Reflected wave enhancement using a single trace and a projection model: application to focused monitoring

Introduction

Common appraisal methods for oil and gas reservoir often begin with 3D seismic and exploration wells. These technologies provide spatial recognition along with focused stratigraphy and subsurface resources content. Even though models and simulations predict a reservoir dynamic, measuring this key component in time complements spatial technologies while providing relevant information regarding field optimization. Such approach is already massively used in history matching to update reservoir models. Time-lapse seismic (Mari et al., 2011) gives significant insight regarding the reservoir activity, and further intents to go toward continuous monitoring demonstrated the capability for seismic to detect daily reliable short-term calendar 4D effect (Berron, et al., 2015) that would be missed by a conventional 4D seismic (Bertrand, et al., 2013). These techniques have proven efficiency but are not necessarly well adapted to dense monitoring. For dense monitoring at specific spot locations, focused monitoring with light seismic spreads have proven efficiency (Morgan et al., 2020, Brun et al, 2021 2022).
After a short review of focused monitoring, we describe the specific procedure which has been developed to enhance reflected waves using a single trace and a projection model. An example of focused monitoring illustrates the efficiency of the processing procedure.

Focused monitoring

Focus seismic monitoring at a specific spot location defined by reservoir engineer studies had been investigated for the past 5 years (Szabados et al, 2022). This approach allows a very high temporal density monitoring tool and is economically attractive. The detection attributes, mainly time shifts, are computed on reflected events observed on raw traces. The optimum area for source and receivers is chosen over the resulting Common Spot Gather (Morgan et al.,2020) to avoid ground roll, surface noise generator or artefact such as guided waves. The de-migration process of the 3D block is reapplied on seismic horizons situated on the overburden and below the reservoir zone to confirm that the selected seismic events observed on a single trace are really reflected events.
To improve the selection of reflected events, a specific procedure has been implemented to enhance reflected waves observed on a single trace – the optimal trace- using projection models.

Reflected wave enhancement using projection models

The optimal trace belongs to a shot point from the base acquisition which can be conventionally processed. For reflection seismic imaging, the processing of a shot point is done to extract the primary reflected events. The processing of shot point gather or a common midpoint gather is done using single channel process or multi-channel process. Single channel process includes amplitude recovery, mute, frequency filter, deconvolution, static and NMO corrections. Multichannel process includes velocity analysis, velocity scan, wave separation done using multichannel filters such as f-k filter or SVD filter (Mari et al.,1999).

Figure 1a left panel is an example of seismic gather processing from the base acquisition. On the raw shot (Fig. 1a), the first arrival wave is a refracted wave which appears with the strongest energy. Single channel process is applied to the shot. It includes mute and deconvolution. Multichannel process is then applied. It includes wavenumber filter (to cancel events with negative wavenumber), NMO corrections using the migration velocity model and f-k filter to enhance reflected events, inverse NMO corrections. Figure 1a right panel shows the reflected waves. Figure 1b shows the NMO corrected shots compared to the corresponding migrated section. Such a multichannel process allows to define a projection model of reflected events for the optimal trace. This model is used to design a first operator of projection WB1(t) to extract the reflected events from the deconvolved base trace. Such a procedure allows to enhance reflected waves using a selected single trace and a projection model. In the aim of enhancing the comparison of the results with migrated section, the output of the WB1(t) projection is deconvolved in the frequency bandwidth of the migrated section. A second operator WB2(t) is then designed to fit the migrated section at the "Spot" location.

