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Thinking about Processing in an Unconventional 3D World

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Summary

Increasingly, geophysicists move both into developing unconventional resources (shales, oil sands, tight sands, carbonates, etc.) and into exploration in deeper waters. These plays rarely resemble the low impedance sands that we are proficient at finding. Productive zones are increasingly going to be dim spots. Why? First, most of the ‘bright spots’ have been drilled. Second, a lot of these new plays belong to AVO classes 1 and 2P. These AVO classes are anomalies that produce a dimming with offset (Figure 1), rather than the traditional increase in offset seen in Class 2 and 3 AVO anomalies. For example, geophysicists traditionally define shales in the seismic section by a lack of reflectivity, which means little change in P-impedance. The shales in which we are interested are charged with light hydrocarbons, which puts them squarely into the AVO Class 2 and 2P anomaly space. Special considerations must be made to deal with these reservoirs. Oil sands reservoirs, such as those found in Canada and Venezuela, are very shallow. Geophysicists must make special considerations to properly process seismic in such shallow reservoirs. Oil sands reservoirs also have little reflectivity within them, and, as it turns out, many of them are also AVO Class 2.

Method

To deal with these reservoirs, we must examine two key factors. The first factor is that these reservoirs are often AVO Class 2. This classification means that the polarity of the traces in the gathers will often flip with offset (Figure 1) in shale and oil sands plays. How do you do velocity analysis when the gathers are not consistent in polarity? What happens when the Class 2 gathers in Figure 1 are muted and stacked? In fact, the stack is one of the worst attributes to look at in Class 2P AVO plays. Therefore, we must look at AVO attributes for these plays and looking at these attributes has processing implications.

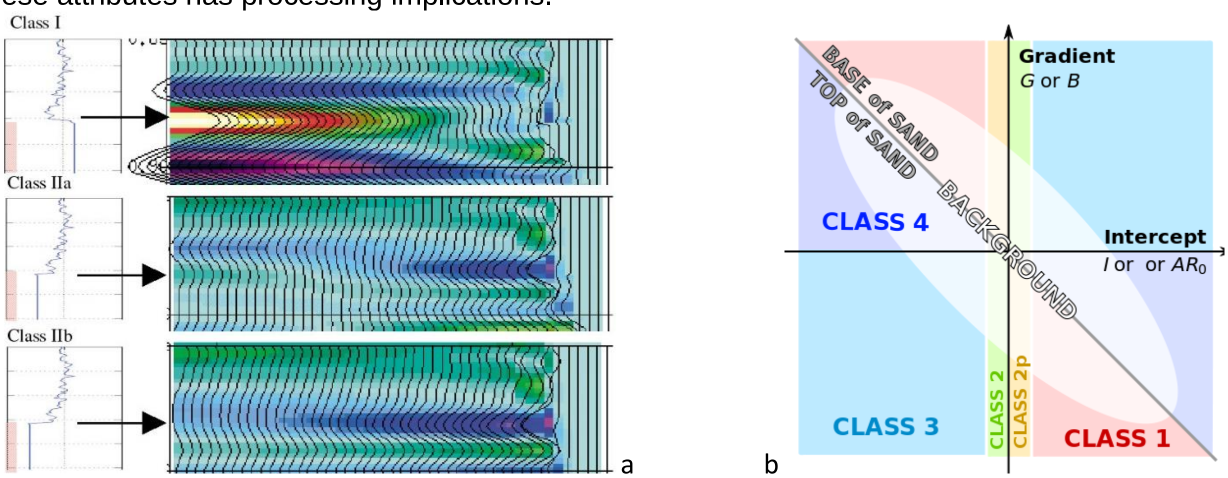

Figure 1: a) Class 1, 2, and 2P AVO (common names) (after Li et al., 2003. They call them I, IIa, and IIb, respectively, which were alternative names used at the time). b) AVO anomalies fall outside of the background. Relative impedance decreases with increasing class number.

