Eventful Microseismic Analysis
Automated Microseismic Imaging

- Fast event locations
- Improved real-time frac engineering
- Improved QC

Leaders in Hydraulic Fracture Mapping
Pinnacle performs more microseismic-based hydraulic fracture mapping projects than all other companies combined, having mapped well over 3000 fracs in the past 5 years. These microseismic images have proven to be a valuable asset for understanding and optimizing hydraulic fractures across reservoirs in all corners of the world. Accurate microseismic images require intensive geophysical processing, including skillful interpretation of the microseismic signals by an experienced analyst, and careful calibration of the seismic velocity model in order to precisely model the microseismic event locations. On most of our projects, preliminary images are produced to provide on-site engineers with near real-time results as the frac is being pumped. In some cases, these near ‘real-time’ images are used to refine perforation targets based on the performance of earlier fracs, or in other cases to prevent fracs from growing into unwanted locations or lithologic units.

Typically, a geophysicist interactively processes the microseismic data as the frac progresses, either directly in the field or in a processing center using prioritized data transfer over satellite using Pinnacle’s SeisMan™ data management system. The geophysicist may also continue with velocity model refinement during the pumping, although the ultimate velocity model calibration and final microseismic processing of all events may not be completed until sometime after the end of the frac. The resulting real-time image is therefore an approximate representation of the fracture geometry and does not necessarily contain every event nor include full velocity model refinement. On our projects, Pinnacle provides an industry-leading quality-control report documenting the quality and accuracy of the microseismic image. Particularly in the case of realtime imaging, this QC report is critical in the image interpretation, to understand the confidence and accuracy of the microseismic event locations.

Advantages and Tradeoffs of Automated Analysis
As an alternative to our real-time interactive processing, we are often asked about completely automated processing. The potential advantage of automated processing is clear in terms of speed of delivery, although like most things, there is a tradeoff and here, it is speed coming at the expense of accuracy. In this document, we discuss the limitations of automatic processing and provide an overview of Pinnacle’s latest development efforts in this area.

One of the biggest challenges facing microseismic monitoring is the same with most geophysical technologies: the battle of signal versus noise. Figure 1 below shows a typical magnitude versus distance plot, which Pinnacle uses to assess the sensitivity, ‘hearing distance’ and potential spatial bias in a microseismic image. Along with the plot, we have included three events of various sizes. The biggest event has very clear signals with very high signal-to-noise ratios (SNR). Although there are only a handful of these big events, automatic processing can easily produce an accurate estimate of the microseism location. However, the microseisms follow normal earthquake statistics relating magnitude with frequency of occurrence, and the common signal type has much lower SNR. In fact, the most numerous events have a low SNR, down near the limit of what can be recorded at a given distance. Other Pinnacle Tech Updates describe how we use the best downhole technology to provide the highest quality data, and how our patent pending

![Figure 1. Detection range plot showing the signal quality loss with progressively smaller sized microseisms.](image)
digital stacking technique improves the SNR. However, microseismic processing often pushes the boundary of the lowest possible SNR to maximize the sensitivity and recording distance. The challenge of automatic processing is not trivial; for any given project the majority of the microseisms will always have a low SNR which are where conventional automatic processing and event pickers fail. We feel this reality check is important to recognize before discussing any automatic processing. The fact is that NO automated processing will be quite as accurate as Pinnacle’s team of the industry’s most experienced microseismic analysts utilizing our interactive interpretation technique combining automatic and manual event processing.

Automatic identification of seismic wave arrival times is an ongoing challenge of earthquake seismologists, and continues to be a topic of intense research in seismic laboratories around the globe. Seismologists are a motivated group in this regard, having suffered collectively through manually interpreting numerous seismic wiggles. Automatic picking techniques can work for simple, good quality seismic traces but as we have discussed, the majority are low quality data. The problem is exacerbated in microseismic monitoring during noisy pumping operations, and seismic traces can be complex with recording of additional seismic waves from refractions and reflections. Currently no completely automatic processing technique exists which will perform as robustly on these poor quality signals as our traditional interactive processing technique.

**Microseismic Processing Techniques**

Although it is a challenge to reliably pick the exact onset times of the seismic waves, the presence of p- and s-waves can be reliably identified. Identification of these waves lends itself to an alternative processing strategy, utilizing Kirchoff migration-based processing techniques that are routinely used for processing seismic reflection data. While normal microseismic processing techniques involve determining the point in space which matches the observed arrival times of the seismic waves, migration based techniques work by focusing the recorded seismic energy back onto a spatial grid of points. The migration based location technique that Pinnacle developed works by adding up the recorded seismic energy within short time windows for the expected arrival of seismic energy for a given grid point. When the grid point is aligned with the true microseism location, the expected arrival time windows will align with the seismic waves across the seismic wave and the resulting summed seismic energy will reach a maximum. For example, Figure 2 shows a grid based contour map of the migrated seismic energy for a good quality seismogram. In this case, the point of maximum migrated energy is a good match to our traditional interactively processed microseism location.
Figure 3 reviews how the automatic migration based algorithm worked for an entire frac. In this particular example, 173 microseisms were interactively processed compared to 136 for which automatic locations were determined (about 80%). For the most part, most automatic locations agree reasonably well with the interactive locations although obviously there are some events which locate poorly. There are a multitude of reasons, generally related to complex signals. For example, Figure 4 shows a complicated signal where the automated processing migrates into two discrete clusters associated with a large and small microseism which occur close together in time. Consequently, some migrated locations will not be as accurate as our interactively processed results. Even in the case of high quality data, the migrated results will never be quite as precise as our traditional location based on exact onset times. With our traditional method, there will be a distinct location which matches manually picked onset times while the migration technique provides a useful but slightly “fuzzier” image of the source location probability.

**Confidence in the Data**

Although not as accurate, there are numerous instances where automated processing can be useful. However, one of the important aspects of interpreting automatic processed results involves considering the confidence of the solution. As part of Pinnacle’s standard processing quality control report, we calculate a confidence factor for each event based on signal quality for conventional processing. Along with uncertainty estimates, this confidence factor provides critical information for the frac engineer to understand the data confidence associated with various aspects of our
microseismic images. With the additional technical challenges associated with automatic migration solutions, we are developing new ways to similarly measure the data confidence in the resulting images.

**Applications for Automated Processing**

Let’s now consider how this automated location could be used. Obviously it provides a quick look into a microseismic project, providing approximate locations and an estimate of the number of microseisms. Pinnacle’s data management system has a signal classification functionality, which can be used to prioritize the processing workflow and also automate the order for remote data transfer. By classifying the signals by the confidence measurement of the automatic result, processors can focus the quality control and refinement efforts on functionality, where the data is classified by migration confidence. This allows the data to be organized based on the migration, and allows the opportunity for a processor to quality control and refine the results. Just like Pinnacle’s real-time interactive processing, the automated results will generally use a preliminary velocity model prior to the final velocity optimization.

At Pinnacle, we strive to provide our clients with the most accurate and timely fracture images possible. Part of this development includes developing fully automated processing methods, which can be used by our geophysicists to produce realtime frac images. Nevertheless, to provide the most accurate final microseismic images, the “Gold Standard” will continue to be Pinnacle’s proven interactive processing technique.

For more information about how Eventful Microseismic Analysis can help improve your well productivity, email us at fracturemap@Halliburton.com or visit www.halliburton.com

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