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# The benefits of low frequencies in seismic inversion: a land example

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***Summary***

*Seismic inversion generally suffers from the lack of low frequency content of the seismic reflectivity data, which is important for absolute attribute extractions for reservoir characterization. The low frequency information is generally obtained from well logs. However, this information is only locally available. Over the past few years, improvements in vibroseis based land seismic acquisition has allowed to extend the bandwidth of seismic data at the low end of the frequency spectrum. Using Full Waveform Inversion (FWI) this low frequency seismic data provides more accurate velocity model for migration and subsequently better seismic imaging. This broadband seismic also allows improved absolute impedance prediction from seismic inversion. In this paper we will illustrate the benefits of low frequencies down to 1.5 Hz in reservoir characterization using deterministic seismic inversion results of an experimental 2D land seismic data acquired in Inner Mongolia, China.*

***Keywords****: Seismic inversion, Broadband seismic, Full waveform inversion, Acoustic impedance, Reservoir characterization*

## Acquisition and Processing

By using the full wavefield, FWI has the potential to become a key tool to interpret seismic data acquired in complex geological settings. However, its application requires low frequencies and large offset data. This approach has been successfully illustrated with marine data sets. To evaluate the relevance of this approach for onshore data, a dedicated experiment was carried out in Inner Mongolia, China in 2009. The broadband seismic was acquired with long offsets, up to 25 km and a fixed receiver spread of 20 km by 360 m was used w ith shots spaced at 25 m along a 30 km shot line. The sources were vibroseis trucks, which emitted non-linear sweeps with a flat weighted sum spectrum over the 1.5 to 80 Hz bandwidth. The receivers were distributed on a regular grid with a 7.5 by 7.5 m spacing. This dense acquisition design facilitated the removal of ground roll, which was required to better balance the low frequency content up to 1.5 Hz and apply the acoustic FWI for migration velocity model building. The pre-processing sequence contained the compensation of the geophone response, an f-k filter to remove the noise and stacking to finally give a single 2D seismic line. The FWI was carried out in frequency domain with a very rough 1D initial model, constructed from average local velocities (Plessix et al., 2010, Baeten et al., 2011). After FWI, the continuity in the image and the resolution have greatly im proved. The different fault blocks are clearly imaged and the FWI velocity model conforms well to the geological structures, at least down to the basement, as shown in Figure 1.

To further evaluate the benefit of low frequencies for reservoir characterization, a deterministic seismic inversion was carried out using the Mongolia broadband seismic data.

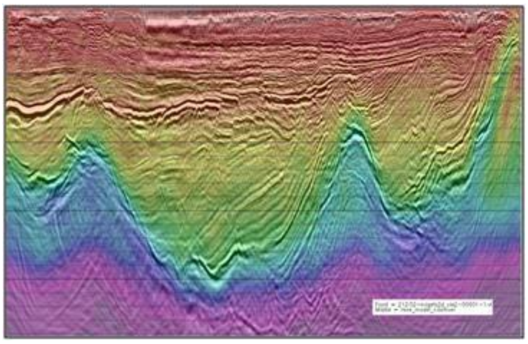

Figure 1: Migrated section with the FWI velocity model in the background.

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## Seismic Inversion Theory

The derivation of the low frequent background model is an important step in seismic inversion (Tarantola, 1987). Conventional seismic is generally lacking low - frequent information below 6-7 Hz, which therefore needs to be supplied in the form of a low frequency background model. The choice of the low frequency model influences the absolute acoustic impedance and therefore an y reservoir property derived using the impedance volumes. In seismic inversion studies this low frequency gap is commonly closed using well log information (local information only) as well as (compaction) trends from seismic velocities, extrapolated along the main horizons of interest.

With the availability of low frequencies in the seismic data itself, the seismic inversion is less dependent on the accuracy of the background information, as illustrated in Figure 2.

## Field example- Mongolia broadband land seismic data

To assess the impact of low frequencies and the novel imaging techniques, deterministic seismic inversion was carried out on the Mongolia 2D broadband seismic data using Fugro-Jason's Geosciences' Constrained Sparse Spike module. The impact of different low frequency models, derived from different combinations of well data and FWI seismic velocities, as well as different merge frequencies was tested. The main observations from these tests are described below.

