Image enhancement through data-domain least-squares migration: an Orphan basin example

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PGS

Summary

Depth migration techniques have been widely used in areas with strong lateral velocity variation. Though very robust, these methods suffer from acquisition and propagation effects that limit resolution and impact amplitudes of seismic images. Least-Squares migration (LSM) is becoming a standard in areas with complex geology. It compensates for acquisition limitations and variable illumination, and results in more reliable amplitude information with higher resolution. In this case study, data-domain LSM is applied to a deep water seismic data from offshore Canada targeting vertical resolution and fault definition improvements.

Introduction

In 2018, a PGS-TGS joint venture acquired Tablelands 3D in the eastern part of the Orphan basin, offshore Canada. The area is under-explored and has potential sandstone reservoirs and Late to Mid Jurassic source rocks.

The combination of new broadband seismic data and imaging technology is crucial to develop this under-explored region. The broadband data, rich in low and high frequency information, can be used to estimate acoustic properties that are required to differentiate the rock properties and fluid content of potential reservoirs. Full Waveform Inversion and Least-Squares Migration use broadband data to better estimate a subsurface velocity field and produce a robust image of the subsurface, respectively. In combination, they can minimize drilling risks and aid reservoir characterization.

In this case study, we applied a data-domain Least-Squares Migration around the Great Barasway F-66 well (Figure 1), to improve resolution and fault definition in the Tertiary and Jurassic section. This area is characterized by small scale Tertiary channel systems that distorts the wavefield, introducing uncertainty through structural undulations, unreliable amplitude variations and limited resolution.

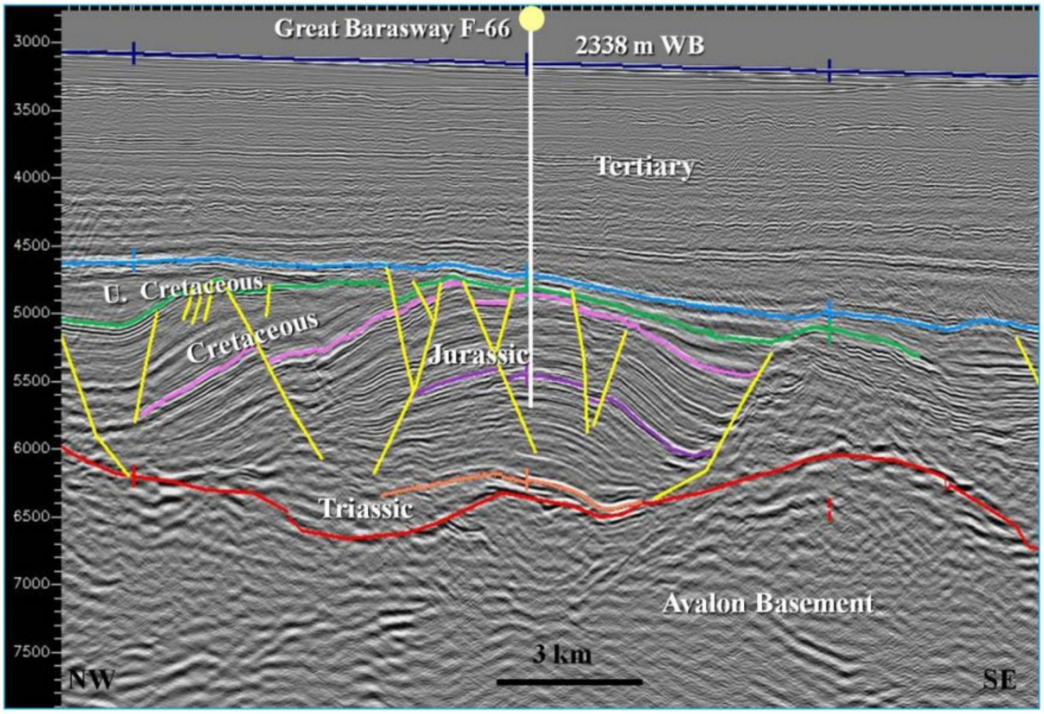

Figure 1. Great Barasway F-66 context (Enachescu et al., 2010). The well was placed in a structural high with AVO anomaly. Though unsuccessful, this well did encounter reservoir quality rocks and intervals of Kimmeridgian source rock.

Least-squares migration

Migration produces a blurred representation of the earth's reflectivity using a given velocity model. The image resolution and seismic amplitudes are affected by different factors ranging from acquisition parameters; earth properties, and the migration algorithm. In areas with complex geology and non-optimum acquisition parameters, both the illumination and wavenumber content of the migrated images are affected.

