# Toward time-lapse study of anisotropic parameters over the Genesis field

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## ABSTRACT

We estimate a 3D vertical transverse isotropy (VTI) model for the Genesis dataset. We reprocess the time-lapse seismic data set to attenuate the spatial aliasing problem, and to minimize the impact of different processing workflows conducted by different companies. Time-lapse reverse-time migration (RTM) from the Genesis dataset, suggests that we have obtained an accurate initial VTI model. Production-induced change has been observed with the help of angle domain common image gathers (ADCIG). We compute the gradient for velocity and anisotropic parameters, and the results suggest that long offset data may help us identify anisotropic parameter change during production.

## INTRODUCTION

The Genesis field has experienced reservoir compaction during production (Magesan et al., 2005; Hodgson et al., 2007; Herwanger and Horne, 2009). In a recent study, negative velocity change has been observed via full-waveform inversion (FWI) and has been associated with the overburden dilation. Therefore, it is reasonable to assume the anisotropic parameters in the overburden of the reservoir also change because of geomechanical effects associated with production.

The time-lapse surveys with data collected by the towed streamers over the Genesis field have been cross equalized to improve the similarity between baseline survey and monitor survey. Each midpoint gather has 30 different offsets, ranging from 1146 ft to 15414 ft with spacing 492 ft. Chevron processes the monitor dataset along without cross equalization, using offset up to 24000 ft with offset spacing 200 ft. From the prospective of the wave propagation, the data is aliased in space and therefore reprocessing is required. We design a workflow to interpolate the data along the offset axis in order to attenuate the spatial aliasing problem, and to minimize the impact of different processing workflows. Subsurface angular illumination is limited because of the acquisition geometry (towed streamer). We extract both source gathers and receiver gathers to enhance the illumination using the principle of reciprocity.

We analyze the quality of the VTI models and the data processing procedures by examining the subsurface angle gathers with the VTI wave equation. We see production induced change at different angles at different midpoint locations, which gives us some understanding about the size of the area that changed during production.

ADCIG suggests that our initial VTI model is accurate because we get flat gathers in most places.

We compute gradients from the baseline and two monitor datasets processed by CGG and Chevron separately. The anisotropic parameters only get weak updating, particularly at the reservoir level. We also observe that far offset parts of the monitor data provide useful information around the reservoir and in the overburden area.

## OVERVIEW OF GENESIS DATASET AND DATA PROCESSING

The time-lapse datasets from the Genesis field were acquired with towed streamers. The baseline survey was conducted in 1990 with offset up to 4700 meters. The monitor survey in 2002 contains offset up to 7200 meters. CGG co-processed the baseline and monitor datasets with offset up to 4700 meters. Chevron processed the monitor separately with full range offset. The different processing workflows make it challenging for us to use the long offset monitor data in time-lapse FWI.

The reservoir is located at depth around 3500 to 3600 meters. For the baseline survey with offset up to 4700 meters, we observe mostly reflection data which provides very limited constrain on the anisotropic parameters. Therefore we would like to use long offset data to estimate the anisotropic parameters.

Different processing workflows lead to different amplitude correction, signal-to-noise ratio and even different kinematics for the same monitor survey. To illustrate one of the challenges, we show the amplitude as a function of time in Figure 1, which indicates that different spherical divergence corrections have been applied to the data. Therefore, we designed the following workflow to correct the long offset monitor data, in order to match the co-processed short offset data.

1. shift midpoint location northing by $10^7$ ft and easting by $2 \times 10^6$ ft;
2. rotate offset by 90 degree so that sources and receivers is aligned with the boat sailing direction;
3. shift origin of offset axis from 400 ft to 360 ft;
4. shift zero time $t_0$ by 6 ms;
5. apply spherical divergence correction to match the baseline data;
6. apply NMO correction to flatten the CMP gather;
7. interpolate along offset axis;
8. apply inverse NMO correction to recover kinematics;

9. sort to shot and receiver gathers.

Step 1 and step 2 are obvious from the geometry of the traces. Step 3 and step 4 are introduced to register RTM images from two monitor datasets processed by CGG and Chevron separately. The parameters are determined from semblance scanning, visual inspection of the image registration and flatness of the angle gathers. Step 5 is used to match the amplitude of different datasets. Step 6 through step 9 are standard procedures to get dense sampling of sources and receivers, which will improve the RTM image and FWI gradient by reducing the spatial aliasing problems.

Figure 2 and 3 show the final shot gathers from monitor data processed by CGG and Chevron separately. We have aligned the two monitor datasets. The signal-to-noise levels are still different, and matching the noise level is beyond our capacity.

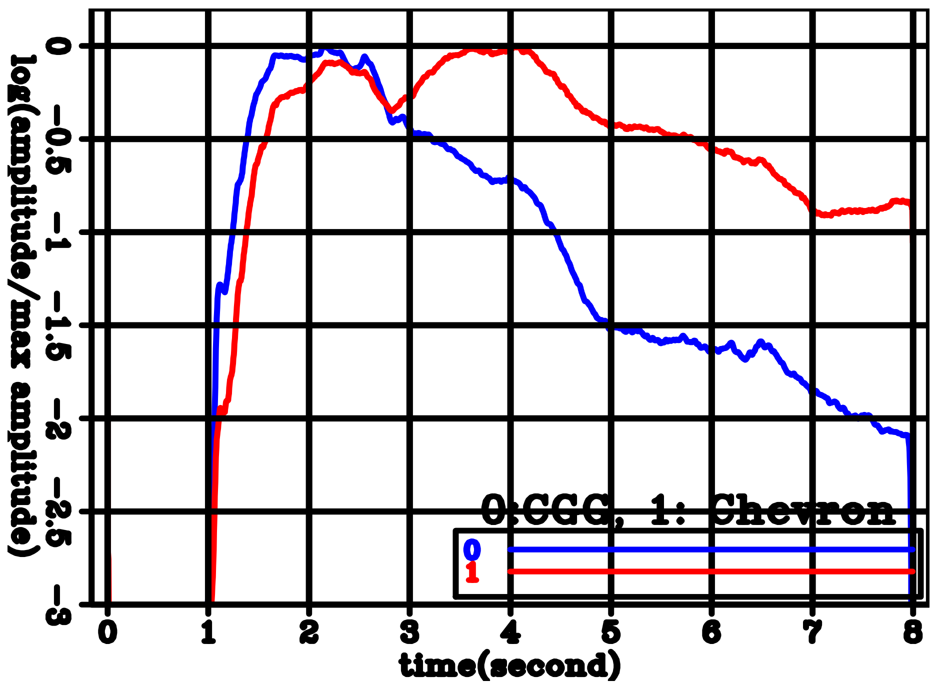


Figure 1: Amplitude of monitor data as a function of time, by stacking the envelope function of all traces. CGG and Chevron have applied different amplitude correction. [**CR**]

