PS 3-D Seismic Attribute-Assisted Analysis of Microseismic Events within the Marcellus Shale*

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Abstract

Microseismic monitoring is often used during the process of oil and gas exploitation to monitor seismicity induced by hydraulic fracturing, a common practice in the Appalachian Basin. Anthropogenically induced minor upward fracture growth is not uncommon in the Marcellus shale; however, in the area of study, more extensive upward fracture growth was observed. In order to ascertain which areas are more likely to experience brittle failure first, 3D seismic data are analyzed to uncover variations in acoustic properties associated with upward growth zones overlying the Marcellus. The reservoir's response to hydraulic fracture treatments from six horizontal wells provides considerable insight into local stress anisotropy and optimal well spacing needed to maximize drainage area during the field development phase. 3D seismic attributes such as 3D curvature, chaos, dip deviation, variance, and ant tracking will be used to identify more intensely deformed areas. Areas of higher curvature and local seismic discontinuity, for example, generally define more intensely deformed areas. In turn, more intensely deformed strata are generally associated with zones of increased fracture intensity, and these zones may represent areas of increased risk for out-of-zone stress release in response to hydraulic fracturing. In addition to the 3D seismic and microseismic surveys, completions data such as stage and perforation locations, pumping pressure, and proppant concentration are incorporated into the analysis of upward growth phenomena. Hydraulic fracture treatments were alternated between wells in a "zipper fracture" fashion so that well-to-well interactions associated with alternating treatments can also be examined to identify the possible extent of cross-stage fracturing or re-fracturing and their possible role in the development of out-of-zone growth. The outgrowths of this study will provide insights that may help improve real time fracture control, well placement and spacing, and increase effective drainage area. The results of the study may lead to the development of 3D seismic interpretation workflows that can be used to vary treatment design, increase cost-effectiveness and improve recovery efficiency of field-scale shale gas development efforts.

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Abstract

Microseismic monitoring is often used during the process of oil and gas exploitation to monitor seismicity induced by hydraulic fracturing, a common practice in the Appalachian Basin. Anthropogenically-induced minor upward fracture growth is not uncommon in the Marcellus shale; however, in the area of study, more extensive upward microseismic activity (Figure 1) was observed. In order to ascertain which areas are more likely to experience brittle failure first, 3D seismic data are analyzed to uncover variations in acoustic properties associated with upward growth zones overlying the Marcellus. The reservoir's response to hydraulic fracture treatments from six horizontal wells provides considerable insight into local stress anisotropy and optimal well spacing needed to maximize drainage area during the field development phase. 3D seismic attributes such as 3D curvature, chaos, dip deviation, variance, and ant tracking will be used to identify more intensely deformed areas. Areas of higher curvature and local seismic discontinuity, for example, generally define more intensely deformed areas. In turn, more intensely deformed strata are generally associated with zones of increased fracture intensity, and these zones may represent areas of increased risk for out-of-zone stress release in response to hydraulic fracturing.

In addition to the 3D seismic and microseismic surveys, completions data such as stage and perforation locations, pumping pressure, and proppant concentration are incorporated into the analysis of upward growth phenomena. Hydraulic fracture treatments were alternated between wells in a "zipper frac" fashion so that well-to-well interactions associated with alternating treatments can also be examined to identify the possible extent of cross-stage fracturing or re-fracturing and their possible role in the development of out-of-zone growth. The outgrowths of this study will provide insights that may help improve real time fracture control, well placement and spacing, and increase effective drainage area. The results of the study may lead to the development of 3D seismic interpretation workflows that can be used to vary treatment design, increase cost-effectiveness and improve recovery efficiency of field-scale shale gas development efforts.

