Eye-Openers from Re-Processing of Oil Sands Seismic Data

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Summary

It has been shown that density is the acoustic property that is most closely correlated with reservoir properties of interest in oil sands development, such as saturation, shale content and porosity (e.g. Gray, 2011). Estimates of density can be extracted via amplitude versus offset (AVO) techniques applied to wide-angle seismic data. Modern 3D seismic data acquired over oil sands plays typically has sufficient shot-receiver offset to produce incident angles of the seismic wave that allow the extraction of density from it. In order to do this, we have re-processed our seismic data with the express purpose of optimizing the wide angles for the extraction of density. In doing so, we have encountered several eye-openers that have caused us to re-think how and why certain processes are applied to the data. These eye-openers are the subject of this paper.

Introduction

Density must be extracted from seismic data to gain estimates of reservoir properties useful for the exploitation of oil sands. (e.g. Gray et al, 2004; Roy et al, 2008; Gray, 2011). The extraction of density from seismic data requires wide angles, typically $>45^{o}$. Fortunately, modern surface seismic data designed for oil sands are already acquired with the shot-receiver offsets required to produce angles $>50^{o}$ Due to the presence of shallow glacial overburden, such wide angle data are also required for refraction statics corrections. .Therefore, these datasets are good candidates for the extraction of density. For convenience, normal processing typically mutes the furthest offsets, excluding them from analysis. Special processing is required in order to prepare these wide angles for density extraction. In particular, both VTI and HTI anisotropy must be corrected to flatten the seismic gathers at these wide angles. Wide-angle noise such as multiples, converted-waves, refractions, and first-break reverberations must also be attenuated. In addition, there is often a major unconformity below most oil sands reservoirs where the low-velocity, loosely-consolidated oil sands overlie a section composed of high-velocity, massive carbonates and carbonaceous shales. This creates a huge velocity/impedance contrast that must be taken into consideration to properly process oil sands seismic data.

Examples

A significant unconformity exists at the base of many oil sands reservoirs in the Athabasca region. Above the unconformity are unconsolidated bitumen sands and shales. Below the unconformity, the section is composed of high-velocity carbonates and shales. The seismic velocities in the overlying bitumen sands and shales typically range from 2000 – 2500 m/s; the seismic velocities approximately double in the carbonate section. . This high velocity contrast at the Cretaceous – Devonian unconformity causes numerous processing issues. That factor of two is important, as it approximates the Vp/Vs ratio in carbonates (Pickett, 1963). This means that the shear-wave velocities in the carbonate section are approximately on trend with the P-wave velocities in the overlying clastic section.

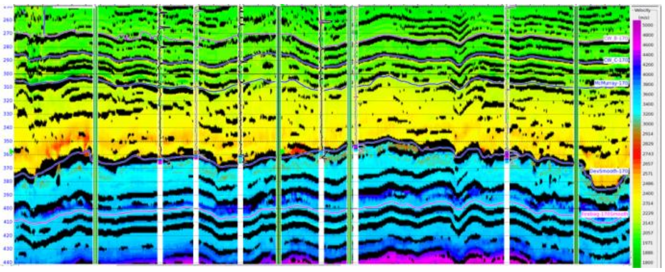

Figure 1: Image showing velocities doubling at Cretaceous - Devonian unconformity at 350-370 ms.

