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Using Stage Level Microseismic Analysis to Investigate Correlate and Ground Truth Cored Hydraulic Fractures

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Abstract

The Hydraulic Fracture Test Site in Reagan County, Texas contains a valuable dataset to correlate the occurrence, position and frequency of microseismic events in relation to physical observations of hydraulic fractures taken from a low-angle whole core acquired immediately adjacent and subsequent to a modern hydraulically fractured horizontal well within the Upper & Middle Wolfcamp formations. Microseismic event density maps visualized through time locate concentrations of microseismic activity in relation to independently documented hydraulic and naturally occurring fractures. Microseismic activity observed over the duration of a single completion stage at the closest proximity to the cored interval demonstrates conformity and correlation with the presence of hydraulic fractures. Changes in microseismic signature are also correlated with changes in pump rates and pressures throughout treatment. A positive correlation was found between the high certainty hydraulic fractures observed in the core and areas of highest microseismic density in the stage of the neighboring horizontal nearest to the Upper Wolfcamp cored interval of the slant well, demonstrating that microseismic density can be a reliable indicator of hydraulic fracture density and complexity around the stimulated well. Given caveats often cited with microseismic acquisition, processing and interpretation, this study provides a ground truth example and insights into the degree of accuracy microseismic can offer as a technology in discerning the efficacy of modern completions.

Introduction

The Hydraulic Fracture Test Site (HFTS) in Reagan County, Texas consists of 11 horizontal development wells in the Wolfcamp Formation along with two preexisting Wolfcamp wells which were refrac'ed on the eastern side of the package (Figure 1) (Courtier et al, 2016, 2017). The primary objective of the HFTS throughout the course of testing was to evaluate subsurface controls and operational impacts on hydraulic fracture geometry and completion efficiency, with one of the main undertakings of the project involving the drilling and coring of a slant well between two of the completed wells in the package in order to determine the presence and distribution of hydraulic fractures and proppant.

Analysis of the core in conjunction with downhole microseismic data provides unique insight into the representation of fracture propagation and proppant distribution from nearby stages with microseismic events recorded via downhole arrays. Through careful analysis of the density of the microseismic events and viewing the animation of events together with the pump schedule, relationships can be ascertained between the concentration and behavior of microseismic events and the hydraulic fractures and proppant identified within the slant core. It is the intention of this paper to ground truth these data through empirical observations involving best-certainty hydraulic fractures noted in the core with kernel density estimate maps of microseismic events.

Since the main subject of this paper is relating the microseismic to fractures identified within the slant well core (hereafter referred to as the 6TW), the focus from this point forward will be primarily on analyzing the microseismic of the 6U well to the east and lesser so the 6M well to the west. In particular, the focus will be largely on the stages immediately adjacent to the cored locations of the 6TW slant core well - Stages 23-24 in the 6U.