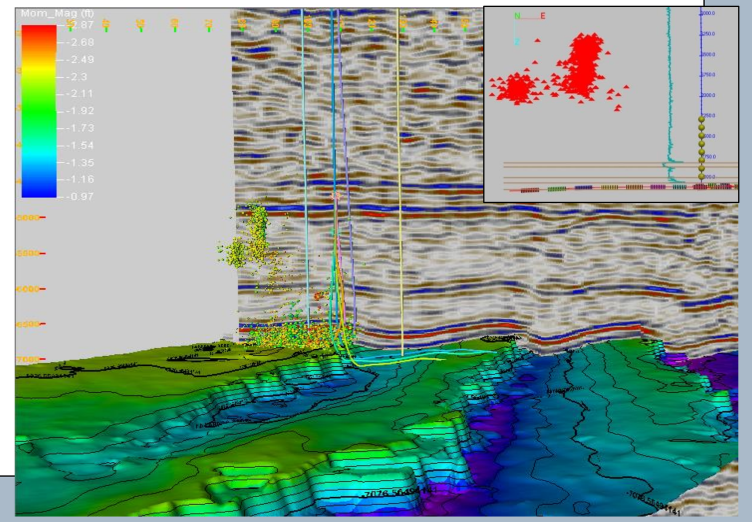

Figure 1: Depth-converted seismic with all wells shown (6 laterals and 2 monitoring wells) on the surface of the Onondaga Limestone. Microseismic events are not SNR filtered. Shown inset are borehole geophone locations. The array stretches to the Sonyea, but is not near the same level as the out-of-zone events.

Study Area

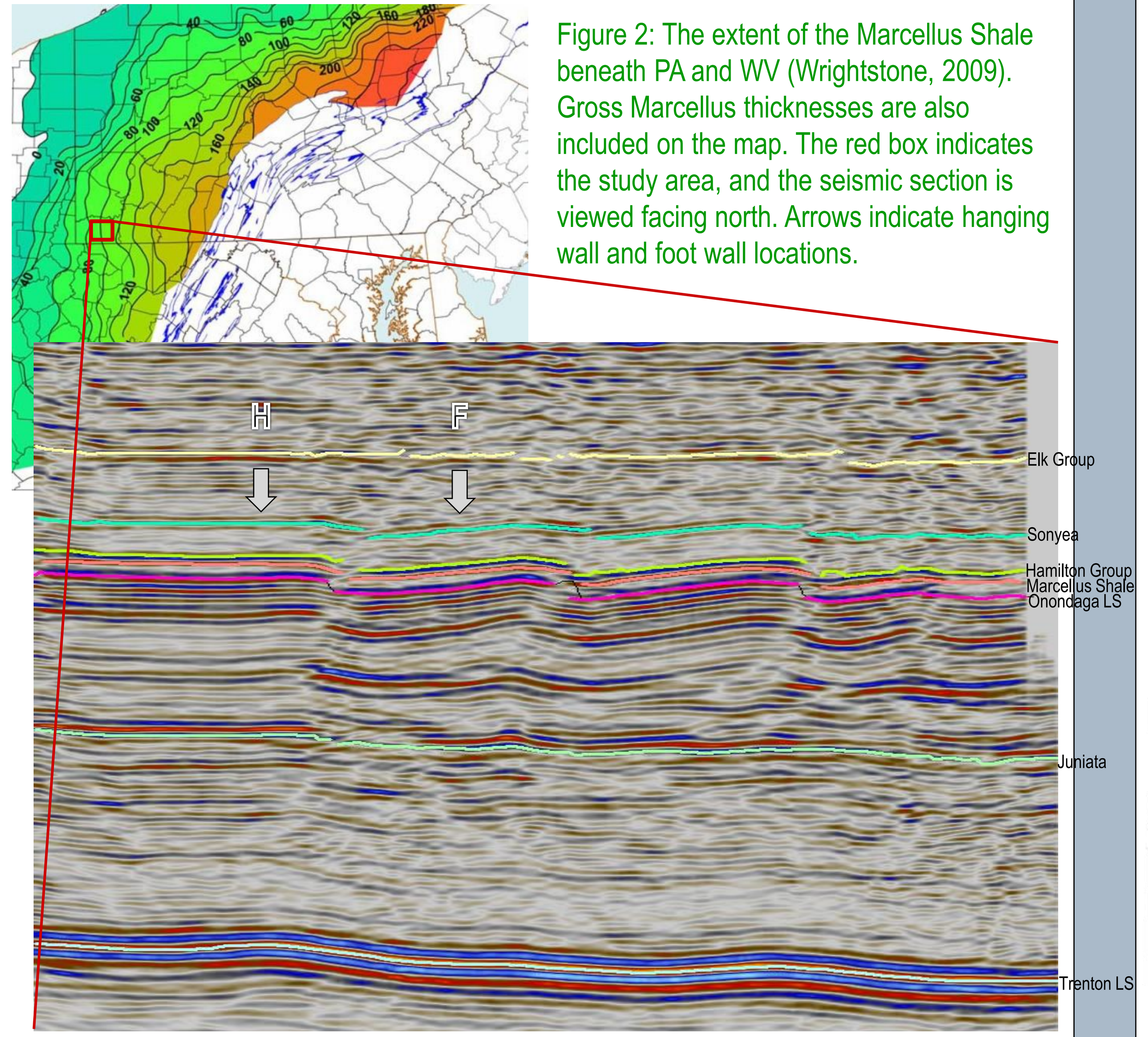

Figure 2: The extent of the Marcellus Shale beneath PA and WV (Wrightstone, 2009). Gross Marcellus thicknesses are also included on the map. The red box indicates the study area, and the seismic section is viewed facing north. Arrows indicate hanging wall and foot wall locations.