Least-squares migration can overcome these limitations by posing imaging as an inverse problem (Nemeth et al., 1999), resulting in an image that is closer to the earth's reflectivity. Different implementations of LSM exist in the industry ranging from image-domain point spread functions (Valenciano, 2008, Valenciano et. al, 2015, Klochikhina et al., 2016, Martin et al., 2019) to data-domain approaches (Lu et al., 2017, Arasanipalai et al., 2019, Korsmo et al., 2019). In this work, a data-domain Least-squares migration using a visco-acoustic one-way wave-equation operator is applied in deep water Canada targeting resolution and fault definition improvements.

A data-domain LSM is initiated with synthetic shot generation through Born modeling using an estimate of the earth reflectivity and an accurate velocity model. A residual is estimated by minimizing the difference between the observed (d_{obs}) and synthetic data (d_{syn}) and the image is updated in an iterative manner as shown in Figure 2.

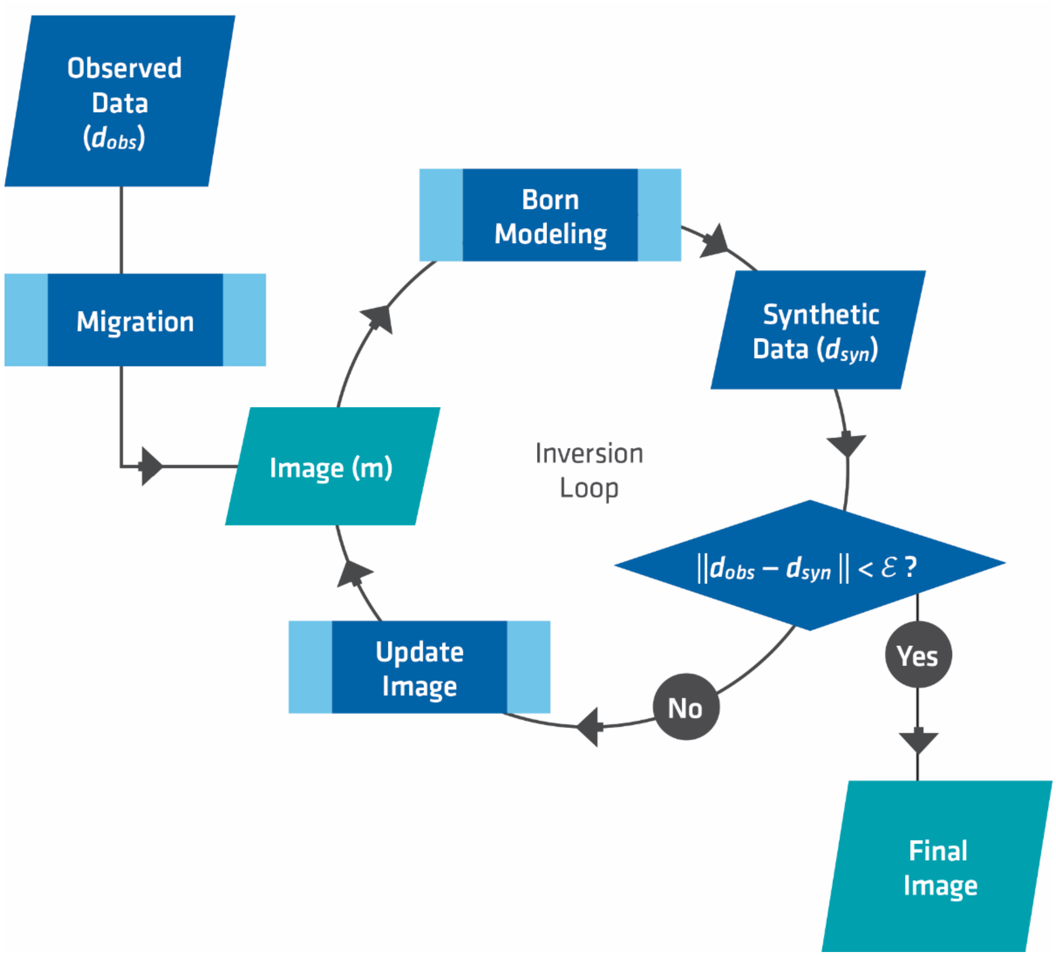

Figure 2. LSM workflow

The importance of an accurate velocity model within LSM

Tarantola (1984) and Mora (1989) described the seismic inversion experiment as a simultaneous migration and reflection tomography. In this LSM experiment, reflection amplitudes are resolved by the high wavenumber component (migration/reflectivity) while the hyperbola shape and positioning are controlled by the low wavenumber component (FWI). To avoid an undesired mismatch between observed and modeled shots in LSM, the velocity model must be resolved first.

