

# Confidence and Accuracy of Microseismic Images

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## Summary

Effective interpretation of microseismic images requires fundamental quality and confidence information about the seismogram data and final image. A number of fundamental attributes provide critical parameters for quality control and assurance, including signal-to-noise ratio, arrival time and direction residuals. Background noise and magnitude distribution is documented to examine the image completeness, and can be used to assess whether the entire seismic deformation has been detected. Finally, images of location uncertainties from both the arrival time and direction components and the velocity model are also critical. These parameters allow an interpreter to define the confidence in either regions or through the entire microseismic image, and also for the recorded trace data and computed seismic parameters.

## Introduction

Passive microseismic imaging is a growing technology for mapping hydraulic fractures and reservoir monitoring (eg. Maxwell et al., 2003). Generally microseismic images are used to track the spatial and temporal development of fracture creation and reactivation, mostly based on the spatial and temporal variations of the hypocentral location of the acoustic emissions associated with the seismic deformation. As with all geophysical images, quantification of the image resolution and confidence is critical for proper image interpretation. Microseismic image quality is related to a number of quantifiable data attributes that can be used to for control and assurance of optimal image quality.

The microseismic image resolution is primarily controlled by the hypocentral accuracy. Random hypocenter uncertainties can generally be estimated during the hypocentral inversion by estimating the propagation of the data uncertainties (Lee and Stewart, 1981). Systematic uncertainties can also be estimated through the propagation of velocity model uncertainties (eg. Maxwell, 2005). Although uncertainties in the forward model can be minimized, for example by calibrating with controlled sources from known locations, finite uncertainties will always exist. Systematic errors can also be introduced through sensor and wellbore positioning errors, although these can generally be mitigated through accurate measurement. However, beyond the propagation of statistical errors through the hypocentral inversion, basic seismic data attributes such as signal-to-noise ratio will also impact the confidence in the event location.

In addition to image confidence and resolution, the sensitivity of microseismic image is another import QC issue. The smallest magnitude microseism that is recorded will be controlled by the level background seismic noise (eg. Maxwell, 2005). Therefore, the noise level and the variation with time is a critical component. The completeness of the microseismic image will vary with position, and depends on the detection sensitivity compared to the size range of the microseisms. This image completeness will also impact the total number of individual microseisms, and is controlled by the detection limits attenuating the

more numerous smaller events from the image. The most critical impact of the completeness is whether the entire seismic deformation is imaged, or if regions are too far away from the seismic array to be detected.

Since the image confidence, resolution and sensitivity vary between images, there is a fundamental need to quantify and communication these characteristics and enable proper image interpretation. In this paper we highlight key attributes to efficiently convey the critical image and data parameters, which also serves as QC and QA elements for the image. The discussion is primarily focused on monitoring in a single observation well, although the aspects can also be applied to more general monitoring geometries.

### Background Noise

Background seismic noise varies with location and depth, and can also vary with time. For example, Figure 1 shows the average background noise during a hydraulic fracture stimulation. The noise level was measured over continuous time windows, some of which corresponded to the arrival time of induced seismic events resulting in a localized “noise” spike. Of particular interest in this example, is the fact that the noise level rises significantly with time, corresponding to the growth of the hydraulic fracture into the observation well. By the end of the treatment, the noise level rises to a level that masks the signal strength of the microseismic events. Individual plots of the noise with time on each sensor provide a comprehensive QC of the array sensitivity.

### Microseismic Sensitivity

Figure 2 shows a plot of magnitude versus distance of the event from the array, which shows the typical trend that the smallest detected event increases in size with distance from the array. The plot can be used to QC the completeness of the image and ensure that at the furthest offsets there is a range of magnitudes that are not limited by the detection limits. The plot can also be used to define a magnitude threshold that can be used to remove the distance bias from the image. The data can also be used to assess the frequency-magnitude distribution of the dataset.