A 25 mi^2 3D seismic data set from Greene County, PA (Figure 2), microseismic data, post job reports, and 114 wells are used for this study. Much emphasis is placed on the analysis of the 3D seismic data, as the main objective of this study is to determine whether out-of-zone microseismic activity could have been anticipated based on anomalous seismic response. The 3D seismic data can be probed for evidence of faulting and other indicators of stress which is what makes it a valuable tool for the microseismic analysis.

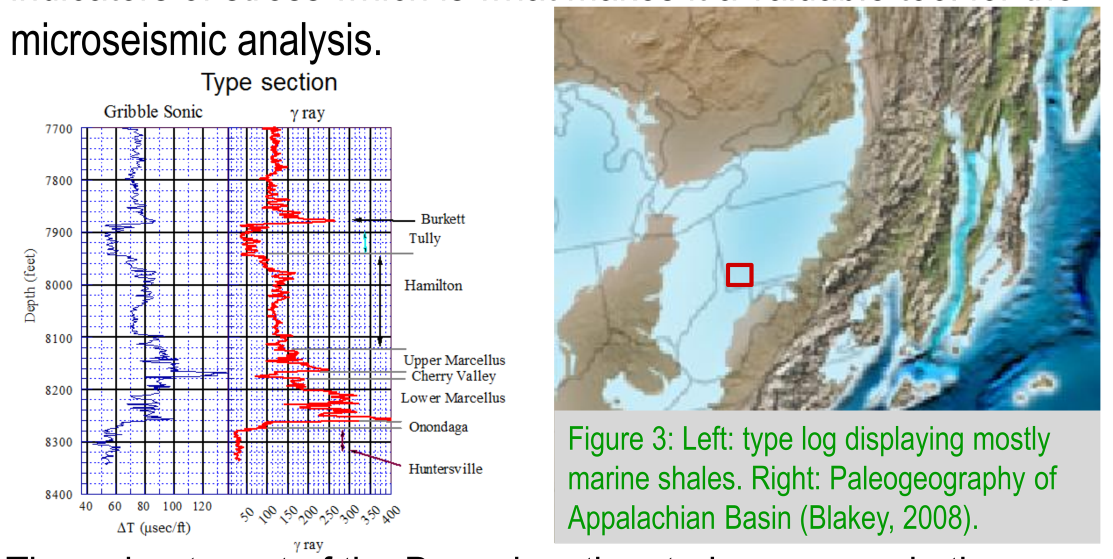

Figure 3: Left: type log displaying mostly marine shales. Right: Paleogeography of Appalachian Basin (Blakey, 2008).

Throughout most of the Devonian, the study area was in the distal region of the basin plain (Figure 3); thus, most of the stratigraphy is comprised of marine shales with some carbonaceous influence. This can be confirmed by core, the lack of amplitude contrast in the seismic data through much of the Devonian strata, and well logs run in this region.

Seismic Attribute Evaluation

Numerous volume attributes were extracted from the 3D seismic data set, but few provided insights into geologic factors that could have facilitated out of zone microseismic activity. The ant tracking and 3D curvature attributes provided useful insights into possible structural controls that might facilitate out-of-zone stress release; these attributes revealed the presence and orientation of subtle seismic-scale discontinuities (Figure 4) which may be associated with widespread fracture zones and faults.

