PS Seismic Methodologies Adapted for Use in Acoustic Logging*

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Abstract

As our industry transitions to a dependence on the more costly unconventional reservoirs, we strive to find new and more efficient ways to produce from those reservoirs. There has been much focus on drilling and hydraulic fracturing technologies, but what about identifying natural fractures? It is well known that natural fractures exist in the producing zones. It is also well known that only about twenty percent of the fraced area actually produces. If we, as an industry, were better able to identify the naturally fractured zones – we would be able to focus on that twenty percent of producing zones. Currently, the industry uses acoustic logging or imaging to infer or find fractured zones. Unfortunately, however, the move to unconventional reservoirs has brought shortcomings in those techniques to the forefront. For images, widespread use of oil-based mud and the common practice of drilling high angle wells render image data mostly unusable. For shear wave anisotropy, fractures are simply inferred and, for many reasons, that inference cannot be relied on, particularly in unconventional reservoirs. Perhaps imaging and shear wave anisotropy need to make way for different processing techniques. Furthermore, present day tools are only able to detect anisotropy when logged sections are more than five percent anisotropic, leaving the subtle fracture systems undetected. For this last issue, we need look no further than seismic and microseismic techniques for guidance. Due to issues with signal attenuation and a high signal-to-noise ratio, seismic has long used several techniques, such as stacking, to improve results and amplify anomalies. In this discussion, we explore how we have adopted techniques from seismic and microseismic to provide useful and informative results on fractures creating a new processing technique for acoustic logging.

Seismic Methodologies Adapted for Use in Acoustic Logging

By: Partha Biswas & Shreya Biswas Ley

ABSTRACT

As our industry transitions to a dependence on the more costly unconventional reservoirs, we strive to find new and more efficient ways to produce from those reservoirs. There has been much focus on drilling and hydraulic fracturing technologies, but what about identifying natural fractures? It is well known that natural fractures exist in the producing zones. It is also well known that only about twenty percent of the fraced area actually produces. If we, as an industry, were better able to identify the naturally fractured zones – we would be able to focus on that twenty percent of producing zones.

Currently, the industry uses acoustic logging or imaging to infer or find fractured zones. Unfortunately, however, the move to unconventional reservoirs has brought shortcomings in those techniques to the forefront. For images, widespread use of oil-based mud and the common practice of drilling high angle wells render image data mostly unusable. For shear wave anisotropy, fractures are simply inferred and, for many reasons, that inference cannot be relied on, particularly in unconventional reservoirs. Perhaps imaging and shear wave anisotropy **n**eed to make way for different processing techniques.

Furthermore, present day tools are only able to detect anisotropy when logged sections are more than five percent anisotropic, leaving the subtle fracture systems undetected. For this last issue, we need look no further than seismic and microseismic techniques for guidance. Due to issues with signal attenuation and a high signal-to-noise ratio, seismic has long used several techniques, such as stacking, to improve results and amplify anomalies.

OBJECTIVES:

- To overcome known limitations of shear anisotropy in well logging
- To more directly map naturally fractured zones from acoustic data in unconventional plays

Seismology Research - We looked to seismology & seismic research for novel methodologies acoustic interpretation and

It lead us in two directions.

Compressional Wave Splitting

DEAD END

WHY?

Although this appeared most promising because an Alford-type analysis could be used like with shear wave anisotropy, this ended up being a dead end. Either current tools are unable to detect compressional splitting at the small scale of the wellbore (if it exists), or

Compressional Wave

THEORY

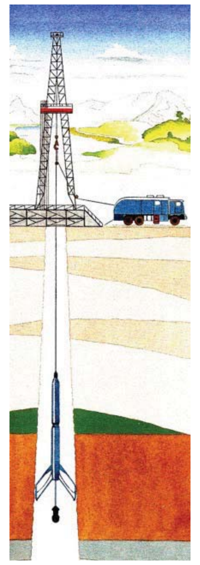
The waveform energy through a homogenous formation will remain relatively constant due to the short travel distance in well logging. However, when encountering a fracture - or a break in the homogeneity, the waveform energy will experience a sharp drop picked up by the transmitter. Experiments in Seismic and Seismology research demonstrate the effectiveness of mapping

WHY?

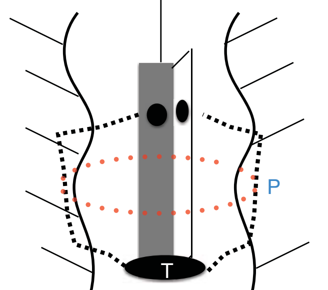
Sometimes the wells drilled exhibit unpredicted or unusual water production in an otherwise oil-producing zone, or exhibit unpredicted or unusual gas production in an expected liquid area, or within a field one well will be productive while the next will fall short of expectations or will create issues in neighboring wells. For these flow-related issues, natural fracture patterns are normally the guilty party. These naturally fractured zones play a crucial role in flow and, therefore, production. It stands to reason, then, that by better characterizing and identifying the naturally fractured zones, the completions plans could more effectively target the producing areas and reduce unnecessary perforations or unnecessary lifting costs.

