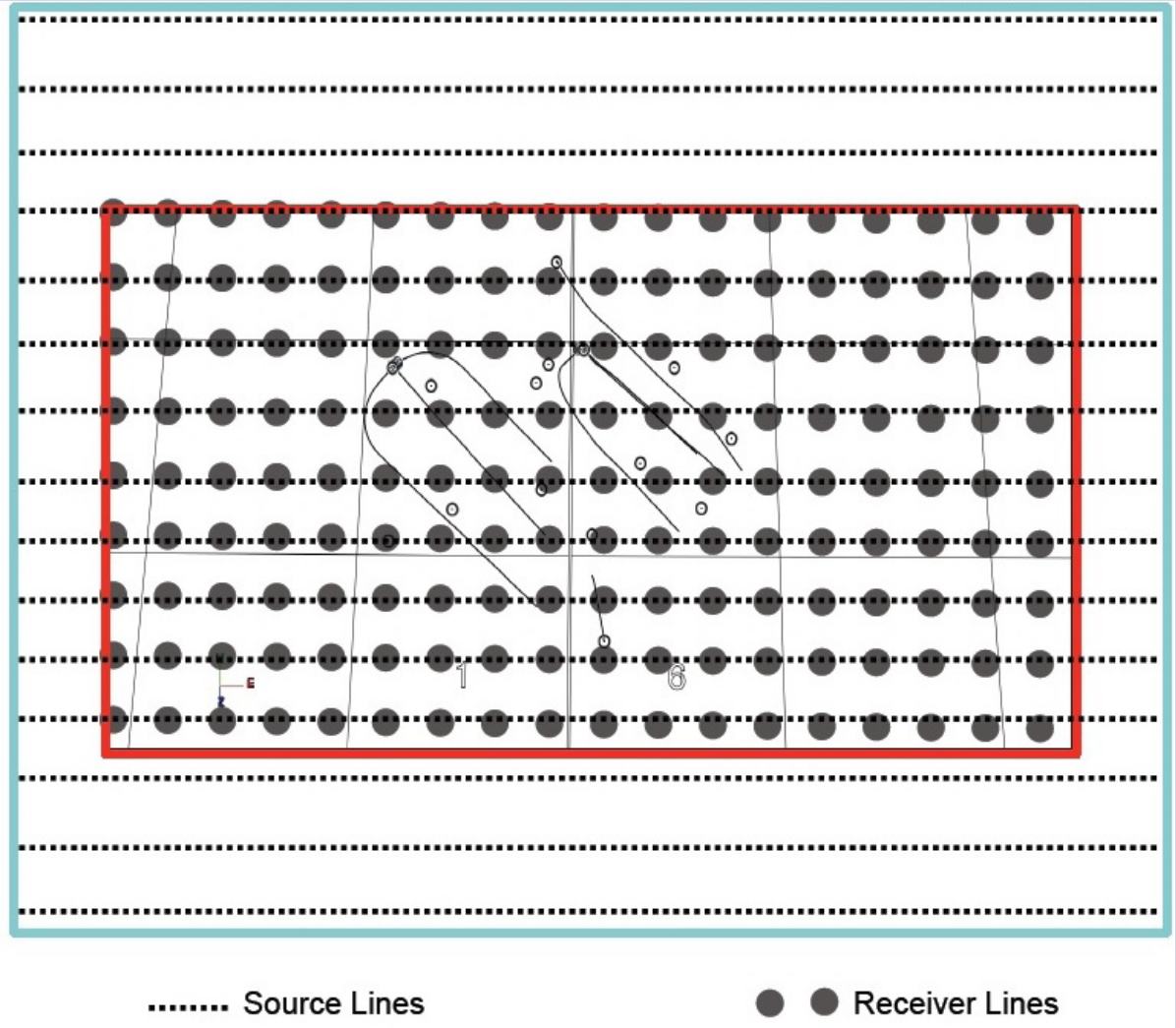
Triassic Montney Formation in the Peace River Arch region (Courtesy of Talisman Energy)