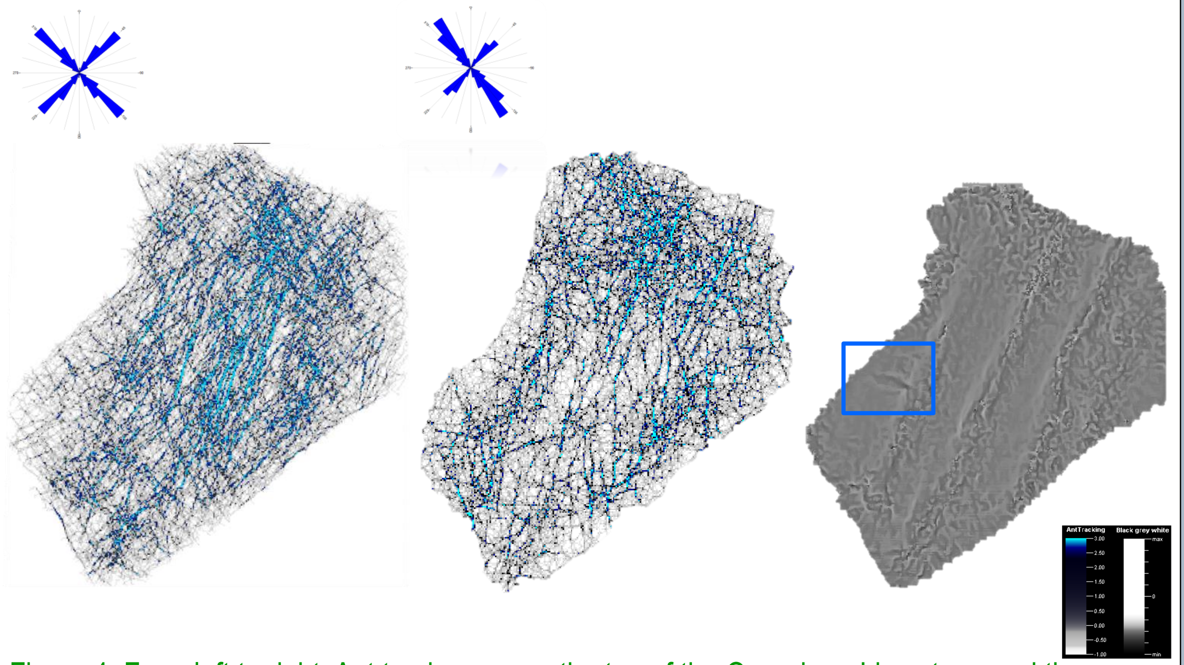

Figure 4: From left to right: Ant track maps on the top of the Onondaga Limestone and the Lower Marcellus, and a Most Extreme Curvature map of the top of the Onondaga Limestone. Ant track maps are accompanied by rose diagrams which depict dominant fracture azimuth orientations. An interesting feature to note on the Most Extreme Curvature map would be the large cross-structural discontinuity shown in the blue box.

The ant tracking and 3D curvature maps were beneficial for risk analyses and could be a valuable tool in the well planning phase. The 3D curvature map helped me identify the extent of 3 large faults and other possible features that could be associated with deformation. I was also able to determine dominant discontinuity orientations for the Onondaga Limestone and multiple slices through the Marcellus Shale (the Marcellus in this region can be up to 140' thick). Also, dominant orientations highlighted on Ant track maps correlated quite well with microseismic activity (Figure 5).

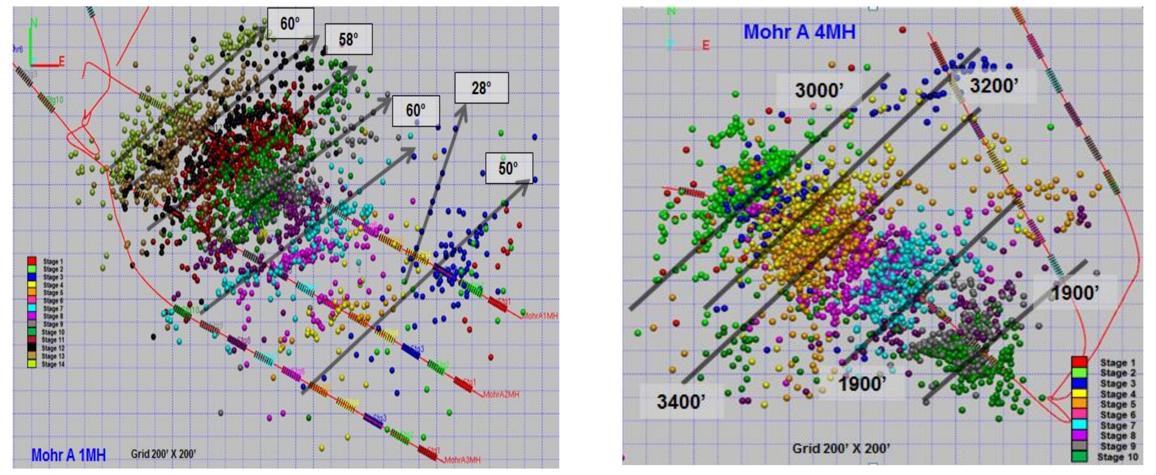

Figure 5: MH1 and MH4 perceived fracture networks. Zero phase perforations were used for each well and the Lower Marcellus was the target, so one would expect to see fracture patterns similar to those of the Onondaga Limestone. (Image courtesy of Weatherford)