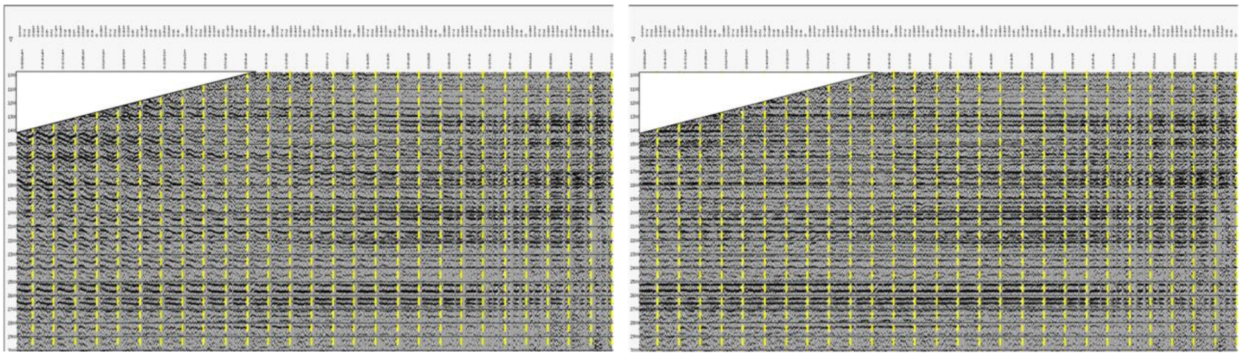

Figure 2:COCA cubes showing azimuthal velocity variations (left) and after application of azimuthal velocities (right).