In this case study, the low wavenumber component was obtained through a combination of ray-based wavelet shift tomography (Sherwood et al., 2011) and a unique implementation of FWI (Ramos-Martinez et al., 2016). The result of this workflow (Frugier et al., 2020), was a geologically consistent velocity model with a good tie between observed and modeled shots (Figures 3 and 4, respectively).

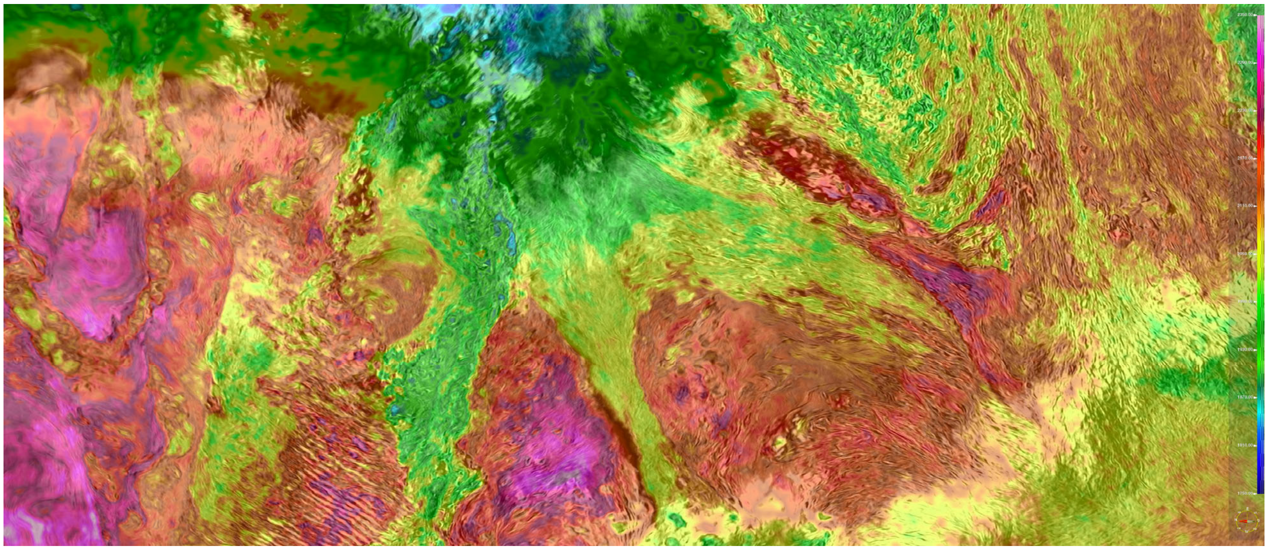

Figure 3. Depth slice of the velocity model showing the details incorporated by the VMB workflow.

