Impact of adequate QC steps on seismic reservoir characterization

Ritesh Kumar Sharma[†*]*, Satinder Chopra*[†] *and Larry R. Lines*[+]
[†]*TGS, Calgary;* [+] *University of Calgary, Canada*

Summary

One of the most important tools for carrying out seismic reservoir characterization is impedance inversion, which transforms seismic amplitudes representing subsurface rock interfaces into impedance attributes that represent interval properties. The key steps that lend confidence in impedance inversion and quantitative prediction made therefrom are, proper seismic data conditioning, robust initial models, and adequate parameterization in inversion analysis. In this study we elaborate on the data conditioning aspect. We begin by providing an appropriate workflow for seismic data conditioning in the offset-azimuth domain which enhances the quality of the far-offset stack and then highlight the impact of adequate velocity model used in offset-angle transformation. These key steps are often overlooked, and we demonstrate the added value that our proposed workflow brings about for effective seismic reservoir characterization by showing comparisons of data examples, with and without its application.

Introduction

The reflections seen on seismic data represent subsurface rock interfaces, while, the important petrophysical and mechanical properties required to identify the sweet spots in conventional and unconventional play are interval properties. Therefore, seismic impedance inversion is carried out to transform seismic reflectivity data into such properties. Seismic data conditioning, accurate low frequency model generation and parameterization of inversion analysis are the key components of an impedance inversion workflow (Singleton, 2009; Yu et al., 2017). A proper quality control (QC) workflow needs to be followed during the individual steps. Our endeavor in this whole exercise is to elaborate on different quality control steps that are considered at different stages of the inversion, for bringing in accuracy in the characterization of a reservoir. In Figure 1, we show the correlation between the gamma ray, P-velocity and density well log curves with seismic from the Fox Creek area in Alberta, Canada. The formation tops extend from the Montney formation down to the Duvernay formation.

The Montney is a thick and regionally charged formation of unconventional tight gas distributed in an area extending from north central Alberta to northwest British Columbia, Canada. The primary focus is the Lower and Upper Montney units for horizontal drilling. The Duvernay shale is fine-grained and silica-rich shale unit, which is overlaid by the Ireton (calcareous) and Winterburn shale units, over which lies the Wabamun limestone unit. The Duvernay unit is underlain by a thin carbonate-rich shale layer that overlies the Swan Hills reefal unit. The simplified seismic-based stratigraphic column shown to the left of Figure 1 illustrates these units. In the same figure, we see the correlation of P-velocity, density, and gamma-ray curves (Figure 1a), and the synthetic seismogram (Figure 1b) with stacked data (Figure 1c). The zones of our interest span through the Montney and Duvernay formations.

