Inversion Fundamentals - Case Study

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Summary

Following up on the presentation of the introduction and overview of the inversion and quantitative interpretation process, this paper shows an example of the inversion workflow. Not only are elastic properties obtained that are relevant to the reservoir, but these properties are interpreted into geologically meaningful classes that show more insight than conventional interpretation on its own. The example is from the Alberta oil sands; however, the process is applicable to many different geological settings.

Classic Interpretation

Classic interpretation includes identifying the reflections at the top and base of reservoir. These can be used for structure maps, as well as for defining windows used in calculating amplitude attributes. In the case of the McMurray, the reservoir interval can be quite thick, consisting of more than ten internal reflections. While this thickness allows for multiple structures to be picked, the geological complexity means that these internal reflections are not always continuous. What seems like a single reflection can actually be different geological features of similar depth (e.g. mud plug, point bars, channel sands, etc.).

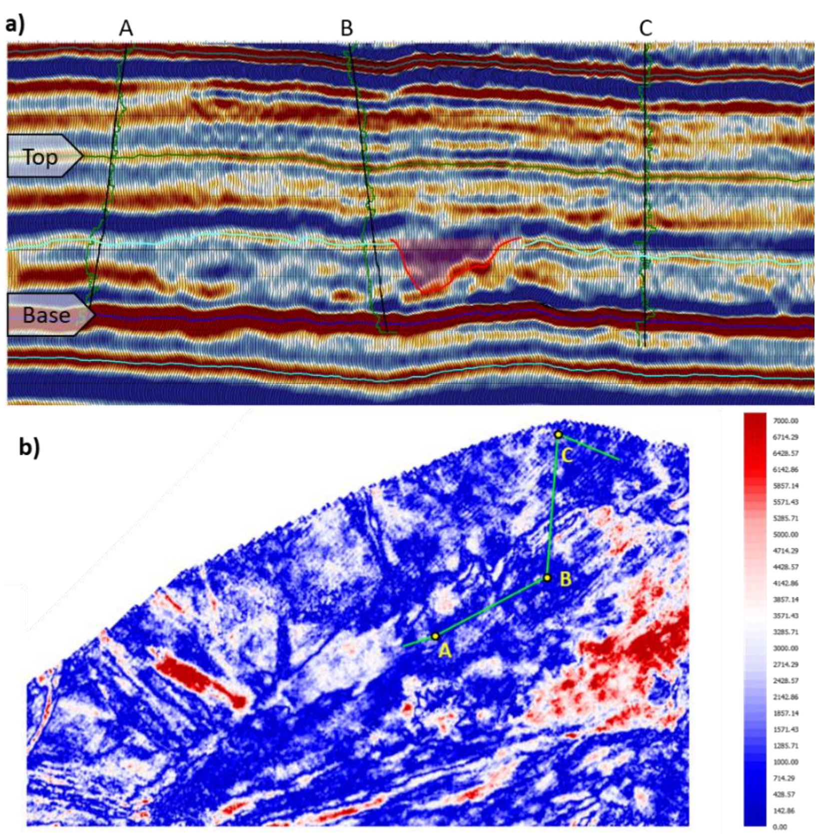

Figure 1. *a) Stacked section showing the McMurray interval with a discontinuity (Red) along an internal reflection (light blue). The data on either side of this discontinuity appear to be similar in nature. b) An amplitude map extracted 20 ms above the base of the reservoir. A higher-amplitude streak appears to split wells B and C, which share a similar amplitude response.*

Figure 1a shows the stacked seismic data with horizon interpretation and V_{clay} logs. Within the reservoir, between wells B and C, there is a break in the light-blue horizon, with one possible interpretation shown. The horizon slice (Figure 1b), 20 ms above the base of the reservoir, indicates that this possible interpretation is plausible; consistent amplitudes at the wells on either side of a higher amplitude zone. In fact, only the logs below the light-blue horizon indicate that something more may be going on, with an increase in V_{clay} below the horizon at well C.

Careful analysis of the amplitude variations, taking into account the structural changes, and integrating the well-log data are all crucial components of classic interpretation. These approaches should not be abandoned, rather they should be assisted by the inversion process, which considers exactly the same factors in an analytical manner.