Figure 3 show the absolute acoustic impedance obtained using broadband seismic from 6 Hz onwards, which is typically used as lowest usable frequency in seismic inversion of conventional data. Figure 4 shows the acoustic impedance but now using all seismic frequencies from the broadband seismic. The above tests used FWI velocities as low frequency model. The comparison clearly shows the softening of the main reservoir rock (above the inclined arrows), as well as hardening of the layer above, when more seismically measured low frequencies are included in the inversion. The features indicated by the vertical arrows, interpreted as top seal of the reservoir, moved to the right is seen as the right seal of the reservoir.

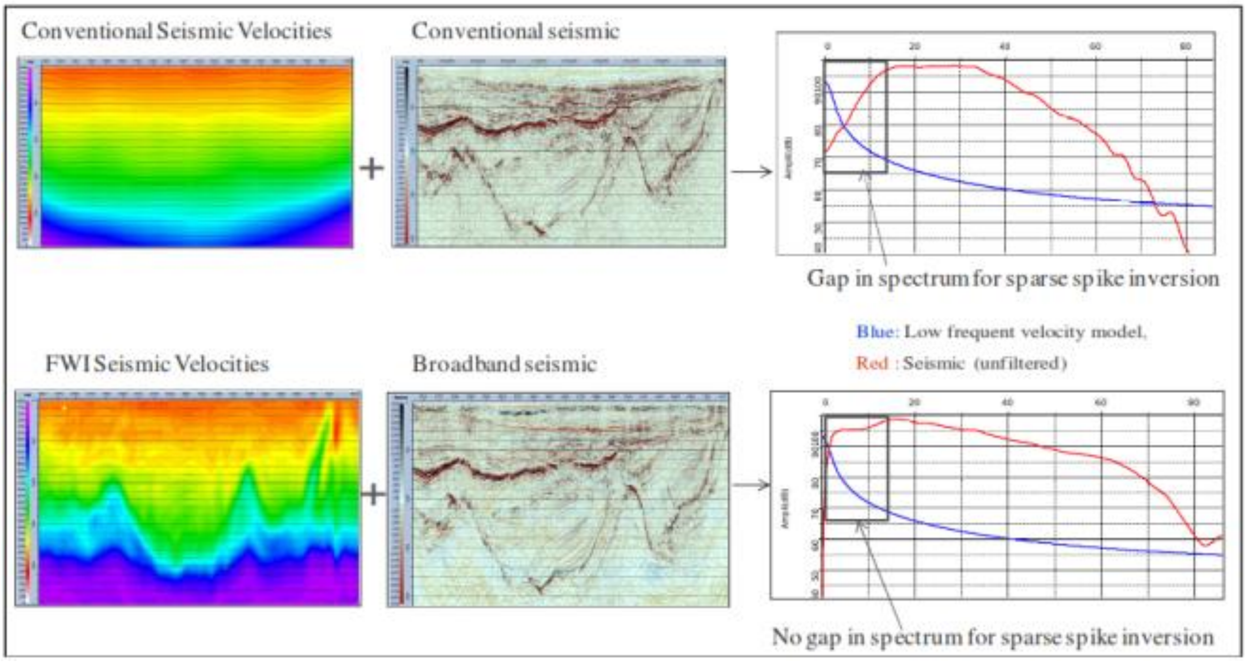


Figure 2: Combination of broadband seismic and FWI seismic velocities can provide the full spectrum for seismic inversion without the gap, which is usually filled with well information.

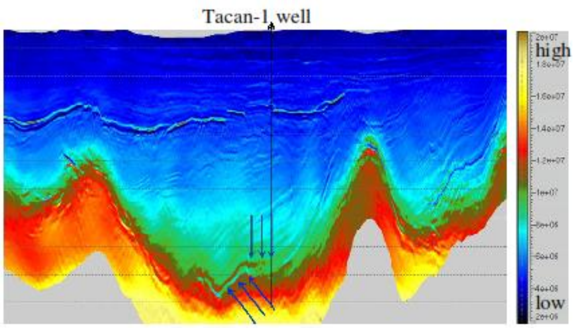


Figure 3: Acoustic impedance inversion using FWI model and seismic data from 6 Hz onwards.