Adequate data conditioning workflow

Enhancing the quality of far-stack seismic data

Generally, the prestack seismic data provided for traditional AVO or prestack impedance inversion are azimuthally-stacked and available in the form of offset-gathers. Sometimes however, azimuthally sectored data generated for AVAz (azimuth-variation with azimuth) analysis are provided for AVO analysis as well. We use this data for our study here and begin with seismic data conditioning aimed at enhancing the signal-to-noise ratio by following a workflow that begins with the stacking of azimuthally sectored (6 sectors of 30º each) prestack data which yields the prestack migrated gathers. Though the fluid and lithology information reside on the far offsets, the quality of the far-offset stack is usually not as good as the near- or mid-offset stacks. The reasons for the often-observed degradation of the far-stack data vary from noise contamination, lower frequency and amplitude distortion due to anisotropy. These prestack migrated gathers are then put through a series of steps, comprising bandpass filtering, generating supergathers, applying random noise attenuation and trim statics, etc. as shown to the right of Figure 2. All this is also traditionally done in the offset-domain during processing of seismic data. In doing so, amplitude distortion due to anisotropy is overlooked. We believe that traces exhibiting azimuthal velocity variations due to anisotropy when stacked deteriorate the quality of the far stack, which is essential for extracting the fluid information from seismic data as mentioned above. What we are proposing by way of this study is that the above sequence for conditioning of data is not an optimum way, and hence recommend another workflow to be followed as shown to the left of Figure 2. Instead of stacking the azimuthally-sectored NMO corrected traces at every CMP, we suggest generating supergathers using adjacent CMPs and organizing those supergather traces in a snail gather or a common-offset common-azimuth gather for every CMP. In Figure 3a we show such a snail gather plot where there are 6 subtraces (one for each 30º azimuth sector) and offsets increasing from left to right. At shorter-offset traces, no azimuthal velocity variation is seen, and reflection events are seen aligned horizontally. As we get to the larger-offsets, we begin to see the azimuthal velocity variations in the form of undulations, as indicated with cyan arrows. Before the individual azimuth traces are stacked within every CMP trace, the azimuthal variation should be removed so that the traces are aligned for a better-quality azimuthal stack. It may be mentioned here that in the azimuthal AVO analysis such azimuthal variation is quantified into attributes such as fracture intensity and orientation. But for preparation of prestack seismic data for traditional AVO analysis or impedance inversion, the azimuthal variation does not need to be quantified. One of the methods for aligning the azimuthal variation on individual azimuth traces is to pick some horizons at appropriate intervals on the stacked data, and then overlaying them on the CMP gathers. Using a cross-correlation procedure within individual intervals (bounded by horizons indicated with colored arrows), the reflection events are aligned. We show the application of this procedure in Figure 3b. On comparing with Figure 3a, one can see the alignment that the events have gone through. Now if the individual azimuthal traces are stacked for every CMP, the resulting gather traces

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appear flatter after conditioning and alignment. In Figure 4a and b, we show a comparison of far-angle stacks when conditioning is followed in offset-domain and offset-azimuth domain, respectively. Notice the improved reflection events at the Montney and Ireton marker levels. The strong seismic events corresponding to Wabamun, Ireton and Swan Hill markers have been further strengthened after following the proposed data conditioning workflow. Such conditioned data when taken into the impedance inversion shows improved quality and detail.

Impact of velocity on offset-angle transformation

While data conditioning has been performed in offset-azimuth domain up to this point, prestack impedance inversion and AVO analysis are executed in the angle domain. Thus, offset-to-angle transformation is required, and performed with the help of velocity. There are two ways of obtaining the velocity field. One is to make use of the seismic velocity field obtained from processing of the seismic data, and the other is the well-driven velocity field generated using the sonic log curves. Besides lack of confidence in the estimated seismic velocity, its inconsistency with horizons picked on the stacked seismic data makes geoscientists somewhat reluctant in using it. Consequently, well-driven velocity is preferred. However, it needs to be ascertained if the velocity field generated with a single well and constrained with horizons is enough to represent the whole seismic survey, or more than one well is required for the purpose. Practically, though a multiwell velocity field is considered superior than a single well velocity field as it captures the complexities associated with unconventional plays, the interpolation of the velocity field between two wells is challenging as it can exhibit artifacts. Therefore, a workflow that uses both the seismic velocity and well velocity in building the final velocity field is proposed for offset-to-angle transformation and further analysis therefrom.

Segments of sections from the seismic, as well as well-driven interval velocity field are shown in Figure 5a and b, with a sonic log curve (filtered to seismic bandwidth) overlaid on them. Notice the variation on the seismic interval velocity section, both laterally and vertically, as no significant geologic changes are expected. The well-driven velocity field looks more reasonable in terms of interval consistency and correlation, and so appears to be more authentic and hence should be used. A comparison of angle estimation using both seismic and well-driven velocities is shown in Figure 5c and d, respectively. Notice a difference in the angle range in the two cases as indicated with the two white block arrows. Such differences may have significant impact on the further analysis such as AVA/AVAz (amplitude variation with angle/azimuth). The AVA analysis has been widely used for discriminating hydrocarbons from brine-saturated rocks based on the interpretation of intercept and gradient stacks that are computed by fitting Shuey's two-term equation (Shuey, 1985) on the prestack seismic data. For angle of incidence (θ) up to 30 degrees, Shuey's equation is given as $R(\theta) = A + B\sin^2\theta$, wherein the first term A, is called the zero-offset reflectivity or intercept stack and is a function of only P-wave velocity and density. The second term B, referred to as the gradient stack, has a dependence on P-wave velocity, S-wave velocity and density, and thus has an appreciable influence on the seismic amplitude as a function of offset or angle. The changes noticed in the gradient stack could be indicative of the fluid content or lithology.

