

INSIGHTS INTO THE ANADARKO BASIN

In the current market companies are required to increase emphasis on efficiency and competitiveness within and between various play trends. Companies have undergone considerable restructuring to reduce costs and overheads, so what is next? With thin margins companies must assess 'costs' versus 'investments' which provide an appropriate return. No different than other cycles, the key drivers for success will be innovation and application of work flows and products that deliver enhanced productivity.

This article provides a perspective on how integration of well data, high resolution seismic, basin wide modelling, and advanced integrated interpretation delivers valuable insight into delivering results.

Anadarko Basin: geology

The Anadarko Basin is a mature hydrocarbon producing trend which remains one of the most significant and active exploration and development areas in the onshore US. New plays continue to emerge

FELICIA BRYAN, JAMES KEAY, BRAD TORRY, PETER CARY, AND IAN DEIGHTON, TGS, EXPLAIN HOW DATA INTEGRATION BRINGS ADVANCED GEOTECHNICAL UNDERSTANDING TO THE SCOOP AND STACK.



along the eastern flank, with the SCOOP and STACK trends receiving much of the recent attention. Elongated northwest – southeast and extending to southern Kansas and southeast Colorado, the Anadarko Basin is asymmetric, dipping to the south-southwest with the deepest portion of the basin centred in the eastern Texas Panhandle and western Oklahoma (Figure 1).

The basin formed by subsidence throughout the Paleozoic, and subsequently reshaped by the Wichita Orogeny in the

Mississippian and Pennsylvanian. It is bounded sharply on the south by the Amarillo uplift and Wichita Mountain fault zone and to the east by the Nemaha Uplift.

With knowledge of the structural history and influences, next must come an understanding of the petroleum systems and the rocks. Basin fill is primarily lower and middle Paleozoic carbonates (with a few notable clastic units) and mixed lithologies in the upper Paleozoic. The depositional history is complex, setting up an extensive variety of stratigraphic plays