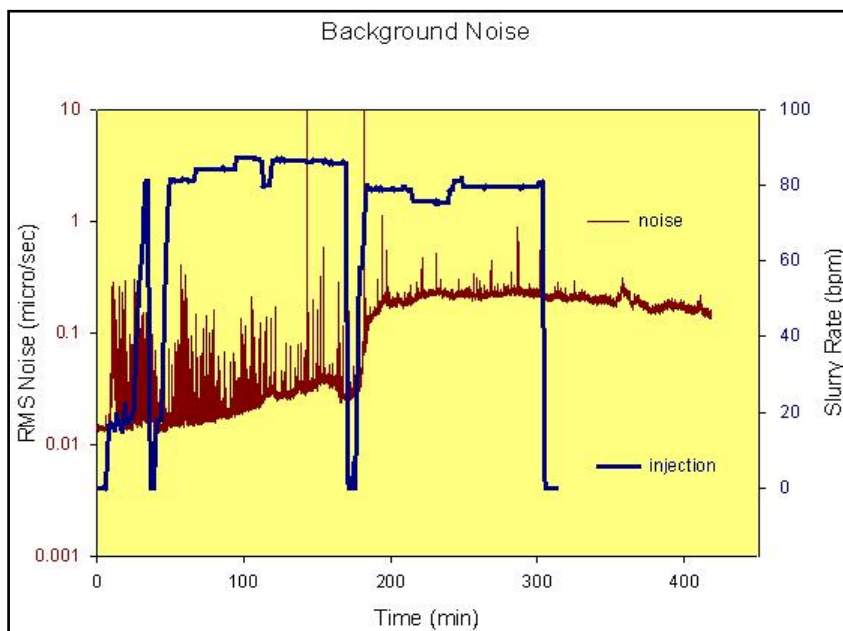


Figure 1. Average background noise for a hydraulic fracture.

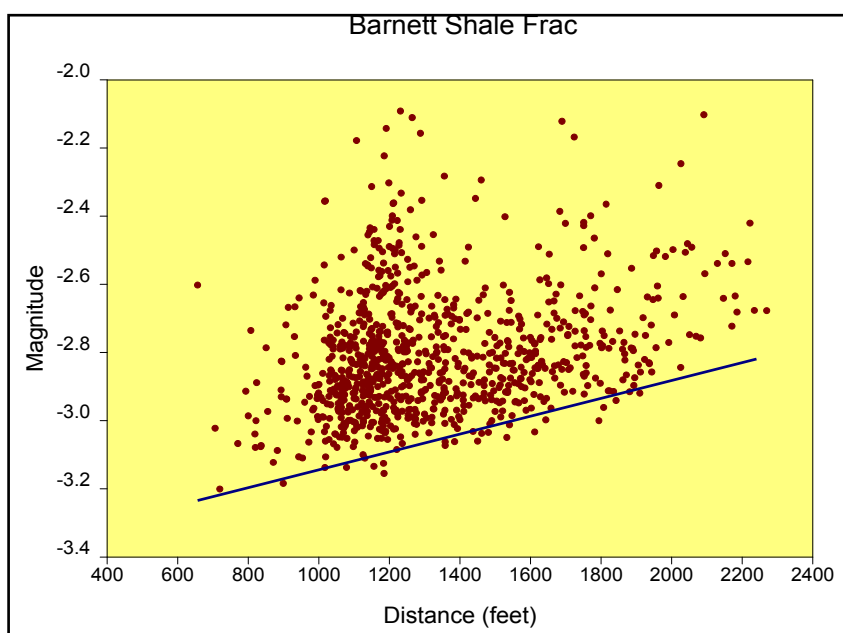


Figure 2. Magnitude versus distance plot.

## Seismogram Attributes

The signal-to-noise ratio (SNR) provides an important QC element of the trace data quality. SNR indicates the basic trace confidence of the data, where obviously the higher the SNR the more confident the data. SNR is somewhat limited to magnitude, although the signal strength also depends on distance and it is useful to have visualize the variation through the microseismic image of SNR of both p- and s-waves as well as the percentage of the seismic array where each wave is visible.. This provides a basis to assess the relative confidence during comparison of different images. It also provides an indication of potential issues such as low confidence in some cases where a particular phase tends to have low SNR, (occasionally an issue where shear radiation patterns result in relatively low p-wave amplitudes which can tend to approach noise levels for lower amplitude events).

Another important aspect is visualization of the individual arrival time residuals (difference between observed and forward model results) for different sensors. Systematic trends in the residuals through the array (as in Figure 3 as an example) can be an indication of velocity model inaccuracies, although QC

of the velocity model also generally involves independently ensuring that calibration events such as orientation shots are accurately located. The residuals can also be used to measure apparent velocity errors for formal calculation of hypocentral location uncertainties. A similar plot of directional residuals can also be produced from hodogram directions, to QC the direction data and computed sensor orientations.

## Location Accuracy

Directional location uncertainties can be computed from the data uncertainties and velocity model uncertainties. For the sake of brevity, the important aspect of estimating location uncertainty will only be mentioned here in passing. However, it is important for proper QC that velocity model uncertainties are also taken into account. Furthermore, all locations uncertainties are clearly a fundamental component of a passive seismic interpretation.

