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Microseismic facies analysis: A novel approach to partitioning and interpreting unconventional reservoirs

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Abstract

Microseismic event analysis is often used to assess the effectiveness of hydraulic fracture treatments of unconventional reservoirs. Here we introduce a new approach, *Microseismic Facies Analysis*, to extract additional information from microseismic event clusters. Our approach is based on proposed links between magnitude-frequency distributions and scaling properties of reservoirs such as mechanical bed thickness. In a case study in the Hoadley tight sand reservoir of central Alberta, we correlate *microseismic facies* with surface seismic attributes from a coincident 3-D seismic survey. On the basis of this correlation, we delineate reservoir partitions that we interpret to reflect lithofacies variations associated with depositional trends.

Introduction

Microseismic event analysis and interpretation provide geoscientists with valuable information about reservoir characteristics. Although there are numerous microseismic studies that focus on unconventional plays, relatively little attention has been given to microseismic attribute analysis. In this study we use microseismic dataset that was recorded using downhole seismic monitoring array during stimulation of two horizontal wells in a Glauconitic tight sand of the Mannville Group. Over 1660 microseismic events were recorded and located during this 24-stage treatment, including 259 post-pumping events (Eaton et al., 2014a, 2014b). In addition, data from a coincident 3D seismic survey was used to compute multi-attributes and are correlated here with microseismic observations.

Microseismic attributes such as mean-magnitude and standard deviation, allow interpreters to map subtle stratigraphic details, structural deformation, fracture orientation, stimulated rock volume and stress compartmentalization within a reservoir (Eaton et al., 2014a). A possible link between microseismic magnitude statistics and reservoir properties was suggested by Eaton et al. (2014c), who showed that mechanical layering in a reservoir could result in stratabound discrete fracture networks (DFNs) that can lead to preferred scaling behaviour of magnitudes. In this study, we exploit this link and introduce a new approach to compute microseismic attributes. For validation of inferred reservoir sub-regions, microseismic observations are integrated with interpretation of seismic edge-detector attributes.

Geological setting

Lower Cretaceous base glauconitic sandstone of the Mannville Group comprises a 7.5-24m thick pay zone (Chiang, 1985). In central Alberta this Glauconitic sandstone member contains shallow marine sandstone deposits interpreted to have formed as an extensive barrier bar complex trending SW-NE (Chiang, 1985). The middle and southwestern portion of the barrier bar is saturated with gas and natural

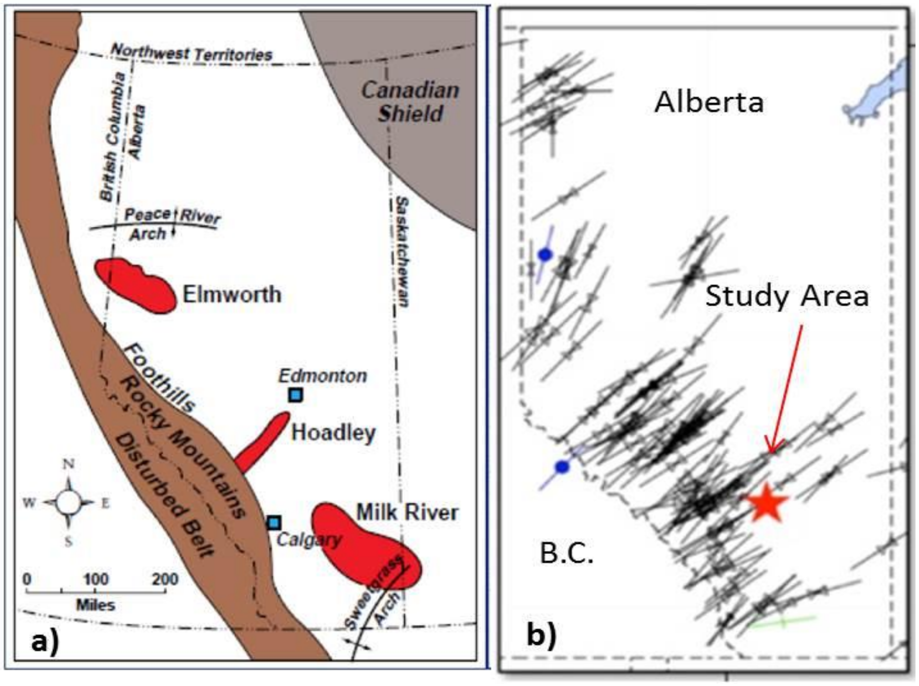

Figure 1: *a) Geological map of Hoadley area. b) Regional stress orientation map showing NE-SW trending maximum horizontal stress direction (Chiang, 1985 and world-stress-map.org).*

gas liquids, trapped laterally by impermeable shale and up-dip by shale-filled tidal channels (Chiang, 1985). The field is estimated to contain an ultimate potential recoverable reserve of 6 to 7 tcf of gas and 350 to 400 million barrels of associated natural gas liquids. Regional stress orientation, which is NE-SW is shown in Figure 1.

