Microseismic Monitoring - Methods and Interpretation

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SUMMARY

Microseismic monitoring is attracting great interest due to the application of passive seismic to shale play completion activities and the successful expansion of the method from downhole to surface and near-surface acquisition geometries. Fundamental to this application is the science behind the interpretations: The inherent capabilities and limitations of downhole, surface and near-surface recording systems and the processing and imaging applications enabled by these recordings must be appreciated to understand the results.

These considerations inform issues such as: microseismic event detectability and position uncertainty; the characterization of geological features; sensitivity to hydraulic fracturing methods; rock failure modes; and well to pad to field-wide implications of large scale 'horizontally drill and hydraulically fracture' development programs.

Ultimately interpretation workflows determine microseismic event pointsets, modelling of discrete fracture networks and calculation of stimulated rock volumes.

As microseismic monitoring matures understanding the relationship of recording geometry, imaging capability and interpretation workflows will fuel expanded utilization.

Here the basic issues surrounding passive seismic acquisition methods and microseismic interpretation will be reviewed and discussed.

Key words: Unconventional, Seismic Interpretation, Case Histories, Seismic Acquisition

INTRODUCTION

Microseismic monitoring has been in use in oil and gas applications for over 30 years, and is attracting even greater interest due to the huge growth in shale play completion activities accompanied with the successful expansion of the method from downhole to surface and near-surface acquisition geometries. To appreciate the inherent capabilities of methods the science behind the interpretations applied must be taken into consideration. The inherent capabilities and limitations of downhole, surface and near-surface recording systems and the processing and imaging applications enabled by these recordings must be appreciated to understand the results.

These considerations will include: microseismic event detectability and position uncertainty; the characterization of geological features; sensitivity to the various hydraulic fracturing methods; rock failure modes; and well to pad to field-wide implications of large scale 'horizontally drill and hydraulically fracture' development programs.

Interpretation workflows, by which raw pointsets, containing both false positive and true positive candidate events are culled to determine predominantly true positive microseismic event pointsets, become the inputs for modelling microseismic based discrete fracture networks and calculation of stimulated rock volumes.

Understanding the relationship of recording geometry, imaging capability and interpretation workflows will enable high confidence applications in areas such as stress characterization and response to stimulation, drainage/depletion constraints and production estimates leading to multidisciplinary interest and expanded utilization.

ACQUISITION METHODS

The application of microseismic monitoring for oil and gas activities grew out of earthquake seismology during the pre-'shale gale' era. This first microseismic monitoring predominantly utilized downhole, limited aperture, limited sensor-count arrays and classic P and S arrival picking together with particle motion analysis to determine distance and direction from an event to the observation well's array (Warpinski, et al, 2012). As unconventional shale play developments expanded after 2000, the use of microseismic monitoring also grew rapidly: The growing number of applications and variety of project conditions, along with location and budget constraints on drilling observation wells, motivated the development of surface and near-surface monitoring options (Duncan and Eisner, 2010). The enabling technology for these methods is imaging which requires acquisition geometries akin to those developed in active seismic applications.

Downhole

The downhole acquisition geometry is the legacy microseismic monitoring geometry as applied in oil and gas operations. Typically deployed in a single observation well, the receiving array consists of 8-40+ levels of 3C sensors deployed from just above the interval to be stimulated upwards if in a vertical observation well, and within a the set of horizontal boreholes

in a multi-lateral, pad drilling development. The downhole technique utilizes both P and S arrivals, along with particle motions to determine distance and direction to a candidate microseismic event. Proximity of the microseismic activity to the observation wellbore is key to high quality, low positional uncertainty microseismic imaging. Increasingly, the use of multiple observation wells is recognized as a means to lower positional uncertainty and possibly characterize rock failure modes (Sarkar, et al, 2012).

Surface and Near-Surface

Surface and near-surface acquisition geometries emerged after 2000 in response to the need for non-borehole based methods in hydrofracturing applications as well as to extend microseismic monitoring to reservoir applications such as depletion and stress change monitoring during production (Duncan and Eisner, 2010). In contrast to downhole geometry approach, close proximity to the microseismic activity is obviated and replaced by imaging inside the surface or near-surface footprint with wide azimuth, high fold and large aperture seismic deployments. SNR becomes the primary event attribute for determining high quality, low positional uncertainty, true positive event selection (Thornton and Eisner, 2011). Such systems can be aerially extensive allowing for laterally consistent positional uncertainty over great distances enabling pad to field wide microseismic applications with one installation.

Downhole and Surface Comparison

Downhole and surface acquisition approaches allow for complimentary applications but also introduce several challenges for direct comparison. These challenges include differences in wave propagation, frequencies, event-sensor distance and processing methodology. Several of the comparison considerations are summarized in Table 1.