## VTI MODEL CONSTRUCTION FOR GENESIS DATASET

We received stacking NMO velocity and $\eta$ from the previous time-lapse study on the Genesis dataset, as functions of midpoint and travel time. In this section, we briefly describe our approach to extract a 3D initial VTI model for the GENESIS dataset.

The stacking NMO velocity and parameter $\eta$ are obtained as follows (Wang and

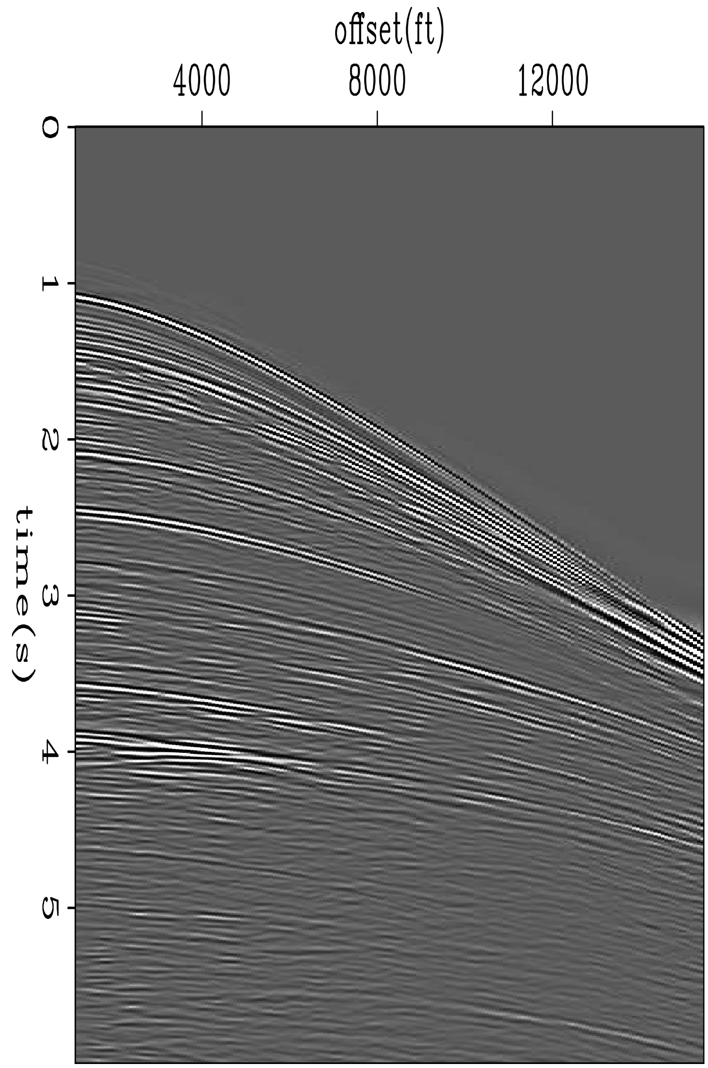


Figure 2: Shot gather from CGG processed monitor dataset. [**CR**]