To assess the impact of velocity on the gradient attribute computation, we generate it using both the seismic velocity as well as the well-driven velocity fields and compare them. In Figure 6a and b we exhibit such a comparison for a dataset from central Alberta, Canada. A significant improvement at the locations highlighted by arrows can be seen on the section when well-driven velocity is used in the analysis. The interpretation of the intercept and gradient attributes is usually carried out by judiciously selecting the data covering the zone of interest from the two attributes and displaying them in crossplot space. While the background lithologies plot along a linear trend along a diagonal, the hydrocarbon-bearing facies form a cluster separated from the background trend. Such interpretation follows the premise that data that are statistically anomalous, are geologically interesting. In Figure 7 we show a comparison of crossplots between the intercept and gradient attributes, when the seismic velocity field (Figure 7a) and when the well-driven velocity field are used (Figure 7b). The data cluster points are colored with time. Notice that the cluster points in Figure 7a fall along a single trend that we understand would be the background lithology trend. In Figure 7b however, in addition to the background trend, we also see some deviation of cluster points that can be picked up for further interpretation. As an attempt to do this, we enclose a set of cluster points within a red polygon and back project them on an arbitrary vertical section as shown in Figure 7c. We notice these points highlight the zone that is suspected to be the Duvernay source rock. For confirming that it is so, we generated the intercept and gradient attributes on a modeled AVO elastic gather for one well, and crossplotted them as shown in Figure 8. There is a striking resemblance in the points enclosed in the red ellipse in Figure 8b and the outlier points coming from the Duvernay zone in the crossplot of the intercept and gradient attributes of the modeled gather in Figure 8b. This lends strong support to our interpretation.

Conclusions

Considering the importance of data conditioning as well as offset-angle transformation in seismic reservoir characterization work, we have proposed a proper workflow of data conditioning in which we stressed on performing it in offset-azimuth domain with the help of data examples from the WCSB. Additionally, we have demonstrated the role of velocity model in angle computation and its impact on AVA analysis. Following this analysis, we conclude that a robust velocity model that honors the well-log data and spatial variation of seismic velocity must be used in the reservoir characterization work.

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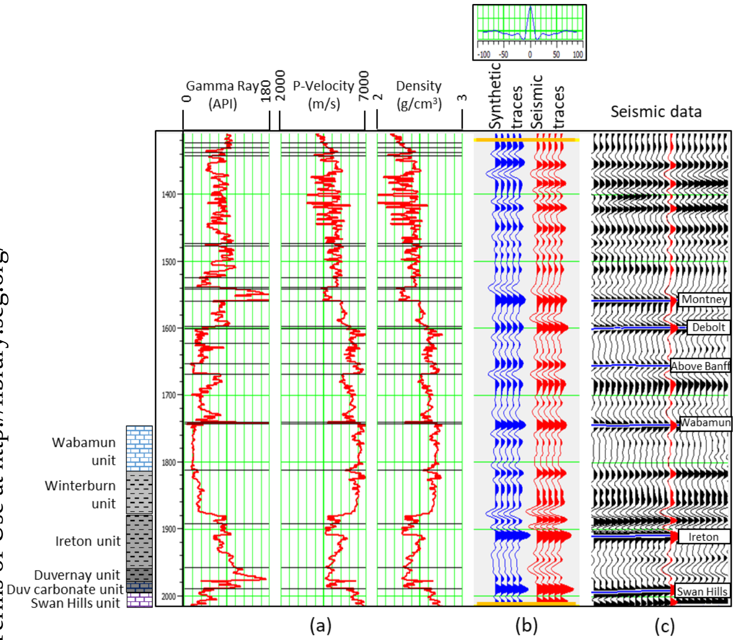