Prestack Inversion

As discussed in the introduction paper, inversion transforms prestack seismic amplitude changes into models of P-impedance, S-impedance, and density. To achieve this outcome, inversion uses the following components in its calculations:

Component	Purpose
- Prestack seismic gathers	- Amplitude changes with incidence angle according to properties
- Wavelet	- Accounts for the effects of reduced resolution of boundaries
- Reflectivity equations	- Relate seismic amplitudes to impedances and density
- Well impedances/density	- Provide the correct magnitude of values as a starting point

Processes that are carried out as part of the inversion are done with the goal of making these components more closely meet their purpose. For example: noise attenuation on the prestack seismic gathers ensures that amplitude changes are a result of the rock properties, rather than unpredictable sources; selecting an appropriate window for the wavelet extraction is done to match the frequency content of the zone of interest, rather than data above or below.

The various steps for the inversion are illustrated using the seismic data example discussed. The final volumes of P-impedance, S-impedance, and density can be transformed into a multitude of other elastic parameters. The density section corresponding to the seismic stack shown in Figure 1a is shown in Figure 2. It is now apparent that while there does appear to be a discontinuity

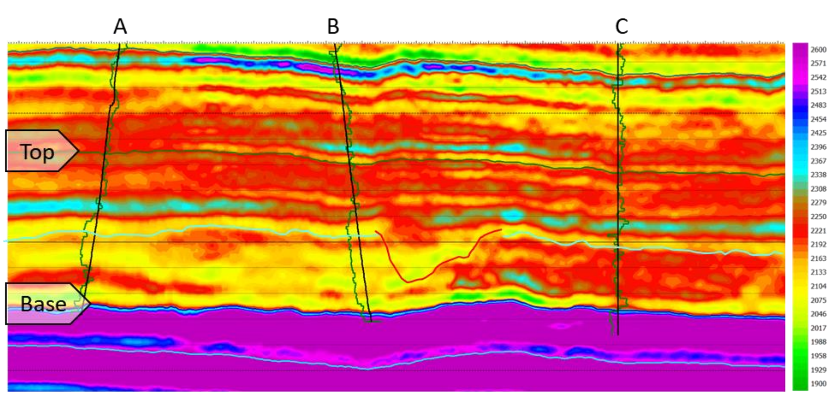

Figure 2. *Density section corresponding to the line shown in Figure 1a. The values in the reservoir at well C are distinctly higher than at well B. The interpretation now needs geological context.*

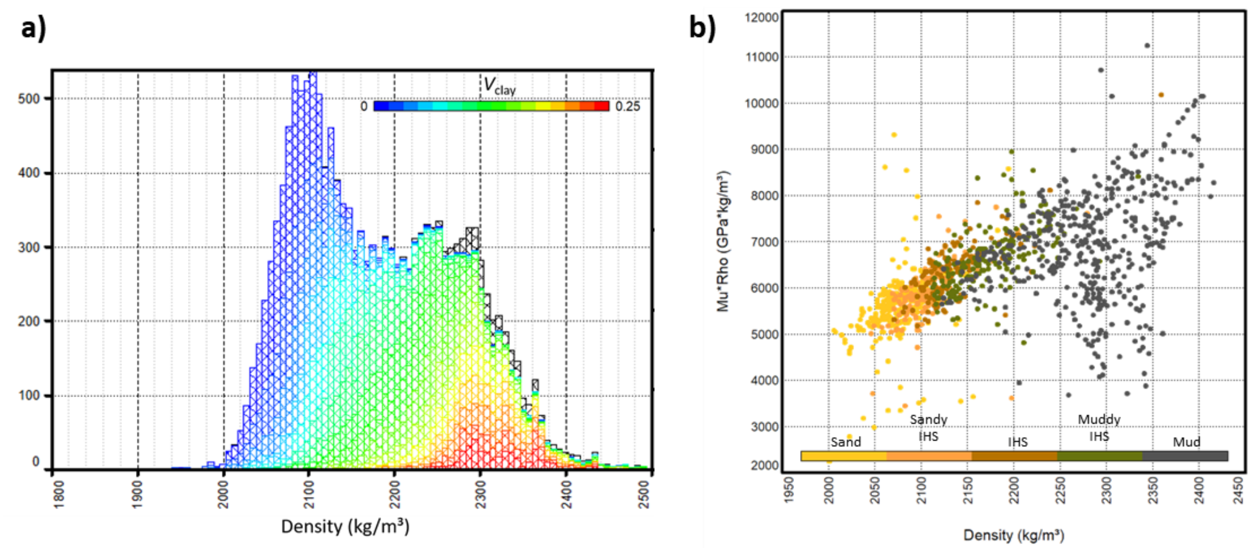

Figure 3. *a) Histogram of density values from McMurray well logs, coloured by V_{clay}. The higher-clay points are centred at higher densities, making density a useful attribute for facies distinction. b) A crossplot of MuRho vs. density showing well points coloured by facies. The choice of crossplot axes provides a good separation of the different facies types.*

between wells B and C, the properties on either side of this discontinuity are not, in fact, similar. Well C shows as having high density, while the discontinuity between the wells is comparatively low. It is now a valuable function of the interpreter to explain what these differences mean in a geological context.