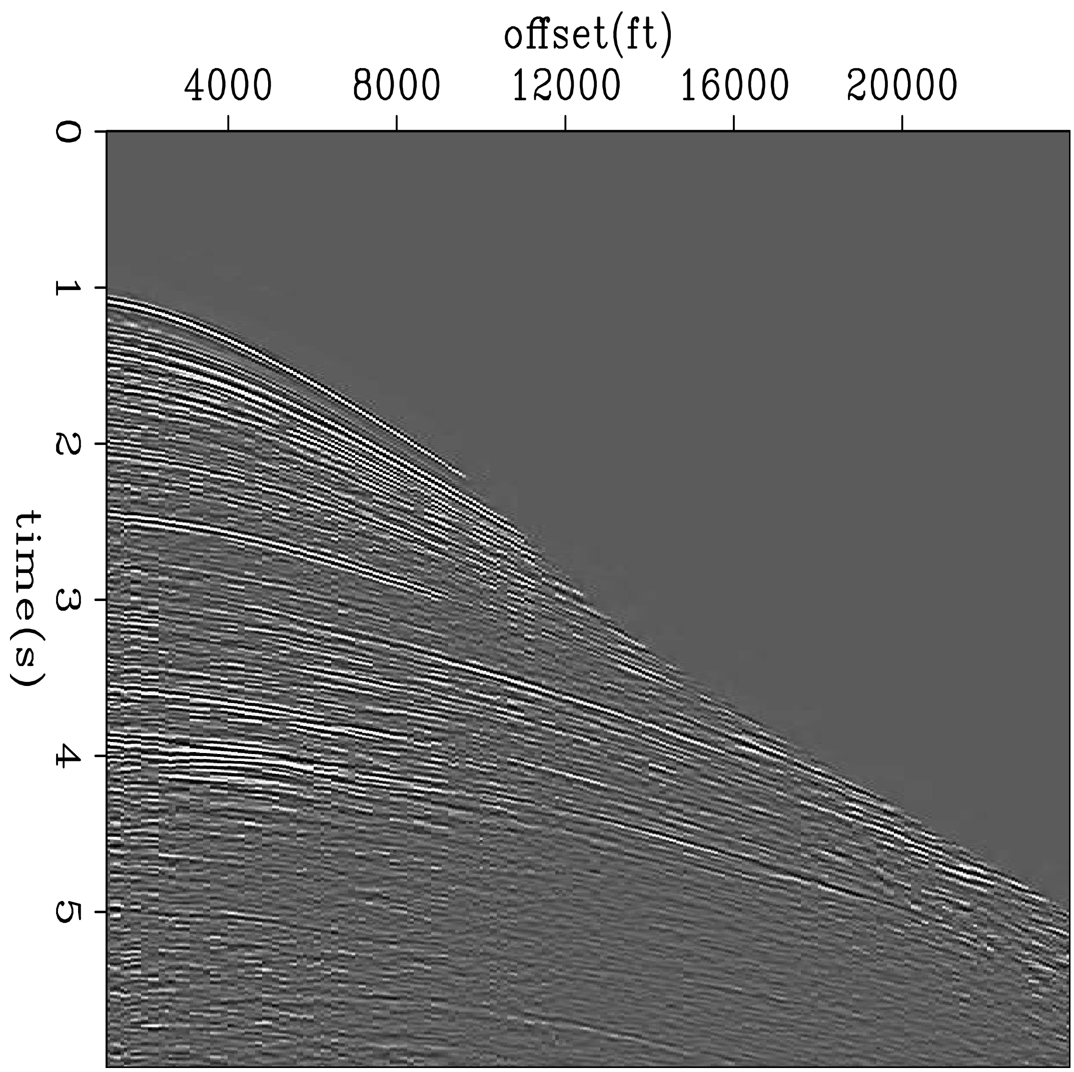


Figure 3: Shot gather from Chevron processed monitor dataset. [**CR**]

Tsvankin, 2009):

$$(V_{NMO,stack}(N))^2 = \frac{1}{t_0(N)} \sum_{i=1}^{N} (V_{NMO,int}(i))^2 (t_0(i) - t_0(i-1)), \quad (1)$$

$$\eta_{stack}(N) = \frac{\sum_{i=1}^{N} (V_{NMO,int}(i))^4 (1 + 8\eta_{int}(i)) (t_0(i) - t_0(i-1))}{8 (V_{NMO,stack}(N))^4 t_0(N)} - \frac{1}{8}, \quad (2)$$

where $V_{NMO,stack}(N)$ is the stacking NMO velocity at layer $N$, $t_0(N)$ is the zero-offset travel time at layer $N$, $V_{NMO,int}(i)$ is the interval NMO velocity at layer $i$, $\eta_{stack}(N)$ and $\eta_{int}(i)$ are the stacking and interval parameter $\eta$ separately.

We designed a stable inversion algorithm to estimate the smooth interval parameters from equation 1 and 2. The details of the algorithm are discussed in an ealier report (Ma et al., 2016). In Figure 4 and 5, we show our inverted VTI model.

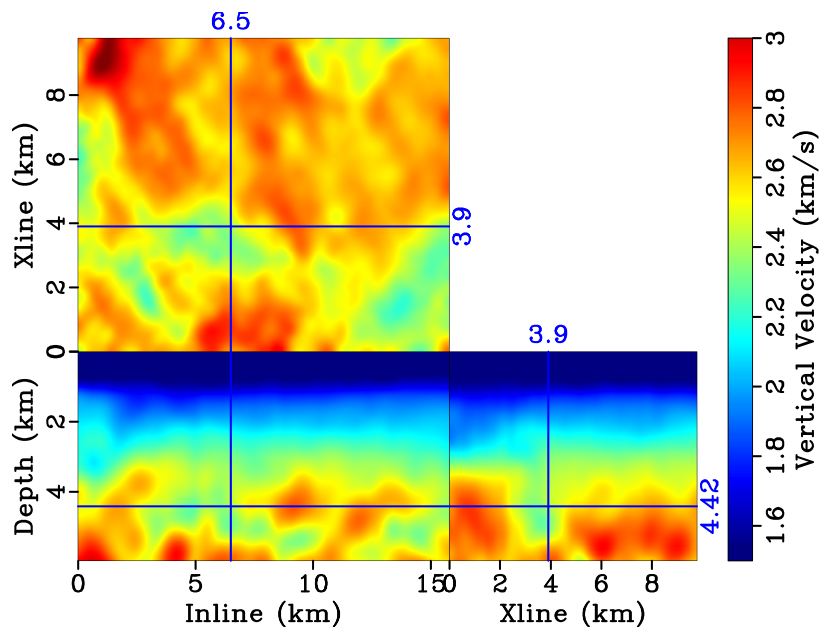


Figure 4: Inverted initial vertical velocity model. [**CR**]

## RTM ANALYSIS OF GENESIS DATASET

In this section, we use RTM to analyze the quality of the VTI model constructed in the previous section, and the production-induced time-lapse change.

We compute zero-offset RTM images and ADCIG at a selected 2D line (inline number 11040) from the Genesis dataset using the VTI wave equation (Zhang and Zhang, 2009). Figure 6 shows the results from the baseline survey and Figure 7 shows the results from the monitor survey. From the zero-offset image, we estimate 8 to 10 meters vertical shift of the reflectors after production. From the ADCIG,