Figure 1: Correlation of well log curves with seismic data. Blue traces represent the synthetics (generated with the wavelet shown above) while the red traces represent the seismic data. The overall correlation between the synthetic and red traces is good. *(Data courtesy: TGS, Canada)*

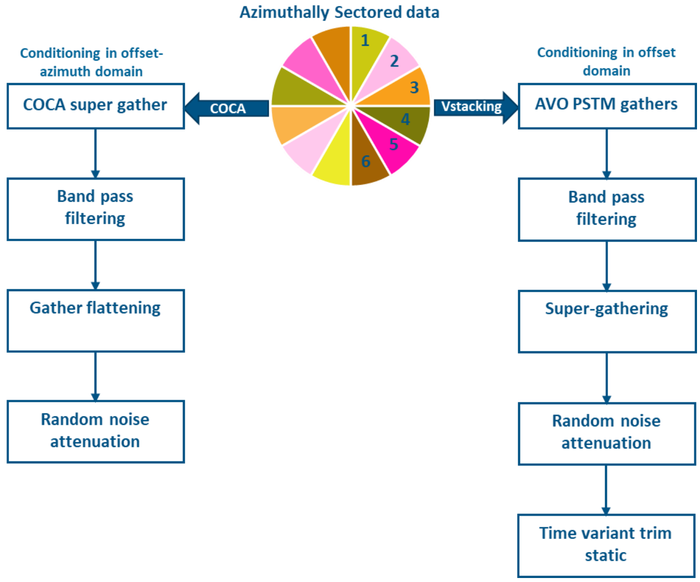
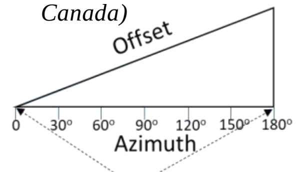


Figure 2: Flowchart for conditioning azimuthally sectored seismic data for simultaneous impedance inversion. The azimuthal amplitude variations in the data if stacked as such can deteriorate the quality of the far stack data.