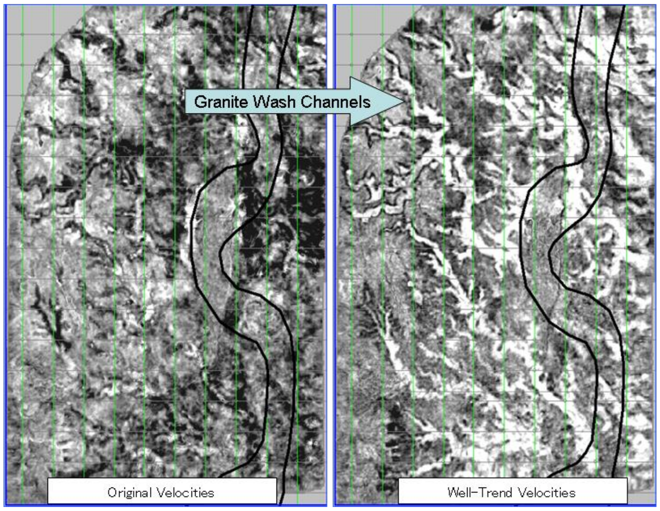

Figure 3: Imaging of Granite Wash channels immediately above the basement with original velocities (left) and velocities following the well trend (right). Note the significant improvement in imaging with the well-trend velocities. (The black lines denote the location of a shallow Quaternary channel that affects imaging.)

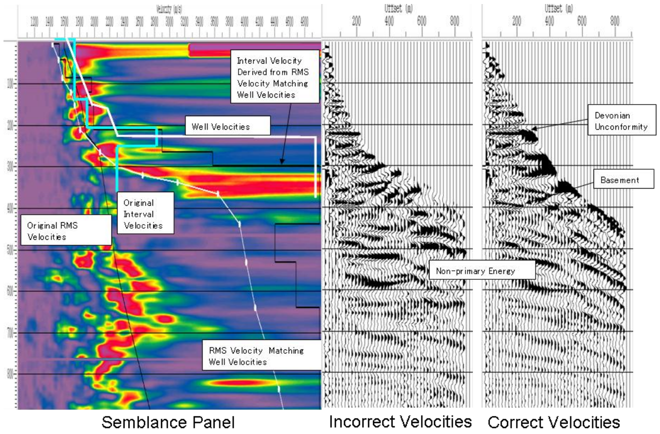

Figure 2: Velocity analysis showing incorrect (black trace on the left over semblance display) and correct (white trace over semblance) RMS velocities. Their effect on a gather is shown on the right. Interval velocities from both velocities are also shown and can be compared to the well velocities.

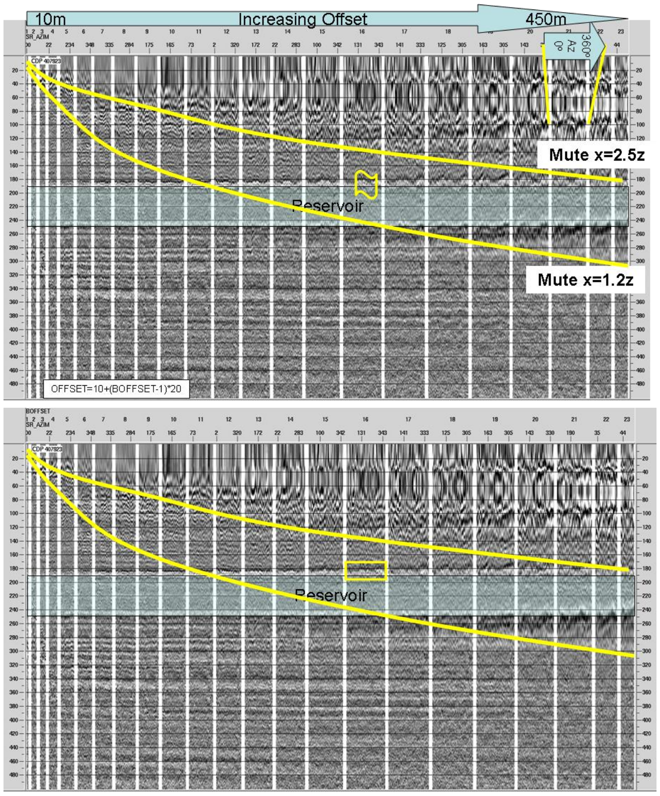

Figure 4: Snail gathers (a spiral moving outward in the offset-azimuth domain) showing azimuthal anisotropy (top). The anisotropy causes the sinusoidal wobble seen at the top of the oil sands reservoir at offsets past the narrowest mute. The data between the two mutes are the wide angles from which density can be estimated. It can be corrected with azimuthal NMO (bottom) allowing the use of wider angles in AVO.

