Correlation of azimuthal velocity anisotropy and seismic inversion attributes to Austin Chalk production: a south central Texas case study

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Summary

The Austin Chalk play is a productive geologic trend that extends from southern Maverick County, TX near the Mexican Border more than 300 miles to the northeast to Madison County, TX. Giddings Field lies near the eastern end of this trend and has been a focus of Austin Chalk development since the early 1970s. In 2015, a 710 square mile, high-fold, wide-azimuth onshore 3D seismic survey was acquired with a primary objective of imaging the Austin Chalk and Eagle Ford reservoir intervals within Giddings Field. Azimuth-preserving, AVO-compliant processing was performed over a 50 square mile test area within this dataset to evaluate the possible integration of seismic inversion and azimuthal velocity anisotropy (VVAZ) attributes to help guide future development of the field. This evaluation revealed strong correlations between these seismic attributes and historical production within the test area.

Introduction

The Upper Cretaceous Austin Chalk is a low permeability formation made up of micritic chalks interbedded with marls of varying clay content (Dawson, 1995 among others). Average matrix porosity is generally very low, so fracture systems with primary orientation parallel to the underlying Lower Cretaceous shelf edge (NE-SW in the Giddings area) provide the permeability and storage capacity to support commercial oil and gas production (Pearson, 2012). The source rock responsible for charging the fracture system within the Austin Chalk interval is the underlying organic rich Eagle Ford shale.

Oil was first produced in commercial quantities from vertical wells within Giddings field beginning in 1973. A second phase of development coincided with the advent of early horizontal drilling in the mid 1980’s but really came into full swing in the early 1990’s as horizontal drilling technology became more reliable and repeatable (Haymond, 1991). These wells were generally open-hole completions that were treated with a small amount of acid before flow-back. Given this completion methodology, it was vital for horizontal wells to encounter natural fractures in order establish commercial production. It is not until more recently that wells have begun to be completed using modern hydraulic fracturing techniques. As will be seen later, this lack of hydraulic fracturing completion overprint greatly simplifies our analysis in comparison to other, more recently developed unconventional plays.

Within Giddings Field, the Austin Chalk formation ranges from 6,000-11,000 ft depth. Within the 3D seismic test area, the Austin Chalk is approximately 800 ft thick and is underlain by 150 ft of Eagle Ford shale. The highly fractured nature of the Austin Chalk and Eagle Ford Shale as well as the large combined thickness of the interval make this an ideal candidate for VVAZ analysis. Indeed, prior authors have noted high degrees of azimuthal anisotropy within the Austin Chalk formation in this area as well (Lynn, 2000).

Methodology

In 2015, Seitel, Inc. acquired a 195-fold wide-azimuth 3D that was designed with 990 ft source line spacing, 1155 ft receiver line spacing, 165 ft shot and receiver group intervals, and an active patch size of 28,875 x 29,935 ft. Natural binning for this survey is 82.5 x 82.5 ft.

Within a 50 square mile subset of the 3D seismic survey, processing was performed by Arcis Seismic Solutions using a flow designed to preserve amplitude variations across both offset and azimuth coordinates. One of the key pieces of this processing flow involved 5D interpolation onto a mixed Cartesian-polar coordinate grid defined by cmp-x, cmp-y, offset, and azimuth. This choice of grid definition allowed for the generation of a densely sampled set of CMP gathers, regularly sampled across both offset and azimuth domains. Interpolated traces that existed too far from recorded data traces to be considered reliable were culled prior to grouping the remaining traces by common offset-azimuth indices to produce single-fold common offset vector ensembles for input into prestack time migration (in this case a “VTI-aware” migration was performed in which the travel time engine included the effects of vertical transverse isotropy). Following VTI-PSTM, the data were submitted to a post-migration noise attenuation process operating piecewise on individual azimuth “spokes”. This process is described in detail in a companion paper (Perz et al., 2017). Finally these noise-attenuated data were input toVVAZ inversion via the Generalized Dix Inversion methodology in order to generate Vint-fast, Vint-slow, and Vint-fast azimuth from their corresponding RMS counterparts (Grechka, 1999).