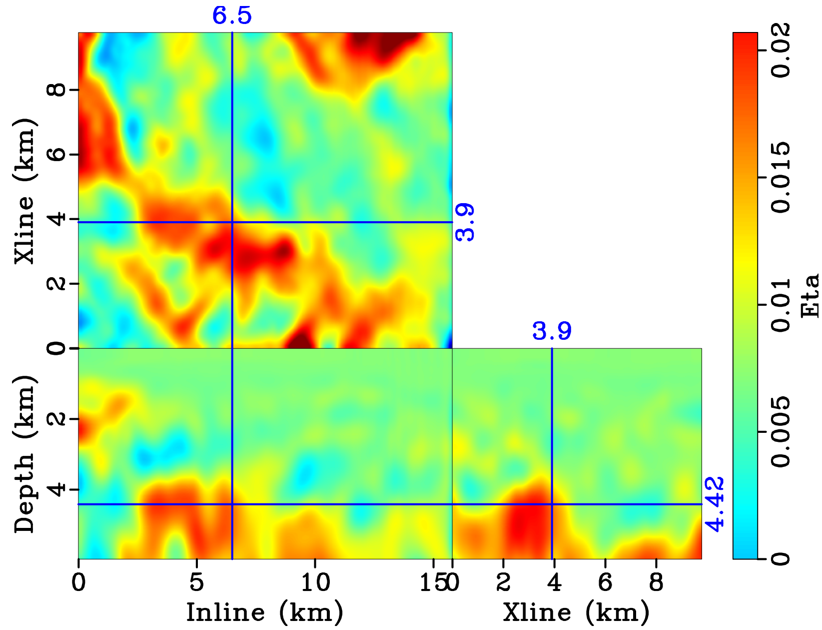


Figure 5: Inverted initial $\eta$ model. [**CR**]

at different midpoint locations around the reservoir location, we observe time-lapse change at different angles. The observations can be explained if there is a limited area affected by production in the overburden area (along the path of the well, for example).

After we have obtained the results in Figure 6 and Figure 7, we find evidence that the line we selected previously contains an acquisition gap and the gap is filled during the processing. To reduce the effect of the acquisition geometry, we choose a different 2D line away from the platform (inline number 11125) for the rest of the work in this report. In Figure 8, we show the overlay of the vertical velocity model and RTM image for the newly selected 2D line.

We computed ADCIG for the baseline survey and two monitor surveys from different processing workflows. The inaccuracy of the VTI model will lead to curvature in the angle gathers. In Figure 9, we show the ADCIG computed using the monitor datasets with offset up to 7200 meters. Most of the reflectors are flat in the angle gathers, indicating our initial VTI model is accurate.

## GRADIENT ANALYSIS FOR ANISOTROPIC PARAMETERS

In this section, we compute the FWI gradients on velocity and anisotropic parameters. The gradients will be used to update the baseline models and time-lapse change in the future.

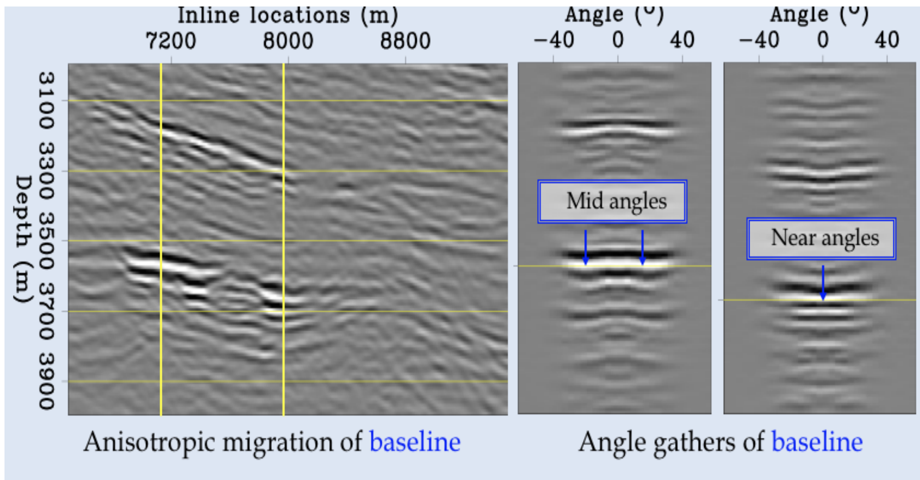


Figure 6: ADCIG from baseline dataset [**NR**]

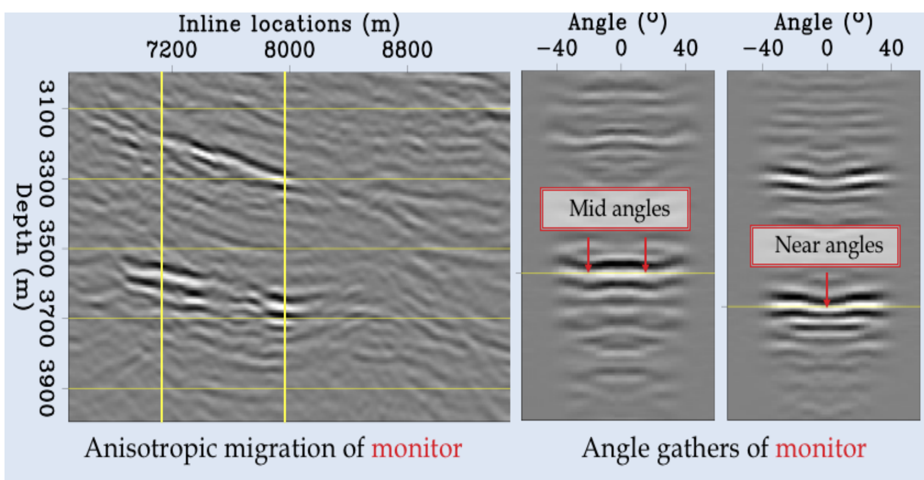


Figure 7: ADCIG from monitor dataset [**NR**]