Seismic processing velocities should always be related to well velocities. If velocities are picked following the clastic trend into the carbonate section, there is ample risk of picking events associated with shear-wave conversions (e.g. Figure 2). Any competent processor will pick velocities on trend if there is no additional information. An interpreter ties the wells to the seismic section and is thus aware of velocity trends observed in the geology and how they should fit the seismic. It should be the role of the interpreter to ensure that the processor is aware of major or unusual velocity trends, as is the case here. Processing velocities should follow the trend in the well velocities to ensure that correct velocities are picked, as in Figure 2. In oil sands seismic data, correct velocities, especially below the Devonian unconformity, may look over-corrected to the processor. Tying processing derived interval velocities to the well logs is one way of ensuring that the correct velocities are used. A lack of "apparently over-corrected" reflections in the carbonate section here may be an indicator that velocities are too low because there are such strong shear-wave conversions. AVO modeling based on well control in the area confirmed that these low-velocity reflections are likely shear-wave conversions. The validity of the well-trend velocities used in this dataset is confirmed by the improved imaging of the Granite Wash channels, cut into the basement in the sub-Devonian section (Figure 3).

The large velocity contrast at the unconformity suggests that the subsurface in these plays can be approximately described as a half-space. One implication is that the strong reflection from the Devonian unconformity may dominate all processes that rely on signal correlations, including deconvolution and residual statics algorithms. While reprocessing, it was observed that localized structure at the Devonian unconformity appeared to dominate the response of conventionally implemented residual statics corrections. Structure was reduced within the Devonian unconformity and the difference imprinted on overlying reflectors – most noticeably the reservoir cap-rock. Structure may be critical in properly characterizing cap-rock integrity. In this survey example, exclusion of the unconformity from cross-correlation windows resulted in proper statics corrections. Proper statics eliminate incorrect cap-rock structure and allow for correct interpretation of the stress in the cap-rock.

Deriving density requires much wider angles than those typically utilized, i.e. offsets of greater than 50^o (Gray, 2011). When pushing out to these larger angles, special considerations must be taken in event conditioning. In particular, anisotropy must be considered to properly flatten events. At wide angles, both VTI anisotropy and azimuthal (HTI) anisotropy can introduce significant time distortions that are not adequately corrected with typical NMO velocities. Gathers should be examined for evidence of anisotropy and these effects must be removed before attempting to estimate density. Roy et al. (2008) show the improvement to be gained from the use of VTI anisotropic imaging. Figure 4 shows the effects of HTI anisotropy on the gathers in the region that we now want to use to estimate density. There is an azimuthal wobble of about 10 ms highlighted by the sinusoidal box in the figure, which becomes stronger at wider angles, but is insignificant inside the narrower mute typical of most processing. The reasons for this apparent anisotropy are debated and could be: anisotropy, velocity heterogeneity, structure, statics, or something else. Regardless of the reason, in order to use these gathers to estimate density, this effect must be removed. The lower image in Figure 4 shows how successful azimuthal NMO is at removing this effect. There are also forms of noise at wide angles that may require special considerations such as reverberations from the first breaks, refractions, converted waves and multiples.

Conclusions

This reprocessing showed that significant improvements can be made with careful attention to detail. The key points to consider are:

1. Velocities
    a. The large velocity change at the Cretaceous – Devonian unconformity and its effects on:

        i. Velocity analysis
        ii. Assessment of statics and cap-rock integrity
        iii. Deconvolution
2. Wide-angles. Extracting density requires wider angles than are typically processed. At these wide angles:
    a. VTI anisotropy must be considered and even small amounts of HTI anisotropy have much larger effects than in conventional processing.
    b. Special consideration must be given to wide-angle noise.
        i. First break reverberations
        ii. Multiples and converted waves
        iii. Refractions
3. Assume nothing
    a. This shallow reservoir with unusual properties forces the re-examination of many if not all processes. Think about how to properly process the seismic data in the context of the geology of the reservoir and an understanding of the physics of the seismic wave passing through it.
    b. Interaction between the interpreter and processor is critical.

Acknowledgements

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