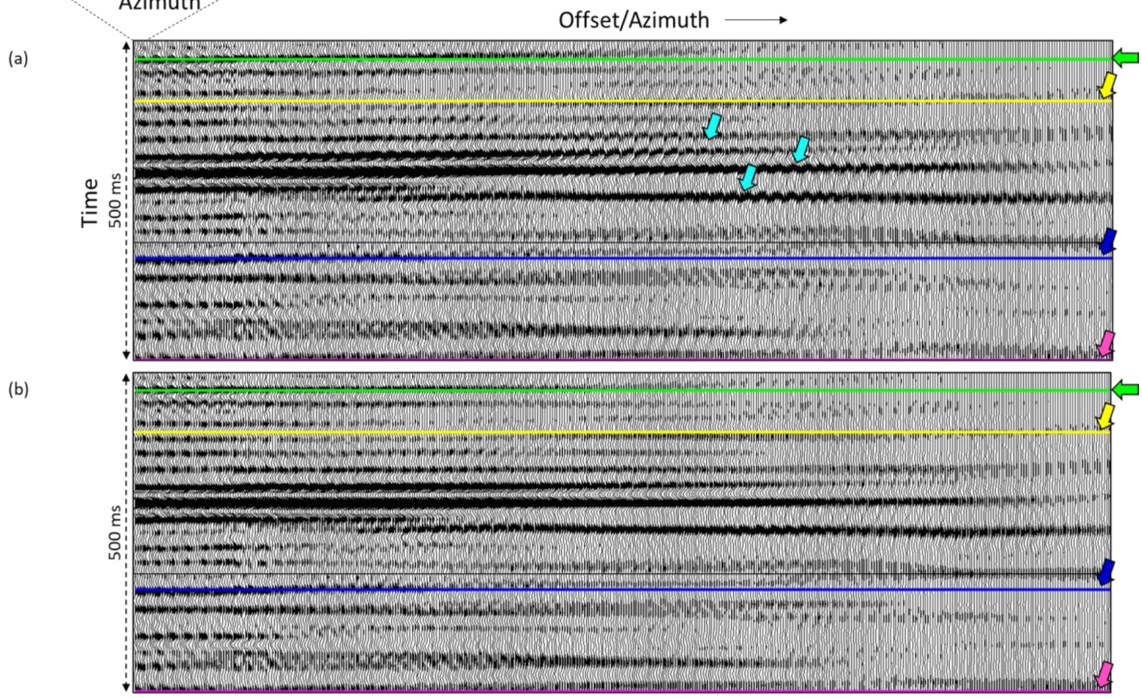
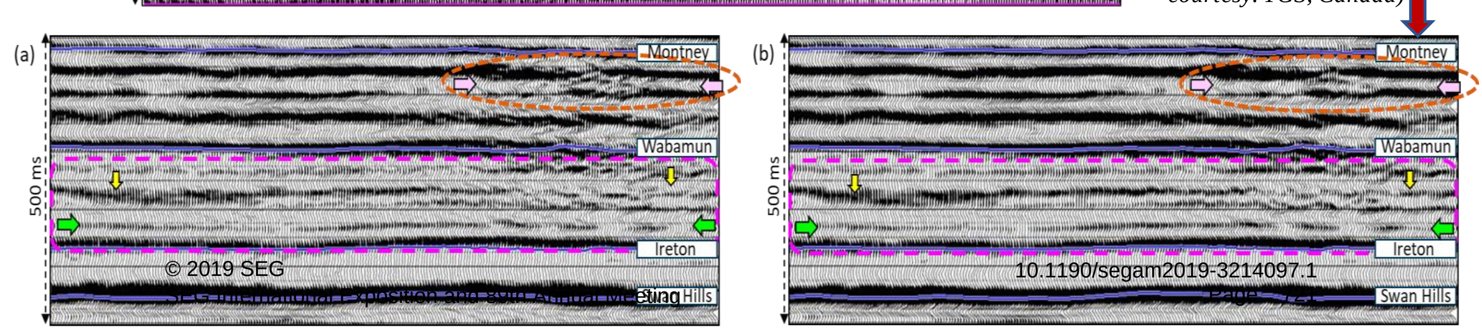


Figure 3: (a) A snail supergather, where each offset trace also has six 30° azimuthally sectored traces as shown on the top left. The azimuthal variations are seen more pronounced from the mid-to-far offsets. (b) The same gather as shown in (a), after aligning the azimuthal variations using a crosscorrelation technique within an interval defined by consecutive horizons picked on stacked seismic data. *(Data courtesy: TGS, Canada)*

Figure 4: Segments of far-angle stacked seismic sections (a) before, and (b) after offset/azimuth domain conditioning. The highlighted areas in orange and magenta outlines represent the zones of interest. The reflection events between the block arrows in pink, yellow and green seem strengthened after the proposed conditioning. Such enhanced definition of reflection events contribute to better characterization of the reservoir properties. *(Data courtesy: TGS, Canada)*