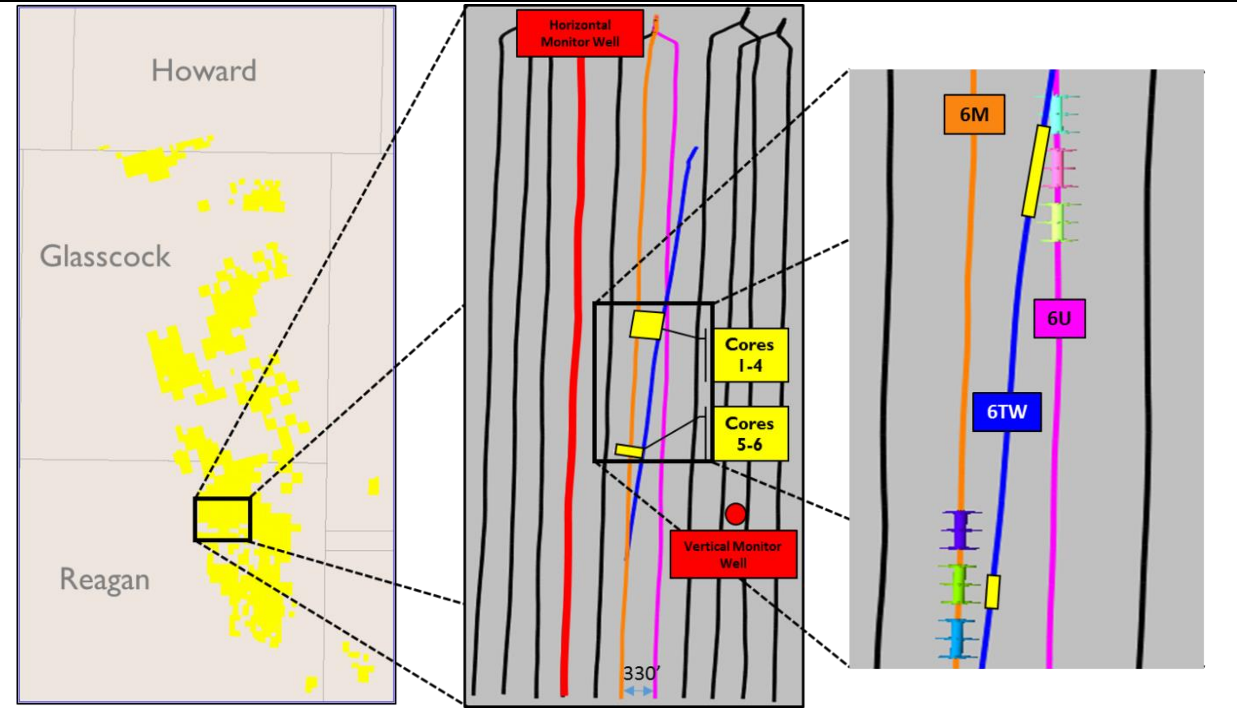

Figure 1: Whole core were successfully obtained in 4 separate runs (Core 1-4) in the Upper Wolfcamp portion of the slant well after the 6U and 6M wells were completed. Core segments 5-6 were collected in the Middle Wolfcamp for a total of 594 feet of whole core. Downhole microseismic data were also collected throughout the completion of these wells.

Method

The 6U and 6M are two of eleven wells drilled during the HFTS study. These wells were triple zipper frac'ed along with the 5U well directly west of the 6M with alternating stages in the three wells sequentially stimulated from the toe to heel by completing a stage on one well before moving to complete a stage on an adjacent well. The completion utilizes 100 mesh proppant pumped during the first 25 minutes of the stage completion before transitioning to 40/70 mesh proppant 30 minutes into the treatment. Varying colors of proppant were pumped in discrete stages, with the intention of correlating a particular colored proppant associated with a specific stage, with its physical presence traced within the core.

Application of Microseismic

During completion, real-time microseismic data was acquired for the entire HFTS package in order to monitor the efficiency of the refrac treatment on the two parent wells east of the package, evaluate the impact of completion design variations chosen for the wells, and ensure all chosen designs were effectively stimulating the reservoir as reflected in the real-time microseismic events. The data were acquired over all of the test wells and geophone monitor locations were moved several times throughout the completion of the pad as the frac moved from east to west, in order to mitigate monitor bias and accurately map event locations (Stegent et. al, 2018). During stimulation of the 6U and 6M wells, geophones were located in one vertical well to the east of the 6U and in one horizontal Wolfcamp well 660 feet to the west of the 6M.

Microseismic data subsequently went through iterative processing to constrain event locations, magnitudes, and confidence, however, the real-time microseismic was still highly valuable in gaining insight into the behavior of the stimulated reservoir during the course of treatment.

Real-time microseismic in the vicinity of the planned coring location was thoroughly analyzed and used to determine final coring locations within the slant well. Three nearest stages between the 6U and the slant well and three nearest stages between the 6M and the slant well were prioritized to undergo a higher degree of processing. Prior to analysis of real-time processed microseismic, coring locales of the slant well were based on the closest encounter to the neighboring horizontals, lithology contacts, and the hypothesized hydraulic volume extents at the time**.** Processed microseismic of the stages nearest to the planned location of the slant core revealed a high density microseismic cloud in Stages 23 of the 6U that formed two fracture planes and passed slightly above the planned coring interval (Figure 2).