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Interpretation

The resulting map from these interval VVAZ attributes for the Top Austin Chalk to Top Buda interval is shown in Figure 1. The map is comprised of glyphs plotted at the center of 9 bin blocks throughout the 3D test area, the symbology of which is described in detail within the figure caption. Vint-fast is variable across the survey area, particularly in the vicinity of faults. However, areas with high percent anisotropy (i.e. long glyphs) tend to have a very stable Vint-fast azimuth of roughly N45ºE. These areas also tend to be associated with anomalously slow Vint-slow values (red glyph colors). We interpret these high percent anisotropy fairways to be associated with areas that exhibit a high degree of natural fracturing oriented parallel to the Vint-fast azimuth. Imaging of fault patterns within the test area suggests a highly complex series of overprinting episodes of normal faulting at various azimuths, likely related to movement of the underlying Louann Salt. However, it is interesting to note that despite this structural complexity, Vint-fast azimuth within the high anisotropy fairways is a very stable N45ºE. Perhaps not coincidentally, this azimuth is parallel to the regional maximum horizontal compressive stress, possibly indicating that natural fractures with this orientation may preferentially be more open than fractures oriented at other

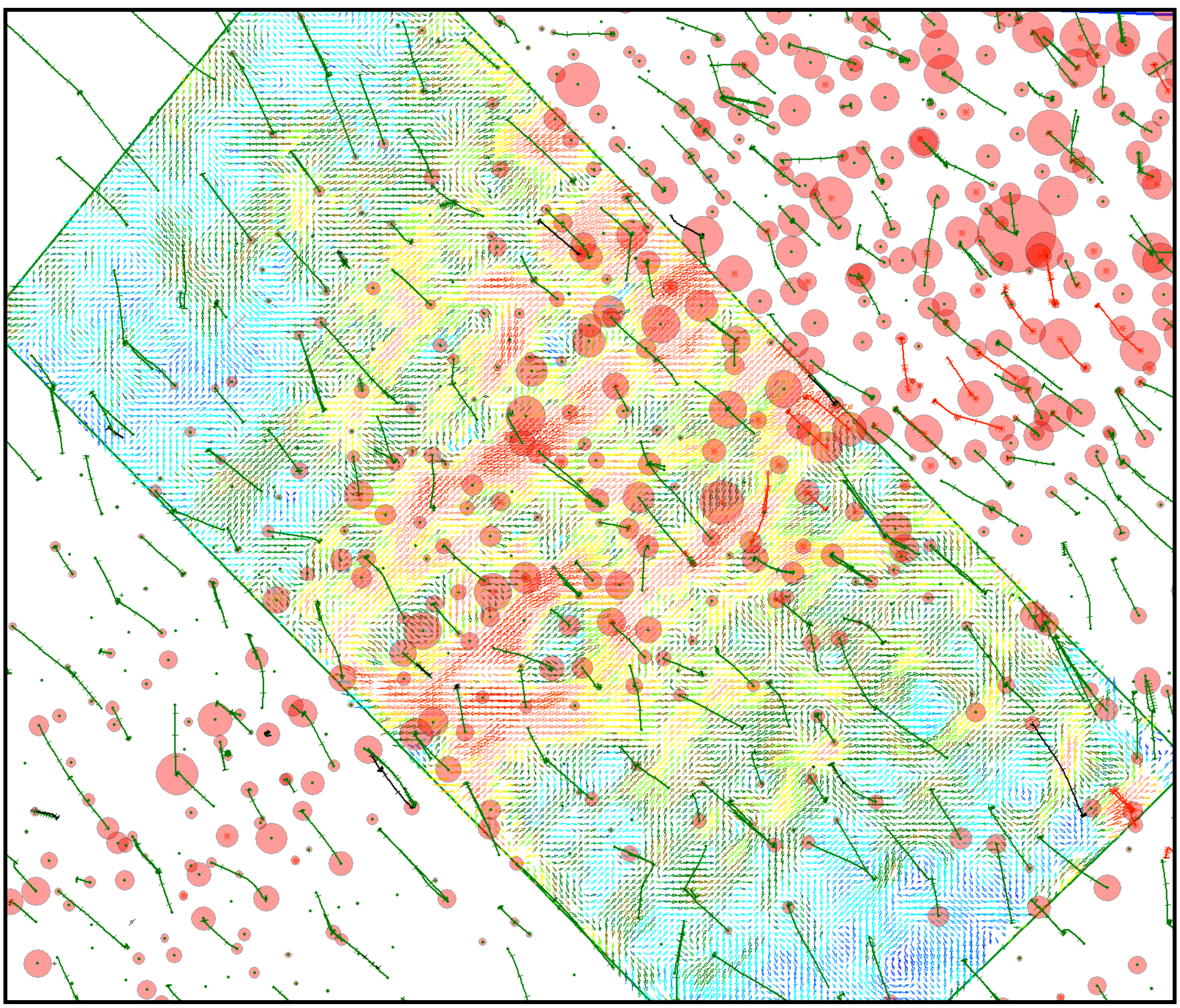

Figure 1: Azimuthal interval velocity anisotropy map with cumulative production bubble overlay. The reservoir zone used for calculation of the interval velocity attributes extends from the top of the Austin Chalk to the top of the Buda and thus encompasses the entirety of the Austin Chalk and Eagle Ford formations. The interval velocity attributes are displayed as follows: glyph color = Vint-slow (warm colors are slower than cold colors), glyph length = % Vint Anisotropy, glyph azimuth = Vint-fast azimuth. The map shows a clear visual correlation between the interval velocity attributes and cumulative Austin Chalk production.

azimuths.

