STUDYING HYDRAULIC FRACTURING THROUGH TIME-VARIANT SEISMIC ANISOTROPY

An Undergraduate Research Scholars Thesis (Chapter I)

by

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ABSTRACT

Studying Hydraulic Fracturing through Time-variant Seismic Anisotropy. (Dec 2013)

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Hydraulic fracturing is an important modern technique of exploiting natural gas and oil, in which a high-pressure liquid mixture is injected into a wellbore to create small fractures in order to release fluids such as natural gas and petroleum. Studying seismic anisotropy by shear wave splitting can help us better understand the relationship between hydraulic fracturing and fracture systems. Shear wave splitting can be caused by fracturing and also can naturally take place in most sedimentary rocks. It will separate the incident shear-wave produced from microseismic event into two orthogonally polarized fast and slow shear waves. Conversely, measurements can be used to infer information related to the fracturing. The microseismic data this article is based on have three components in orthogonal directions and also have a long time span over one month. The data are very ideal for studying time-variant shear-wave splitting in the subsurface. We will build a time-dependent history of splitting in the site we study and compare it with the time and location information of the recorded hydraulic fracturing events. Finally, we will attempt to find a cause and effect relation between the hydraulic fracturing and the subsurface fracture changes as well as other possible relations.

DEDICATION

I dedicate this research to my parents. Without their continued support this opportunity would not have been possible.

ACKNOWLEDGEMENT

I would like to thank Dr. Richard Gibson for his tremendous support. His teaching has been paramount to the production of this thesis and my improvement as a student and person.

CHAPTER I

INTRODUCTION

Hydraulic fracturing is an effective technique that has been widely used to enhance oil and gas productivity by causing fractures in the reservoir volume and increasing reservoir permeability. Consequently, the microseismic event frequency near the fracturing area will be significantly increased. It has been proven that oil production was much more successful where the wider seismic zone is observed (Phillips et al. 1998). However, other than fracturing location, very limited information can be simulated by typical methods about the fracture systems that are caused by hydraulic fracturing and to increase hydrocarbon mobility. In this article, we attempt to find a more detailed relation between hydraulic fracturing and the subsurface fracture systems by the study of seismic anisotropy.

Theoretically, every microseismic event creates its characteristic seismic waves, including primary wave (P-wave) and secondary wave (S-wave, or Shear-wave). When hydraulic fracturing is taking place, there will be a considerable amount of microseismic events in the related area. In depths ranging from the hydraulic fracturing formation to the near surface, seismic anisotropy is ubiquitous in the geological materials, and “shear wave splitting” will be produced when shear waves travel through it.

Shear wave-splitting is arguably the only reliable indicator of seismic anisotropy. It arises when a shear wave naturally polarizes into a fast wave (S1) parallel to the fracture and a slow wave (S2) perpendicular to it. Splitting can be described by two parameters: the fast polarization direction

(ϕ) that is related to the orientation of the anisotropic symmetry axes; the lag time between fast and slow shear waves (δ_t) that indicates the anisotropy magnitude in the direction of wave propagation. A standard method to deal with shear-wave splitting is the splitting correction method of Silver and Chan (1991) and an improvement of window selection by Teanby, Kendall and van der Baan (2004). These methods will be discussed in detail in the next section. The result of this process should indicate the best fit value of polarization direction ϕ and lag time δ_t for each splitting window.

There are basically two types of anisotropy in terms of their origin: anisotropy caused by aligned fractures in the subsurface and the anisotropy caused by fundamental properties of rock (in most cases of our study, shale). The fracture related anisotropy has seismic properties varying with azimuth while the anisotropy caused by shales typically does not. By the polarization directions we derived from Silver and Chan (1991) method, we will filter those anisotropy caused by fracturing and attempt to infer location and orientation of the subsurface fracture system at each time domain. Previous work has shown that it is possible to monitor changes in crack properties induced by changes in pore pressure or stress (Teanby, Kendall, Jones and Barkved 2004).