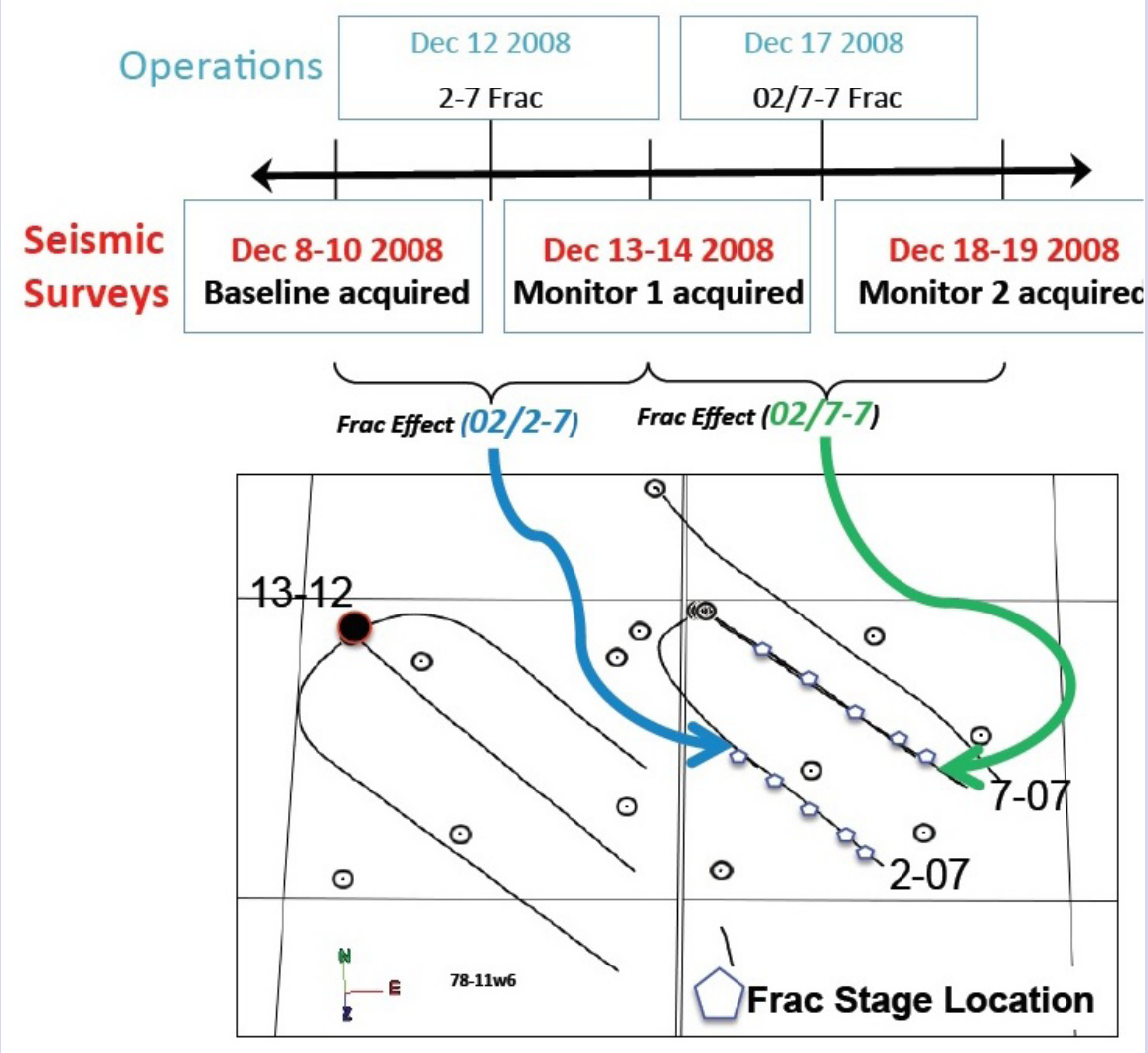
Acquisition Parameters

- Recorded by CGGVeritas
- Record Length: 6.0 sec with 2 msec sample interval
- Source: Dynamite Geo Prime, single hole, 0.5 Kg at 5.5 m depth
- Geophones: OYO Geospace, 3C at 3.5 m
- Source Interval and Receiver Interval of 100 m
- Source lines and receiver lines with 200 meters separation
- Patch: 9 lines × 16 Stations or 1600 m × 3000 m

Pouce Coupe time-lapse, multicomponent seismic survey acquisition layout



Pouce Coupe time-lapse seismic and field operations timeline



Processing Flow

- Processing completed by Sensor Geophysical Ltd.
- Static corrections
- Pre-stack noise attenuation
- Surface consistent deconvolution
- CDP Stacking
- FK (frequency enhancement) filter
- Radon multiple
- RADAR (Receiver Azimuth Detection and Rotation)