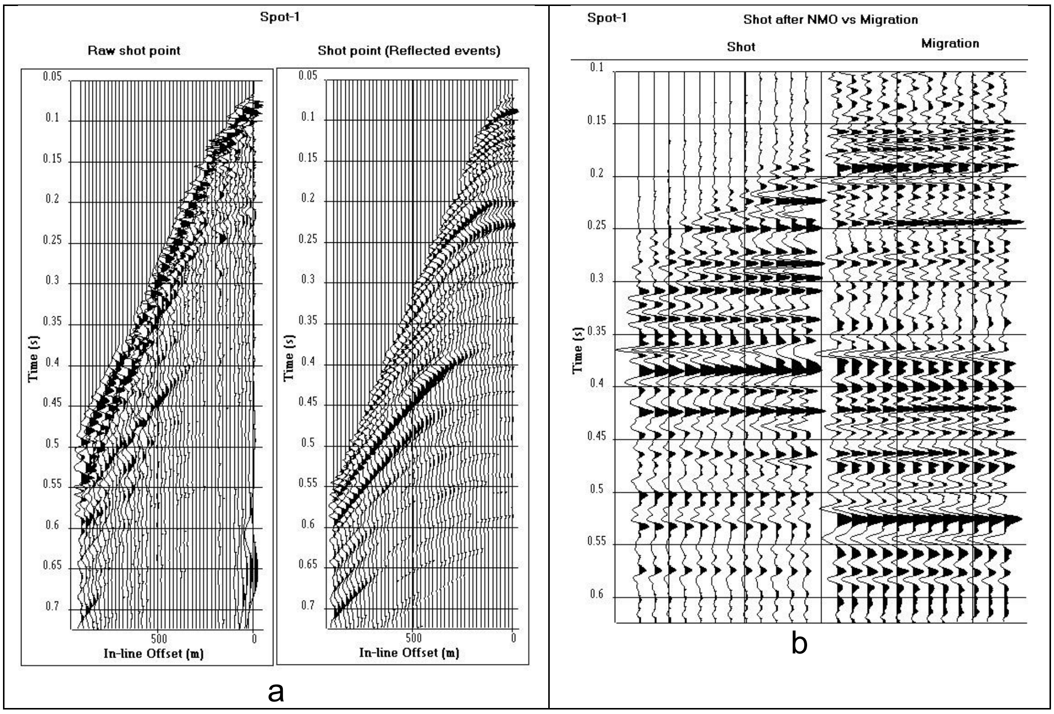

Figure.1: *Processing of a shot point associated with Spot-1*
Raw shot and reflected events (a), Reflected events after NMO vs Migration (b)

Application to monitoring

A Monitoring Spot Gather (MSG) is a set of seismic traces composed of a base and monitors. All the traces have been recorded at 5 different monitor calendar times with the same light recording spread (a source location and a receiver location). The operators WB(t) designed on the base are also applied to the monitors to preserve the variations of amplitude and time shift which could be observed on the reflected waves between the base and the monitors. Results of these steps are shown on Figure 2, from left to right:

- The RAW MSG dataset
- The MSG after WB1(t) projection after single channel processing: MSG-WB1
- The MSG-WB1 deconvolved in the migrated bandwidth after WB2(t) projection
- A section of the migrated seismic, where the left trace is the Spot migrated trace

The pseudo- migrated MSGs are obtained with a single offset. The signal to noise ratio is lower on the MSG than it is on the migrated section. However, we can observe a good correlation of the main seismic horizons between the MSG's and the migrated section. The processing is done to favour reflected events on MSG's and to preserve monitoring effects.

Uncertainties

Before doing measurements of monitoring parameters such as time shifts, it is important to evaluate the signal-to-noise between the base and the monitors. Several methods are available using Hilbert's transform, Power Spectral Density (Mari et al., 1999) or Bakulin's approach (Bakulin et al., 2022). The picking uncertainties must also be evaluated. The uncertainty (Ɛ) in time-shift measurement between seismic traces is inversely proportional to the signal to noise ratio (S/N) and the frequency bandwidth (Bf) (Mari et al.,2019). It can be estimated by the following formula where α depends on the number of independent frequencies:

$$\varepsilon = \frac{\alpha}{\left(\frac{S}{N}\right) Bf}$$

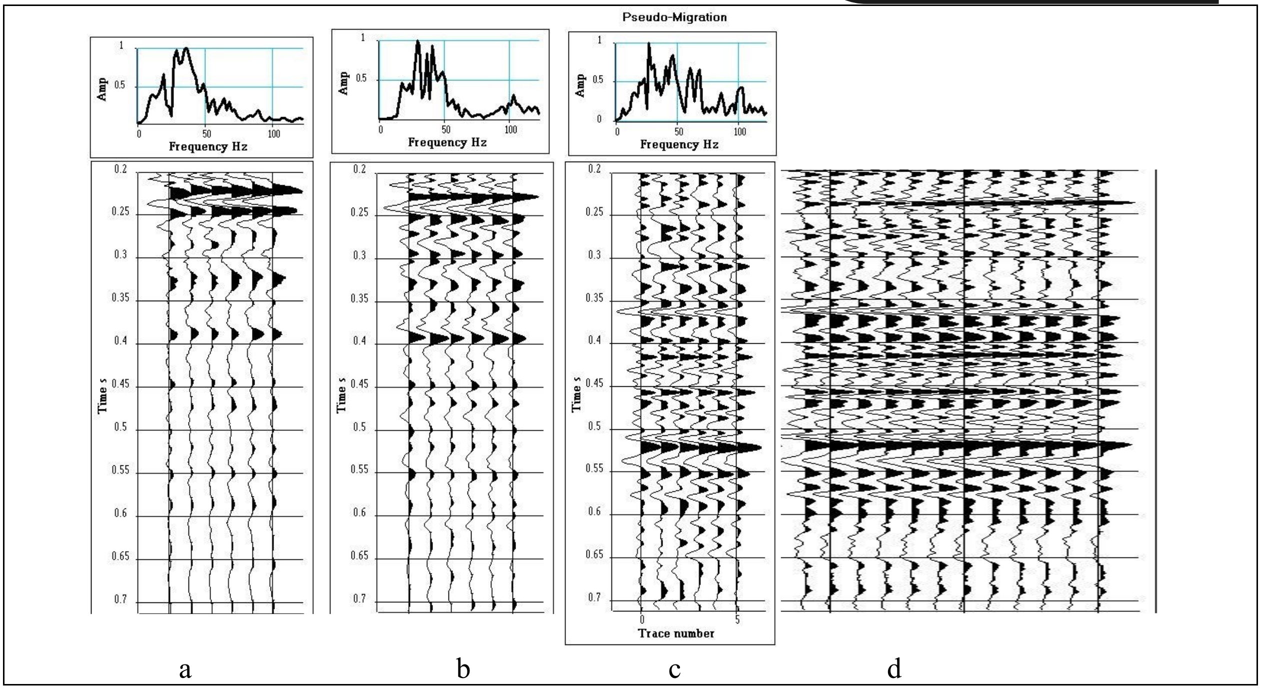

Figure.2: *Monitoring processing steps at Spot-1. Display of raw MSG and frequency filtering (a), deconvolution and reflected wavefield extraction (b), deconvolution and pseudo-migration (c), migrated section (d)*

The monitoring spot gather 1 has been processed (figure 3)