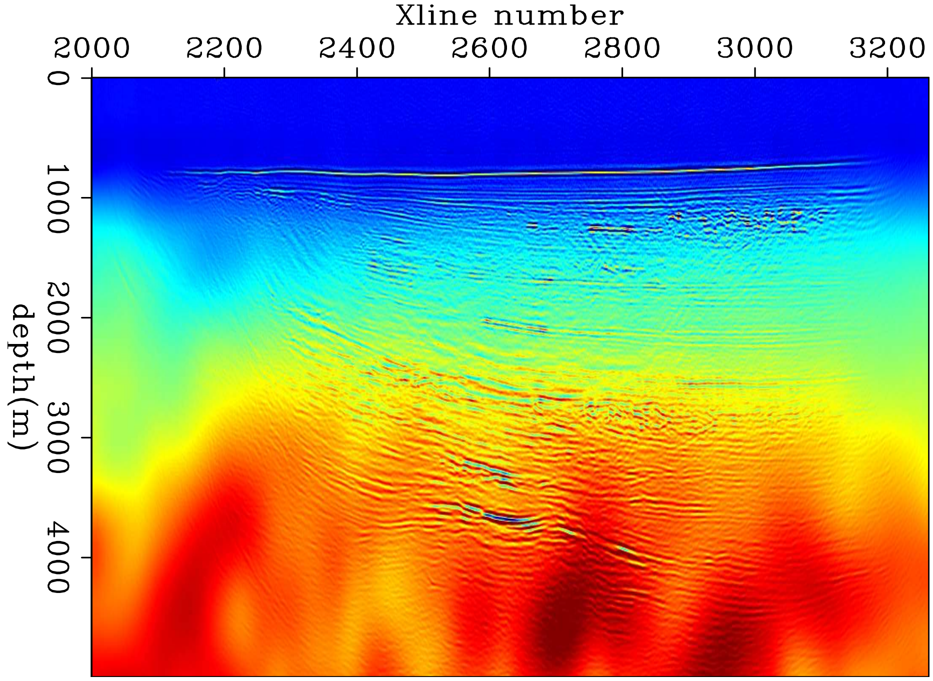


Figure 8: Overlay of RTM image and the velocity model [**CR**]

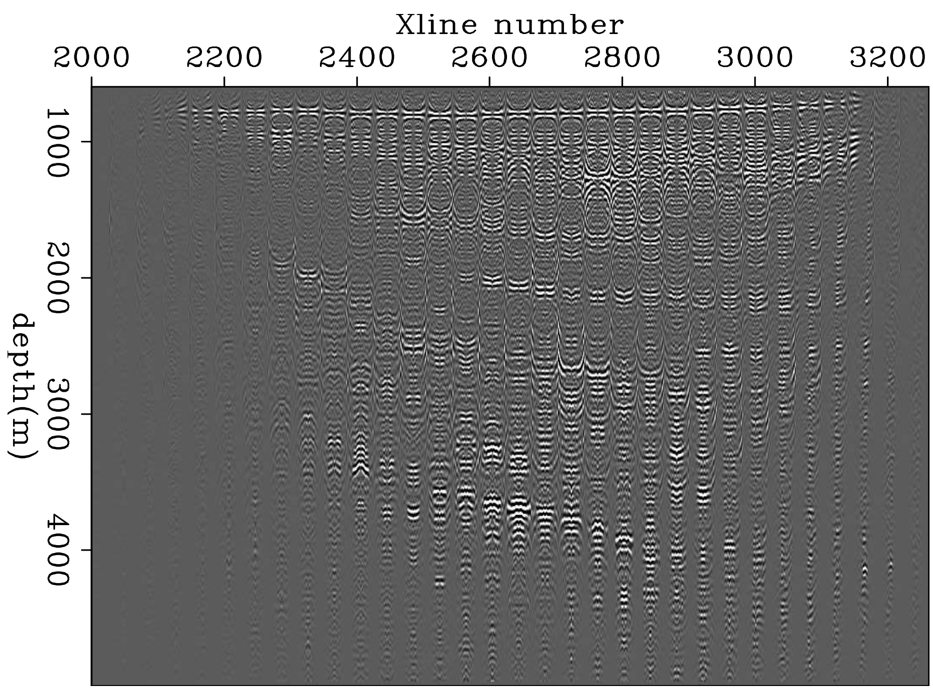


Figure 9: ADCIG computed with long offset monitor dataset. [**CR**]

We compare four sets of gradients from different dataset/offset ranges. First, we show the gradient from baseline data processed by CGG in Figure 10 and 11. Then we show gradients from monitor data processed by CGG in Figure 12 and 13. The gradients from monitor data processed by Chevron, with offset up to 4700 meters, shown in Figure 14 and 15. Finally gradients from monitor data processed by Chevron, with offset larger than 4700 meters, shown in Figure 16 and 17.

By comparing the baseline gradients and monitor gradients in Figure 10, 11, 12 and 13, we observe that they have similar structure away from the reservoir and the overburden area, indicating that we need to update the initial VTI model. The reflectors around the reservoir from the monitor data are deeper than the reflectors from the baseline data, caused by reservoir compaction and overburden dilation.

By comparing the monitor gradients from data processed by different workflows in Figure 12, 13, 14 and 15, we observe that the gradients register in most places, which validates our modification to the geometry of the data. The amplitude and signal-to-noise ratio are different which requires a careful design of the time-lapse FWI objective function for the Genesis dataset.

The gradients from far offset are shown in Figure 16 and 17. The shallow part of the model is not updated with far offset data because a stretch mute has been applied to the monitor data. The model around the reservoir and the overburden can still be updated from the far offset data.