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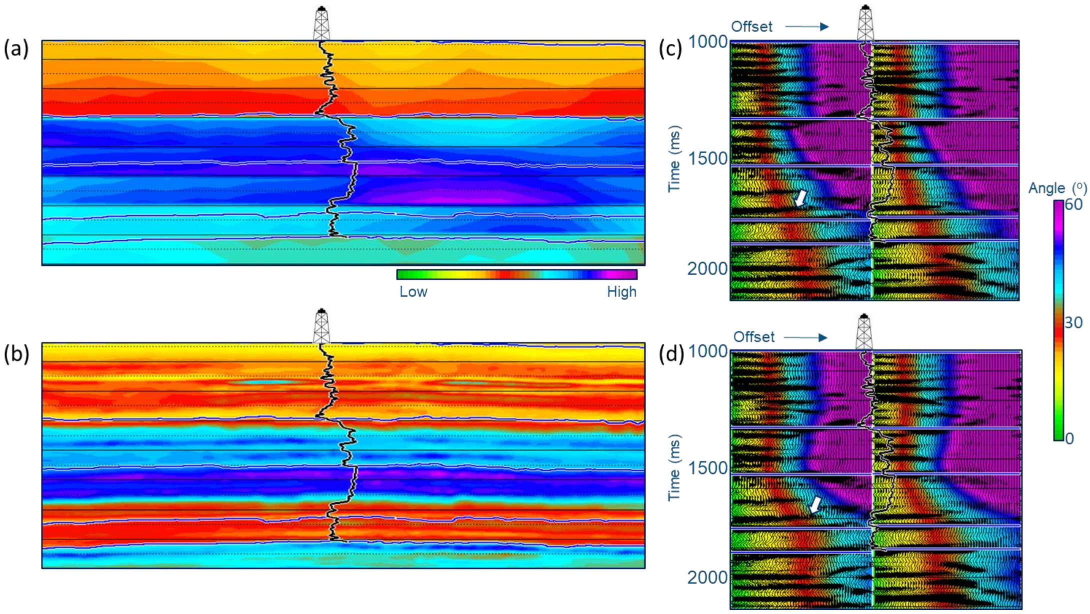


Figure 5: A segment of the velocity field (a) seismic (b) well-driven around the location of the gathers. Angle information overlain on two offset gathers (c),(d) is also shown for both cases, respectively. Not only does the well-driven velocity field look more meaningful in terms of being horizon constrained and its correlation with individual intervals, the angle information derived from seismic velocities is higher than that derived from the well-driven velocities, as can be checked at the location of the white block arrows. In (c) the white arrow is well into the cyan color, and in (d) it is at the end of red colour. *(Data courtesy: TGS, Canada)*