Energy Comparison

Radiated Seismic energy is computed by summing the energy released for recorded microseismic events (Eaton & Boroumand, 2012). While radiated seismic energy is a small fraction of total energy output, it is curious that energy output differed greatly from the hanging wall to the foot wall. Radiated seismic energy output was ~346kJ in the foot wall and ~118kJ in the hanging wall; reasons for this energy output discrepancy are currently being researched. While we do not yet have specific numbers, we know that production was significantly less in the hanging wall. This poor production may be related to energy transfer into shallower strata. (Figure 6 and 7).

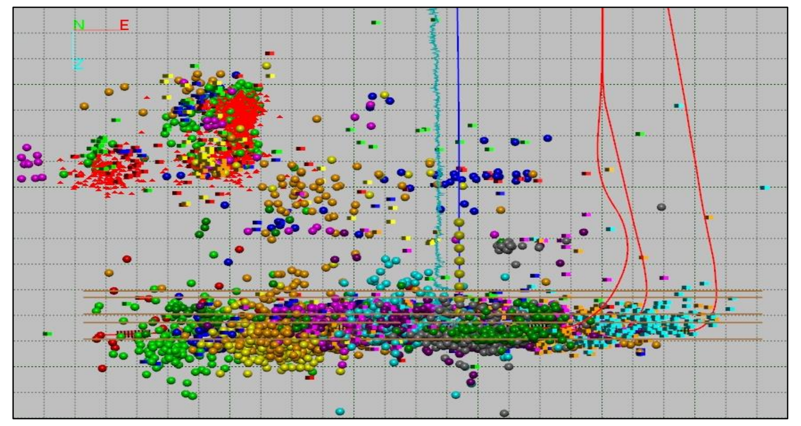

Figure 6: All events for MH4, MH5, and MH6. Notice the large amount of out-of-zone microseismic activity. A large cluster of events stretches as far upsection as the Elk Group.

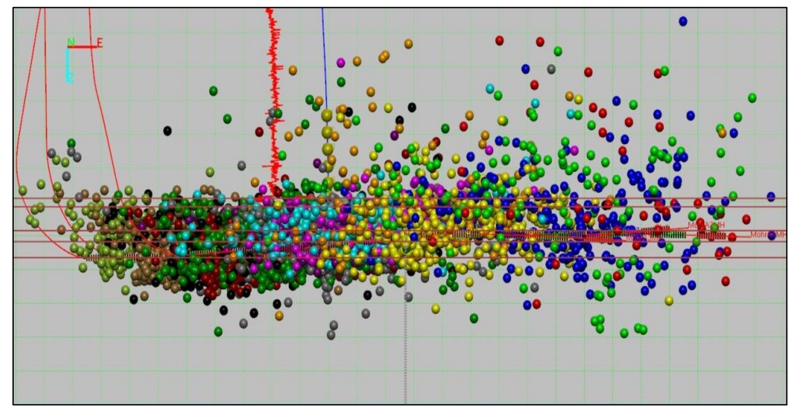

Figure 7: All events for MH1, MH2, and MH3. For the most part microseismic events stayed within the Marcellus Shale. Very few propagate above the Tully Limestone.

Also of interest to this study are the radiated seismic energy release discrepancies amongst neighboring stages. I use stages 6 and 7 from MH5 as an example (Figure 8) because there were only minor differences in pumping parameters. Preliminary research efforts indicate these discrepancies are related to the local geology. Seismic discontinuities can be seen stretching across multiple wells, and anomalous stage behavior seems to cluster along these discontinuities.