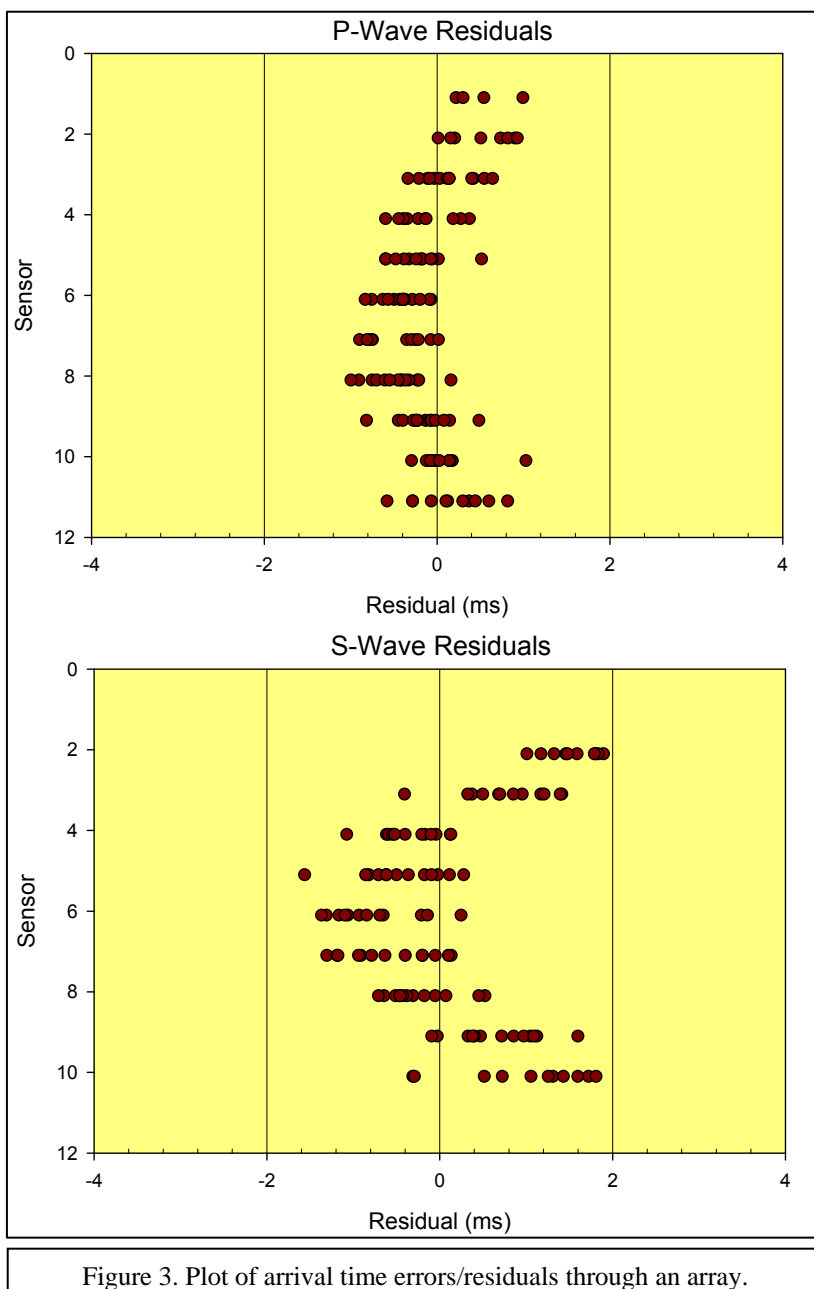


Figure 3. Plot of arrival time errors/residuals through an array.

## **Conclusions**

Specific QC attributes are described including background noise, SNR, arrival time and direction residuals, confidence factor, magnitude distribution and hypocentral uncertainties. The proposed attributes are specifically designed to effectively communicate the critical parameters in a concise format, provide fundamental QC/QA information for effective image interpretation.

## **References**

Lee, W.H.K., and Stewart, S.W., 1981, Principles and Applications of Microearthquake Networks, Special Issue of Advances in Geophysics, Academic Press, New York..

Maxwell, S.C., 2005, A Brief Guide to Passive Seismic Monitoring, CSEG National Convention.

Maxwell, S.C., et al., 2003, Passive Seismic Imaging of Deformation Associated with Injection for Secondary Recovery, 73rd Ann. Internat. Mtg., Soc. Expl. Geophys..