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Bayesian Facies Classification using depth trends and elastic values from Simultaneous and Facies-based Inversions: A Montney case

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Summary

In this work we present and compare the results of applying a Bayesian facies classification using two types of Seismic Inversions: Simultaneous and Facies-based at the Montney formation.

The obtained elastic parameters are quite similar at the well locations used to build the Low-frequency Model (LFM) that was used for Simultaneous Inversion. However, the methodology applied in both methods are quite different, where the facies-based inversion method provides a LFM.

Facies definition

Unsupervised clustering techniques were applied to create facies for using in seismic inversion. The input to the clustering was phiT, Vker, Vcl, Vss, AI, and Vp/Vs.

The resulting facies definitions are:

Tight Organic & Porous Kerogen Rich Silstone + Porous Kerogen Rich Shale + Soft Organic Rich Carbonate
Low Organic Shale
Tight Organic Rich Carbonate
Tight Clay Rich Organic Shale
DOIG Vclay > 0.15
DOIG Vclay < 0.15

Table 1. Resulting facies definitions

Bayesian Classification

Bayesian classification is a probabilistic approach to learning and inference, in which probability is used to represent uncertainty about the relationship being learnt. Prior models about what the true relationship might be are expressed in a probability distribution (or probability distribution function or pdf). After the data is revised, our revised models are captured by a posterior distribution.

Mathematically, the probability of an element x to belong to a class w is:

$P(w_j|x) = \frac{p(x|w_j)P(w_j)}{p(x)}$ [1], where $p(x|w_j)$ are the respective pdfs

The classification is then defined as:

Assign x to $w_i = argmax_{w_j}^{max} p(x|w_j)P(w_j)$

Depth Trend Analysis and pdfs

Depth Trend Analysis describe the Rock Physic relationships between the elastic parameters (Vp, Vs, Rhob, P-Impedance, S-Impedance and Vp/Vs) in depth per facies.

The depth trends are defined by a mean value (per facies), which can change with depth, and a standard deviation.

An example of depth trends analysis (DTA) used in this study is shown in figure [1]:

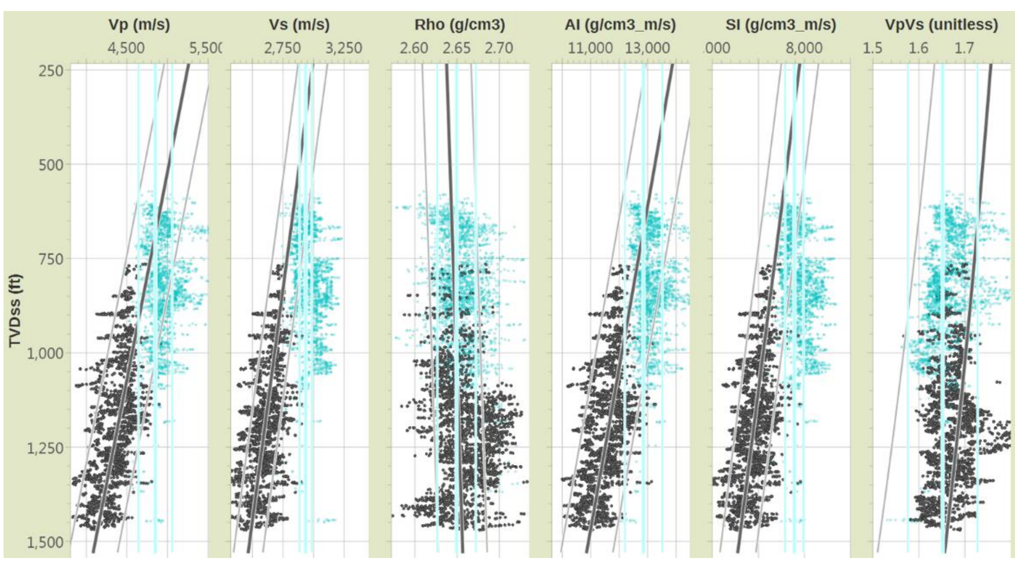

Figure 1. Depth Trends Analysis for 3 different facies. Thick lines represent the main value of the elastic property with depth. Light lines show the 1st standard deviation

As seen in figure 1 the DTAs are defined using well log data. They could also be defined using theoretical rock-physics models, so the presence of wells in the area of study to perform the classification is not necessary.

