Compensating for near surface changes in time lapse processing of land seismic. A case history from Midland Basin.

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Introduction

This case history describes the data processing workflow, and associated challenges, for a time-lapse land surface seismic CO_2 injection monitoring project located in the Northern portion of the Midland Basin. The associated field produces from a porous carbonate section of the San Andres Formation; over the last 20 years the field has had many cycles of enhanced oil recovery (EOR) using water and CO_2 injection. The time-lapse project was aiming to capture changes in seismic response associated with EOR using a base and monitor survey acquired 20 years apart. Such a long timeframe between time-lapse acquisitions resulted in noticeable changes within the weathering layer due to natural factors and possible water table changes. In addition to non-repeatable noise on seismic records, low fold and sparse acquisition geometry, the near-surface property changes were one of the key challenges to overcome during time-lapse processing. This work provides details of the processing workflow implemented to overcome these challenges and successfully achieve the project goals.

Background

The base line survey was acquired in 1996 using vibroseis sources and a relatively sparse orthogonal geometry with nominal fold of 30. Assuming the expected changes in the subsurface can be detected by time-lapse surface seismic measurements there are many contributing factors that determine the success of time-lapse projects. It is well-known that the repeatability of the seismic acquisition experiment is one of the most important factors when planning for a successful outcome (Jack, 1997). The monitor survey was acquired in 2017 using identical source and detector arrays, and great care was taken to repeat the geometry to ensure minimal deviations in shot and detector positions.

As the processing commenced, it became clear that the most significant source of non-repeatability between the base and monitor surveys was related to apparent weathering zone changes that had accumulated over the 20 years in addition to short period water saturation changes of the ground. These changes resulted in relative, but not constant, timing shifts between the base and monitor datasets, caused by the associated, localized velocity changes. At the same time, amplitude and spectral differences were also observed which may be attributed to coupling differences and changes in absorption properties at the near surface. Initial testing focused on using a conventional time-lapse processing flow, based on joint surface-consistent statics, deconvolution and amplitude corrections. This was done to minimize the differences, but during this process it became clear that further steps were required to fully correct for remaining timing and spectral differences.

Near-surface non-repeatability compensation

The base and monitor surveys were first processed with independent refraction-based surface-consistent static solutions, but this approach failed to fully resolve the relative static differences. A joint surface-consistent refraction and residual static solution gave some improvement, but significant relative time shifts still remained. Figure 1a shows the seismic difference between the base and monitor survey after a joint statics solution was applied. Note the strong differences that were a result of the non-repeatable near-surface related timing and spectral effects. To address the timing component of the differences, a workflow to derive a relative calibration static for all collocated stations between the base and monitor surveys was introduced. This used the fact that the monitor was a very good repeat of the base survey, and assumed that any impact from geometrical non-repeatability was negligible and could be removed from consideration when matching the two datasets. Furthermore, by assuming that refracted and reflected events have very similar, almost vertical, travel paths near the surface ,the observed differences can be attributed to changes in the near surface. As such, refraction energy was utilized to compute relative time shifts as the first step of the calibration process. Refraction-based linear moveout (LMO)-corrected shot stacks were produced and crosscorrelated between the base and the monitor surveys. The computed crosscorrelation shifts were then applied to the monitor survey data in an attempt to correct for the source component of the calibration statics. The same procedure was then repeated using LMO-corrected receiver stacks in order to correct for the receiver component. Figure 1b shows the seismic difference stack after applying of the final refraction-based timing calibration step.

While the refraction-based timing calibration step reduced most of the observed relative time shifts between the two datasets, the timing differences were further improved by means of a second static calibration step based on the *reflection* energy. Reflection-based normal moveout (NMO)-corrected limited-offset common shot stacks were produced and crosscorrelated between the base and the monitor surveys using a time window above the target zone. The computed time shifts were applied to the monitor survey data to correct for the source component, after which the procedure was repeated for common receiver stacks. Figure 1c is the seismic difference stack after both the refraction and reflection-based timing calibration steps and clearly shows that the amount of coherent energy from the near-surface non-repeatbaility was dramatically reduced. A similar concept of time-related non-repeatability compensation was described by Bergman at. al. (2014) where *prestack* crosscorrelations of *reflections* only were employed for the same purpose.