In the case of our study, there was a series of hydraulic fracturing stages conducted at difference known sites at precisely recorded times which cover more than a one month span. This provides a good data set for us to find the relation between the man-made hydraulic fracturing events and the potential time-variant fracture changes they cause. Two potential factors, tidal loading and oil production need to be filtered out. Their influence on stress, cracks and pore pressure might lead to another series of time-variant shear-wave splitting (N. Teanby et al. 2004). After testing for tidal effects, we will compare the time-variant fracture changes with the hydraulic fracturing data correspondingly and attempt to find the relation between them.

CHAPTER II

METHODS

The microseismic data of this research are from a seismic monitoring project with one month time span and over more than ten production wells. There were two monitoring groups deployed underground, both of which contain seven active recording geophones arrayed in vertical and horizontal lines respectively. The original data base is gigantic so we need to select the good subsets of data to study with.

After filtering out potentially inaccurate data and small magnitude event data, we select the microseismic data which contains relatively big magnitude events and shows good time and space concentration.

Seismic Analysis Code (SAC) is used in this research to interpret multidirectional microseismic data in SAC format. The data acquired are originally in SEG2 formats. We use seg2_edit to convert selected microseismic data from SEG2 format into SAC. By using plot command in SAC, we are able to read the seismogram which contains P wave and S wave data at the interested time. P wave data can help us to find specific microseismic events by its clear big magnitude vibration signals compared with seismic noises. S wave signals are always recorded soon after P wave signals. By finding those interested S wave signals and use particle motion plot command in SAC, we are able to see the character of irregular nonlinear motions. They are the sign of shear wave-splitting during the wave propagation from seismic source to the recording geophones. We will further analysis these irregular S wave motion and interpret its motion route in three dimensions. The character of the three dimensional motion over a short time span will give us delay time and direction information about the seismic anisotropy structure which causes shear wave-splitting. By using this relation, we will be able to interpret subsurface anisotropy structures by shear wave-splitting phenomena and formulate the report.

CHAPTER III

RESULTS

Part 1: B Value Variance Analysis and Finding Subset of Microseismic Data

The first task was filtering and selecting the subset of microseismic data we would study with in this project.

For filtering, we induce the Gutenberg-Richter Law:

In seismology, the relationship between the magnitude and total number of earthquakes in any given region and time period of at least that magnitude:

$$\log_{10} N = a - bM$$

Where N is the number of events having a magnitude bigger or equal to M,

a and b are constants.

The constant b is typically equal to 1.0 in seismic active regions.

To filter out potentially inaccurate data, we did “b value” statistical analysis through the entire region.