Downhole	**Surface/near-surface**
1D or multi-1D	2D
Borehole access	Surface access
Horizontal propagation	Vertical propagation
Proximal – great detail	Distant – extended volume
Detection to ~-3.0	Detection to ~-2.5
Well to pad scale	Well to field scale
10s of sensors; 3C	100s to 1000s of sensors; 1,3C
Frequency 15-200+Hz	Frequency 10-70Hz
Break picking, particle motion, limited imaging	Signal processing, imaging, stacking
Multi-mode (P and S)	Single-mode (1C) Multi-mode (3C)

Table 1. A comparison of several factors inherent in downhole and surface/near-surface acquisition geometries.

INTERPRETATION ISSUES

The interpretation of microseismic hypocentres includes several issues which cross seismological to processing to application factors. Understanding these interpretation factors will allow for improved application development.

Tensile/shear failure: for the vast majority of microseismic monitoring geometries tensile breakage of rock undergoing stimulation is too seismically weak to be detected. The ability to detect tensile events requires extremely close proximity and high SNR events. The vast majority of microseismic events available from either downhole or surface/near-surface geometries are due to shear motions which result in higher strength signals. Resolving these source mechanisms requires appropriate wavefield sampling necessitating multiple observation wells or wide azimuth, high fold, large aperture surface acquisition systems.

Microseismic 'fractures': The language ubiquitously used in microseismic applications equates microseismic events with fractures. This is interpretive in its nature. The observed event is the result of some type of breakage or slippage in the rock mass as a result of the change in stresses from the introduction of high volumes of stimulation fluids and proppants or from the drawdown of fluids during production.

Hypocentre positional uncertainty: the uncertainty in position of each microseismic hypocentre is not routinely presented. However, this attribute of microseismic monitoring has a first order impact on virtually all applications. For downhole geometries, the positional uncertainty is related to event SNR and proximity to the observation well. For surface/near-surface geometries the positional uncertainty is related to event SNR. Both geometries critically depend on calibration of known events prior to imaging of events due to hydrofracturing activities or fluid drawdown.

Pointset event count: it is almost universal in microseismic applications to witness an emphasis on event count as a factor in assessing a project's success. This thinking encourages the inclusion of many events in a pointset that are of weak signal strength, low SNR, or possessing other false-positive attributes. In evaluating hydrofracturing applications the most important characteristics of a pointset is its overall geometry: length; width; height, along with event source mechanisms and patterns such as linearity or 'cloudiness' of the pointset.

Pointset surprises: as a direct consequence of the applications of microseismic monitoring to hydrofracture activities is the observation of pointset behaviours such as relatively long distance lineations and other event accumulations separated from the stimulated well. Commonly these features will be interpreted as previously unrecognised, sub-seismic fault or thoroughgoing fractures. Such unexpected features are routinely seen in all settings, but can be particularly prevalent in tectonic regimes. With the emergence of aerially extensive surface and near-surface acquisition systems recognition of these geologic features is increasing. Such features can have a significant effect on the effectiveness of a stimulation program and recognition and mapping of them can provide for informed mitigation.

False positives / true positives: Both downhole and surface microseismic methods involve interpretative procedures for culling false positives from a raw pointset. These interpretations are based on evaluating event attributes such as: amplitude; SNR; arrival coherence; etc. Statistical methods for evaluating thousands to millions of candidate 'events' from a raw processing output pointset are necessary to cull obvious false positives resulting in a manageable subset of potential true positive events for further evaluation and final culling.

Source or focal mechanisms: The computation of source mechanisms for microseismic events is important for determining stress field characteristics as well as the sense of breakage or slippage in a pointset. In order to compute source mechanisms a well sampled wavefield is necessary. The required sampling is available from multiple observation well downhole systems and from wide azimuth, high fold, large aperture surface and near-surface systems.

Discrete fracture network and simulated reservoir volume computations: Deriving 'beyond the dots' estimates of hydrofracture DFN and computing SRVs is of increasing interest as evaluation of the effectiveness of reservoir stimulation matures. There are a number of different ways to calculate a SRV

CONCLUSIONS

A review of both downhole and surface/near-surface recording geometries for use in passive seismic applications was presented. The pros and cons of all acquisition geometries informs fundamental interpretation issues including: determination of tensile vs shear failure modes; what is meant by the terminology 'microseismic fractures'; hypocentre positional uncertainty; pointset event count; pointset 'surprises' revealing previously unknown geological hazards; discrimination of 'false positive' from 'true positive' events. The presentation here provides in one place an overview of the pros and cons of the differing passive seismic geometries and the critical interpretational considerations on the way to providing value to operators in shale and other unconventional oil and gas plays where hydrofracturing is necessary to unlock hydrocarbons.

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