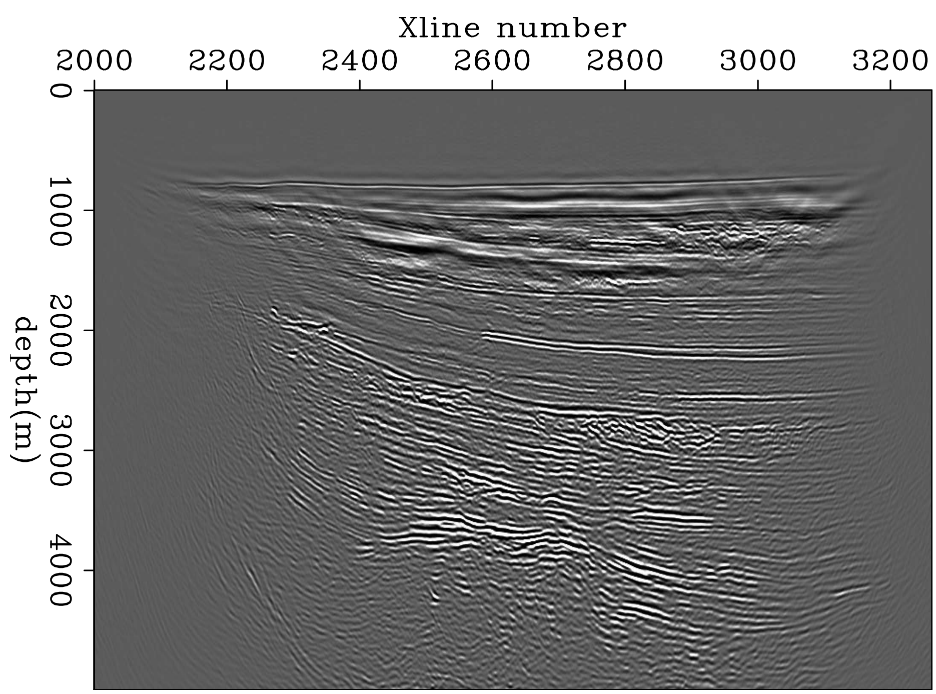


Figure 10: First gradient on velocity from baseline dataset. [**CR**]

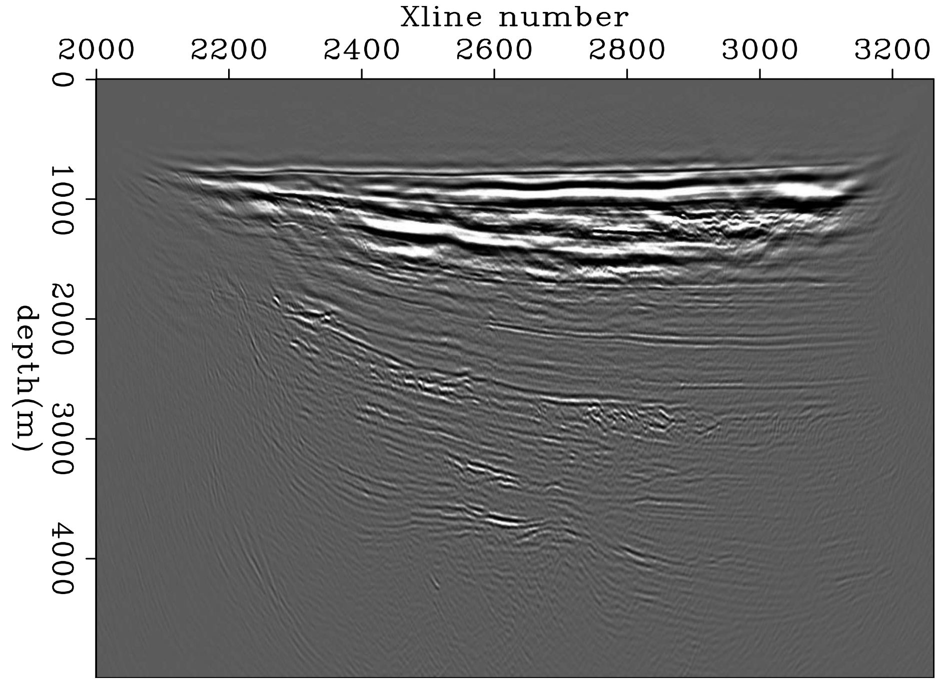


Figure 11: First gradient on $\varepsilon$ from baseline dataset. [**CR**]

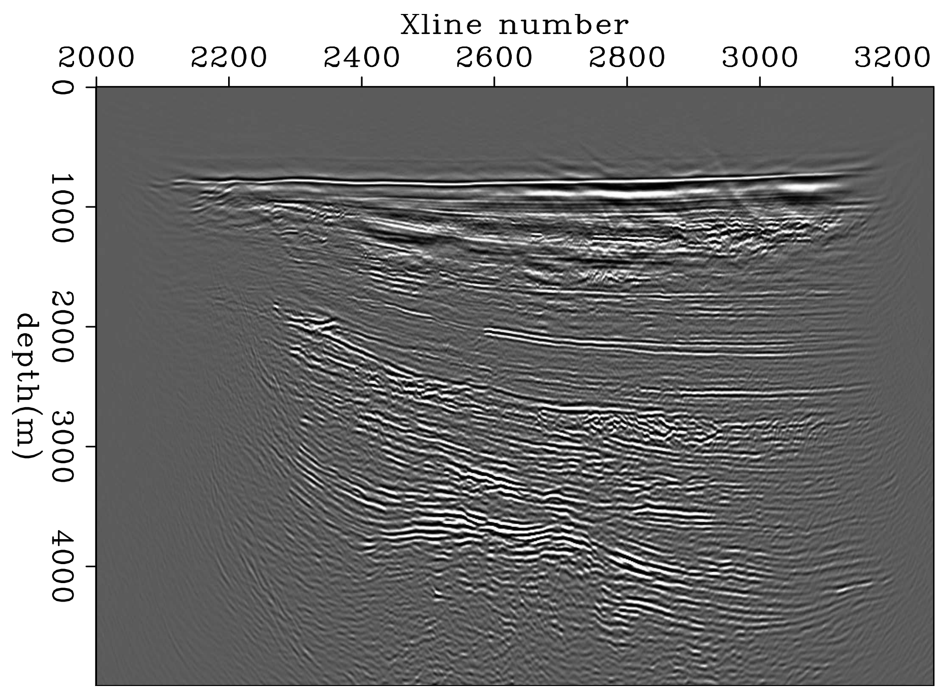


Figure 12: First gradient on velocity from monitor dataset processed by CGG. [**CR**]