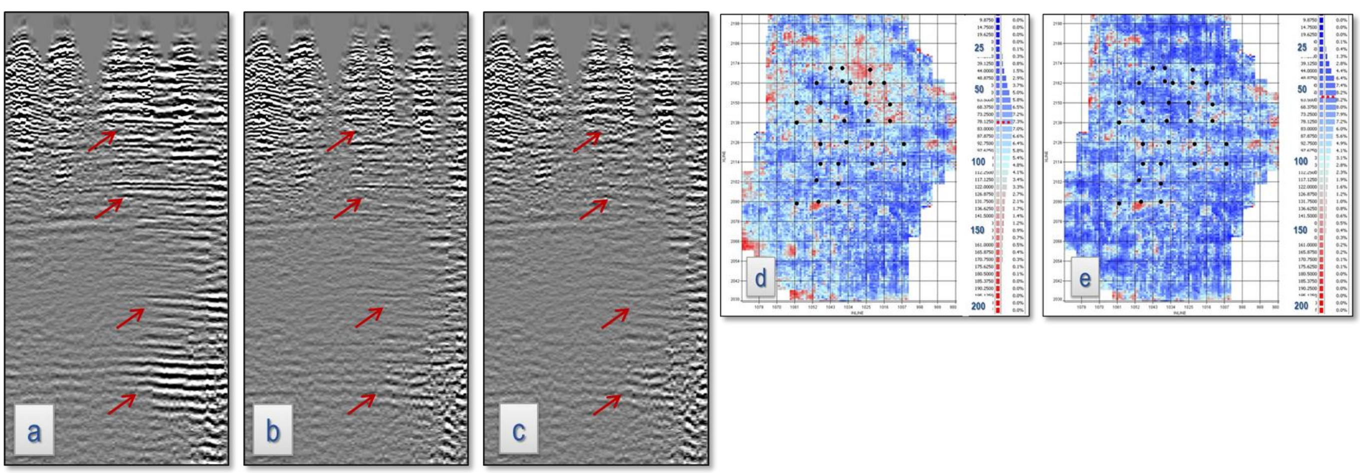

Figure 1, Seismic difference: a) before calibrating static correction, b) after *refraction*-based calibration static correction, c) after *refraction and reflection*-based calibration static correction; NRMS attribute of reference window d) before calibration static correction, e) after *refraction and reflection*-based calibration static correction.

Applying of the described calibration static corrections significantly reduced the observed timing differences associated with the non-repeatable near-surface changes . Throughout the processing flow great care was taken to assess the impact of each step on the standard 4D attributes measured at both a reference level and the key target zone. Figures 1d and 1e show that average normalized roo-mean square (NRMS) level at the reference zone dropped by around 30% after applying of the relative timing calibration.

Following the application of joint surface-consistent deconvolution and amplitude corrections it was clear that residual non-repeatable amplitude and spectral differences still persisted. A similar approach was taken to compute and apply shot-to-shot and receiver-to-receiver residual spectral matching. The source and receiver component of the matching operators were computed from NMO-corrected common shot and common receiver reflection stacks, respectively, using a reference window above the target level. As demonstrated by figures 2a and 2b, further improvement was observed on both the seismic difference displays and the 4D attributes. A comparison of Figures 2c and 2d show that the average NRMS value at the reference zone was further reduced.

