SIGMA³
Microseismic & Borehole Seismic

KEY BENEFITS

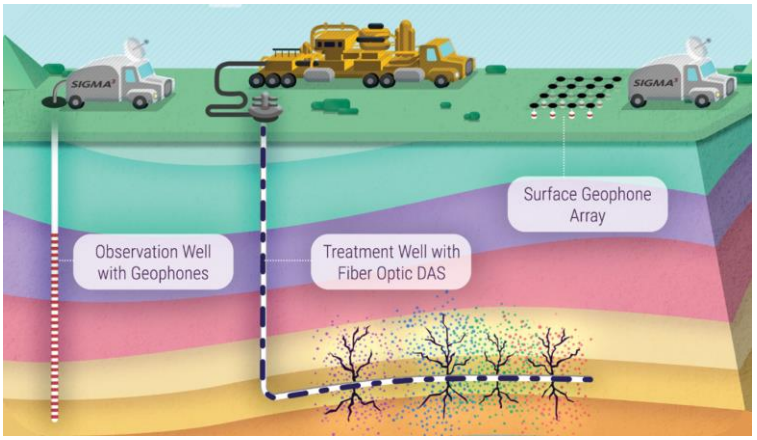
- **Analyze completions design(s) for frac growth, depletion effects, well and frac stage spacing, natural fracture networks to drive development strategy**
- **Update reservoir model with geologically-relevant 3D anisotropic model**

CAPABILITIES

- **Downhole, surface, fiber microseismic**
- **Check Shot quick call out**
- **VSP**
- **Real-time acquisition and processing**
- **Reprocessing**

OVERVIEW

Optimizing your unconventional reservoir development comes down to having a detailed understanding of the geology, coupled with implementing a completion strategy that takes into account geologic and geomechanics factors, effectiveness of stimulation design, well spacing, depletion effects in an area. Companies look to microseismic to help fill in the blanks to answer the question of what completions strategy works best and to refine their earth model to have the most accurate understanding of the subsurface, especially at the reservoir level. Sigma Cubed's microseismic group helps customers accomplish this by delivering turn-key microseismic and processing services through borehole, surface, and fiber (DAS) microseismic acquisition, as well as reprocessing.



AQUISITION

Sigma Cubed's microseismic group delivers borehole, surface, and fiber optic (DAS) microseismic acquisition to help companies answer the question of what completions strategy works best and to refine their earth model to have the most accurate understanding of the subsurface, especially at the reservoir level. We use the longest arrays in the industry, resulting in quality signal extraction, more events, longer monitoring distance, and better geometric coverage.

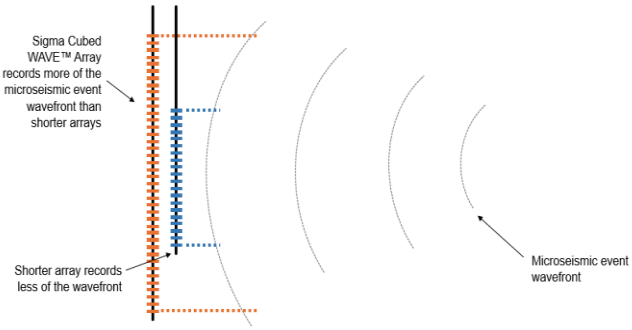
BOREHOLE MICROSEISMIC

Operators wanting to acquire downhole microseismic data can utilize Sigma Cubed's borehole seismic imaging services. Geophones are deployed in monitoring wells using wireline units. Depending on the layout of wells and a client's project goals, the arrays can be deployed as a WAVE™ Array (Wide Aperture Vertically Extended Array) and/or in the horizontal section, including a Split Array™ with a combination of a horizontal and a vertical array in the same monitoring well.

Sigma Cubed's WAVE™ Arrays are the longest arrays in use in the industry. They are typically 40-60 levels per monitoring array, and can be up to 120 for a single array. These arrays can also be configured as a Split Array™. The long array length coupled with the Geospace DS- and DW-150 Slimhole 3C Acquisition System means quality signal extraction, more events, longer monitoring distance, and better geometric coverage.

Sigma Cubed's WAVE™ Arrays are the longest arrays in use in the industry (40-120 sondes). This means better quality signal extraction, locating up to 60% more events than other vendors, and better geometric coverage. The result is a more accurate interpretation of the frac job.