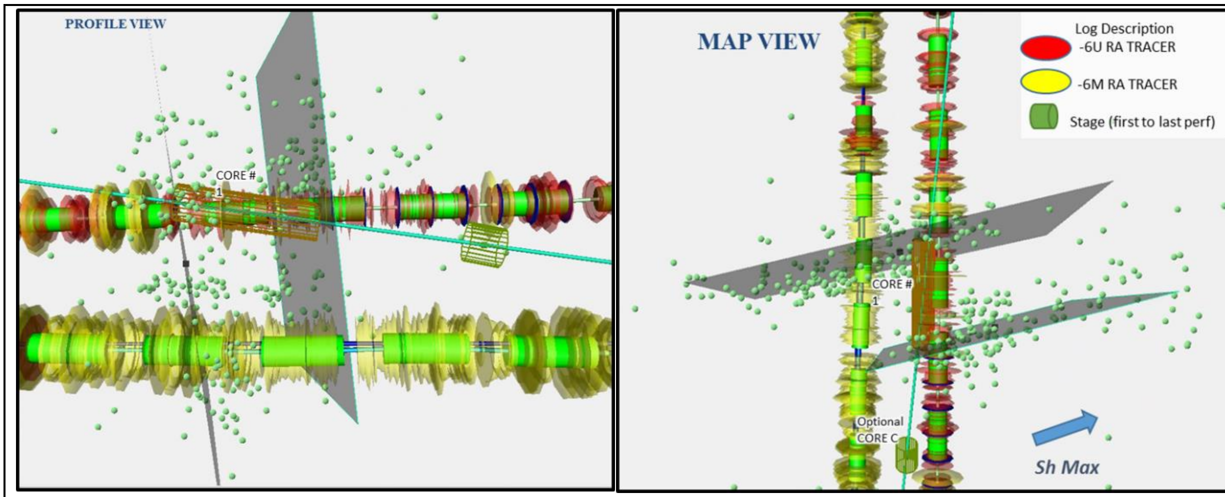

Figure 2: Image of the two "fracture planes" identified by planar microseismic event clouds which were used to alter planned core location to better intersect with both planes and thus increase likelihood of encountering hydraulic fractures.

With this information. the coring interval near the 6U was extended, increasing the coring footage along the closest encounter to the 6U and adjusted to intersect microseismic planar event fields and increase the probability of encountering hydraulic fractures within the core. This allowed the slant core to also pass through a high microseismic density zone near the 6M. The utilization of real-time, processed microseismic events to adjust coring intervals within the slant well increases confidence in encountering hydraulic fractures and potential proppant within the core prior to the slant well being drilled. Subsequently, the slant core well was drilled at an 82 degree angle between the 6U and 6M chevron spaced wells. The closest encounters of the slant well to the neighboring horizontals occurred when it passed within 89 feet of stage 23 on the 6U well and within 135 feet of stage 15 on the 6M well.

Classification of hydraulic fractures in the core

Whole core were successfully obtained in 4 separate runs (Core segments 1-4) in the Upper Wolfcamp portion of the slant well after the 6U and 6M wells were completed. Core segments 5-6 were collected in the Middle Wolfcamp for a total of 594 feet of whole core. All extracted core was analyzed inch by inch to catalog the presence of fractures and their distinguishing features (Gale et al, 2018). Fracture origin interpretations were made as to whether the fractures were natural intact, natural reactivated, hydraulic, drilling induced, core handling induced, connection break, fault or bed parallel natural. The fracture origin observations were classified according to the certainty of their identification: sure, probable or best guess. In this paper, only "Sure" hydraulic fractures will be utilized, hereafter referred to as "best-certainty". It was also noted where proppant was found in the fractures and whether colored proppant was found.

Application of KDE plots

Kernel Density Estimate (KDE) maps provide a way to estimate the probability density function of a group of microseismic events (Fairfield et al, 2018). To illustrate the application of KDE maps, the following example is presented. In Core 2, two proppant packs were found that align with perforation clusters on the nearby Stage 23. The 6TW slant core fracture analysis shows hydraulic fractures present in this range with orange/red colored sand present. This colored sand was pumped from Stage 23. A single microseism intersects with Core 2 at ~9458' md during Stage 23 within a few feet of the colored sand filled hydraulic fractures. However, the microseismic positioning error on this event is +/- 16' N/S, +/- 18' E/W and +/- 36' depth. This error in microseismic positioning makes it impossible to state unequivocally that a specific microseismic event is directly attributable to a hydraulic fracture or proppant pack in a 4" diameter core. However, when taking the representative cloud of events and kernel density estimate maps created with those events, we can assume that those areas under the intensely colored portion of the KDE anomaly are areas of highest energy and thus highest statistical likelihood of being hydraulically fractured.

