Predicting pore-pressure from on-shore seismic data in the Delaware Basin

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Abstract

Based on wireline logs, core data and pressure information obtained directly during drilling, the various shale units within the Wolfcamp Formation in the Delaware Basin are known to be variably pressured with depth, and the pressure can change laterally within the same rock formation. Zones with anomalous high pressure can generally be linked to better producing wells. Unknown overpressured areas are also considered a drilling hazard and being able to predict these cells is of high interest. Pore-pressure prediction using on-shore seismic data is not trivial as the relationship between porosity and overpressure is complicated by a relatively complex geological history. A pre-stack facies-based seismic inversion process, capable of producing physical estimates of impedances and density, was used to invert the seismic dataset for facies and elastic properties. We are discussing this methodology and the results.

Introduction

In on-shore areas where the overpressure is complicated by relative complex geology, low permeability and the presence of TOC in the reservoir rocks, pressure variations can be difficult to measure, making calibration difficult. Pore pressure is a critical input to a geomechanical model and can impact the mechanical behavior of the well. Consequently, comparing the predictions of different geomechanical models can be used to help calibrate the pore pressure model. A well-based workflow was developed which was able to predict the pore pressure and construct a geomechanical model that matched the wellbore measurements. This model was then tested on wells with the requisite log dataset and was able to replicate the observed mechanical wellbore behavior, highlighting the accuracy of the pore pressure prediction.

The seismic dataset was inverted for facies and elastic properties using a facies based seismic inversion tool. This technology requires meticulous pre-processing that accurately preserves amplitude, phase, and bandwidth, and was integrated into DEVON's pre-drilling workflows in 2015. The inclusion of facies in the inversion process removes the requirement for a conventional low frequency model. This ensures that the distribution of laterally discontinuous units are defined only by the seismic reflectivity and not biased by any interpolation assumptions. Secondly, the inversion approach was calibrated using a set of facies-dependent elastic property trends, rather than a single set of trends for the whole inversion window. Therefore, the predicted elastic impedance properties could be expected to honor the rock physics relationships observed in the well log data with greater fidelity. This is important when considering the subsequent geological characterization and geomechanical analysis using the property volumes. The

well based workflow was then applied to inversion results to understand the efficacy of using seismic inversion for pressure prediction.

Method

The generalised workflow undertaken within this study can be summarised as follows;
1. Construct a 1D pore pressure prediction model and blind test against additional wells
2. Construct a 1D geomechanical model and blind test against additional wells. The results of Step 1 are a critical input into deriving the geomechanical model
3. Derive a 3D property model for compressional velocity (Vp), shear velocity (Vs), density (Rho), and lithofacies
4. Integrate the 1D models for pore pressure and geomechanics with the 3D elastic properties and generate a 3D understanding of pressure and stress
5. Calibrate the 3D seismic pressure attributes to production data