When cross-plotting the different elastic properties and using the information of the mean values and standard deviation of the DTA we can define the pdfs per facies necessary to perform the classification as in figure 2:

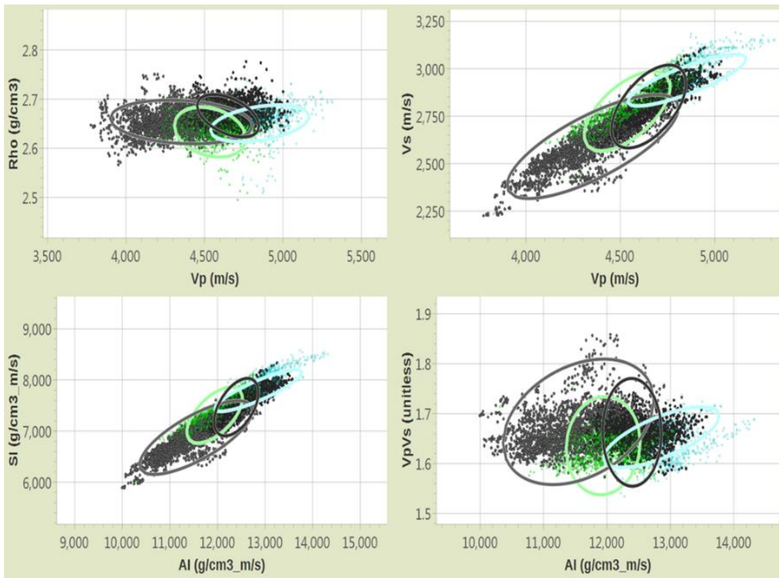

Figure 2. Resulting pdfs obtained from the DTA for 3 different facies: **Tight Organic Rich Carbonate**, **Tight Organic & Porous Kerogen Rich Silstone + Porous Kerogen Rich Shale + Soft Organic Rich Carbonate** and **Tight Clay Rich Organic Shale** (same as in a)) displayed in density

Theory / Method / Workflow

Depth trends can be understood as the rock physics relationships per facies and depth. They are defined at well locations and describe how the values of the main elastic properties (Vp,Vs and Rho) change with depth.

Seismic Inversion is the process from which we can estimate elastic properties from seismic reflectivity data, removing the effect of the wavelets and adding a low-frequency component to the estimated elastic values. In this work we implemented two types of seismic inversion:

1- Simultaneous Seismic Inversion: a prior low-frequency model (LFM) needs to be built and then input into the process of the inversion. Usually, well data interpolation is used to fill up the model. Additionally, more sophisticated methods can also be applied (e.g., Kriging). Then the three main elastic parameters (Vp,Vs, Rho) are inverted simultaneously in order to comply with the AVO equation and match the seismic data. This process adds the band-limited information of the wavelets to the low-frequency model.
   In this case study a background model using log interpolation and variogram per zone) was preferred.

2- Facies-Based Inversion. The depth trends rock-physics relationships are used to constrain the estimated elastic properties, and to estimate the pdfs needed for classification. These trends are assumed to be constant on each target trace and absolute values of estimated elastic properties are obtained from using the constraint from the depth trends and solving the AVO equation. A low-frequency model is then obtained and estimated elastic properties are not affected by the presence and location of wells.

Using the defined pdfs obtained from the TDAs we performed a Facies Classification using the outputs (elastic parameters) from Simultaneous Inversion and Facies-based inversion.

Results

Figure 3 shows results of implementing Facies-based inversion using the depth-trends defined in figure 1 and comparison with Simultaneous Seismic Inversion:

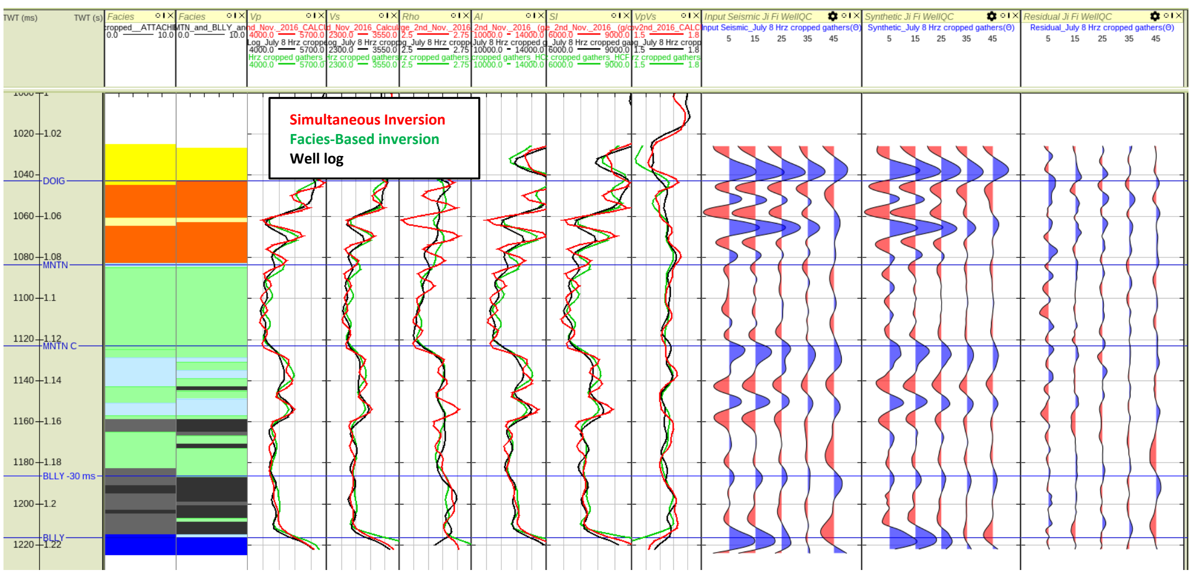

Figure 3. Results of facies-based inversion and comparison with Simultaneous Seismic inversion results.

As seen in figure 3 the results of applying simultaneous seismic inversion and facies-based inversion in this case are very similar, specially at the well locations used for building the LFM used for the Simultaneous Inversion. Theoretically, Facies-based will provide a biased-free estimate away from the well locations and estimates will depend mainly on the seismic data quality.

Figure 4. Shows an arbitrary section showing the obtained Vp for Facies-based and Simultaneous inversions.

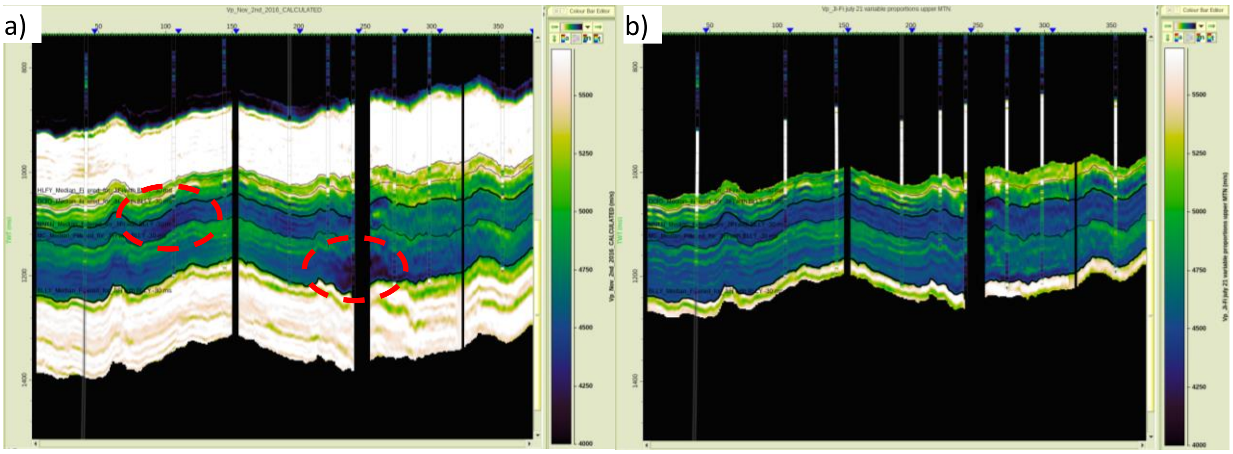

Figure 4. Arbitrary line showing Vp results from a) Simultaneous Inversion and b) Facies-based inversion. Note that in the case of Simultaneous Inversion there are sections where ‘bull-eyes’ (identified with red-dashed ovals) can be observed related with the location of wells.