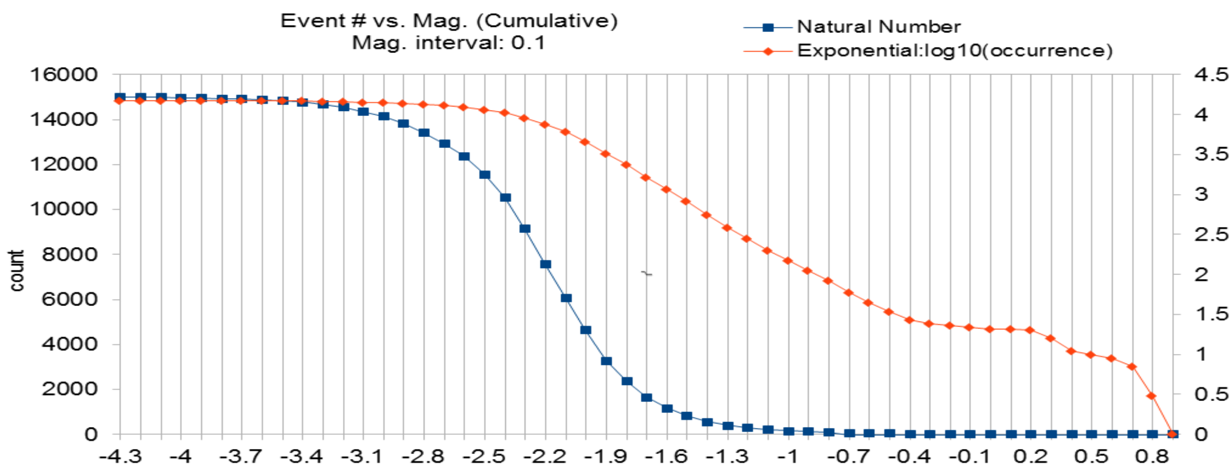

Fig I. Histogram of All Recorded Event at Naught Well Stage 2

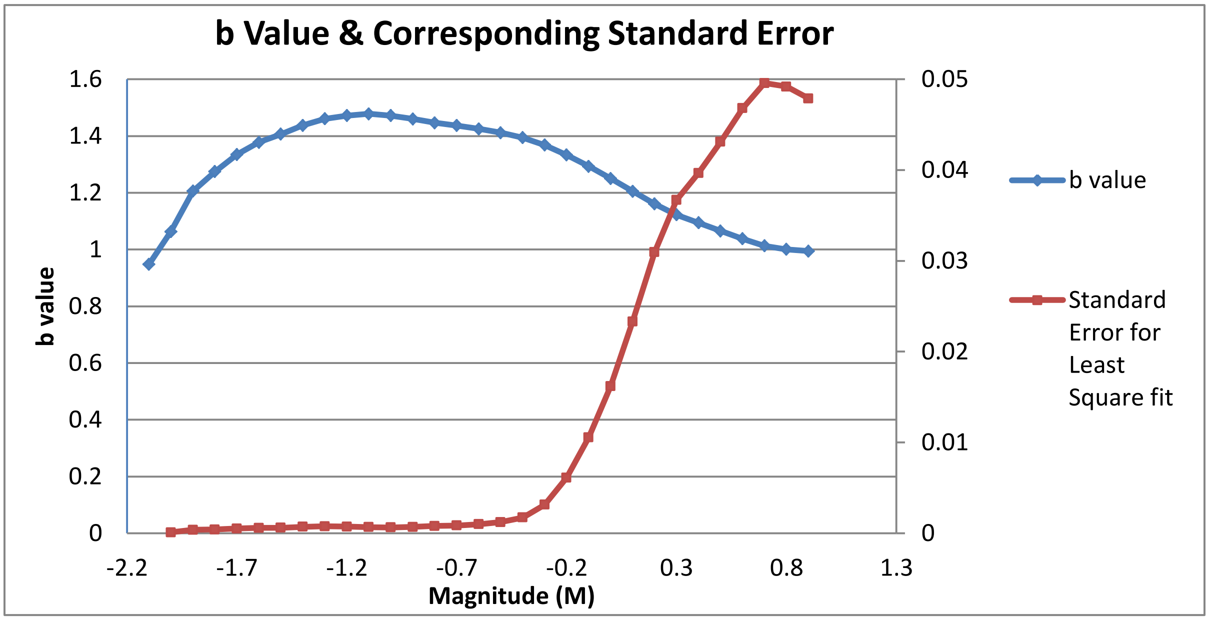

Fig II. b value variance with magnitude

It is clear that the “b value” begins to vary dramatically when magnitude increases to 0.5.

After removing the relevant microseismic events (whose magnitudes are bigger than 0.5, we redid the statistical analysis of “b value” through the entire data set.