The pore pressure model was constructed using direct measurements of pore pressure, taken from either Dynamic Fracture Initiation Tests (DFIT), Drill-Stem Tests (DST), or by an influx as interpreted from the drilling history. The pressure data (expressed as Vertical Effective Stress (VES; Vertical Stress minus Pore Pressure) were cross-plotted against the compressional velocity (Vp) normalised to 5000 ft/s (Bowers, 1994). Each of these data points was then assigned a quality flag based on the lithology it was taken in and the confidence in the wireline data at the same depth. The primary concern was the role of cement producing fast velocities which would have skewed the Vp-VES model being derived. Secondary concerns were Total Organic Carbon (TOC) and in-situ gas but neither of these was a major concern within the reservoir intervals (but remain a source of uncertainty within the non-reservoir units). A test was performed using shear data (Vs) to derive the pressure model but a lack of measured shear sonic logs prevented us from using this approach. However, it is desirable to do this at a later time when either more measured or neural network derived shear logs are available. The final pore pressure model is shown in Figure 1.
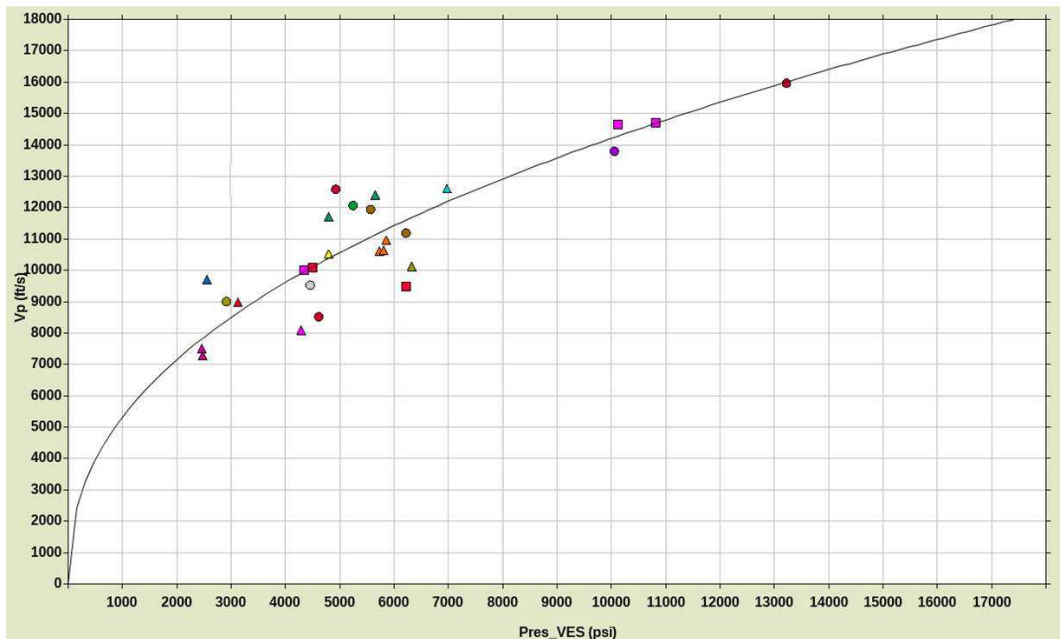

Figure 1: Compressional velocity versus Vertical Effective Stress (VES) cross-plot. The data for this analysis comprised of a series of direct pressure measurements during drilling and measured compressional velocity logs from within the Delaware Basin. The shown power law relationship is used to predict VES and pore-pressure from seismic data.

The geomechanical analysis commenced with an interpretation of available image logs, figure 2. Observations of drilling induced tensile fractures were noted. A 1D analytical geomechanical model was then constructed using the poro-elastic equations (Thiercelin & Plumb, 1994) and the elastic properties calculated from the well logs, using core data to constrain the dynamic to static conversion. The regional strain parameters were calibrated to the minimum horizontal stress by solving the circumferential (hoop) stress around a vertical borehole and matching the predicted shear failure to the occurrence (and non-occurrence) of drilling induced tensile fractures observed in the image logs. The calibrated model was then applied using the up-scaled elastic log data to verify that the expected resolution of the property volumes to be determined by the seismic inversion would be sufficient to predict the tensile failure observed in the image logs. This method only works in areas where the regional strain direction stays static.
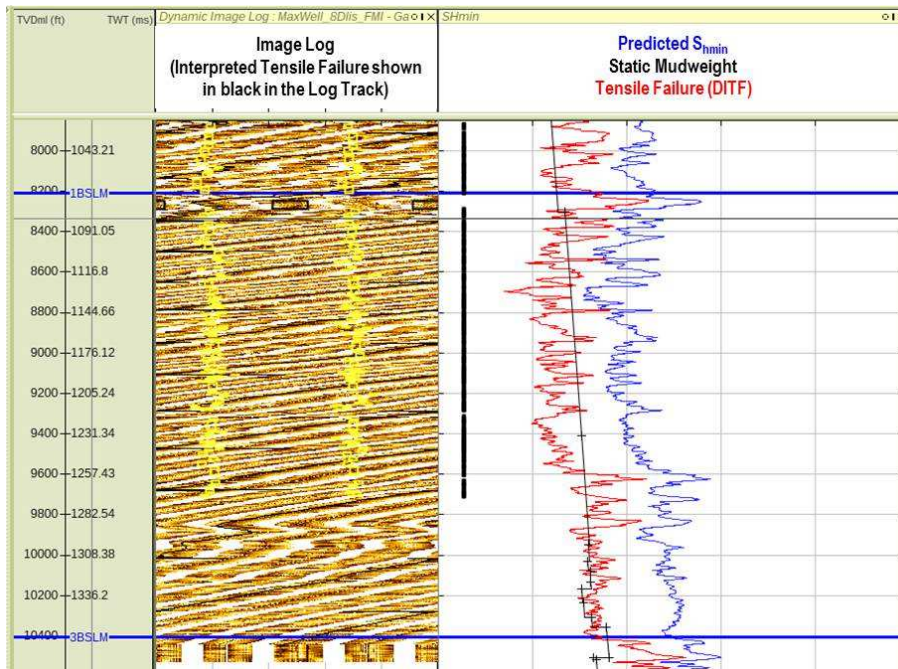

Figure 2: Log derived minimum horizontal stress curve (blue) and tensile failure curve (red) based on the 1D geomechanical model. The model matches the observed wellbore failure as the tensile failure curve is lower pressure than the mudweight (black line).