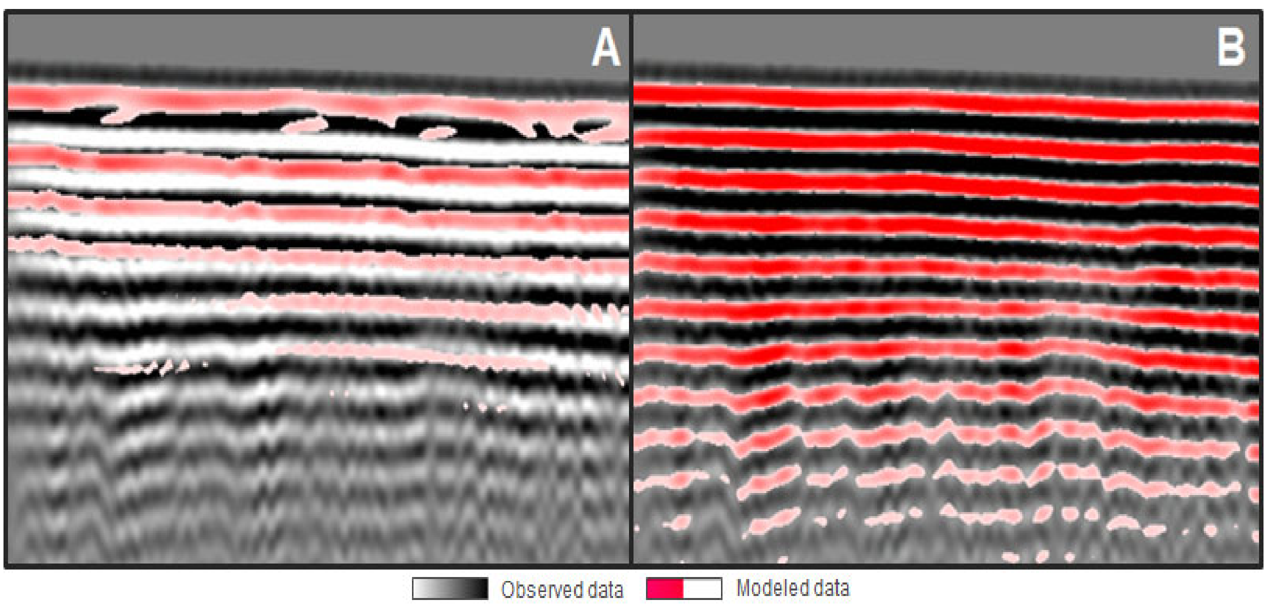

Figure 4. Overlay between observed and modeled data in a common channel. Figure 4A corresponds to modeling using velocity model without FWI. A mismatch between the two datasets can be noticed. Figure 4B corresponds to modeling using the FWI velocity model. The low wavenumber has been resolved and an improved tie between modeled and observed data can be seen.

Results

Although depth migration (Figure 5A) provides a good image at target level, improvements in resolution and fault definition in the Cretaceous and Jurassic sections could help minimizing drilling risks and aid reservoir characterization. To achieve this, an iterative imaging by inversion scheme was used. The input to the LSM flow were: preprocessed shot gathers, migration velocity model (Figure 3) and a 60 Hz one-way wave equation migration (WEM) stack (Figure 5A).

A qualitative comparison between migration (Figure 5A) and inversion (Figure 5B) indicates an uplift throughout the section given by LSM. In the Tertiary level, LSM revealed fine details that are highlighted by yellow circles in Figure 5B. In the deep section, improved fault definition and resolution are more evident (red arrows in Figure 5B).To quantitatively demonstrate these improvements, both amplitude and frequency-wavenumber (FK) spectra were extracted (Figure 5). LSM flattens the amplitude spectrum and broadens the FK content, resulting in a higher resolution image with better fault definition. Furthermore, the coherency attribute was used to evaluate the sharp boundary definition in the Jurassic section (Figure 6). At the target level, LSM yields a sharper image with improved fault definition (yellow circles in figure 6) that could mitigate exploration risks.