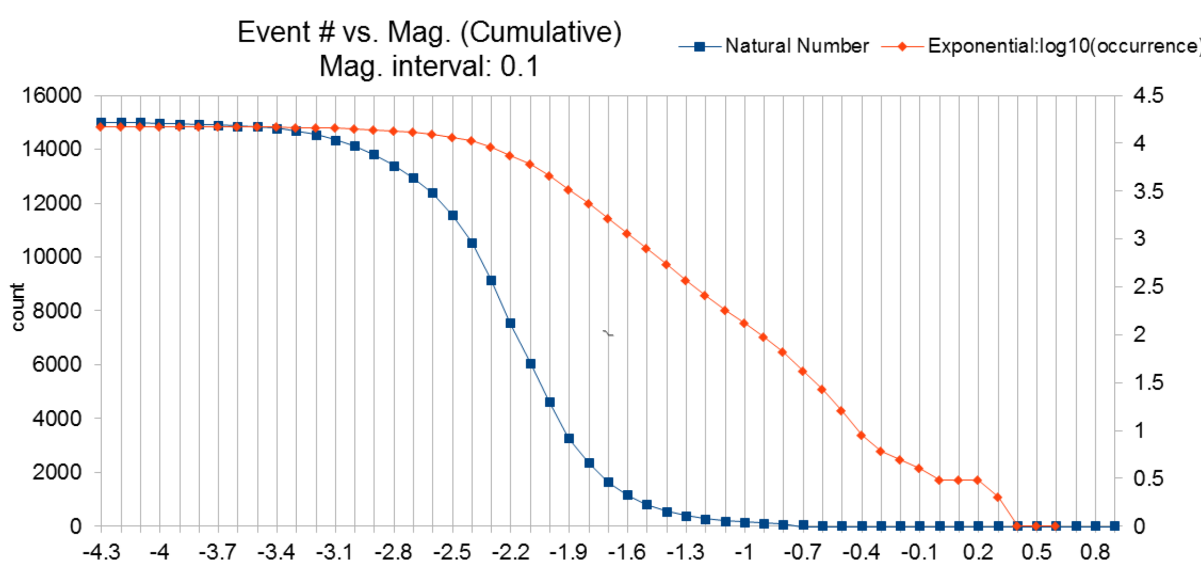

Fig III. Histogram of Events at Naught Well Stage 2 After Filtering

The b value was much more stable. Standard error increased stably when magnitude became bigger. This might be caused by insufficient data.

In the newly filtered data set, we found the best subset of data containing relatively big magnitude events and showing good time and space concentration at Naught Well.

Part 2: Seismic Anisotropy Character Identification

We used seg2_edit to convert the data at Naught Well from .SEG2 format into .SAC and used the plot command in Seismic Analysis Code and Mathematica to identify the characters of seismic anisotropy underground.

The irregular patterns of arriving S wave signals were identified. They were seen coming about 0.1 seconds after P wave signals for major microseismic events but showing nonlinear particle motion patterns rather than regular linear patterns.

An example of the nonlinear particle motion pattern caused can be shown in Table I:

Looking at the particle motion caused by P wave in this example, the components in X, Y, Z directions reached zero and maximum points at synchronously. Thus, its plot showed good linear pattern.

Oppositely in S wave column, the components in Y and X directions reached their peak ~0.001s after Z component. Its plot showed nonlinear motion pattern.

P,S Wave Comparison in D40 F1550
(event: 23/01/2010 15:43:11)

