Guidelines for Standard Deliverables from Microseismic Monitoring of Hydraulic Fracturing

Microseismic Subcommittee of the CSEG Chief Geophysicists Forum

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The recent expansion of microseismic monitoring of hydraulic fracturing has created a need for standardized deliverables. Standardization will facilitate proper archiving of both data and reports, enable opportunities for efficient and effective reprocessing, and support industry exchange and trading of data. The Chief Geophysicists Forum of the CSEG formed a microseismic subcommittee with a remit that includes development of microseismic standards. This document describes suggested guidelines and minimum requirements for standardized microseismic deliverables. The focus of the document is borehole-based monitoring of hydraulic fracturing, although many of the aspects also apply to surface and shallow array monitoring, more general long-term reservoir microseismic monitoring applications, and other monitoring technologies such as tiltmeters.

Microseismic and required supplementary data can be subdivided into the following components:

1. Monitoring details and raw microseismic data with sufficient information for processing.
2. Basic processed data for microseismic locations with sufficient information to interpret hydraulic fracture growth.
3. Advanced processed data for additional microseismic attributes with sufficient information to interpret additional hydraulic fracture aspects, such as moment tensor inversion for source mechanisms.

The minimum required data elements of each of these components are outlined in Appendix A, which has been compiled by combining individual requirements developed by a number of microseismic users over several years.

The various elements of processed microseismic data are typically used to interpret and evaluate hydraulic fracture growth. As such there are various levels of reporting that have evolved, and span from engineering to geophysical interpretation and evaluation of the processed data. The following list describes tiers of reporting and interpretation with increasing complexity:

1. Basic engineering report of the interpreted fracture geometry.
2. Advanced engineering report incorporating basic geophysical analysis of sensitivity and accuracy to interpret fracture geometry and evaluate the hydraulic fracture stimulation.
3. Basic geophysical processing and quality control report describing the workflow employed and corresponding data accuracy and confidence attributes.
4. Advanced processing report describing the workflow and corresponding interpretation.

The minimum requirements of each reporting tier are outlined in Appendix B.

Appendix A: Minimum Microseismic Data Requirements

Microseismic data is stored in technical records similar to a VSP, and should therefore follow equivalent reporting standards. The deliverables are defined as the requirements from each sector of the operation and laid out to be a checklist for QC, technical records, geophysical operations, business unit interpreters, processors and seismic data managers that are involved in data sales or trades.

1. Field Operations and Raw Microseismic Data

1.1 Location/SurveyInformation– Operator Responsibility

- Well pad name
- Well position: GPS surface location in a defined projection systemfor observation and treatment wells, deviation surveys, grid or true north, projection, uncertainty
- Treatment and observation well geometry, Kelly Bushing elevation, uncertainty
- Target formation (name, depth interval in treatment well)
- GPS location of surface geophones if used in conjunction with downhole survey
- Planned perforation locations, perforation phasing and density, or alternate completion such as sliding sleeves type with frac ports, plugs, packers

1.2 Date of acquisition program (start and end date)

1.3 Field Reports – Microseismic Recording Crew Responsibility

1.3.1 Observer's notes – Details and accuracy should be verified by a bird dog/QC contractor, specific attention needs to be paid to array locations, times of any array moves along with new array locations, documentation of any tool failures with data impact and times, any changes to recording parameters during acquisition, acquisition recording system details. Recommend to be documented in a separate document(s) which need to include the following:

- Treatment start and stop times for correlating with pumping information: GPS clock or absolute UTC date and time stamp (no local time zones)
- Method of clock synchronization between all recording systems and frac stage treatment
- Instrument information: manufacturer, type, sample rate, gains, units and format of recorded amplitudes, filter settings in recorder with notes of changes to fixed gain
- Observation boreholes, depth to top of string (measured depth) and live phones, correct names for wells (not abbreviated), fluid level
- Type of sensor (geophone or accelerometer), clamping type, tool sensitivity (e.g. Volts/m/sec), 3C tool polarity convention and wiring diagrams of sensors indicating wiring, sensor orientations (h1, h2 and v) defined from sensor housing, channel order in raw trace data files (i.e. v, h1,h2, or v, h2, h1), channel configuration, details of any engineered alignment between different sensors in the array
- Failure of channels or sensors: It is important to know when a sensor or channel stops functioning and what is done about it during acquisition. Preference is to leave dead channels in raw files

    - if the sensor is removed entirely, needs to be detailed as to which sensor(s) are removed and when
- Any changes to the arrays and what specific action was taken
- Actual and planned perforation locations/string shots, number of shots detected and completed
- Sliding sleeve locations, number of ball drops detected and completed
- Vibroseis or weight drops when used for calibration include:
    - location of vibroseis/weight drop points for each sweep/shot recorded (GPS location)
    - field vibroseis sweep/shot recorded (raw, uncorrelated data in SEG format hereafter meaning SEGD, SEGY, SEG2 or SEG2M)
- Format of raw data and tape header information
    - header format should follow IEEE standards
- Documentation of any background noise monitoring
- Documentation of any instrumentation tests performed

1.3.2 Continuous field raw data in SEG format

- Details of segmented data recording, and specifically if sequential files have time breaks between files or overlapping intervals
- If multiple arrays are 'stitched' together and integrated into one file, ensure order of the arrays are positioned in the file as defined by legs
- If not stitched together, specify which files are associated with which wells
- If there are periods where array systems are disconnected, specify how the data is then still stitched together or stored in separate files
- Specify if GPS time synchronization on any separate acquisition systems and if not, or if temporarily lost, specify if relative timing preserved between systems
- Documentation of any recorded auxiliary channels data
- Any supplemental data acquired not directly input into raw microseismic data set