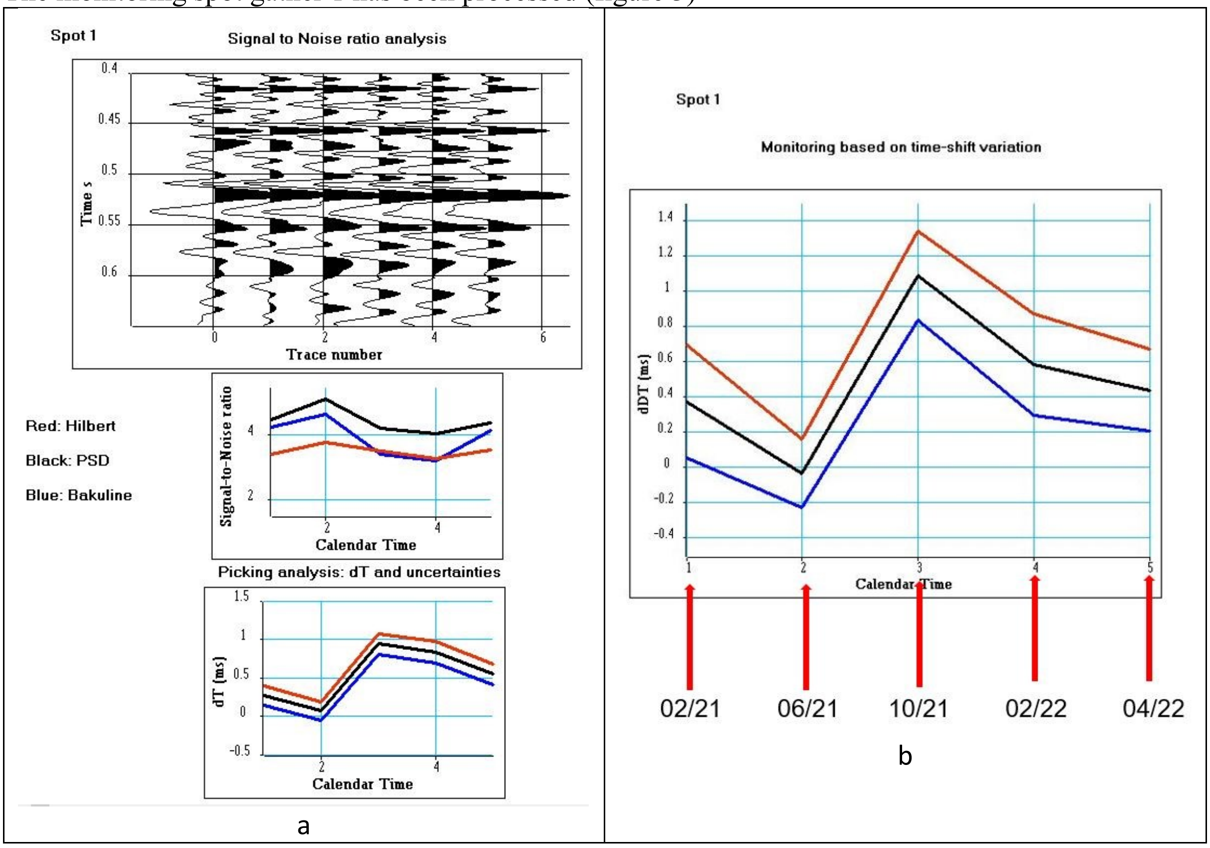

Figure 3 *Monitoring results at Spot1.a: Measurement of time shift and associated uncertainties between the base and the monitors in a time window situated in the under burden. Measurement of Signal to Noise ratio by 3 methods: Hilbert (red curve), Power Spectral density (black curve) and Bakulin (blue curve). b: differential time shift curve and associated time uncertainty between February 2021 and April 2022.*

Figure 3 interpretation is as follows:
• Measurement of time shift and associated uncertainties between the base and the monitors in time windows situated in the under burden and overburden. Measurement of Signal to Noise ratio by 3 methods: Hilbert, Power Spectral density and Bakulin (Fig. 3a)
•Computation of differential time shift curve and associated time uncertainty between February 2021 and April 2022 (Fig. 3b)

The differential time shift curve does not show any trend, consequently no monitoring effect has been detected between September 2018 and April 2022. The methodology has been applied successfully on other spots (not shown here) and monitoring effects have been detected. "Time shifts" given by a full 4D seismic at the same area & calendar time gave similar detection results than the proposed method.

Conclusion

Light or ultra-light continuous monitoring methods have been recently developed and implemented to focus on specific "spot" locations using light seismic spreads. composed of one receiver and one source position. If a single 1C sensor is used, a specific procedure has been developed to design an operator which extracts by projection on a projection model the reflected events of a single trace. The procedure can also be applied for enhancing reflected events if the data have been recorded using sensor arrays. The methodology has been illustrated on a Single-Sensor Monitoring Spot Gather (MSG) of a 3D block.

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