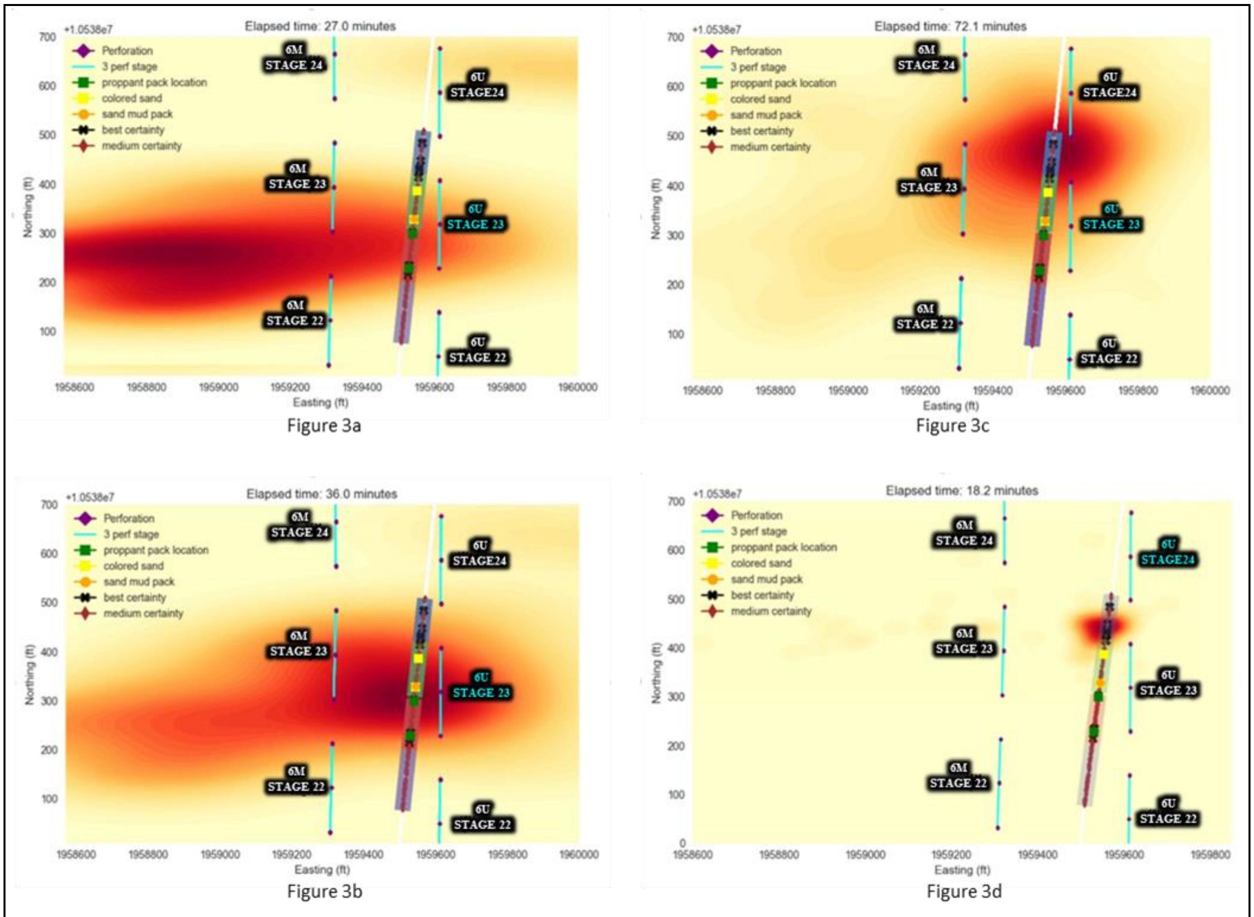

Figure 3: Evolution of KDE microseismic anomalies over stages 23 and 24 on the 6U. Figure 3a shows the far field events present in the data prior to ramp up of casing pressure, the events snap to a location intersecting a proppant pack with colored sand linked to Stage 23 in Figure 3b, later in the treatment, Figure 3c, the anomaly migrates to the heel of the stage over an area of high certainty hydraulic fractures and remains there for the duration of the treatment. Early in Stage 24 the anomaly reoccupies the same location over Core 1 as in the previous stage.