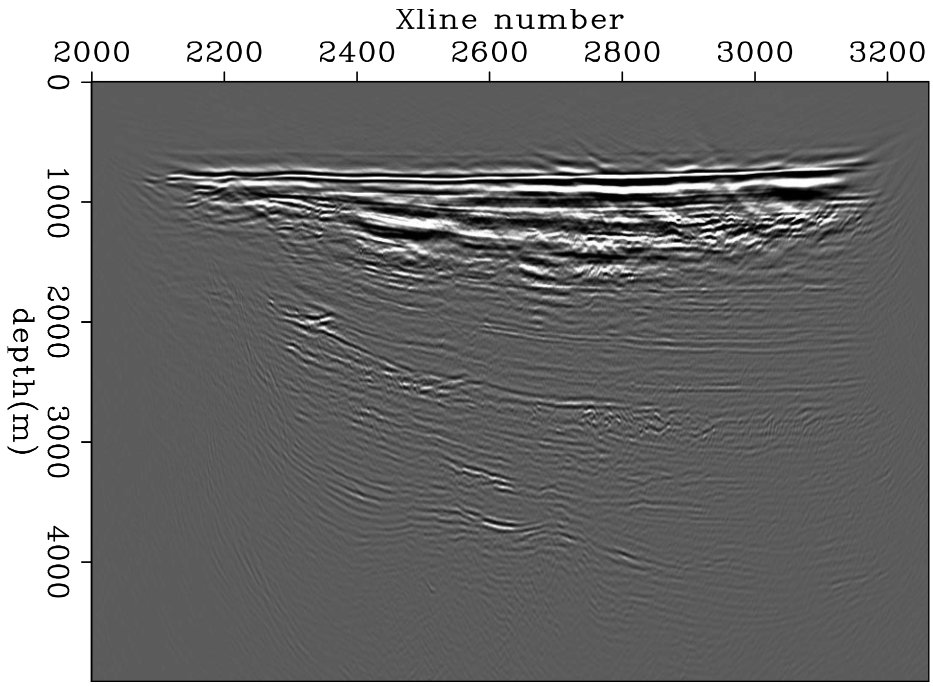


Figure 13: First gradient on $\varepsilon$ from monitor dataset processed by CGG. [**CR**]

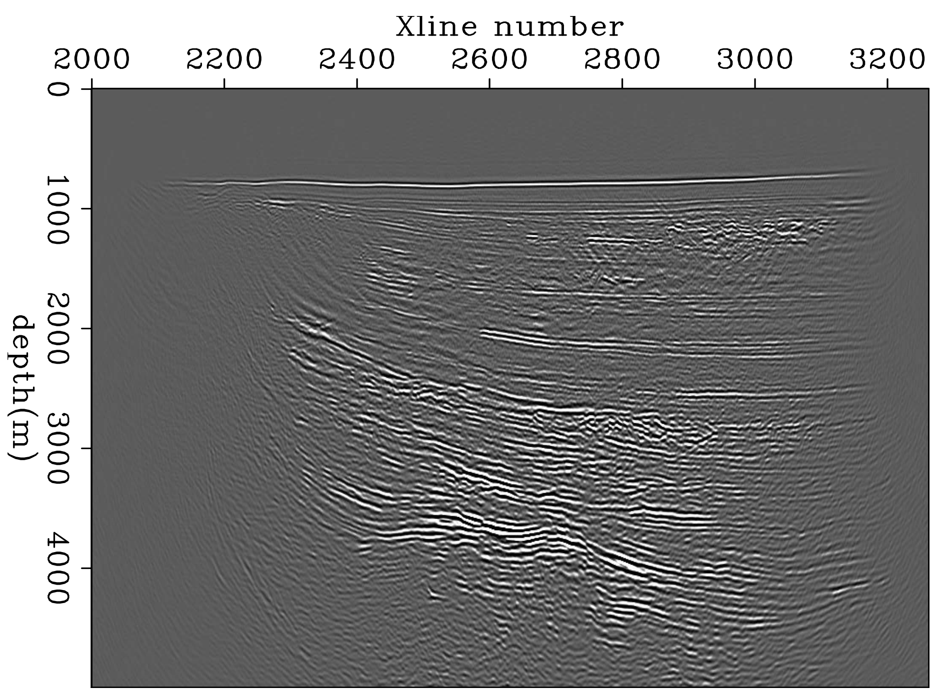


Figure 14: First gradient on velocity from monitor dataset processed by Chevron, with offset from 0 to 4700 meters. [**CR**]

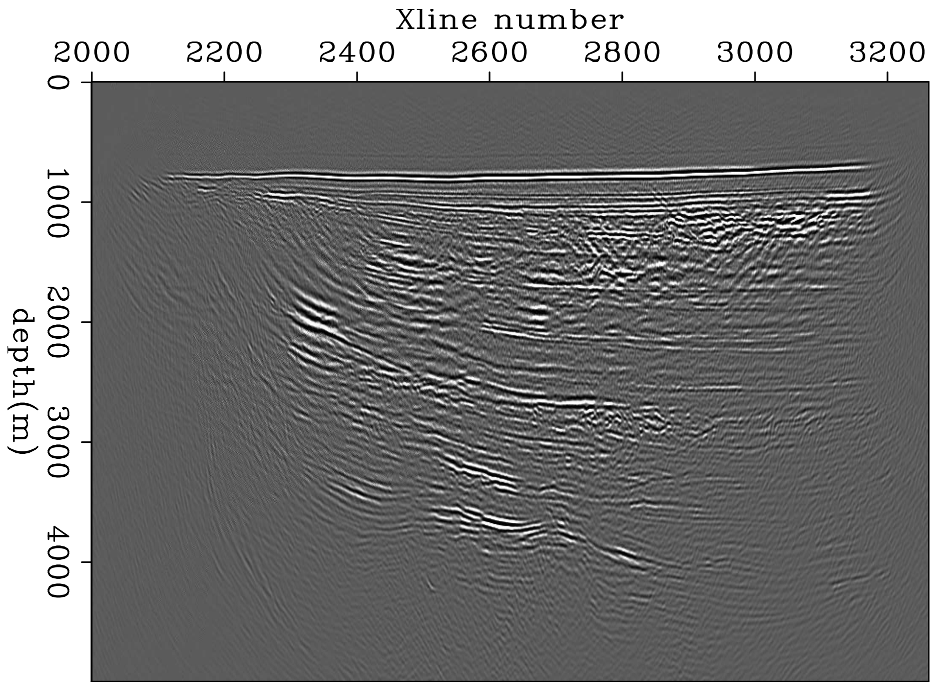


Figure 15: First gradient on $\varepsilon$ from monitor dataset processed by Chevron, with offset from 0 to 4700 meters. [**CR**]