Geological Classification

The critical link between geological properties and elastic properties is found through either well analysis or rock-physics modelling. In this example we will limit ourselves to well data, which matches elastic properties from the sonic, dipole sonic, and density logs with geological properties from other petrophysical curves and analyses. Each reservoir can have unique characteristics, and for the McMurray, density is a key property for distinguishing between the different facies with varying amounts of clay content.

Figure 3a shows a histogram of density values for all well-log points in the McMurray reservoir interval. The histogram points are coloured by V_{clay} and it is apparent that the points with high clay content tend to have higher densities. By identifying multiple attributes that distinguish geological properties, useful interpretive crossplots can be created. Figure 3b shows a crossplot of MuRho vs. density, where the points are coloured by facies. There is a good separation of the sands, IHS facies, and muds. These crossplots of well data provide a template for interpreting the equivalent data from seismic inversion.

The seismic inversion volumes are converted to include a range of elastic properties, including MuRho. Along with density, these points are crossplotted and compared with the well template (Figure 4a). In this case, interpretive cutoffs are applied to the data, corresponding to the log

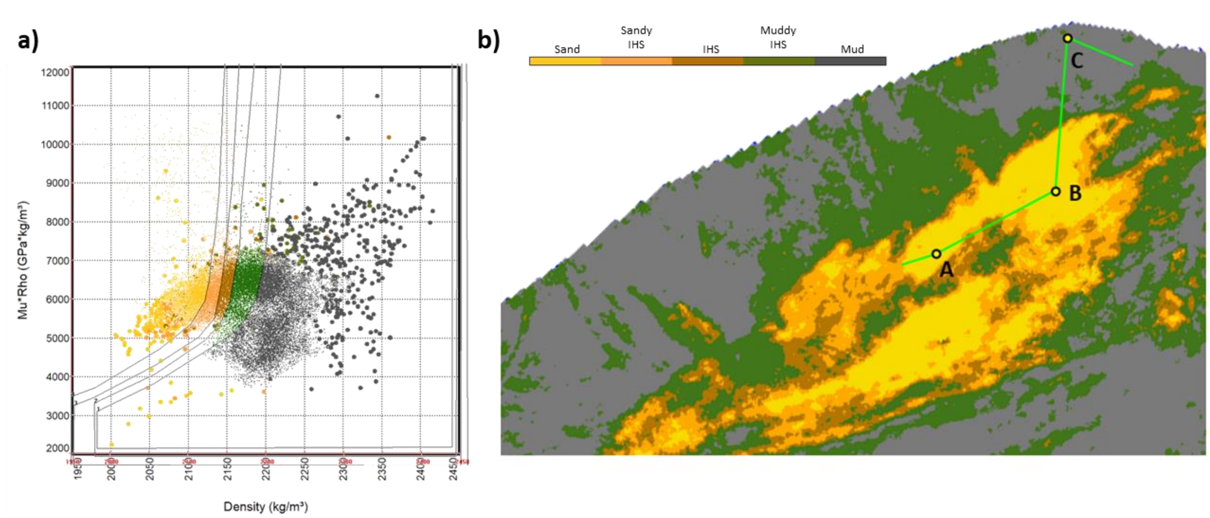

Figure 4. *a) The same crossplot shown in Figure 3b with seismic points overlain. The seismic and well data correlate well, allowing for the well facies to be interpreted on the equivalent seismic points. b) A horizon slice extracted 20 ms above the base of the reservoir through the classified seismic volume. The facies interpretation shows a more clear picture of the geology than from amplitudes alone (Figure 1b).*

facies. A time slice matching Figure 1b is shown through the classified inversion data in Figure 4b. Here is it much more apparent that the properties at wells B and C are more distinct.

Conclusions

Seismic inversion, specifically prestack AVO inversion, is a useful tool for extracting quantitative rock properties from the seismic amplitudes. By calculating properties such as P-impedance, S-impedance, and density through the inversion process, a number of useful elastic properties can be determined. While useful on their own, the elastic properties are more functional when interpreted into a geological context based on well or rock-physics templates.

Using an example from the McMurray oil sands, I demonstrate the steps needed to perform an AVO inversion and where special consideration to parameters is important. The results of the inversion are then compared to the conventional options for interpretation. While consistent with one another, the advantage of the interpreted inversion is that the geological context is more immediately apparent.

Acknowledgements

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