Results

Microseismic events of varying density intersect the 6TW wellbore from stages 15-29 of the 6U, however the cored intervals cover only cover portions of Stages 22-24. The fracture planes on stage 23 are estimated to be oriented at N77 degrees E and 80 degrees S. Regional compressive stress direction was estimated to be 75 deg x 255 deg. When creating KDE maps of the microseismic event clusters throughout time and viewing the animation coincident with the pump data, Stage 23 at the 15 minute mark prior to onset of completion pressure shows far field activity away from the wellbore (Figure 3a). At the 26-30 minute mark, the concentration of microseismic events abruptly snaps to the wellbore precisely when the ramp up in pressure begins, indicating that rock is being fractured, thus generating microseismic events (Figure 3b). At the 36 minute mark, the KDE maps show an area of microseismic event density centered over Core 2 which then migrates to the heel of the stage and stays over Core 1 for the remainder of the stage (Figure 3c). The concentration of the microseismic around the heelward perf correlates to a part of Core 1 where high certainty hydraulic fractures were identified. Similarly, on Stage 24, at the 20 minute mark, the activity snaps to the same Core 1 area of the slant well where high certainty hydraulic fractures were cataloged and the activity remains there throughout the stage, growing outward in an E-W trend (Figure 3d).

a) b)

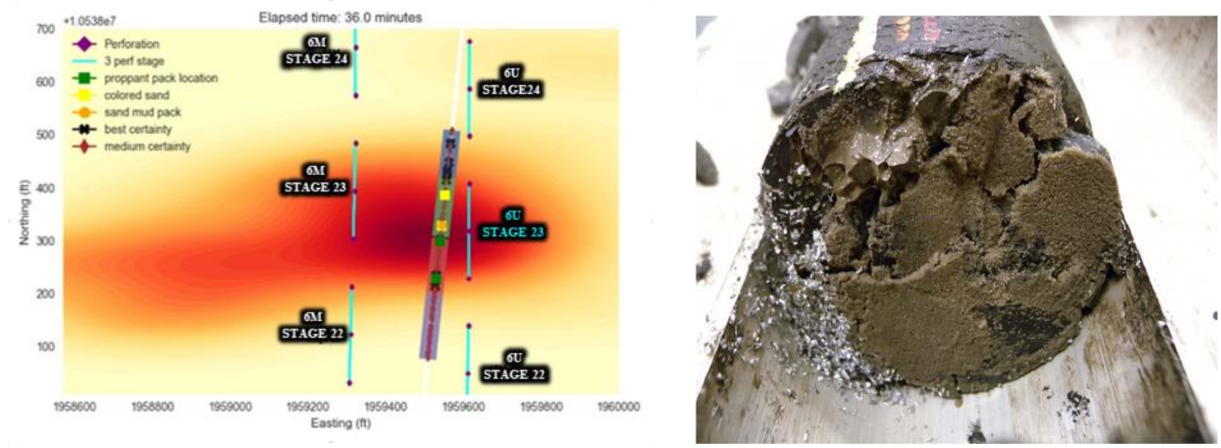

Figure 4: Thirty six minutes into the treatment of Stage 23, a high density cloud of microseismic events gathers around the core intervals 2 and 3 in the same location a large proppant pack, b), and was seen in the core. The microseismic concentration at 36 minutes into treatment of the stage likely is showing the fracture network that emplaced the proppant encountered in the Slant Core.

Discussion

Early in the treatment of Stage 23, the KDE cloud starts over Core 2 where the proppant packs and colored sand were encountered (Elliott et. al., 2018). A statistically significant KDE trend extends through the location of the proppant packs. It is assumed that the proppant packed fractures and colored sand pumped from Stage 23 are placed at that time (Figure 4). As the microseismic migrates toward the heel and coalesces over Core 1, the high certainty hydraulic fractures observed in the core are being created at this time. When overlaying the microseismic events of Stage 23 on a geocellular model, a high calcite interval can be seen arresting the presence of microseisms and thus acting as a fracture barrier. (Figure 5a, 5b) Interestingly, no high certainty fractures were cataloged in Cores 5-6 near the 6M. This may be due to the fact that the core is roughly 46’ further away from the closest 6M stage than that of Core 2 and its closest stage (Stage 23) on the 6U.

Conclusions

Real-time microseismic was successfully utilized to optimize the likelihood of encountering hydraulically induced fractures during the coring of the slant well. Microseismic used in conjunction with additional geological and engineering parameters is an invaluable tool for well spacing optimization and assessing efficiency of completion design. Time series maps of microseismic event density show strong conformance with cored intervals containing not only independently documented, high certainty hydraulic fractures but also proppant packs with colored sand traced to a nearby stage. Changes in microseismic signature are also correlated with changes in pump rates and pressures throughout treatment. These positive correlations along with the use of KDE maps demonstrate that microseismic event density can be a reliable indicator of hydraulic fracture density and complexity around the stimulated well. Given caveats often cited with microseismic acquisition, processing and interpretation, this study provides ground truth examples and insights into the degree of accuracy microseismic can offer as a technology in discerning the effectiveness of modern completions.