The seismic inversion used a facies-based Bayesian pre-stack approach (Kemper and Gunning, 2014). There are two key advantages to applying this approach. First, the inclusion of facies in the inversion process removes the requirement for a conventional low frequency model. This ensured that the distribution of laterally discontinuous debris flow units is defined only by the seismic reflectivity and not biased by any interpolation assumptions. Second, the inversion approach was calibrated using a set of facies-dependent elastic property trends, rather than a single set of trends for the whole inversion window. Therefore, the predicted elastic impedance properties could be expected to honor the rock physics relationships observed in the well log data with greater fidelity. This is important when considering the subsequent geological characterization and geomechanical analysis using the property volumes such as the Vp and density.

Results

Figure 3 displays a comparison of the predicted (blue) and observed (red) minimum horizontal stress and reveals an accurate match to the recorded DFIT (red circle). The black curve shows the predicted pore pressure model. The well shown in this figure was not used to calibrate the geomechanical model and provides a blind test of this model.
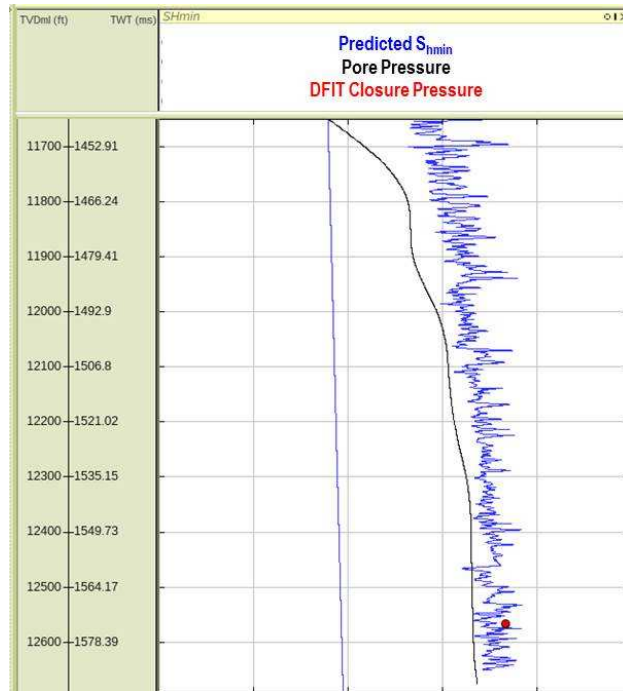
Figure 3: Log derived minimum horizontal stress (blue) based on the calculated geomechanical model and the interpreted pore pressure (black). Both curves match the observed fracture pressure measurement taken in the well (DFIT, red circle).