1.4 Field Reports – Completion Crew Responsibility

- Frac history data: vendor, stage timing, pressures, fluids, proppant, etc. (in xls or csv format)
- Start and stop times of acquisition periods for correlating with pumping information and clock synchronization between all recording systems and frac stage treatment
- Perforation shot times (approximate or measured from signal time picks) and depths for orientation/calibration, well name and details if a string shot, record shot time break if recorded in an auxiliary channel
- Perforation information: depths, timing, raw file name or number, charge size, type, phasing and shots per foot, length of primer cord if a string shot. Perforationtiming system information: description of accuracy and potential delays, schematic of measurement system
- If sliding sleeve/ball drop completion, timing of ball drops and target ball seat position
- Any other orientation/calibration information

2. Basic Processing Results

The majority of microseismic projects involve basic processing for microseismic locations and QC parameters. The following describe associated required data components:

- Processing workflow: all steps in processing of data
- SEG format header parameter document
- Perforation and/or other calibration records (SEG format or jpeg images)
- Hodogram analysis of tool orientation and estimated sensor direction cosines
- Estimated calibration shot location to check velocity calibration
- Velocity model: original Vp and Vs sonic logs (velocity or traveltime/slowness), blocked final calibrated model (LAS format if 1D or SEG format if 3D model), anisotropy parameters and all data used to create model
- P and S arrival time picks or migration/stacking techniques, identification of any overlapping microseismic event times during calibration shot window
- Event detection parameters and description
- Triggered data event files (SEG format)
- Visualization software of microseismic events and injection data (optional)
- Example event signals (jpeg images/PowerPoint)
- Database of microseismic event parameters with specified units: XYZ hypocenters (with coordinate reference frame), origin time reference for time picks, P and S arrival time picks, estimated T_0, magnitudes, S/N (stacked and unstacked from individual sensors), RMS noise, P amplitude, S amplitude, P and S arrival time residuals, direction residuals, uncertainty values, distance from centroid of array
- Additional QC attributes
- Event magnitude calculation description
- Error ellipsoids of event locations (azimuth, distance, depth), perforation or calibration estimated locations
- Stimulated volume estimate and method
- If multi-array locations, individual array locations in addition to collocated locations

3. Advanced Processing Results

Advanced processing is an evolving aspect of microseismic monitoring, but the following provides suggested deliverables for the most common types of processing beyond basic processing.

3.1 Source Parameters

- Source parameters including source radius, stress release and energy, including specification of units
- Description of calculation: equations and constants used, time windows for FFT, are P and S-waves used, integration to displacement spectra, attenuation correction

3.2 Frequency-Magnitude Relationship

- Description of calculation

3.3 Focal Mechanism/Moment Tensor Inversion

- Moment tensor inversion methodology: unconstrained or constrained source type (i.e. double-couple/shear or tensile), attenuation correction, condition number, quality of fit, decomposition, source type analysis, fault planes, strain axis, confidence, units
- Specific elements of moment tensor which allow other decompositions (i.e. M_{xx}, M_{xy}, M_{xz}, M_{yy}, M_{yz}, M_{zz})
- Moment tensor decomposition: double-couple/CLVD/expansion, Hudson k-T, double-couple/tensile/expansion, or isotropic/deviatoric
- Strike and dip of fault plane(s) and orientation of displacement: component projected on fault plane (rake) and on normal
- Strain axis: P, T and B axis trend and plunge
- Graphical depiction with supporting documentation of graphical displays
- Alternate model source parameters associated with a specific failure mode
    - describe methodology
    - refined parameters

3.4 Microseismic Deformation Evaluation

- Spatial/temporal analysis of microseismic deformation or cumulative seismic moment
- Geomechanical analysis of estimated stresses and strains

Appendix B: Minimum Requirements of Tiered Reporting

1. Basic engineering report

Engineering interpretation of the microseismic locations and injection data, with limited geophysical QC information and engineering analysis. At a minimum includes:

i. Location of the treatment well and target formation
ii. Map view of microseismic locations
iii. Cross-section of microseismic locations
iv. Interpretation of frac azimuth, length, height, and stimulated volume
v. Time line of the injection data

2. Advanced engineering analysis report

Engineering evaluation including basic geophysical QC to document the data quality, sensitivity and accuracy. Engineering evaluation may include interpretation of hydraulic fracture characteristics and recommendations for future stimulations, drilling and completion. At a minimum includes:

i. Basic engineering report components plus
ii. Moment magnitude estimates (data sensitivity)
iii. Estimated location uncertainty (data accuracy in each Cartesian direction)
iv. Signal-to-noise ratio (data quality)
v. Integrated microseismic and injection data
vi. Any recommendations for improving the frac

3. Basic geophysical processing/QC report

Sufficient documentation of the data characteristics, processing parameters and algorithms for a trained geophysicist to evaluate the accuracy of the microseismic data. At a minimum includes:

i. Monitoring geometry
ii. Velocity model construction
iii. Calibration of velocity model and potential 3C geophones
iv. Moment magnitude estimates
v. Estimated location uncertainty
vi. Signal-to-noise ratio
vii. Arrival time and direction residuals

4. Advanced geophysical processing report

Processing and interpretation of advanced seismic attributes; include description of the raw signal characteristic, algorithm and uncertainty in the processed attribute. Examples include:

1. Collocation from multiple, simultaneous arrays (multiple downhole, or surface-downhole)
2. Frequency-magnitude evaluation (Gutenberg-Richter *b*-value)
3. Source parameters (source radius, stress release and energy)
4. Focal mechanisms (beach-balls or full moment tensor inversion)
5. Integration with available seismic reflection volumes