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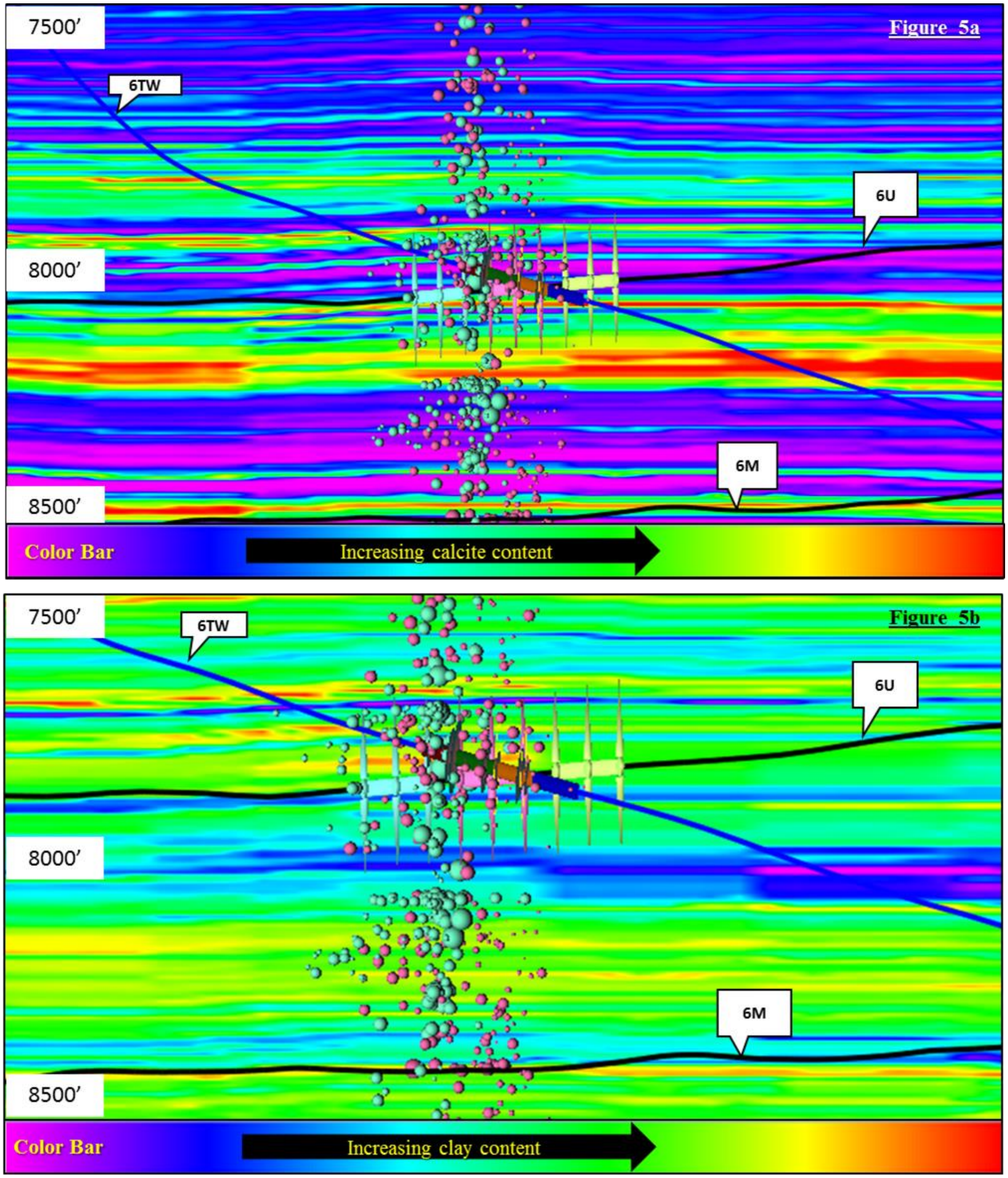

Figure 5a Proprietary geocellular model of calcite volume. Figure 5b: Proprietary geocellular model of clay volume. On both figures, notice the arresting of events in the center of the figure coinciding with elevated calcite/lower clay volume. The cyan microseismic events are from Stage 24, purple events are Stage 23.