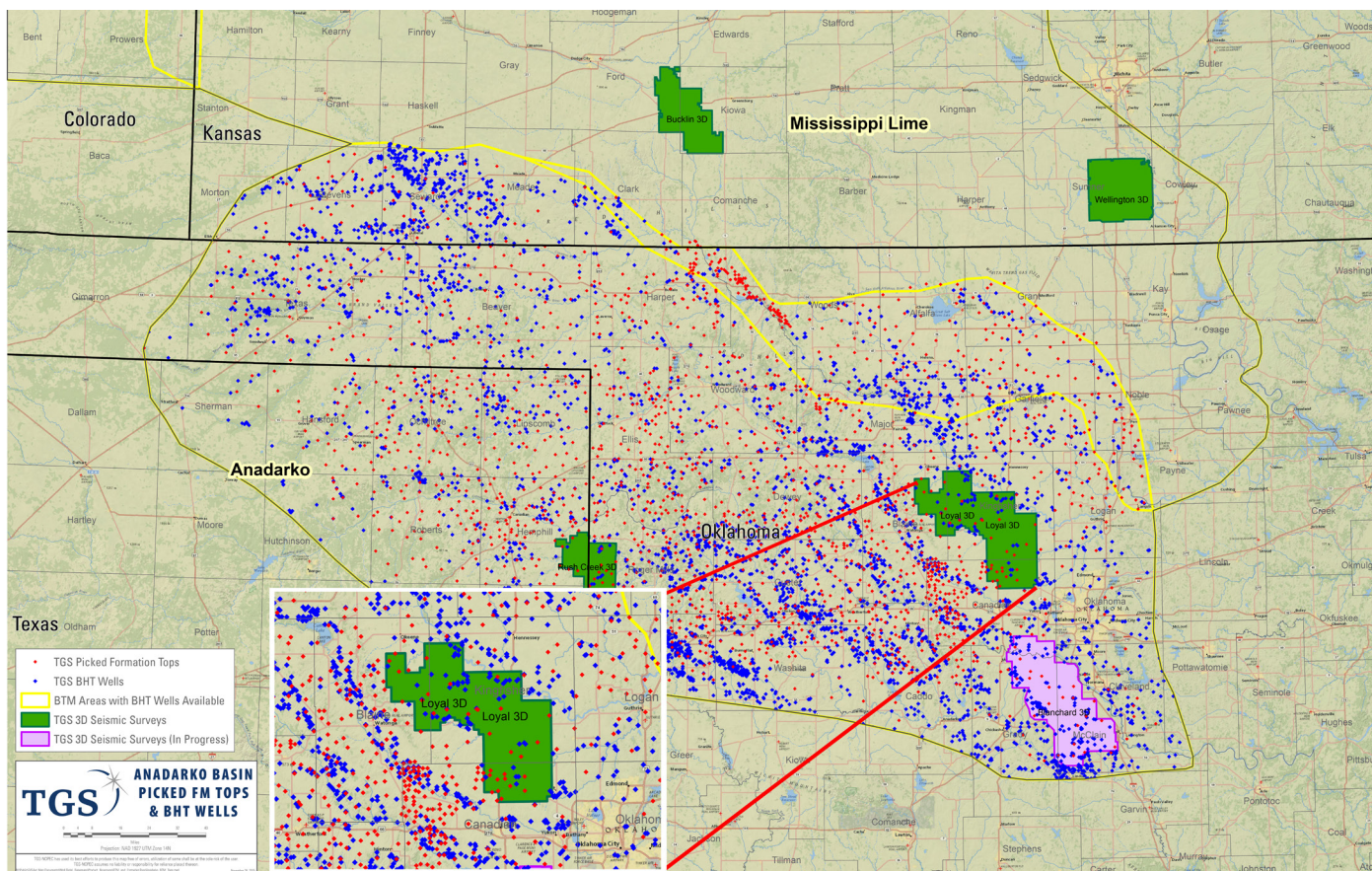


Figure 1. Anadarko Basin outline with Loyal 3D (591 square miles) survey, Oklahoma.



Figure 2. Example of surface well spot correction for validated well headers. Two databases list the same well UWI with different locations. In this case surface elevation data helped confirm the DB2 database entry was correct.

with syn and post-depositional structural influences. The stacked plays along the eastern flank and the granite wash plays along the southwest flank have historically attracted the majority of exploratory drilling.

Along the northeastern flank (STACK), plays focus on the Pennsylvanian Oswego, Mississippian Meramec, Mississippian Osage, Devonian Woodford and Silurian Hunton, all of which are now exploited

with horizontal boreholes. As a primary objective, the Woodford is thermally mature along the flanks, and over mature in the deepest parts of the basin (18 000 ft). Along the eastern flank (proximal to the Loyal 3D) the Woodford occurs at average depths of 9500 ft and varies in thickness from less than 50 ft to over 200 ft.

A general framework for workflows begins with compiling and analysing well information (logs, sample data, well performance data, etc.) and this can be accomplished quickly with regularised data points. Historically some of the major challenges have been validation of the information received. With today's technology, advances in proper positioning of wells contributing to validated well headers (Figure 2) and identification of high value geotechnical data (shear sonic, accurate production and test data, image logs) (Figure 3) allow explorationists to make more confident interpretations.

Subsequently validation of the regional geologic interpretation is confirmed through correlation with seismic data. Figures 4 and 5 show dip and strike images of the compressional wave (PP) data respectively. Events including the (Pennsylvanian) Big Lime, Woodford, and Arbuckle can be interpreted with high confidence. Sequences as well as more subtle and variable events including the Meramec are well imaged as shown in the inset. The increased value of seismic is demonstrated through the identification of the localised and often subtle structural features that can affect depositional facies, as well as post deposition structural influences.

Seismic integration and advances

The Loyal 3D survey is located in the heart of Oklahoma's STACK trend fairway. In the unconventional plays the importance of data statistics becomes critical to understanding reservoir/production variability. A direct requirement of this is large seismic surveys (Figure 1). The 3D survey is located along the prospective corridor for Permian through Silurian intervals.

Interpretation of modern 3D seismic for unconventional plays supports multiple functions including hazard assessment, well positioning optimisation and advanced analysis for rock properties. On the Loyal 3D, the Woodford event falls within the resolvable limits of the data (associated with a strong trough), and can be picked consistently across the survey area (Figures 4 and 5). Integration of validated well locations and performance data becomes critical to calibrating seismic analysis including pre-stack and post-stack inversions, amplitude variation with offset (AVO) analysis, azimuthal analysis of amplitudes and velocities to obtain stress and fracture information (amplitude variation with azimuth – AVAZ; velocity variation with azimuth – VVAZ) and various other attributes (Young's Modulus, Poisson's Ratio, brittleness).