A time-lapse problem

V_{P0}, V_{S0},ρ_0

V_{Pbl}, V_{Sbl},ρ_{bl}

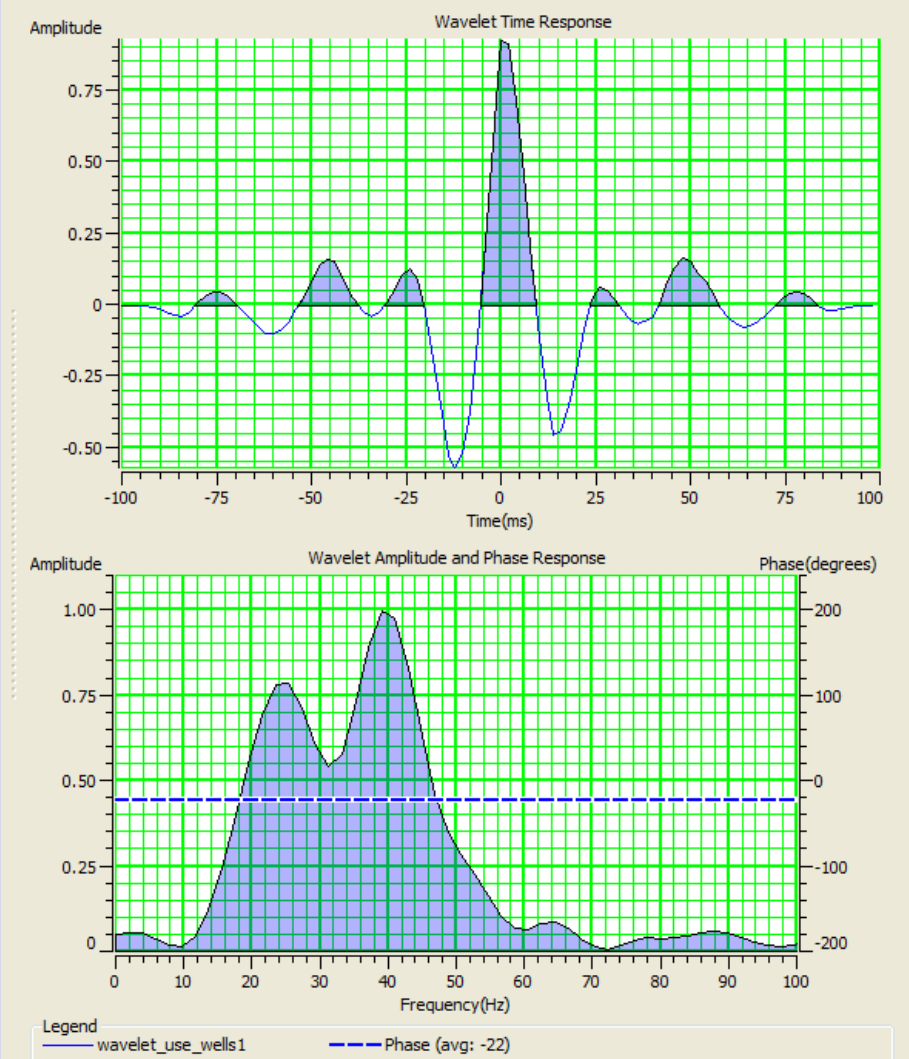
Baseline Survey

V_{P0}, V_{S0},ρ_0

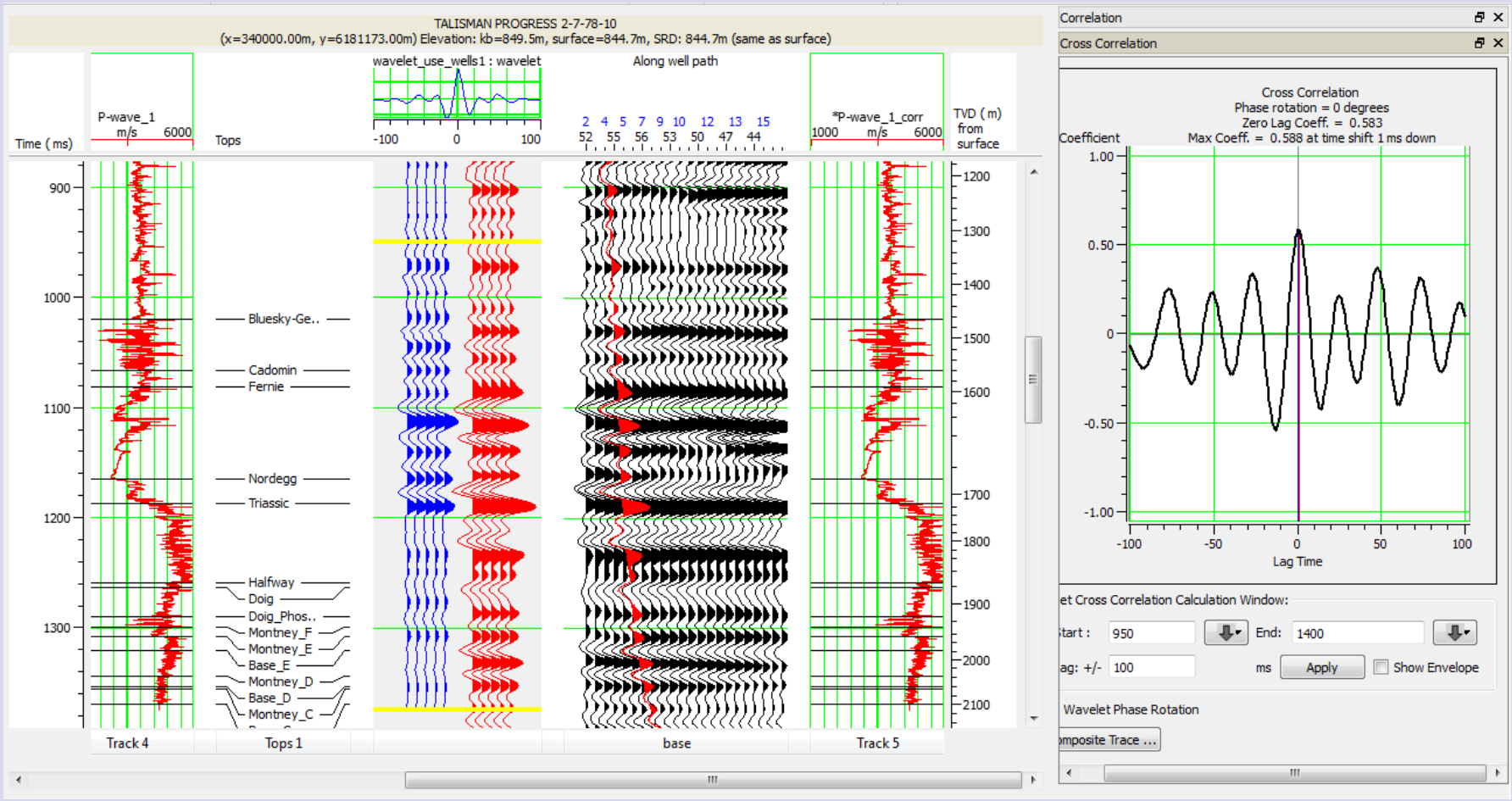
V_{Pm}, V_{Sm},ρ_m

Monitor Survey

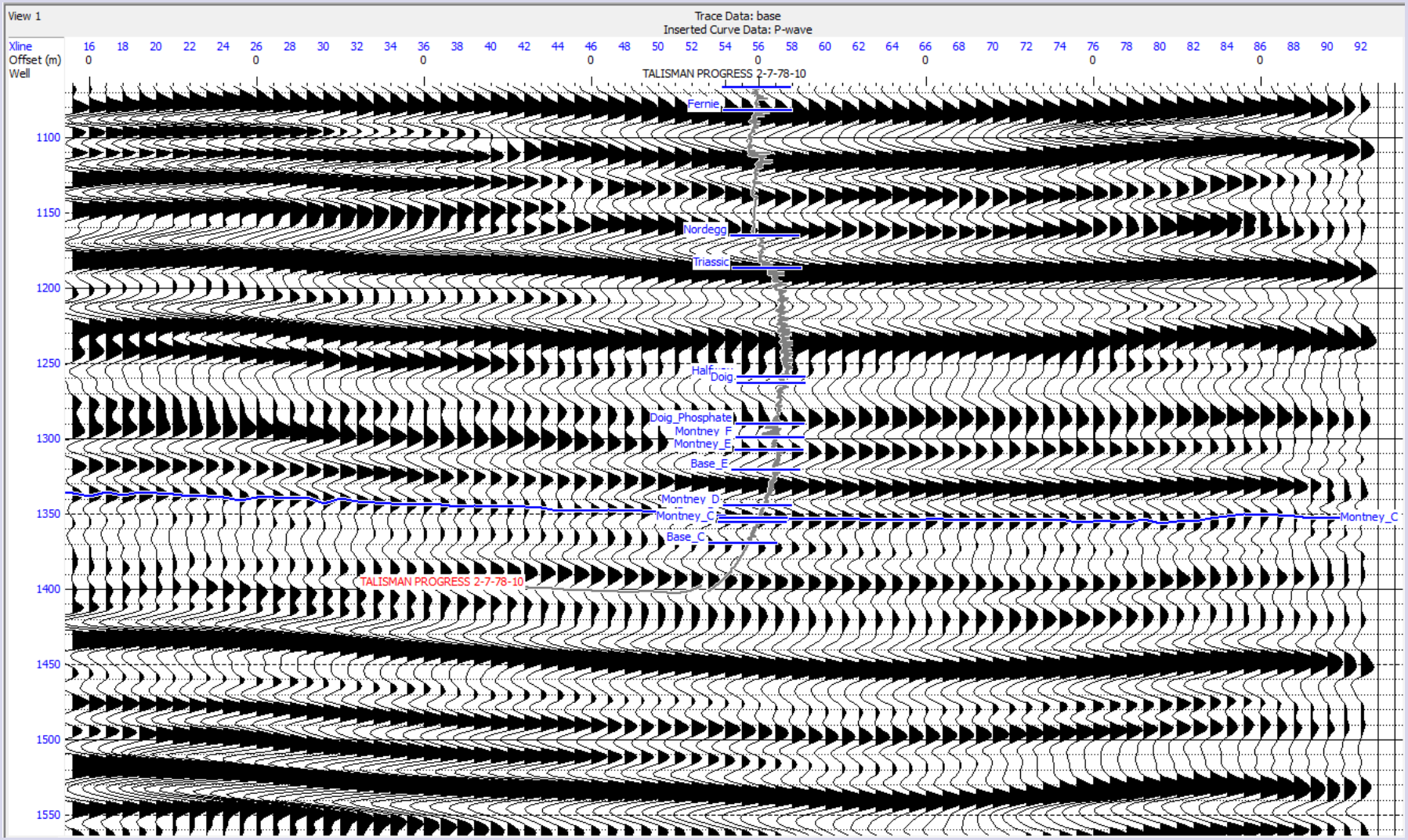
Wavelet extracted from well