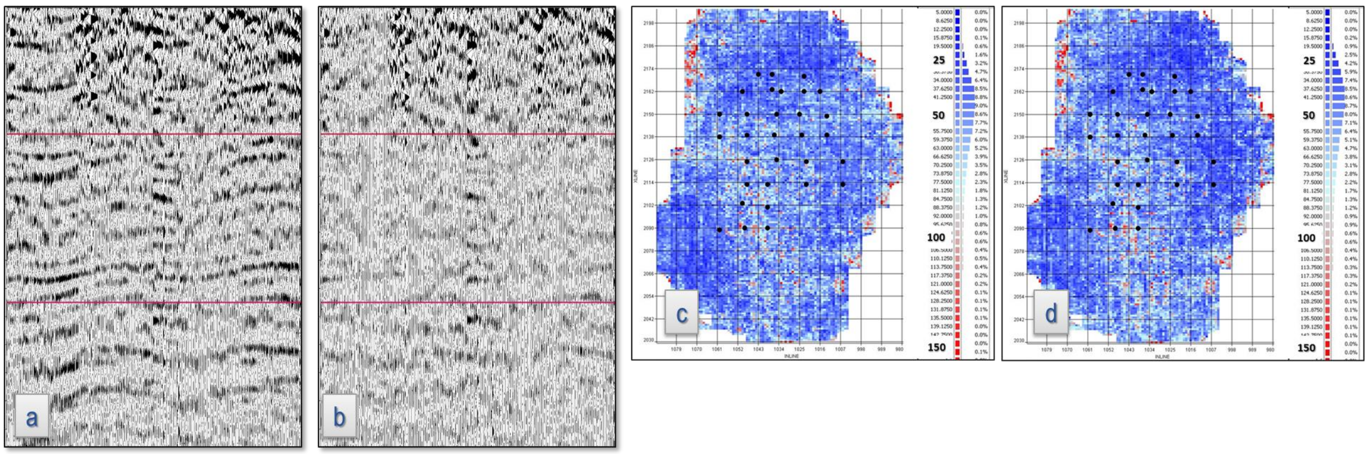

Figure 2, Common receiver stack seismic difference with outlined matching zone a) after timing calibration step but before spectral matching, b) after source and receiver spectral matching; NRMS attribute of reference zone c) after timing calibration step but before spectral matching, d) after source and receiver spectral matching;

The 4D data repeatability was further optimized with additional processing steps before imaging. Steps included 5D noise modelling based on a matching pursuit Fourier interpolation (MPFI) algorithm (Schonewille et al., 2009), and a curvelet transform noise modelling technique (Ma et al., 2010; Skorinski et al., 2017). In addition to these steps, a 4D trace selection was used to reject traces with 4D attributes outside of an acceptable threshold and 3D MPFI was used to fill in missing holes within the target migration bins prior to prestack time migration.Trace-by-trace residual 4D matching was performed on the final migrated stack in order to further enhance survey repeatability. Figure 3 shows the final NRMS plots at the reference and target intervals.

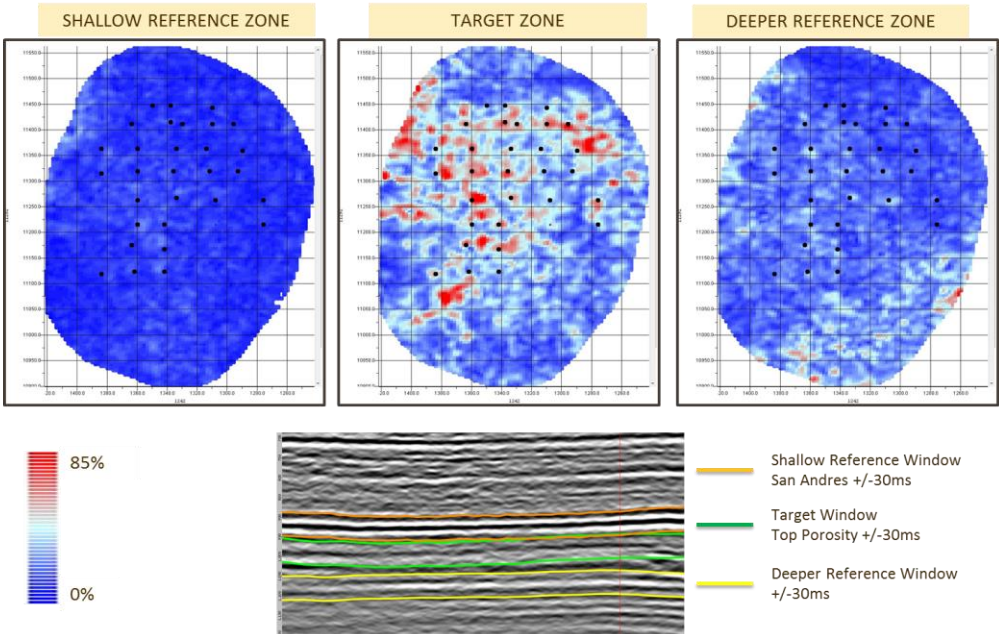

Figure 3, The final NRMS attribute maps with annotated CO2 injecting well locations from: left – shallow reference zone, center- target zone, right – deeper reference zone

Conclusions

With well-repeated acquisition parameters and geometry, it was possible to recover 4D signal in the presence of significant non-repeatable near-surface changes accumulated over two decades. The described relative calibration statics and spectral matching steps were key to reducing the non-repeatability effects between the time-lapse datasets and achieving the final results that show potential 4D changes associated with injecting wells locations at the target interval.

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