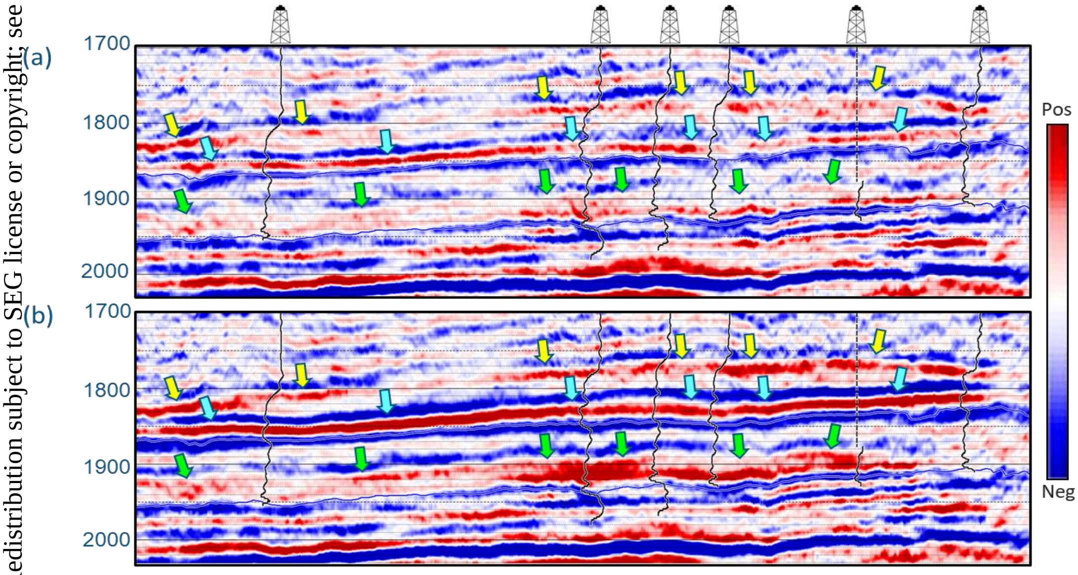


Figure 6: An arbitrary line passing through different wells extracted from the AVO gradient volume generated when (a) seismic velocity, (b) well-driven velocity was used in the analysis. Notice the significant strengthening of the amplitudes in (b) as indicated with the colored arrows (green, cyan and yellow). Such amplitude differences can appreciably impact the derived reservoir properties and hence are important. *(Data courtesy, TGS, Canada)*

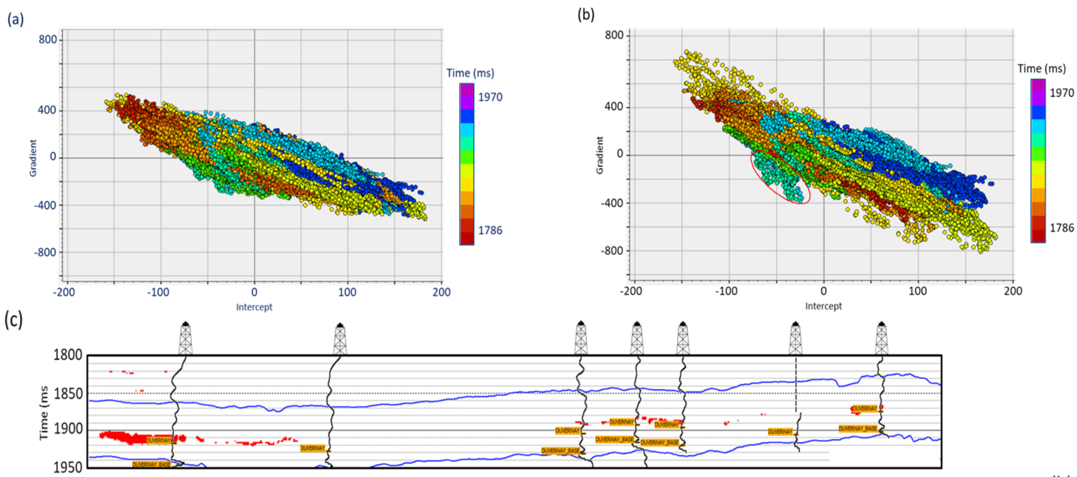
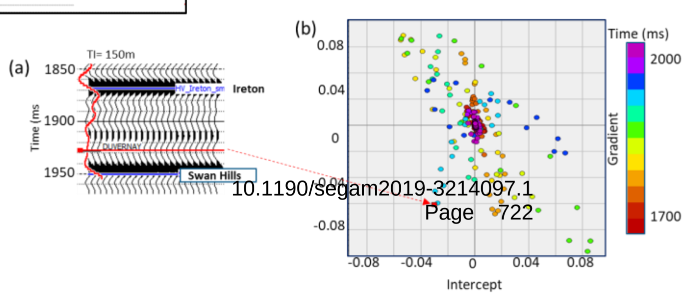


Figure 7: (a) Crossplot of AVO intercept versus gradient over the zone of interest when (a) seismic velocity, (b) well-driven velocity was used in the analysis. (c) When anomalous points on the crossplot are enclosed in a red polygon in (b) and back projected on the seismic section, they highlight the Duvernay zone, which is the source rock. *(Data courtesy, TGS, Canada)*

Figure 8: (a) Segment of an AVO modeled elastic gather over the zone of interest showing the Duvernay source rock formation, and (b) the crossplot of the intercept versus gradient. When anomalous points on the crossplot are enclosed in a red polygon in (b) and back projected on the seismic section, they highlight the Duvernay zone, which is the source rock. *(Data courtesy, TGS, Canada)*



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