The most prevalent processing methods for acoustic data are slowness and finding shear anisotropy; with shear wave anisotropy, fractures are simply inferred and, for many reasons, that inference cannot be relied on in unconventional reservoirs. Shear wave anisotropy measures anisotropy – not fractures. The formation can be, and often is in the case of unconventionals, inherently anisotropic thereby masking anisotropy from fractures. Alternatively, the anisotropy from fractures may be below the tool threshold for detection.

WORKFLOW



Many new wireline tools and all MWD tools collect sectored compressional data. Furthermore, the "Leaky Mode" can simulate a sectored compressional waveform in highly deviated wells. In these cases, any cross-dipole tool may be used for data collection.

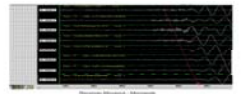


Wireline Tool collects sectored compressional data from within the borehole in time (we, in our processing, correlate time with depth). It is assumed that the standard depth of investigation is 6 inches.

The tool collects 512 samples per depth point. The processing

Input: Raw Sectored Compressional Waveforms

Sectored nature of the waveforms is important because it allows for an azimuthal measurement. Having this data provides a 360º map of the wellbore and also allows for the computation of, not only a



Receiver Orientation Check

Sometimes the tool gets knocked around in the wellbore and receivers stop functioning properly. We check for this and discount data collected

Interactive Filtering

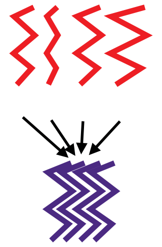
The waveform is muted in time and filtered in frequency. Also the frequency spectrum is analyzed to ensure that the compressional

Filtered Waveform

This is what the resulting waveform looks like for subsequent

STACKING ROUTINE

A commonplace technique in seismic that has not been adapted for well logging due to the less noisy environment of the wellbore. However, with this technique we are looking for finer perturbations in the data. Stacking helps to reduce noise and amplify the anomalies which we are after.



NORMALIZATION OF WAVEFORMS

Purpose of normalization is to ensure that the

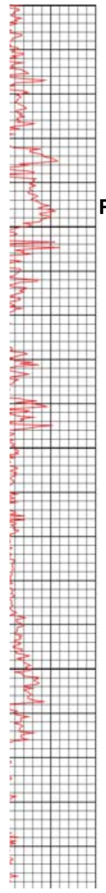
Root Mean Square (RMS) Computation

Typical calculation in well logging. Shear anisotropy calculations also use an RMS computation.

Statistical algorithm picking out the minimum, maximum, and average

Root Mean Square (RMS) Differential

A differential of the statistical values is mapped at each depth point to determine the attenuation experienced circumferentially around the borehole. The idea of seeking the differential is both



Resulting Plot

CONCLUSIONS

- Ideas borrowed from seismic and seismology
  - Overall idea of mapping fracture networks with compressional waveforms
  - Stacking
  - Compressional Splitting - though not feasible at this time, still being considered a viable option as tools develop further
  - Waveform normalization
- Limitations of shear anisotropy apparent in unconventionals
- The differential is key to mapping the drop in energy
- Leaky mode is most effective in highly deviated wells (>45º)
- As this is simply a mathematical computation, there is no distinction between induced or natural fractures.
  - However, induced fractures in the presence of natural fractures tend to have a smaller amplitude or appear as a singularity in the data.
- The minimum fracture aperture for effective interpretation has not yet been determined.
- Fractures that are near-parallel with the wellbore are detectable as a series of peaks.
  - Experiments have only been done down to an 8º fracture direction.