Sigma Cubed's main fleet is in Midland, TX with the ability to deploy to sites throughout the U.S. and Canada. We also partner with local hardware companies in Europe, Latin America, Asia, and the Middle East for acquisition, with processing done in Houston, TX. Multiple crews can run concurrently in the field and support 12- or 24-hr real-time operations. Sigma Cubed is committed to operational excellence and rigorous HSE procedures and include a highly experienced operations management team.



SURFACE MICROSEISMIC

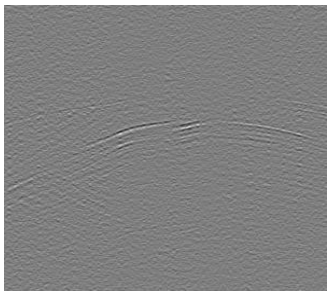
Sigma Cubed couples our advanced processing with select technology partners on surface microseismic acquisition. We work with all of the different array configurations for surface microseismic (star, patch, etc.) and use our basin, reservoir, and processing experience to make recommendations on configuration and other parameters. Surface microseismic can be useful in areas where monitoring wells are not available, or the subsurface is too hot to accommodate monitoring long periods of time and extremely high temperatures.

Delivery of data can be in real-time and final processing includes Sigma Cubed's adaptive signal processing, 3D velocity models and tomography. Sigma Cubed is particularly efficient at computing Moment Tensor Inversion (MTI) for surface, which is an important value-add for those clients looking to understand how the rock behaved during the completion by providing the orientation of slip-plane and direction of slip of the fractures.

FIBER OPTIC DISTRIBUTED ACOUSTIC SENSING (DAS)

Sigma Cubed also has experience in utilizing fiber optic distributed acoustic sensing for fracture monitoring. Like surface microseismic, we combine our advanced processing with select fiber optic technology partners to provide optimized processing with the high channel count data to look at the induced hydraulic fractures.

Some companies look to change the cost structure of their data acquisition by deploying fiber which can then be used for purposes other than fracture monitoring, such as flow monitoring, DTS, and VSPs. Delivery of data can be in real-time and final processing includes Sigma Cubed's adaptive signal processing, 3D velocity models and tomographic inversion for a unified 3D anisotropic velocity model.



- **Sigma Cubed performs a non-linear inversion that resolves effective stress and the full moment tensor simultaneously. This is unique in the industry and accounts for anisotropy at the sources.**

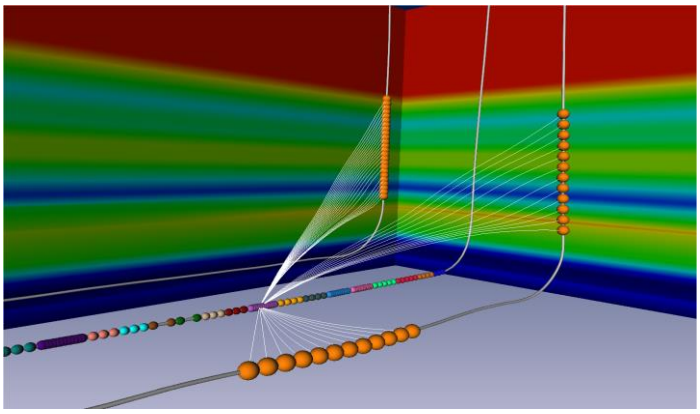
PROCESSING

Processing is a key differentiator to Sigma Cubed's microseismic offering. The processing group at Sigma Cubed is focused on developing best-in-class processing tools and algorithms and constantly works to evolve these tools to deliver the most from the data. Real-time is an area where Sigma Cubed excels. Acquisition quality control and processing provides answers in the shortest time possible, providing the biggest impact on completions by using microseismic data to do adaptive fracture management during the completions job. The processing team also has deep experience in working with non-standard acquisition and integrating downhole, surface, and fiber-optic data, including in real-time.

ANISOTROPIC 3D MODELING

Other microseismic vendors create multiple velocity models along the wellbore often using simplistic layer based ray-tracing, and perform user dependent manual velocity adjustment to fit perforation travel times. The problem with this is that multiple models are being created to satisfy parts of the data, but may not necessarily be geologically relevant. Location artifacts can be readily introduced, leading to a miss-interpretation of the completion.

Sigma Cubed uses known source locations and additionally integrates event locations in our tomographic inversion for a unified 3D anisotropic velocity model. This produces a unified/single 3-dimensional anisotropic model. Utilizing the event locations allows for a wider azimuth and offset control points to help constrain the model away from the treatment lateral. All available data can be incorporated, including horizons (structure), well logs, borehole-seismic and seismic volumes.