The high resolution data allows some advanced interpretation of the Paleozoic section with common desktop tools. Large and fine scale faulting is well defined at the Big Lime and Woodford levels. Coherence attributes on the Big Lime (Figure 6) and Woodford (Figure 7) with time structure overlays clearly image a radial fault pattern on the basin flank. Certain features appear more prevalent throughout the section, and provide insight to the timing of these deformational events and the need to tie these observations back to well performance data.

The next phase of advanced work flows is utilisation of three-component seismic data. Multi component data has been regularly discussed in the geophysical community but limited in published active play application. With new processing algorithms and application, integration of multi-component data should provide further understandings and improved return on drill bit investment. In general, interpretation of converted-wave (PS) reflection data can be used independently or jointly with the primary wave (PP) reflection data in the inversion process. In addition, the PS data can provide independent stress and fracture information via analysis of shear-wave splitting. The wide-azimuth, 3C/3D Loyal seismic survey was processed with these interpretation methods in mind. As with all things geophysical, attention to imaging technical details to obtain final stacks and gathers with broad bandwidth, calibrated to known geology, preservation of the offset and azimuth variations of the signal and comprehensive and effective noise attenuation are critical to extracting the most value.

It is well known that for land seismic data, the near-surface layers are the source of many of the difficulties encountered in seismic processing. Much of the noise, statics, attenuation, and variations in amplitude, phase, and scaling originate from the highly variable, heterogeneous and anisotropic near surface layers. As a result, many passes of different noise attenuation methods are required, each one targeting a different type of noise (linear, random, high-amplitude) in different domains (shot, receiver, common-offset, CDP, cross-spread).

Historically, challenges with handling near surface statics and scaling have limited the utilisation of PS data. Figure 6 shows results after application of new surface-consistent processing techniques developed by Arcis/TGS. These novel approaches are important for attaining high-quality images that should lead to de-risking and improved data analysis to optimise drilling.

Figure 8 shows a representative line of the final anisotropic pre-stack time migrated PP and PS, along with computed spectra from the primary zone of interest. Bandwidth of the PP and PS data are 5 to 70 Hz with strong coherence apparent on both datasets. The time scale is two-way with both datasets registered to the PP time.

Given the quality of the multi component data, interpretation, and cascading these results with PP interpretations, should yield significant new insight into the stress regimes and calibration of rock properties to well data. The application of the new data set revealing new information to traditional workflows should prove valuable in risk mitigation and providing cost-effective development of these unconventional plays.

A final piece to the puzzle: basin temperature modelling

After the comprehensive integration of the well and seismic data, what other data should be integrated? With production rates and commodity type (oil, liquids, gas) critical to return on investment, understanding and integrating the petroleum phases becomes key. Formation temperatures become important as they can be used to help identify favourable liquids/gas ratios in unconventional fairways.

A new approach for basin temperature modelling (BTM) has been developed that utilises large volumes of properly indexed bottom-hole temperature (BHT) data. Historically the range of BHT data recorded on each well varies greatly. Often, area geothermal gradients are

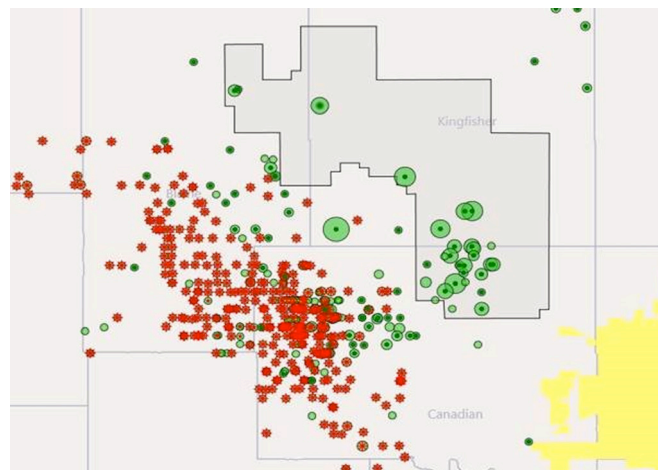


Figure 3. Woodford oil and gas with proportional first three month cumulative oil bubble map taken from TGS' LongBow platform. The Loyal 3D survey is shown in the grey outline.