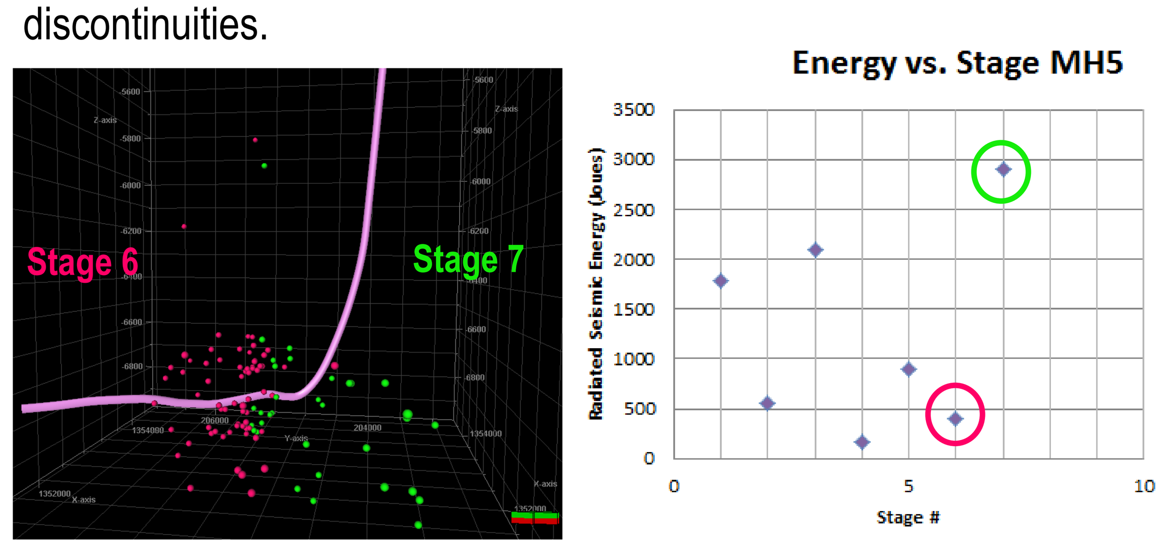

Figure 8: Left: MH5 displayed with microseismic events for stages 6 and 7. Right: a plot showing what the radiated seismic energy output (in Joules) is for each stage from the MH5 well.

Brief Uncertainty Discussion

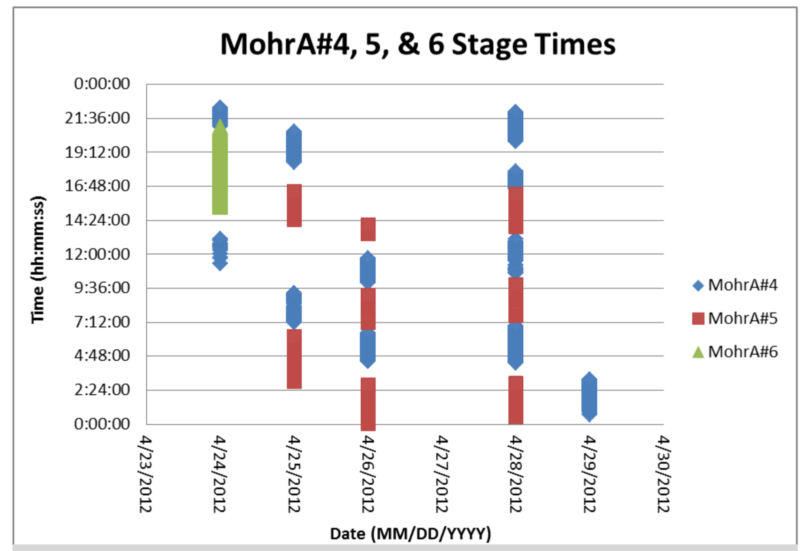

Figure 9: Frac stage times for MH4, MH5, and MH6. Results needed to be plotted as the initial frac plan had changed due to unforeseen circumstances.

By inspecting the graph pictured (Figure 9), one can see that the MH6 well only had one stage completed; the MH6 well was fully completed at a later date without microseismic monitoring. Thus for our energy comparison calculations, we are missing all microseismic data except for one stage from the MH6 well that could be used for radiated seismic energy output estimations. Another area of uncertainty includes microseismic event location uncertainties; we are currently attempting to make contact with the service company and gather this information.

Work in Progress

- Conduct a well log analysis to check for potential hydrocarbon migration via thrust faults.
  - Check gas curves, resistivities, other logs around & away from faults.
- Calculate injection, fracture, and radiated seismic energy for MH1, MH2, and MH3
- Identify differences in pumping parameters between neighboring stages with significantly different energy outputs.
- Develop a hypothesis as to why energy output varies so much between the hanging wall and the footwall.
- Reconstruct study area/make isochore maps to determine fault timing.

Acknowledgments

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