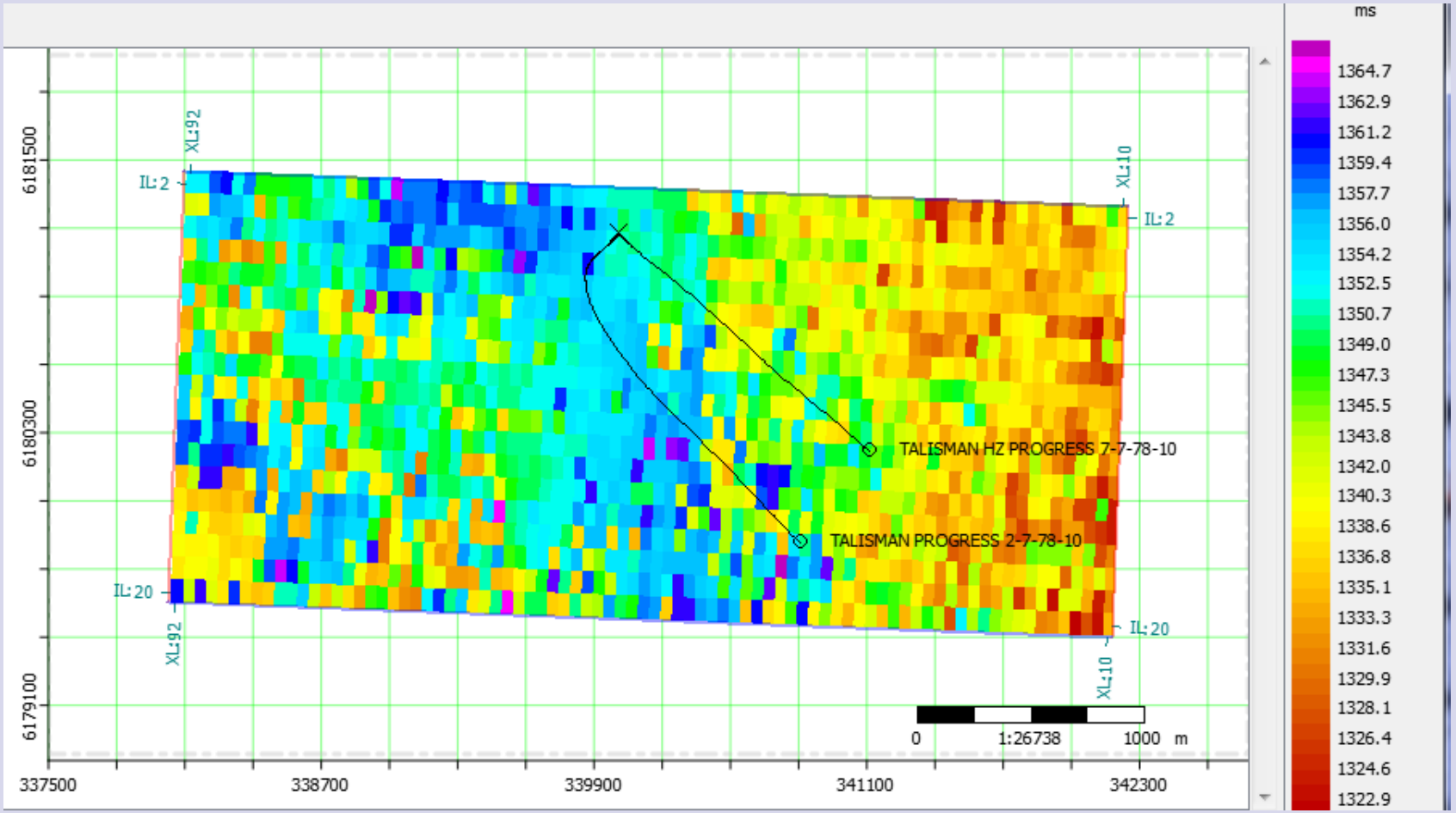
Well Tie for 100-02-07-78-10W6



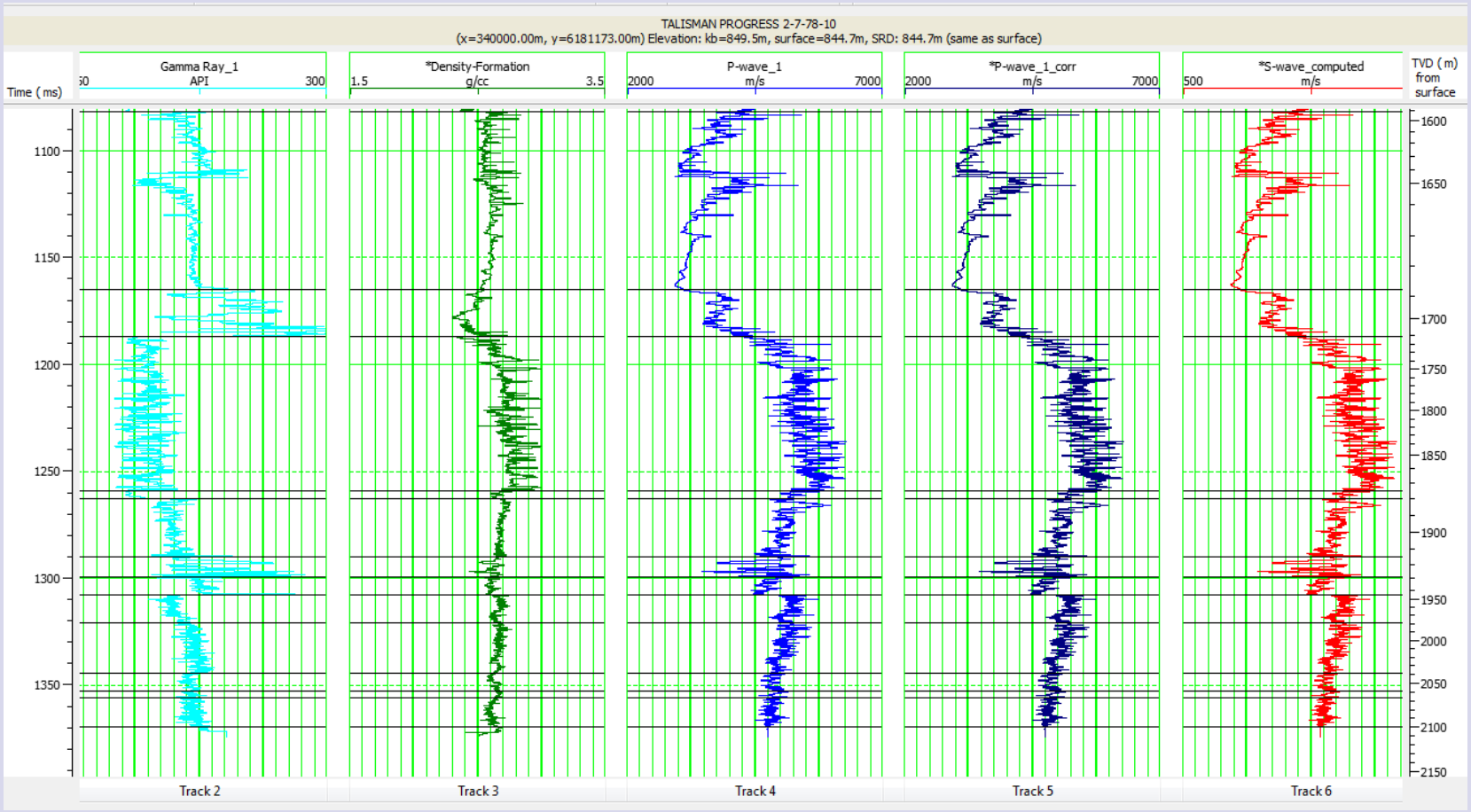
Interpretation of Montney on Baseline



Montney C Horizon



Logs for Well 100-02-07-78-10W6



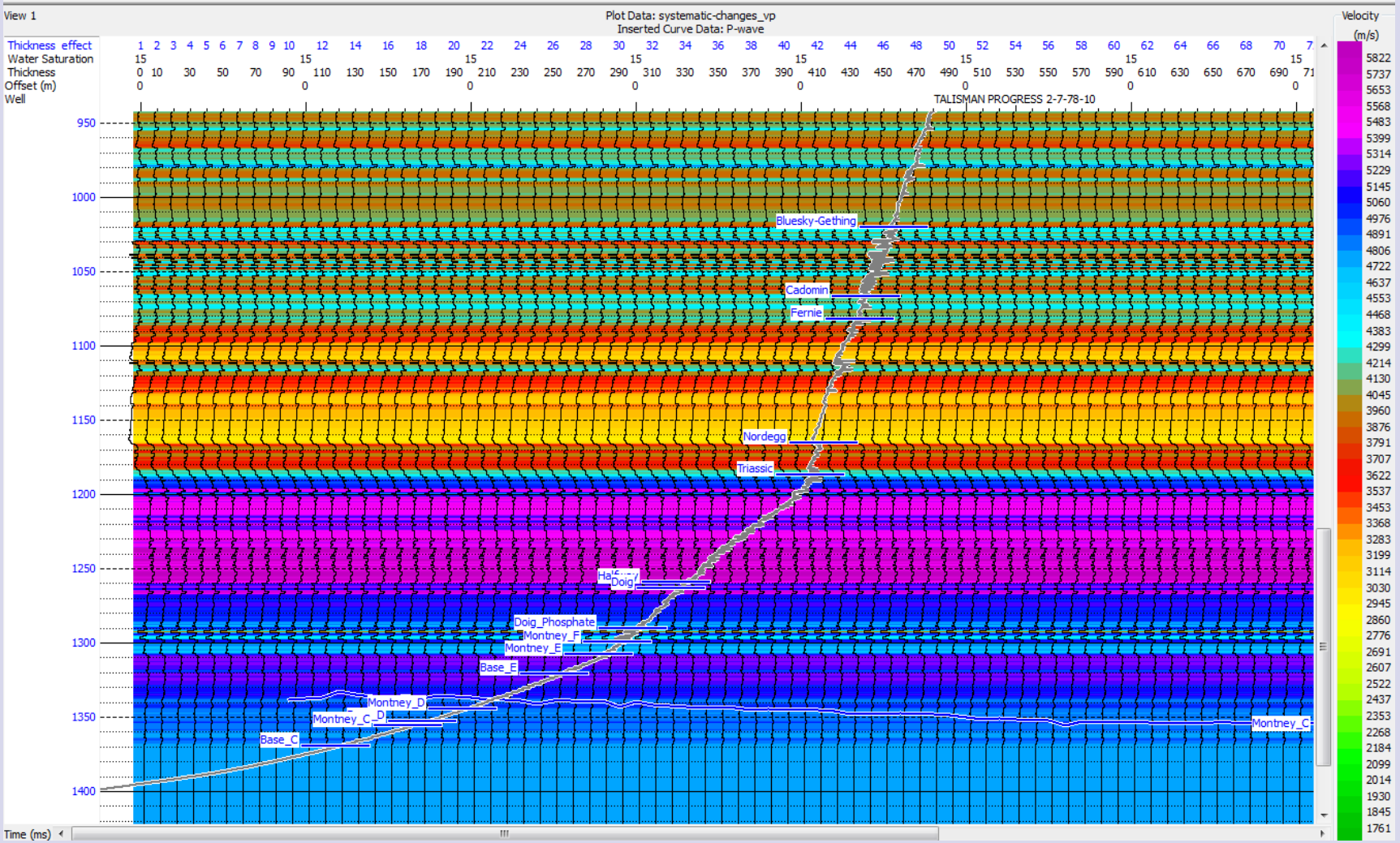
Creating synthetic well logs