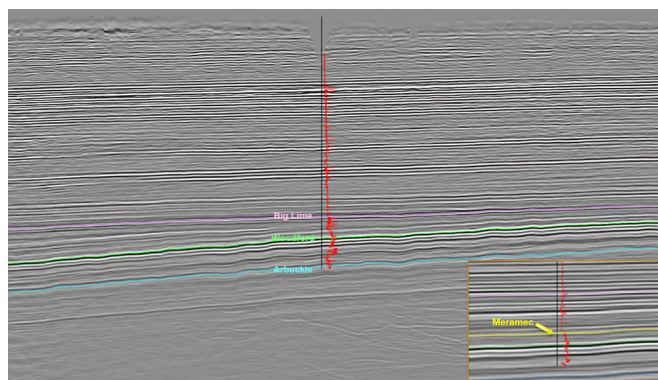


Figure 4. Loyal 3D PP seismic data in a southwest-northeast dip section. Meramec event is shown in yellow in the inset image.

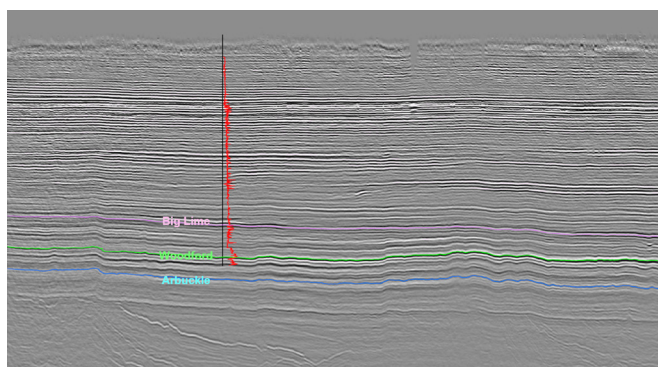


Figure 5. Loyal 3D PP seismic data in a northwest-southeast strike section.

mistakenly generated by a straight line extrapolation to one BHT value. A second mistaken technique would be to apply a regression analysis (often using a depth based function) to each BHT to obtain a 'corrected' bottom-hole temperature. With this new methodology, the theory that borehole temperatures equilibrate, increasing towards formation temperature with elapsed time since fluid circulation (TSC) is honoured. Due to the utilisation of low or improperly recorded TSC values these corrections become skewed, and misrepresent the true thermal interpretation of the formation temperature.

A more scientific, data driven approach is to mine well log databases for key wells, and use the maximum BHT values recorded in a layer (normalised for depth) or cell. Lithostratigraphic units, with common lithologies, have an interval geothermal gradient (IGG) that can be significantly different from their overlying and underlying units and can vary with depth. Therefore, the IGG needs to be determined based on depth and lithology. In this methodology a layered model is constructed from surface to basement, and normalised for each layer. An IGG stacking process is then applied iteratively for each layer moving downwards. Finally, a MaxG 3D temperature volume interpolated from the calculated

depth and temperature data for each horizon and formatted to SEG Y for integration with other geotechnical data.

Results from this work in the Anadarko Basin are shown in Figure 9. In this case, temperature volumes are easily imported to geotechnical software packages for visualisation. Integration of this dataset with other data can subsequently be utilised for interrogating a reservoir's potential production capability.

Conclusions

In today's commodity price environment where reducing costs and uncertainty is key, integration of new data and technologies becomes paramount for innovation to reduce risk and improve return on investment. Incorporating advances in multi component seismic imaging and new basin temperature modelling with validated, standard geological and geophysical data should assist in meeting these challenges. The advanced interpretation products and workflows outlined herein offer a strong technical basis for the industry to better analyse and evaluate investment opportunities in both conventional and unconventional oil and gas exploration and development. ■

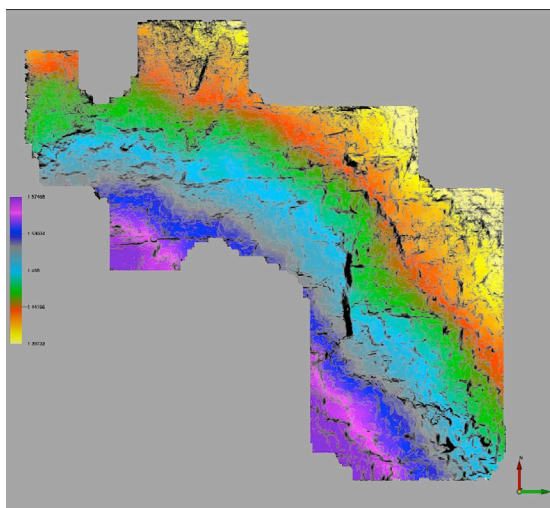


Figure 6. Time structure on coherence attribute on the approximate Big Lime event using TGS Loyal 3D volume.