Interpretation of high percent anisotropy fairways as corresponding to highly fractured areas is consistent with the observation that these fairways are also associated with elevated production (i.e. larger production bubbles shown in Figure 1). Although not completely straightforward, indications of pressure communication tend to occur between producing wells along a roughly N45ºE azimuth parallel to Vint-fast azimuth, and are most common within areas that exhibit a high degree of fracturing. Indications of pressure communication can include mud losses while drilling infill wells, abrupt changes to offset well production history once an infill well is brough online, etc. The observation that pressure communication tends to preferentially occur at an azimuth of N45ºE is also generally consistent with the VVAZ attributes.

In addition to the strong visual correlation of cumulative Austin Chalk production to the VVAZ attribute map in Figure 1, a multivariate analytics model was generated using Transform software and three seismic attributes as input explanatory variables. In order to perform this analysis, we first selected a subset of 50 horizontal Austin Chalk producing wells that had reliable production history

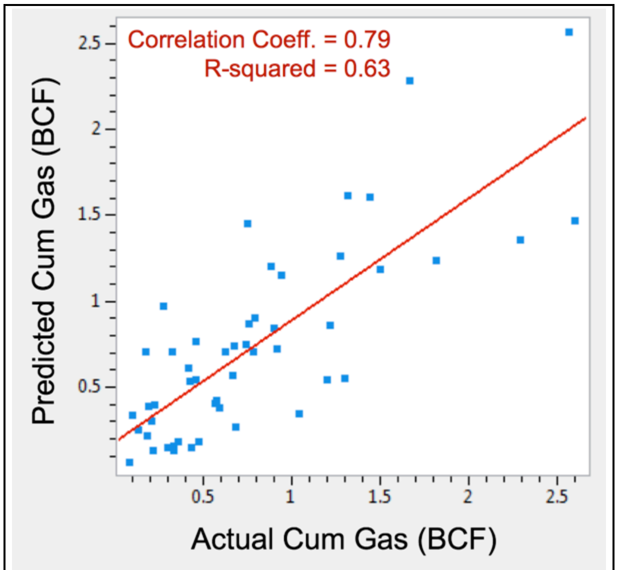

Figure 2: Actual versus predicted cumulative gas production for 50 wells within the 3D seismic test area. Values were extracted from seismic attribute maps along horizontal wellbores and written to wellbore zones. These zone values were then used as explanatory input variables in a non-linear multivariate analytics model in order to predict cumulative gas production. The linear regression of actual vs. predicted values for cum production is ullustrated by the red line above (correlation coefficient = 0.79, r-squared 0.63).

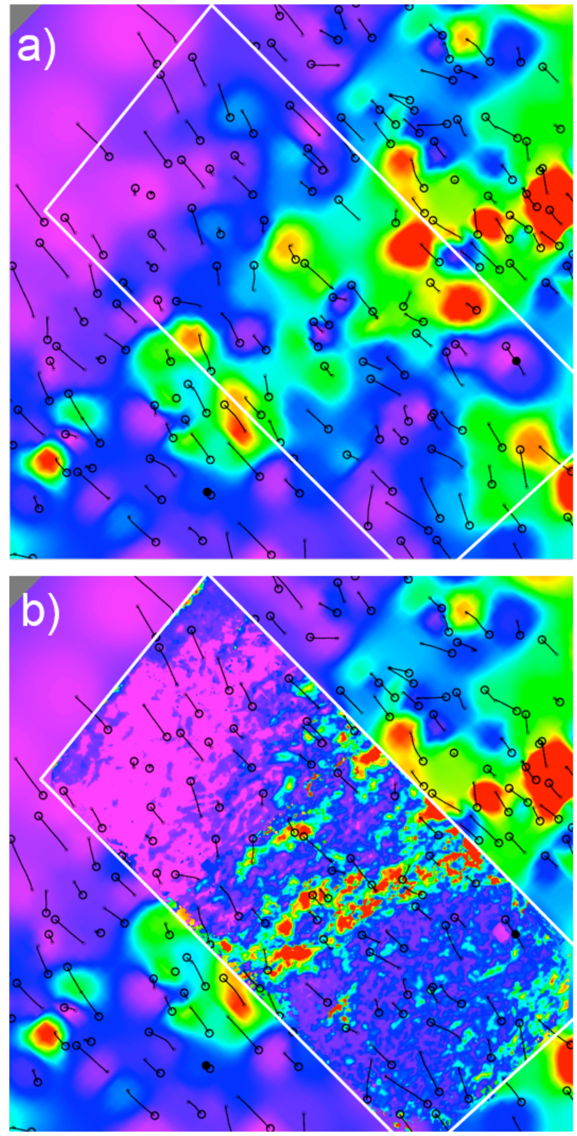

Figure 3: a) Cumulative gas production grid generated from Austin Chalk well production data. Warm colors indicate higher production. The white rectangle denotes the 3D seismic test area, and well locations are shown in black. b) Seismic attribute predicted cumulative gas production grid overlying the cumulative gas production grid from part a). Three seismic attributes were included as explanatory input variables in a non-linear multivariate analytics model in order to predict cumulative gas production.