Figure 4 represents an arbitrary line that was extracted from the calculated pore pressure volume. Blue colours indicate low and red/yellow colours high pressure zones. The black horizon represents the target horizons. Around this interval, the pressure values are lower in some areas.
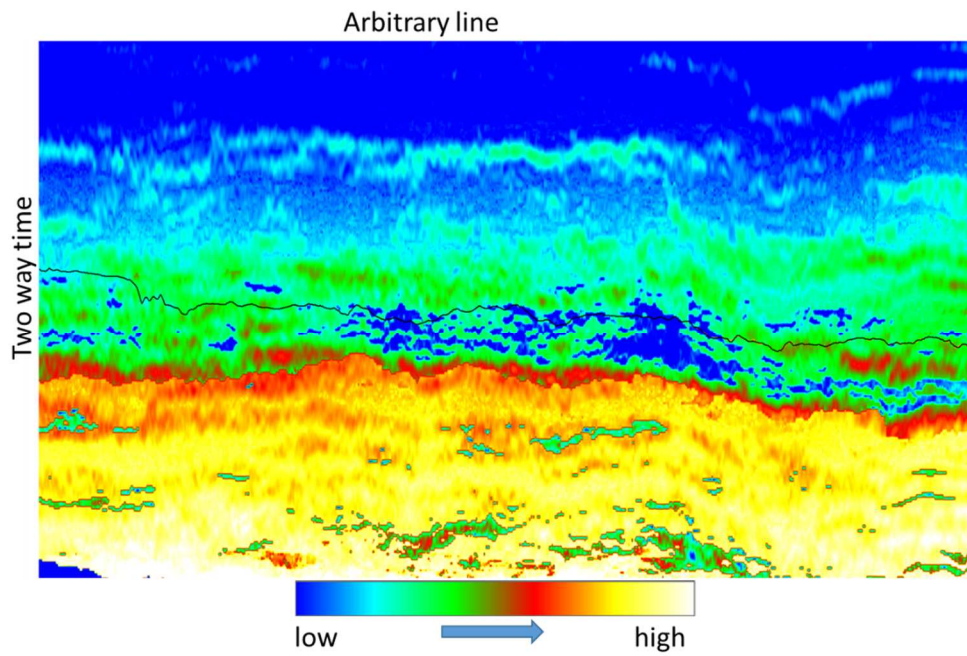
Figure 4: Arbitrary line of pressure volume. Black horizon represents target interval.
Figure 5 displays a target horizon pore pressure map. The absolute values of the pore pressure were extracted using a plus/minus 10ms window. A clear north to south low pressure trend is evident and is in alignment with our current understanding of the reservoir pressure in this part of the Delaware Basin.
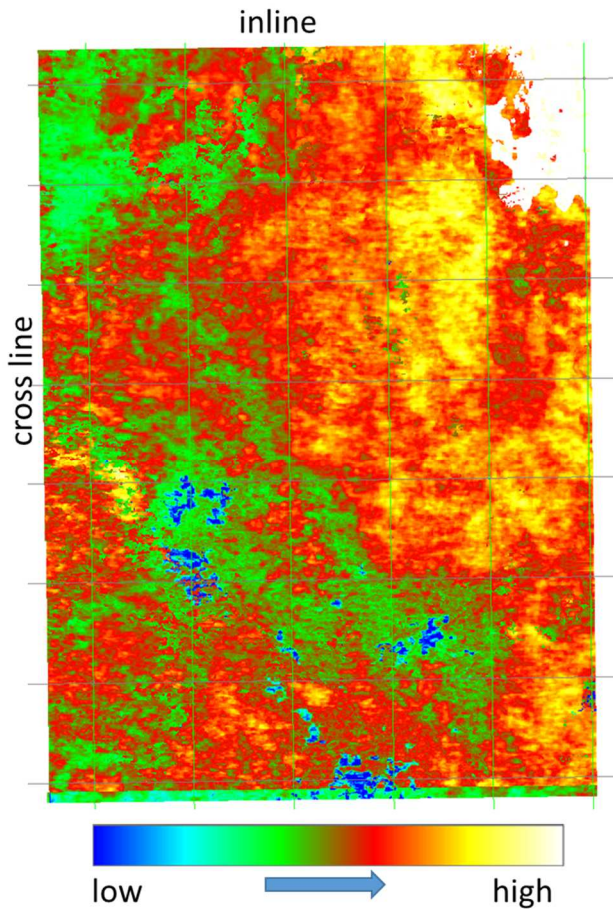

Figure 5: Target horizon pore pressure map. Blue/green colours indicate lower pressure zones.

Conclusions

A pre-stack facies-based seismic inversion process, capable of producing physical estimates of impedances and density, was used to invert the seismic dataset for facies and elastic properties. This technology requires meticulous pre-processing that accurately preserves amplitude, phase, and bandwidth, and was integrated into the pre-drilling workflows in 2015. The inclusion of facies in the inversion process removes the requirement for a conventional low frequency model. This ensures that the distribution of laterally discontinuous units are defined only by the seismic reflectivity and not biased by any interpolation assumptions. Secondly, the inversion approach was calibrated using a set of facies-dependent elastic property trends, rather than a single set of trends for the whole inversion window. Therefore, the predicted elastic impedance properties could be expected to honour the rock physics relationships observed in the well log data with greater fidelity. This is important when considering the subsequent geological characterization and geomechanical analysis using the property volumes. The well based workflow was then applied to inversion results to understand the efficacy of using seismic inversion for pressure prediction. The results are very encouraging and are in alignment with our understanding of the pressure variations within the Delaware Basin.

References

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