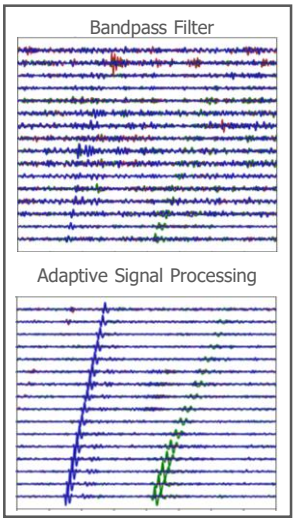
MODEL CALIBRATION

Active source data, perforation shots and microseismic events all provide key information for updating the velocity model. Perforation shot data is often under utilized in microseismic surveys in part due to a failure to record the precise shot time information and in part due to lack of precision workflows to extract this timing information from weak signal.

At Sigma Cubed, be it surface or downhole recorded data, we are able to reliably extract the signal from shot data even when the signal is weak or not detectable in un-processed data by incorporating precise timing information and custom signal processing workflows (see figure below). The tomographic velocity model update based on the perforation shot data provides the best in terms of ground truth for locating the microseismic events that occur in the vicinity of and during the completion.

ADAPTIVE SIGNAL PROCESSING

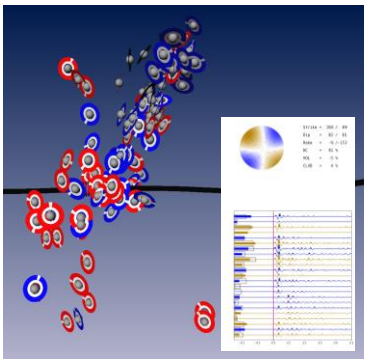
In conventional seismic processing workflows the processing parameters are fixed, often tuned based on an analysis of a sub-set of the data. In a microseismic survey the source characteristics are varied, the noise changes over time, the distance of each event to each geophone varies and thus the optimum parameters for analyzing the signal are not fixed. Sigma Cubed is the only company to employ a fully adaptive approach to signal processing. Each event and each arrival is analyzed on a receiver by receiver basis, be it recorded on surface array, downhole, or fiber data.

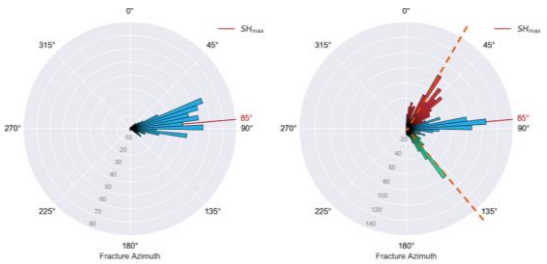


Adaptive noise attenuation is a key tool applied in our signal processing. Components of noise can turn out to be predictable in time and/or spatially correlated. Predictive and adaptive filtering is all about estimating and removing this noise while preserving the signal. Optimal array design coupled with adaptive array based processing techniques are able to extract more signal, detect more events, and extract more information from the data, in even the most challenging of noise environments.

MOMENT TENSOR INVERSION

Baseline microseismic results are the event locations. However, these "dots" are just points in space and time, and do not necessarily give you a full understanding of how the rock behaved during the completion. Moment Tensor Inversion (MTI) provides the orientation of slip-plane and direction of slip of the fractures. Sigma Cubed inversion of the microseismic data is able to extract Moment Tensor information even when the Moment Tensor is poorly constrained by limited array coverage. Operators then use MTI to understand what fractures are induced and which ones are tied to natural fracture networks and faults.





GEOENGINEERING™ ANALYSIS – PUSH YOUR DATA TO THE NEXT LEVEL

The benefit of microseismic does not come from looking at a cloud of events. The real benefit to clients is in advanced analysis that combines geomechanics with geophysical interpretation of the microseismic data in order to answer the questions that are most pressing in reservoir development: what completions strategy works best and how best to constrain their earth model. As part of our standard deliverables, Sigma Cubed performs our GeoEngineering™ Analysis of the data and summarizes observations in a comprehensive final report that is presented in the client's office. In that analysis, we utilize several types of industry accepted (i.e.: rate-transient analysis) and proprietary tools to help clients understand frac height and propagation, well spacing, parent-child well relationships, zipper frac order, type of slip, natural and near-wellbore fracture complexity and more.

"The biggest driver for us to use microseismic was well spacing. Being able to show that we could develop the acreage with 6 wells per section instead of 8 wells with the same effective reserves made a significant change to the economics of the development".

- Permian Operator