An example of classified facies can be seen on figure 5:

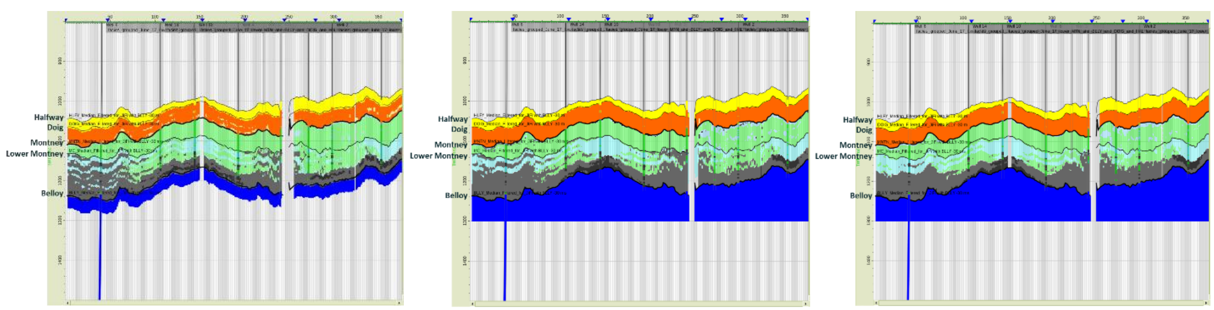

Figure 5. Arbitrary line showing Bayesian facies classification results from a) Facies-based, b) Simultaneous Inversion sing AI and SI; and c) Simultaneous Inversion using AI, SI and Density.

Figure 6 shows a horizon-based (approximately mid-lower Montney) extraction on the facies classification volumes a) facies-based inversion, b) Simultaneous Inversion using AI and SI and c) Simultaneous Inversion using AI, SI and Density

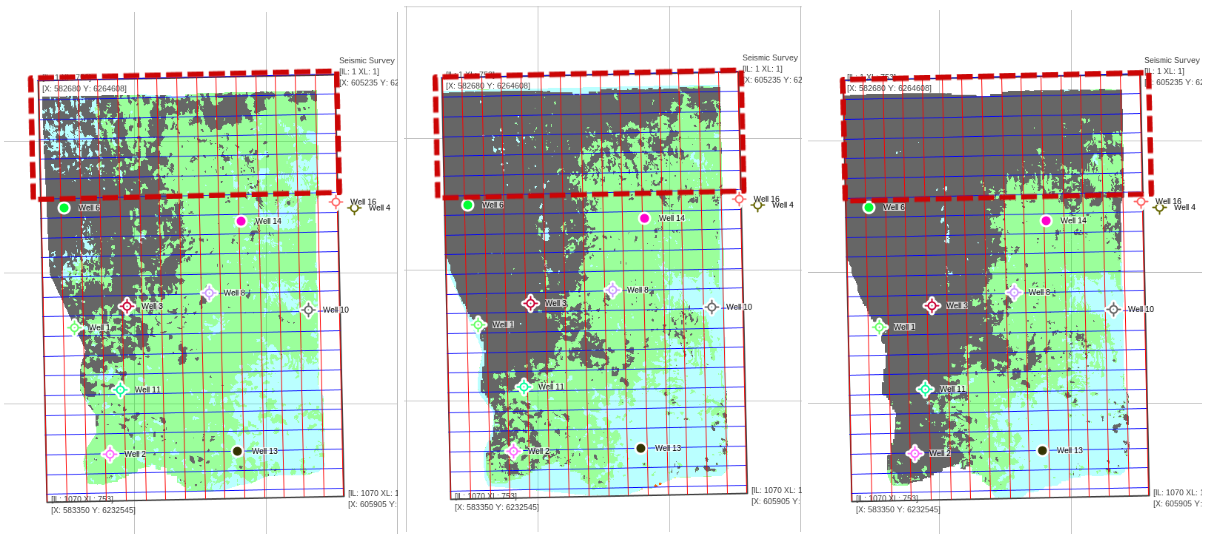

Figure 6. Time horizon (Approx. mid-Lower Montney) showing Bayesian facies classification results from a) Facies-based, b) Simultaneous Inversion sing AI and SI; and c) Simultaneous Inversion using AI, SI and Density. The red-dashed polygons show the area where no wells were used to build the low-frequency model used for Simultaneous Inversion

In Figure 6 we can observe that Simultaneous Inversion facies classification results are more “low Organic Shale” when incorporating the density (from Sim. Inv) into the calculation). The Tight Organic Rich Carbonate facies distribution is similar among the three cases; Facies-based inversion shows some content on the NW area of the survey that Simultaneous Inversion does not classify. Unfortunately, there is no blind test well available to QC the different results.