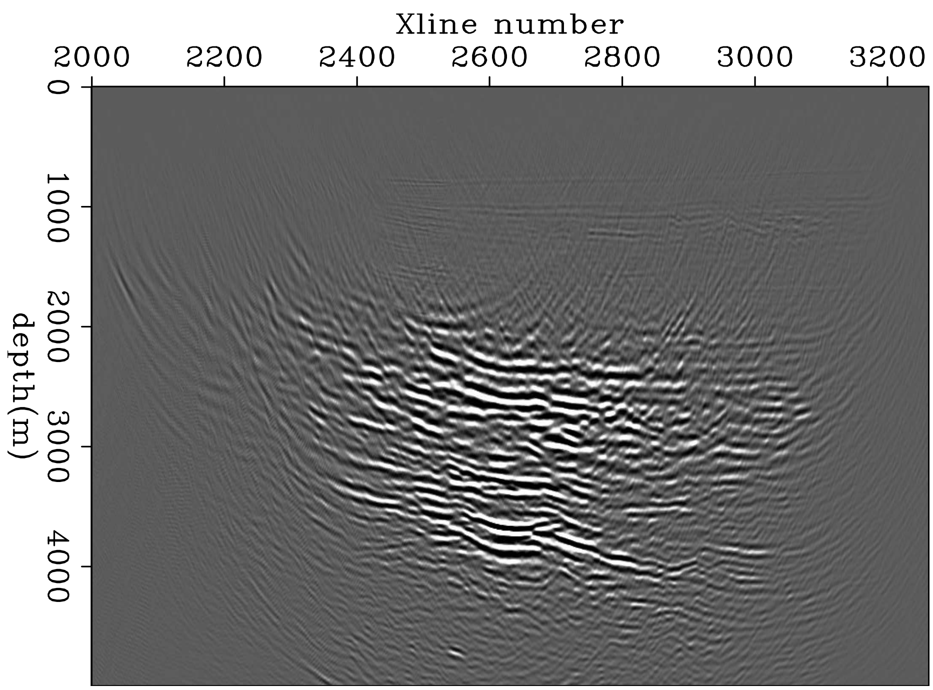


Figure 16: First gradient on velocity from monitor dataset processed by Chevron, with offset from 4700 to 7200 meters. [**CR**]

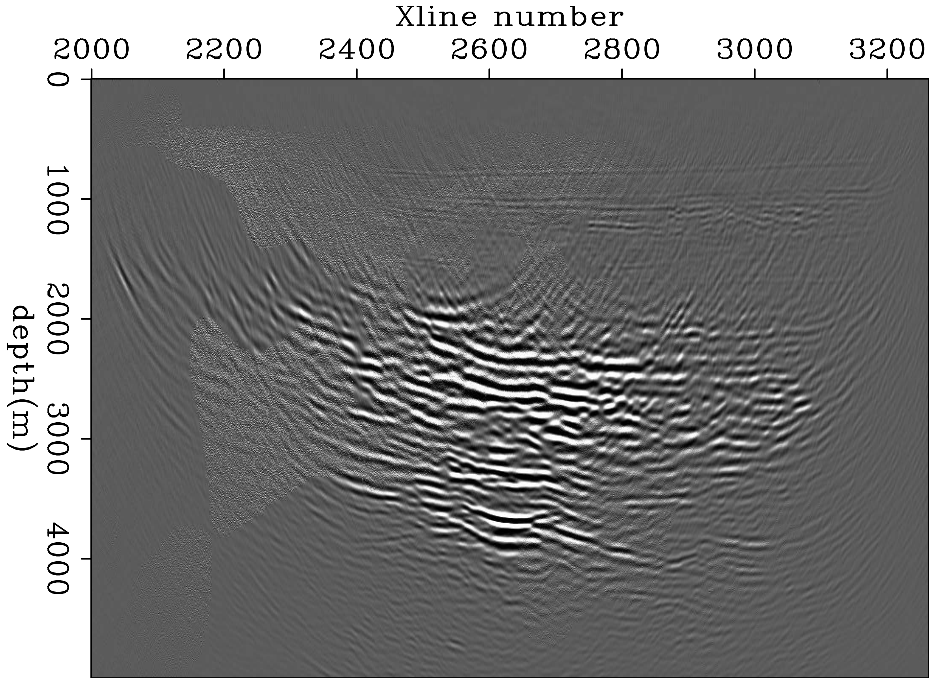


Figure 17: First gradient on $\varepsilon$ from monitor dataset processed by Chevron, with offset from 4700 to 7200 meters. [**CR**]

## CONCLUSIONS AND FUTURE WORK

In conclusion, we have processed the Genesis dataset for the purpose of wave-equation-based methods such as RTM and FWI. We modify the trace header information to align the data from different processing workflows. We have estimated a 3D initial VTI model based on time-domain image.

We compute zero-offset images and angle domain common image gathers. The accuracy of the initial VTI model is confirmed by the flatness of the ADCIG. We also use ADCIG to estimate the area that has observable time-lapse change. We compute gradients to update the vertical velocity and anisotropic parameters. The gradients suggest that the long offset data could potentially constrain the anisotropic parameters, which is critical to 4D anisotropic FWI study.

In the future we plan to estimate an accurate VTI model for the baseline and time-lapse change in the overburden area of the reservoir. One challenge is that baseline survey and monitor survey have different ranges of offset, and we may need to develop a new time-lapse FWI workflow to handle the unique acquisition geometry. Another challenge is that the data processed by different companies show different amplitude correction and signal-to-noise ratio, which requires a FWI objective function focuses only on the kinematics.

## ACKNOWLEDGMENTS

The authors would like to thank the sponsors of the Stanford Exploration Project for their support. We would also like to thank Chevron, ExxonMobil, and BHP for donating the dataset, and giving us the permission to publish the results.

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