and were free of production allocation uncertainties. We then generated three seismic attribute maps for input into the model – P Impedance, V-int slow, and Horizontal Stress. P Impedance was generated using the prestack simultaneous model based inversion methodology described by Hampson and Russel (2005). V-int slow was generated using the VVAZ inversion methodology described in the previous section of this paper, and Horizontal Stress was generated by utilizing the following equation (Sayers, 2010):

Horizontal Stress = (PR)/(1-PR) * vertical stress

In this case, poisson's ratio (PR) is calculated from interval velocities where Vp = Vint-slow and Vs is estimated from Vint-slow using a linear transformation derived from measured dipole sonic logs within the test area.

Values were extracted from these three seismic attribute maps along the horizontal wellbore trajectory for each of the 50 wells to be included in the model. These values were then saved as well scalar attributes and used as input variables for the non-linear multivariate analytics model. The resulting actual cum gas production vs. predicted cum gas production cross plot is shown in Figure 2. A linear regression analysis of this cross plot yields a correlation coefficient of 0.8 and an r-squared value of 0.63, a remarkable result given the fact that no engineering or drilling parameters were included in the analysis.

Once the multivariate analytics model was generated, we were then able to calculate a production prediction map by utilizing the three seismic attribute maps as input. The resulting map is shown in Figure 3 b). One can easily see the uplift in spatial resolution and granularity relative to the gridded cumulative production map generated only from well control that is shown in Figure 3 a). The features that can be seen in the predicted production map look geologically reasonable, and suggest that the fracture fairways that are related to highest production can actually be quite narrow and well defined linear features in map view. Areas of lower production are likely related to areas of less intense faulting and fracturing.

Conclusions

Seismic inversion and VVAZ attributes were generated within a 50 square mile subset of a 3D seismic survey acquired over Giddings Field. The VVAZ attributes exhibit a strong visual correlation to cumulative Austin Chalk production in the area and may be attributed to two main factors. First, because of the history of development within this field, the impact of completion overprint appears to be minor. Most of the wells are open hole completions that were not hydraulically fractured. Secondly, the Austin Chalk is a very thick and highly anisotropic interval that is ideally suited for this type of azimuthal velocity analysis. In cases where VVAZ results appear to be disappointing, the culprit may be lack of strong HTI anisotropy and or a target interval that is insufficiently thick to create stable results.

The results generated with the three-term multivariate analytics model are encouraging and appear to be geologically reasonable within the test area. Future work includes further refinement of this model and expansion of this processing and interpretation methodology to a larger area of the 3D survey.

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EDITED REFERENCES

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REFERENCES

Dawson, W. C., K. Barry, and Robison, V. D., 1995, Austin Chalk petroleum system Upper Cretaceous, southeastern Texas: A case study: Transactions — Gulf Coast Association of Geological Societies, **45**, 157–163.

Hampson, D. P., B. H. Russell, and B. Bankhead, 2005, Simultaneous inversion of pre-stack seismic data: 75th Annual International Meeting, SEG, Expanded Abstracts, 1633–1637, http://doi.org/10.1190/1.2148008.

Haymond, D., 1991, The Austin Chalk — An overview: Houston Geological Society Bulletin, **33**, 27–34.

Lynn, H. B., L. Weathers, and W. Beckham, 2000, The mobil onshore texas 3D full-azimuth full-offset P-wave survey: 9th International Workshop on Seismic Anisotropy, Abstract at http://9iwsa.seg.org/abstracts.

Pearson, K., 2012, Geologic models and evaluation of undiscovered conventional and continuous oil and gas resources—Upper Cretaceous Austin Chalk, U.S. Gulf Coast: U.S. Geological Survey Scientific Investigations Report 2012–5159, 26.

Sayers, C. M., 2010, Geophysics under stress: Geomechanical applications of seismic and borehole acoustic waves: SEG and EAGE.

Vladimir, G., I. Tsvankin, and J. K. Cohen, 1999, Generalized Dix equation and analytic treatment of normal-moveout velocity for anisotropic media: *Geophysical Prospecting,* **47**, 117–148, http://doi.org/10.1046/j.1365-2478.1999.00120.x.