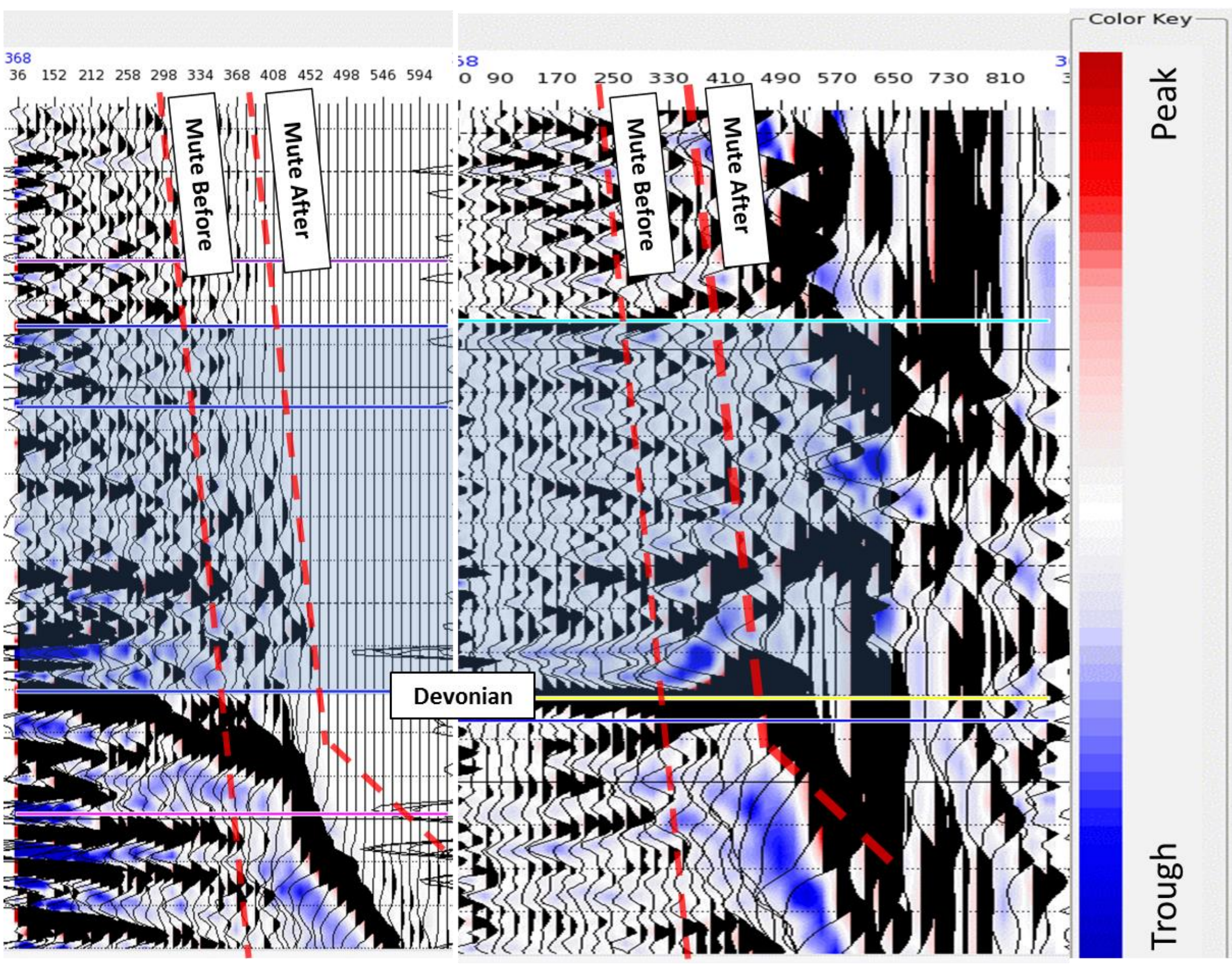

Figure 3: Common offset stack with isotropic NMO (left) and azimuthal NMO (right). Mutes before (left) and after (right) azimuthal NMO are displayed as dashed lines on both stacks. About 25% more offsets become useful after azimuthal NMO, taking the maximum angle from 35 to 50 degrees and allowing for easier extraction of density. The apparent breakdown of the gather in the left is due to azimuthal velocities remaining uncorrected. The 'hockey stick' on the Devonian is because it goes critical at an angle of about 30 degrees (Gray et al., 2015).

The second key factor is that there is usually azimuthal anisotropy in these reservoirs. Velocities also vary with azimuth in shale plays, and as it turns out, in oil sands reservoirs (e.g., Gray, 2007). As we progressively move to wide-azimuth surveys (which we have been using for decades on land), dealing with those azimuthal velocity variations becomes increasingly important. Figure 2 shows a COCA (Common-Offset, Common-Azimuth) cube from a deep basin tight sand. Any reservoirs with fractures (e.g., tight shales, sands, carbonates, or stress anisotropy, i.e. $S_{Hmax} > S_{hmin}$, above the reservoir, e.g. anything close to the mountains), need azimuthal velocities to be applied. Even some narrow-azimuth, towed-streamer surveys benefit from azimuthal velocities (e.g., Williams and Wombell, 2006).

Taking azimuthal velocities into account is critical for AVO. Figure 3 shows that the available offsets can be increased significantly by applying azimuthal NMO. In this case, improving the maximum angle in the reservoir from 35 degrees to 50 degrees allows for a much better probability of getting density, which is critical in the oil sands play from which that gather comes.

If you have azimuthal velocities, then you probably also have azimuthal AVO. You must account for this azimuthal AVO when doing AVO analysis. It can be shown mathematically that the AVO gradient will be wrong by ½ of the azimuthal AVO gradient, affecting estimates for any other isotropic AVO attributes that are related to the gradient, like the S-wave properties and stresses.

Another key, newer tool is 5D (Trad, 2014) or 6D (Ng and Negut, 2017) interpolation and regularization. The regularization aspect is a key component in improving migration. Figure 4 shows the difference that this technology can make in the output image. Furthermore, the gathers can be improved substantially (e.g., Figure 5).