Microseismic facies analysis

Microseismic events from 24-stages open-hole completion in two horizontal wells (Eaton et al., 2014b) are shown in Figure 2a. The following workflow was applied for microseismic facies analysis and correlation with surface seismic attributes:

- Interactive classification of microseismicity into distinct clusters
- Refinement of selected clusters through elimination of outliers by visual inspection (Figure 2b)
- Calculation of stimulated reservoir volume (SRV) for each cluster using convex hull algorithm (Figure 2c)
- Estimation of mean magnitude and standard deviation statistics for each cluster
- Identification of clusters with similar information on mean magnitude vs. standard deviation crossplot. This provides the spatial zonation of cluster (facies) with similar statistics (Figure 2d)
- Correlation of these facies zones with surface seismic attributes (Figure 3).

We are currently developing a new workflow to automate the first two steps, as follows:

- Application of the *k*-means algorithm for clustering. The number of initial main clusters (*k*) needs to be specified by the user
- Use of outlier statistics to eliminate events that fall outside the 2σ limit for specified parameters

- Application of principal-component analysis (PCA) to each cluster. The preferred orientation of each cluster is then estimated and an orientation statistics rose diagram is constructed.

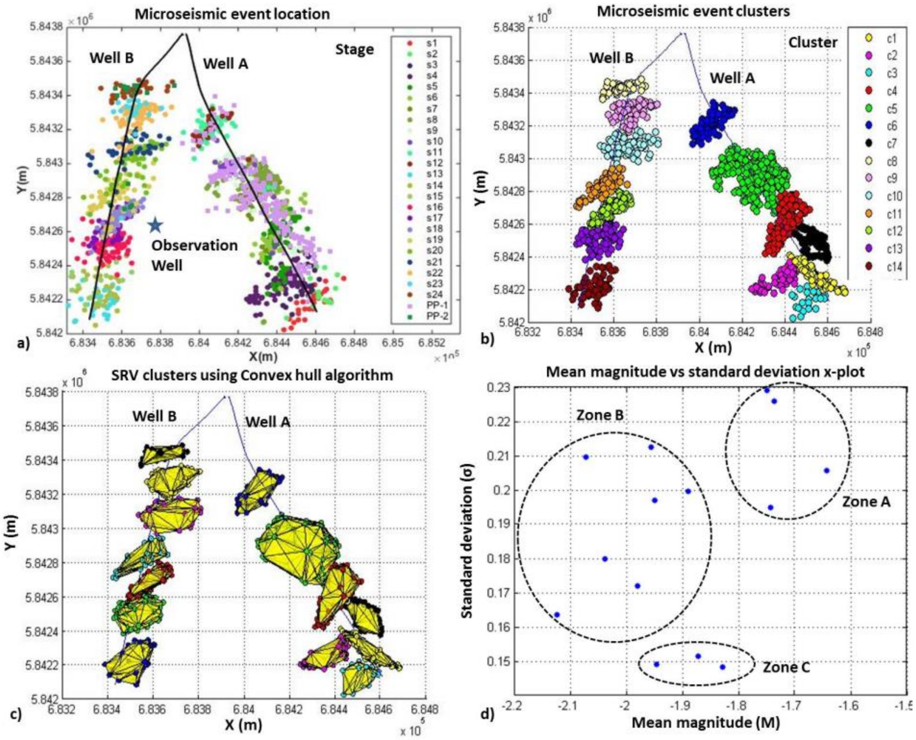

Figure 2: *a) Microseismic event locations for 24 treatment stages b) Clustering of microseismic events using an interactive approach. c) SRV clusters using convex hull algorithm, d) Mean magnitude (M) vs standard deviation (σ) cross-plot. Zones A, B and C are interpreted as three distinct microseismic facies.*

Integrated interpretation of microseismic and surface seismic attributes

In our analysis, we divided the events that occurred during treatment of Well A into seven clusters and those that occurred during the treatment of Well B in seven clusters, as shown in Figure 2b. The clustering analysis resulted in either grouping of events from multiple stages, or elimination of spatial or temporal outliers. Multiple stages are grouped together in cases where there is significant overlap in event locations between stages, including persistence of activity after the treatment time window for a given stage. In general, clusters are elongate in NE-SW direction, which is also the direction of regional maximum horizontal stress (SHmax). Some clusters exhibit trends that deviate significantly from SHmax; these are interpreted as activation of pre-existing fracture systems (Eaton et al., 2014a). We calculated stimulated reservoir volume (SRV) for each cluster using convex hull algorithm (Eaton et al. 2013). In aggregate, the SRV for the entire treatment determined in this way is found to be $27x10^5$ m^3.