- Initial well logs
- Reservoir parameters before fracture
  - 15% water and 85% gas
  - Temperature of 70c, pressure of 22 MPa, and salinity of 100,000 ppm
  - Matrix: 50% Sandstone, 30% limestone, and 20% dolomite
- Fracture induced changes

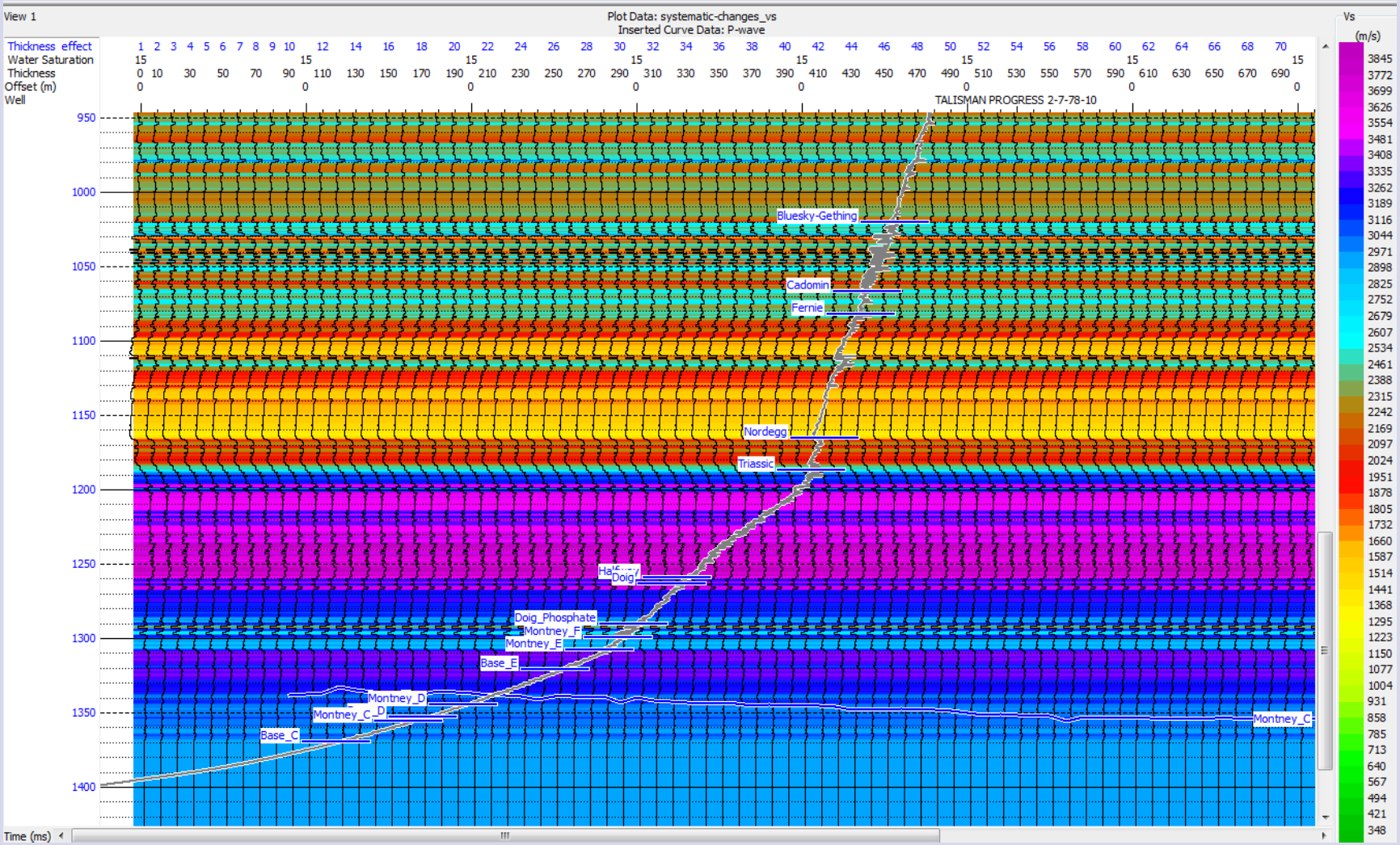
Fracture parameters

- Well 100-02-07-78-10W6 (targeting Montney C) with 1328 m^3 clear frac with 500 tons of proppant on five 200 m-spaced frac
- Well 100-07-07-78-10W6 (targeting Montney D) with 1256 m^3 clear frac with 400 tons of proppant on five 250 m-spaced frac