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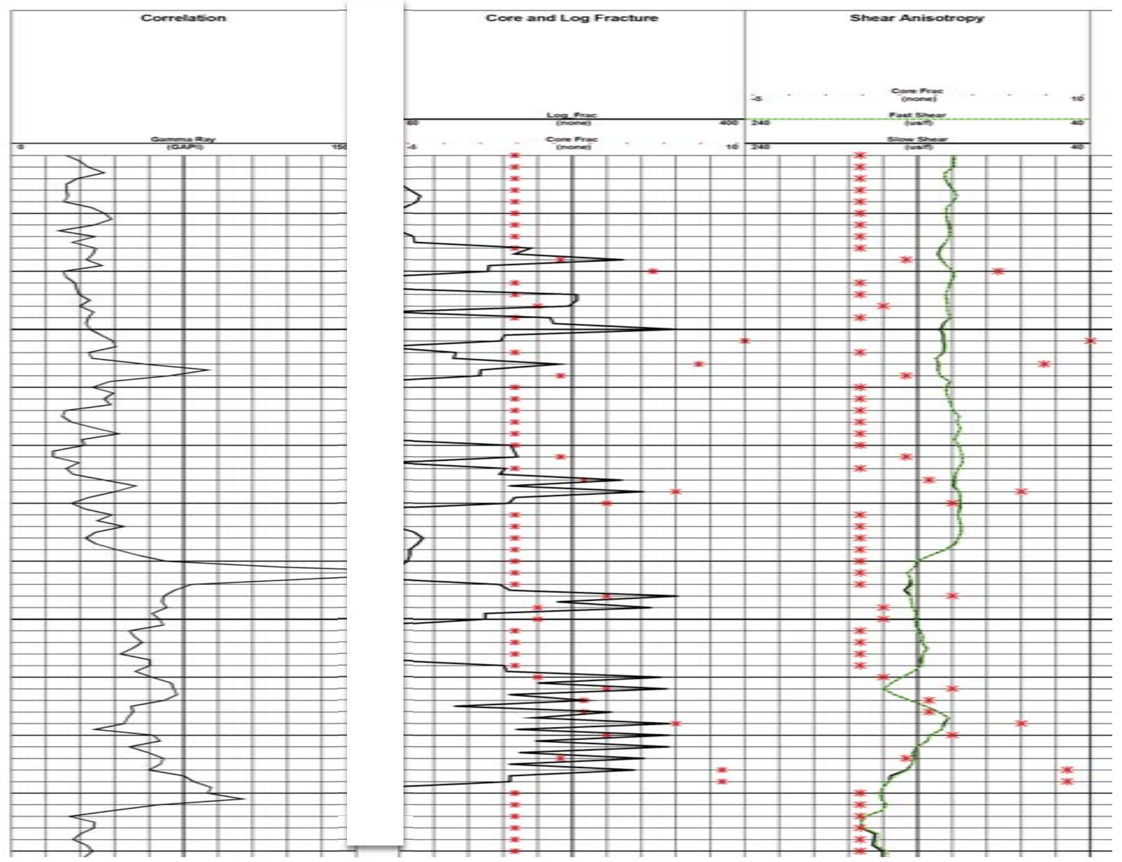
Case Studies



LEGEND:

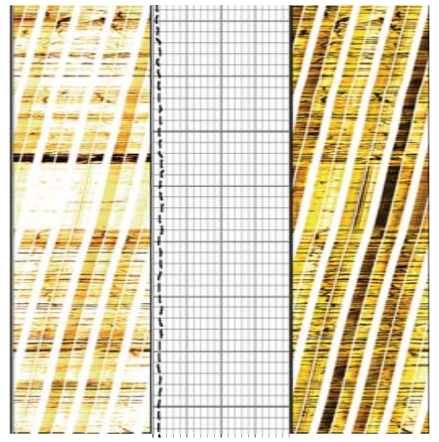
x - Fractures seen in core. The baseline represents "No Fractures." Where the X's deviate from the baseline, there was a fracture seen in core. The higher the deviation, the higher the fracture density in that section.

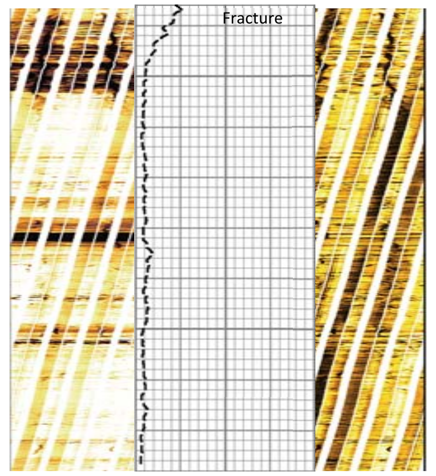
BLIND TEST

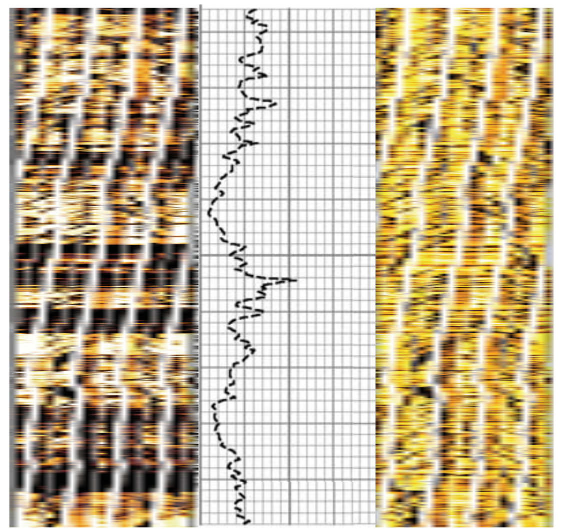
This was a blind test in Eagle Ford. Meaning, that no core results were given prior to the completion of processing.

Ideally, the anisotropy would be displayed by the fast and slow shear splitting when encountering a fractured section. However, in this well, there was little splitting and little-to-no correlation between splitting and fracturing. The causes of this could be that the formation was inherently anisotropic or that the fracturing was below the tool threshold. However, this, we have found, is common in unconventional plays - both shales and fractured carbonates.

On the other hand, the Fracture Identification methodology demonstrated an approximately 80-85% correlation with the core result over fractured and unfractured sections.







BLIND TEST

This was a blind test in Permian against an image result. All three snapshots are from the same well, but different depths. Again, no image results were provided prior to the completion of processing.

The Fracture Identification methodology demonstrated the same sort of 80-85% correlation with the image result over fractured and unfractured sections much like in the Eagle Ford test above.