Magnitudes of microseismic events due to hydraulic fracturing in a layered medium can be strongly influenced by the scale-length of layering (Eaton et al., 2014c). In particular, the common occurrence of fracture arrest at bedding boundaries gives rise to stratabound fracture networks. In these circumstances, the distribution of event magnitudes may deviate significantly from the commonly assumed power-law distribution implied by the Gutenberg-Richter relation from earthquake seismology. In particular, a regular layered bed-set would be expected to produce a magnitude distribution with a small standard deviation, whereas a bed-set with a large range of thicknesses due to complex depositional environment may exhibit a large standard deviation.

Figure 2d shows a cross-plot of mean magnitude versus standard deviation derived from the magnitude distribution within the inferred microseismic clusters. We interpret a number of possible clusters of microseismic facies. According to the interpretive framework outlined above, the four clusters of events with the largest mean magnitude may occur within the most brittle (quartz-rich?) and/or massively bedded region of the reservoir indicated as zone A. In contrast, the three clusters in zone C, with the lowest standard deviation may represent a relatively homogeneous but less brittle region, whereas the remaining seven microseismic clusters shown as zone B may occur within a region that has more diverse bed thickness characteristics but is less brittle than the first set of microseismicity clusters. Based on clusters of events in Figure 2d we divided Well A & B into facies zone A, B and C and for comparison plotted these zones on most positive curvature (k_1) attribute in Figure 3, as this attribute described anticlinal features in a robust way as positive anomaly which is comparable to the major structures in study area.

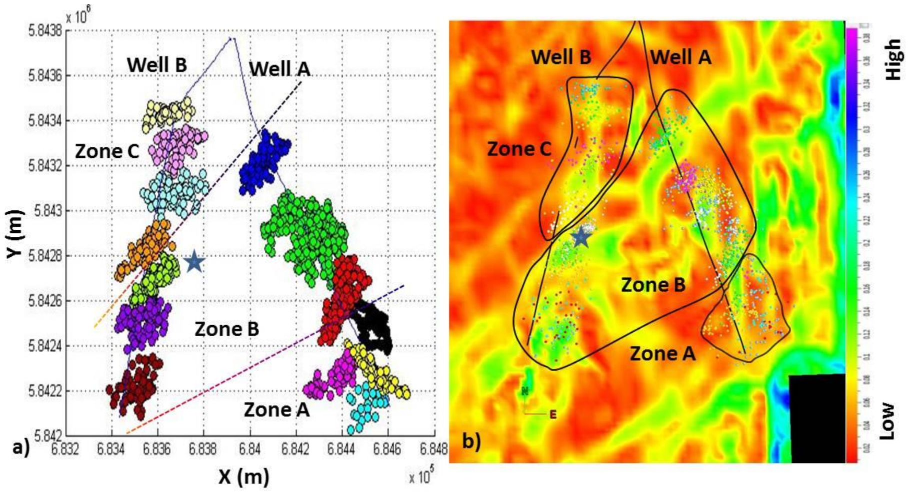

Figure 3: *a) Microseismic zonation of Well A and B based on mean magnitude-standard deviation cross-plot. b) Depth slice of most-positive curvature (k_1) at Z= 2058 m, through base Glauconite overlain with microseismicity and microseismic facies zones. Strong NE-SW (green) lineaments follow major surrounding structure, part of barrier bar complex.*

Conclusions

We performed the analysis of available processed microseismic events from a hydraulic fracturing treatment in western Canada. The dominant orientation of the microseismic cluster is NE trending, which agrees with the regional maximum horizontal stress orientation. Using a convex hull algorithm, we found the total stimulated reservoir volume to be 27×10^5 m^3. The magnitude statistical analysis helped in identification of numerous zones attributed to different facies. This facies information from microseismic data agrees well with spatial partioning of the reservoir based on seismic attributes such as most positive curvature. An automated workflow to perform these steps is currently under development.

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