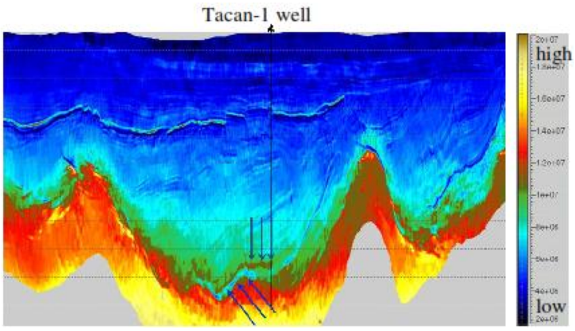


Figure 4: Acoustic impedance inversion using FWI model and all frequencies in the seismic data.

Another important test demonstrates the impact of different low frequency models used in the inversion. Figure 5a shows the acoustic impedance obtained using low frequencies from well logs only and from 6 Hz onwards from seismic. Figure 5b shows the acoustic impedance achieved using the FWI low frequency components and all the seismic frequencies. The comparison of acoustic impedance from these tests shows the bias in quantitative impedance values ach ieved due to the choice of the low frequency model. This is always seen as a typical problem in seismic inversion. The acoustic impedance in Figure 5a also suffers from the imprint of well log interpolation along horizons used in the low frequency model. However, the use of the lowest seismic frequency content available and FWI velocities as background model allows to obtain unbiased absolute acoustic impedance from the inversion, as demonstrated in Figure 5b.

Overall, the quantitative characterization of the reservoir can clearly benefit from the broadband seismic combined with a FWI velocity model. It better characterizes the reservoir even without or with limited initial well information like in exploration and appraisal settings. Unfortunately in this case, due to limited availability of well data, only qualitative comparisons can be made. The assessment of impedances and reservoir property prediction at the well location is needed to quantitatively demonstrate the added value of broadband seismic acquisitions and processing for reservoir characterization

## Conclusions

The broadband, long offset land seismic data with frequencies down to 1.5 Hz result in accurate velocity models from fu ll waveform inversion, which can directly be used as low frequency background model in seismic inversion. The results show clear benefits for reservoir characterization with reduced dependency on well-information and/or (compaction) trends particularly in exploration and appraisal settings.

## References

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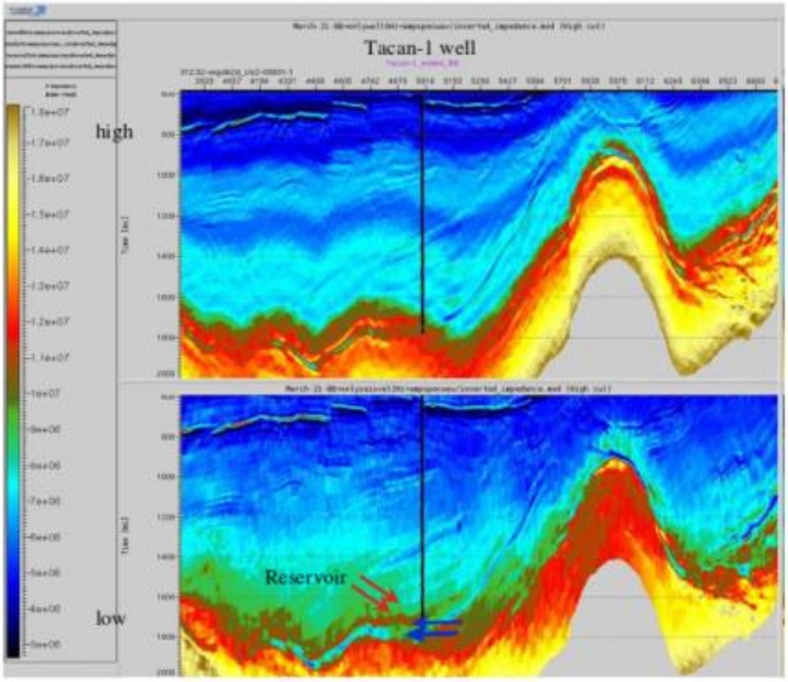


Acoustic impedance inversion using low frequencies from well only and seismic from 6 Hz onwards (5a).

Acoustic impedance inversion using low frequencies from FWI model and all the seismic frequencies (5b).

Figure 5: Comparison of acoustic impedance from broadband seismic showing that reservoir stands out best using low frequency model from FWI model and all the seismic frequencies.