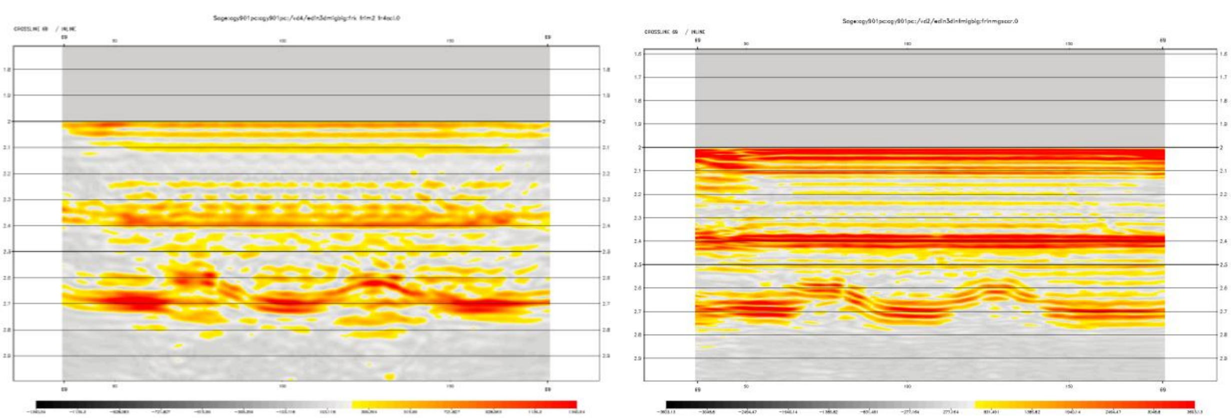

Figure 4: Azimuthal AVO results after azimuthally sectored migration of the input data (left) and 5D interpolated and regularized data (right) (after Gray and Wang, 2009).

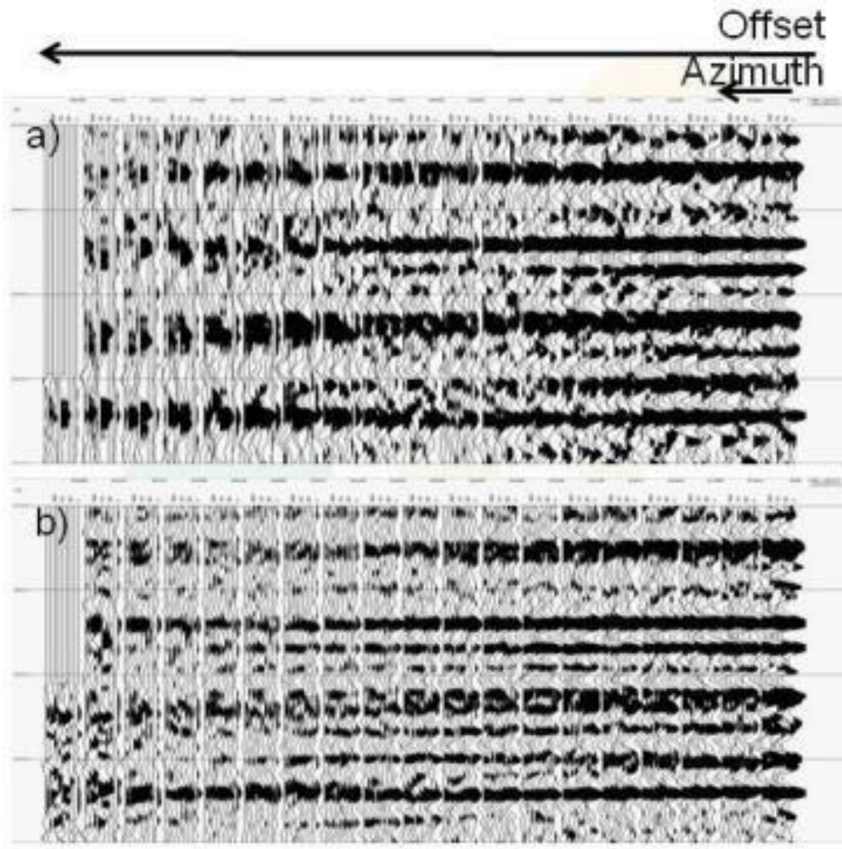

Figure 5: Comparison of common offset, common azimuth gathers with interpolation b) and without a) (after Downton et al., 2010).

Conclusions

Geophysicists must consider the processing that has gone into the data which they interpret. A few processing steps that have been added to the processing toolbox have proven critical for unconventional plays. Thinking about your play and the data that you have available, you and your processor can identify different processing options and can significantly improve the outcome. A key aspect of this process includes working together with the processor, if they understand what you are trying to do, and you understand what they are trying to do, as together you can find tools that will optimize the image of your reservoir.

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