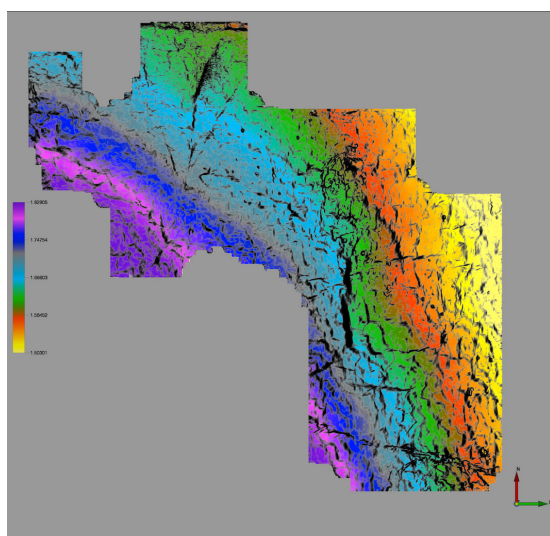


Figure 7. Time structure overlay on coherence attribute on the Woodford displaying large and fine scale faulting along the basin flank using TGS Loyal 3D.

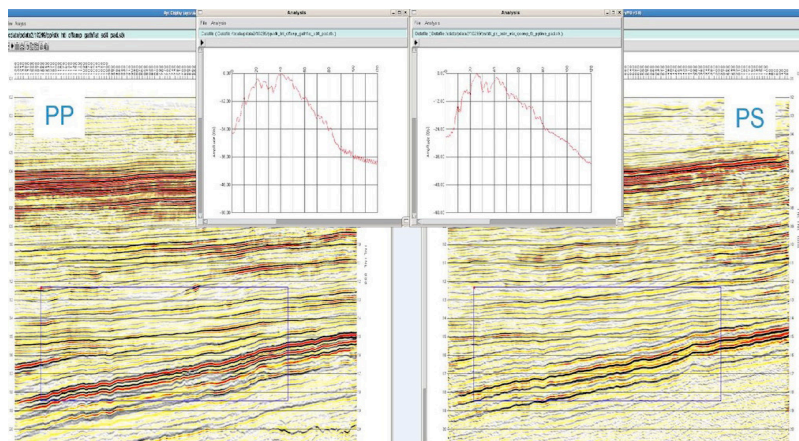


Figure 8. TGS Loyal 3D final anisotropic pre-stack time migration PP and PS inline stacks after 5D interpolation.

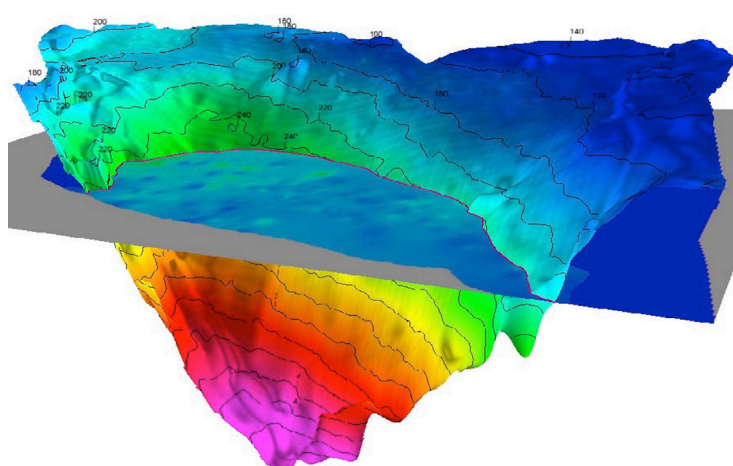


Figure 9. Anadarko basin BTM-Inline and crossline with a contoured 3D Woodford formation layer with temperature depth slice overlaid. The study used 12 053 QC'd BHT data points from 4186 wells. Layering was based on 15 formation tops picked from 2018 wells that are representative of the basin, QC'd for elevation, and have a complete suite of log curve responses.