The Simultaneous Inversion Facies classification and the Facies-Based classification differ the most where no control points (no wells highlighted with the red-dashed polygon) are used to build the low-frequency model in the Simultaneous Inversion case.

Figure 7 shows the resulting Bayesian classification from Simultaneous Inversion when different well sets are used to build the low frequency model. Note how the absolute values of the estimated acoustic impedances (AI 1 vs. AI 2) are different when using different well sets.

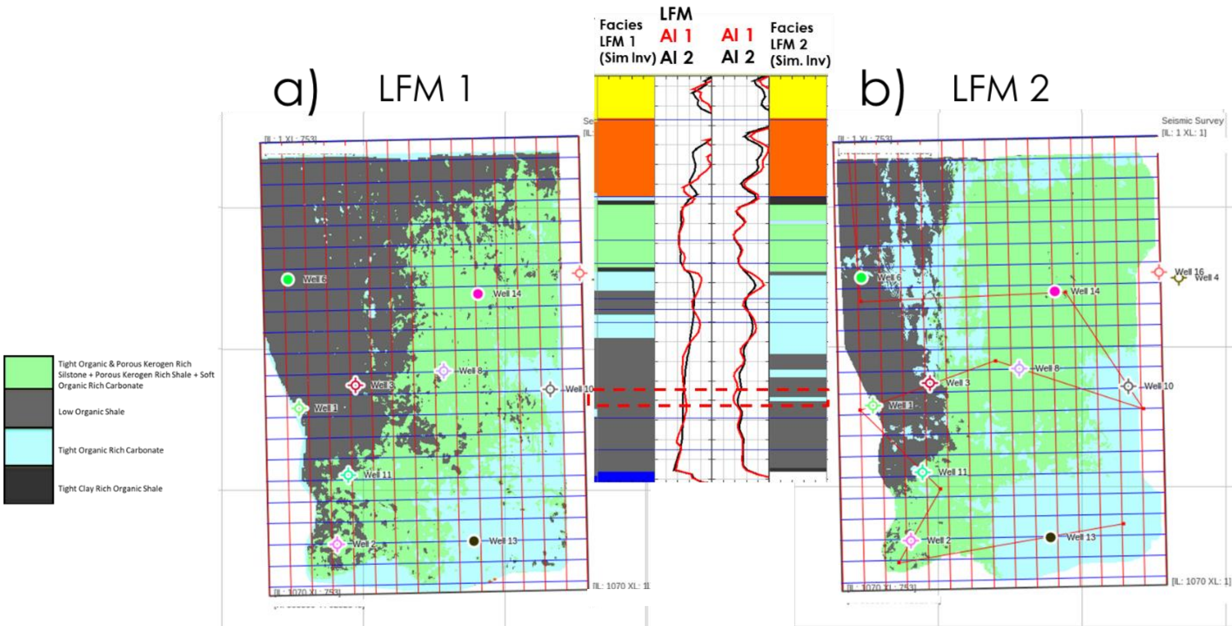

Figure 7. Time horizon (Approx. mid-Lower Montney) showing Bayesian facies classification results from Simultaneous Inversion using AI and SI: a) using all wells, LFM 1 and b) removing wells 6 and 8, LFM 2. The red-dashed polygons show the time interval related with the maps.

Details of the LFM 1 and LFM 2 and absolute values of AI can be seen on figure 8.

Figure 8 a) and b) show the absolute values of acoustic impedances obtained from the LFM defined in c) and d) respectively.