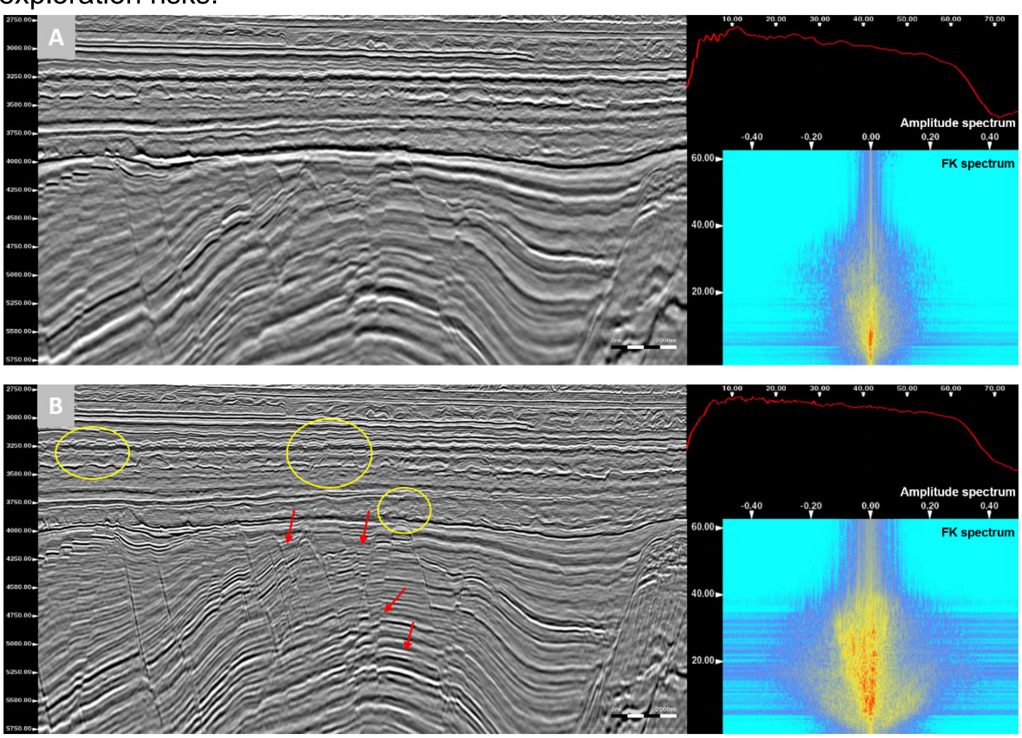

Figure 5. 60 Hz one-way wave equation migration (A) and Least squares migration (B) with amplitude and FK spectra. LSM flatten amplitude spectrum and broaden FK, resulting in a higher resolution image with better fault definition. Yellow circles indicates improvements in the Tertiary level. Red arrows indicates improvements in the Cretaceous and Jurassic.

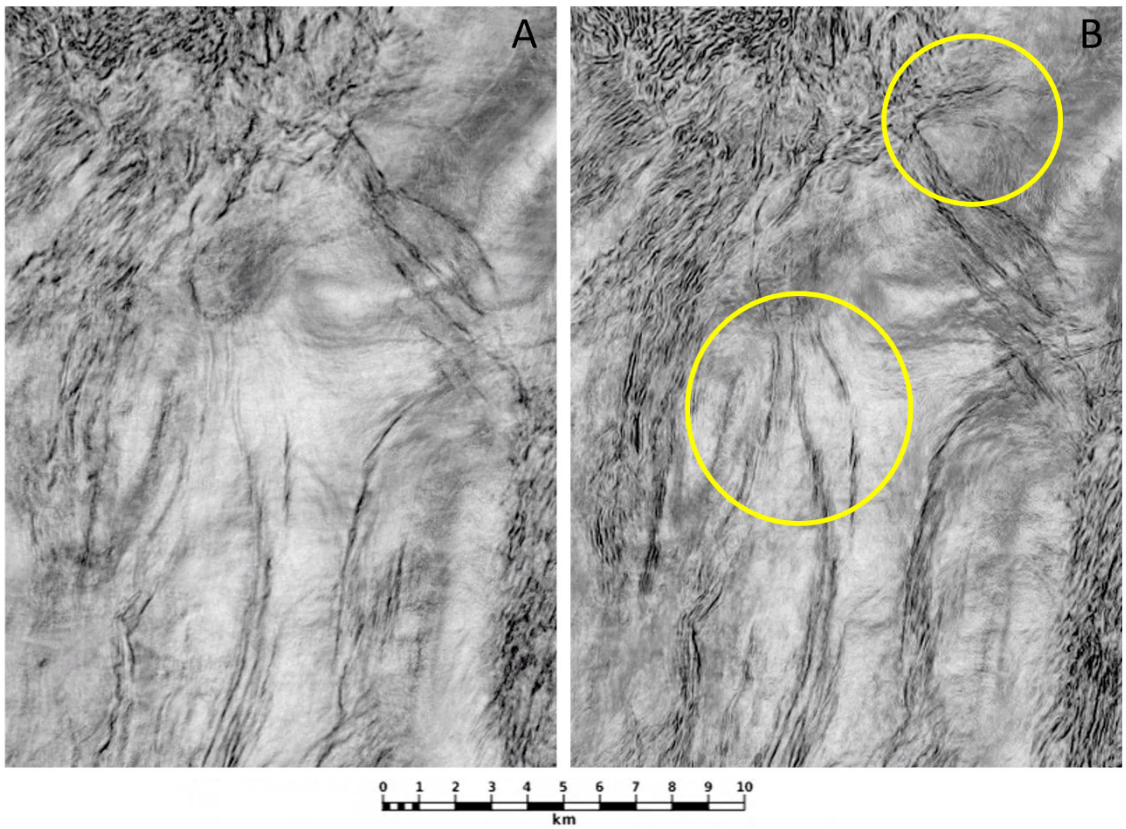

Figure 6. 60 Hz WEM (A) and LSM (B) coherency attribute in the Jurassic section (5.5 km depth slice). LSM provides a sharper image with improved fault definition (yellow circles).

Conclusions

Data-domain least-squares migration has been successfully applied to improve resolution and fault definition. Full waveform inversion was necessary to estimate a robust velocity model that minimizes differences between observed and synthetic shots and, consequentially, enable high frequency inversion without image degradation caused by cycle-skipping. The improvements given by this method can greatly benefit exploration and production stages by minimizing the drilling risks in areas with heavily faulted sediments where conventional migration provides a substandard representation of the subsurface.

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