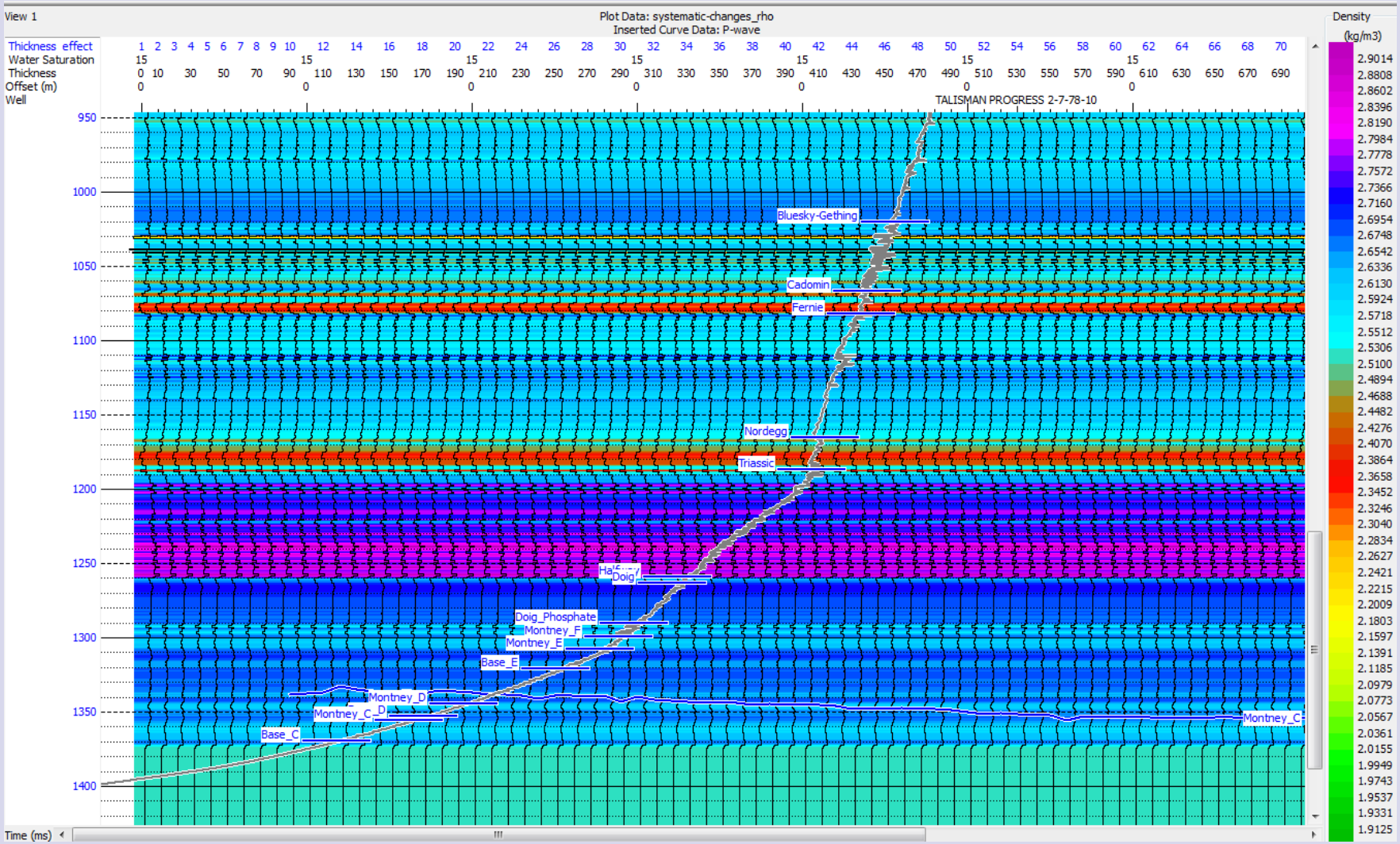
Systematic changes for P-wave velocity



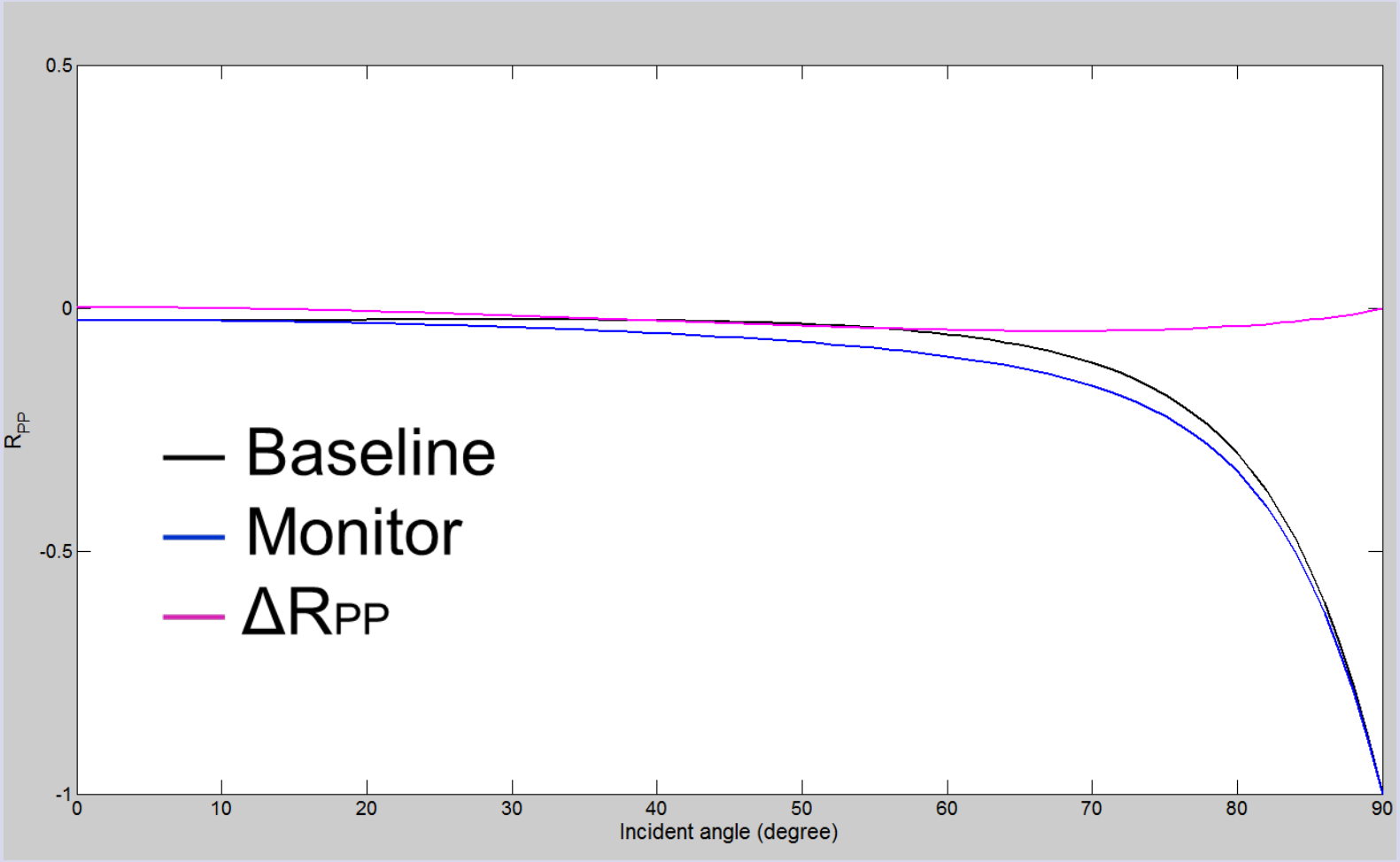
Systematic changes for S-wave velocity



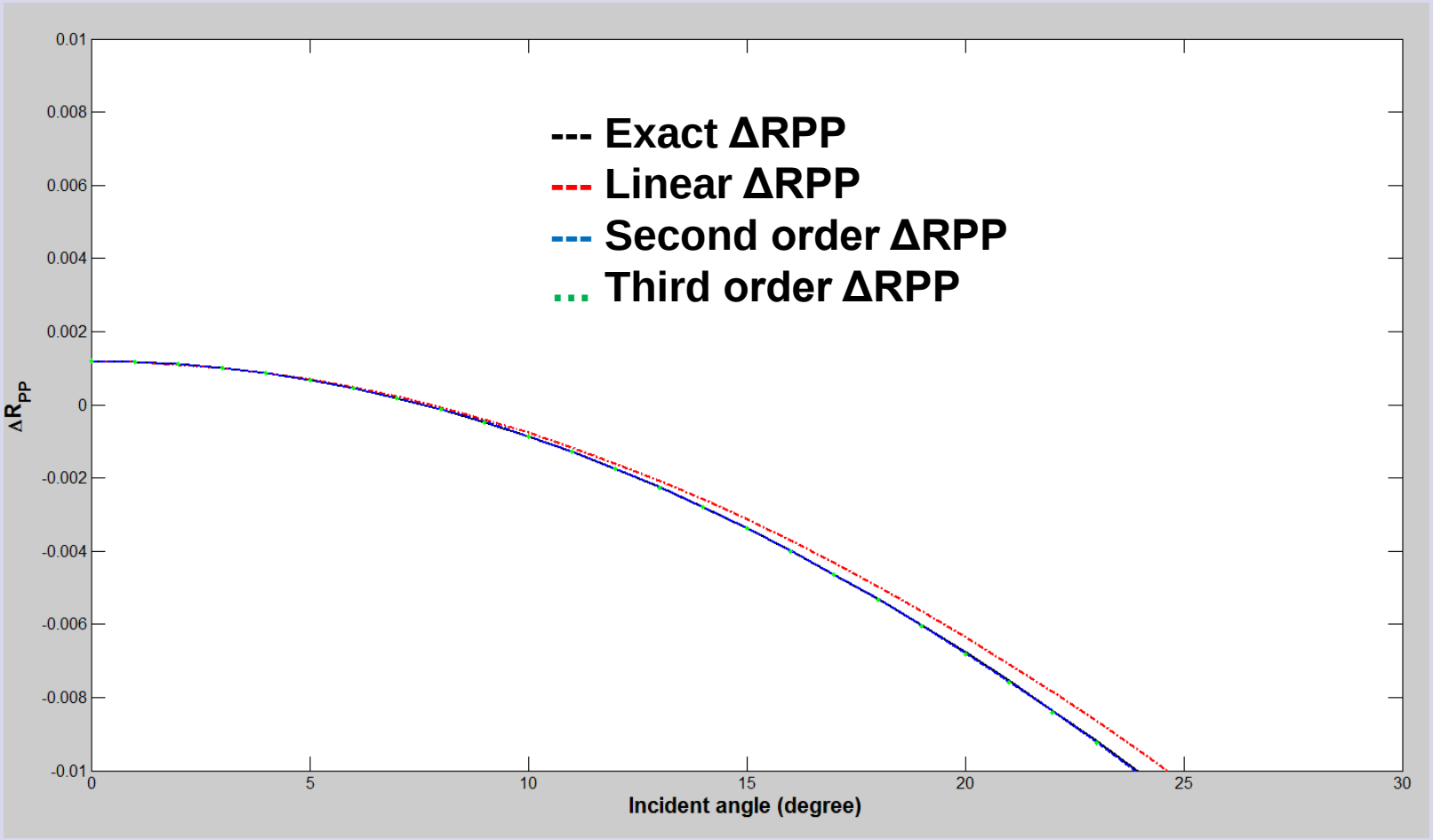
Systematic changes for density



R_{PP} for baseline and monitor surveys with their difference



ΔR_{PP} for the exact, linear, second and third order approximation



Future Plans

- Continuing in investigating of non-linearity of time-lapse AVO for P-wave
- Shear wave splitting produces measurable results as a monitor of time-lapse changes.

Acknowledgements

- Dr. Kris Innanen
- Talisman Energy Inc. and David D'Amico
- Dr. Jeff Grossman and Dr. Helen Isaac
- Hampson Russell Software & Services
- CREWES Students and Staffs specially David Henley, Shahin Moradi, Rafael Asuaje, and Raúl Cova
- CREWES Sponsors and NSERC (Natural Science and Engineering Research Council of Canada)

Castagna’s Equation

- Vs=a.Vp+b a=0.8619 b=-1172

Montney regional production

- Recoverable resources of 175 TcF
- Total over 2000 wells in excess of 1500 horizontal wells
- 2 TCF production till 2011
- Pouce Coupe: 15 vertical and two horizontal wells in this study