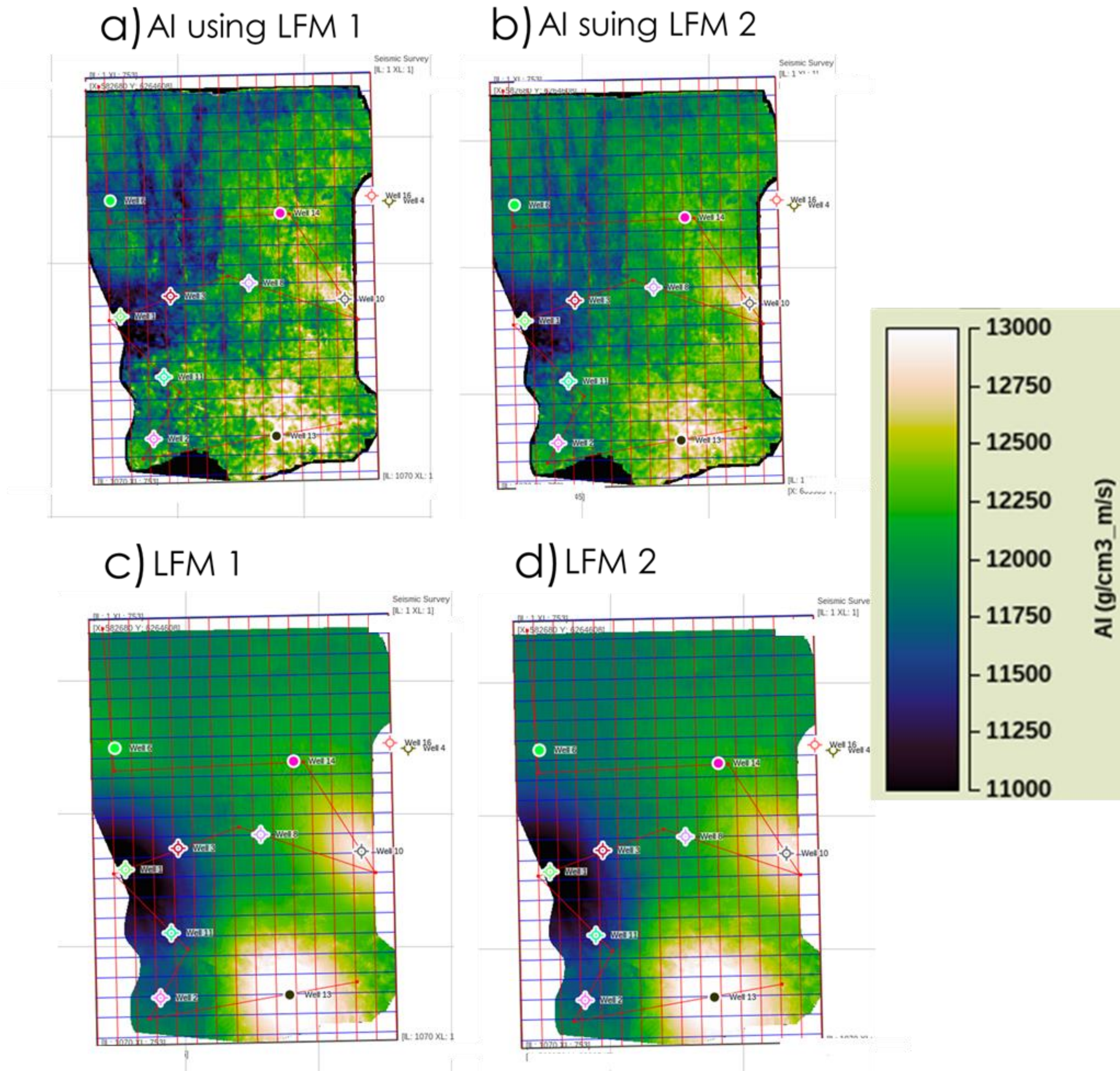

Figure 8. Time horizon (Approx. mid-Lower Montney) showing details of Acoustic Impedance values (a) and b))from Simultaneous Inversion using different low frequency models (c) and d)).

Novel/Additive Information

We presented a Bayesian facies classification using PDFs obtained from the Depth Trend Analysis which describe the Rock Physic relationships between the elastic parameters (Vp, Vs, Rhob, P-Impedance, S-Impedance and Vp/Vs) in depth per facies.

Results were very comparable with the exception in areas where no well data was available to build the low-frequency model used in the Simultaneous Inversion. Facies-based inversion in the

other hand, do not need a low-frequency model so it is of interest obtain data where the different data set differs. When using different well sets to build the low frequency model, different acoustic impedance values were obtained, and different facies classified.
From the implementation point of view, Facies-based inversion has an advantage over Simultaneous Inversion since no low-frequency model is needed. Results as seen in figure 6 using Facies-based inversion may be unbiased towards the low-frequency model that the simultaneous inversion uses.

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