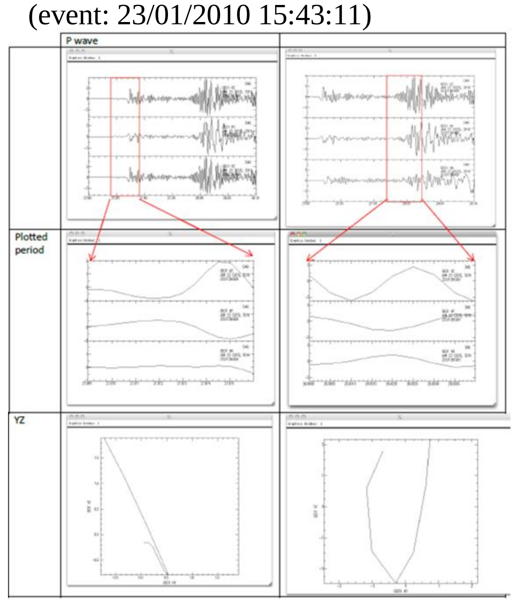

Table I. 2D example of nonlinear particle motion caused by S wave

Applying this observation to more events at Naught Well Stage 2, the results could be classified into two types: 1. particle motion caused by S wave showing nonlinear pattern and 2. particle motion caused by S wave showing linear pattern. Type 1 indicates anisotropy effects at the wave propagation path. Type 2 does not.

Table II. Example 3D plots of Linear S wave Particle Motion

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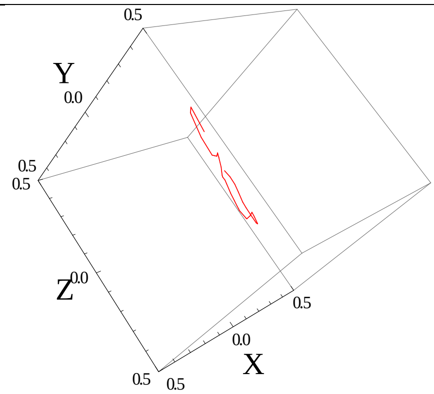
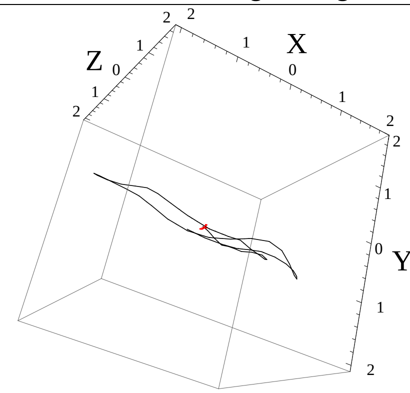
<tr><td>1604</td><td>
</td><td>
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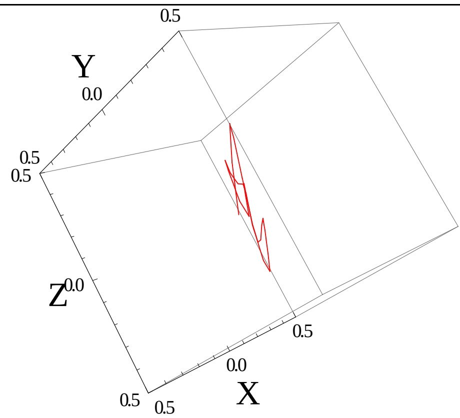
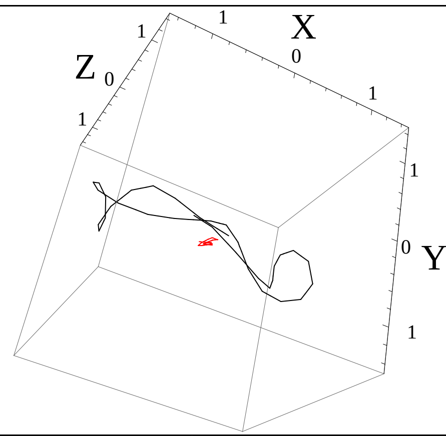
<tr><td>1603</td><td>
</td><td>
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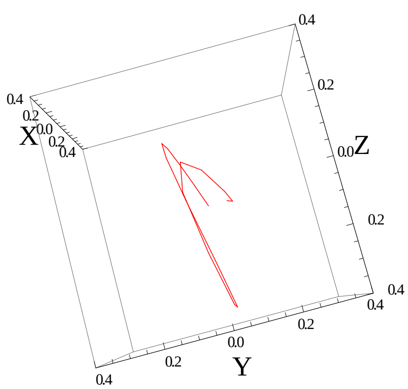
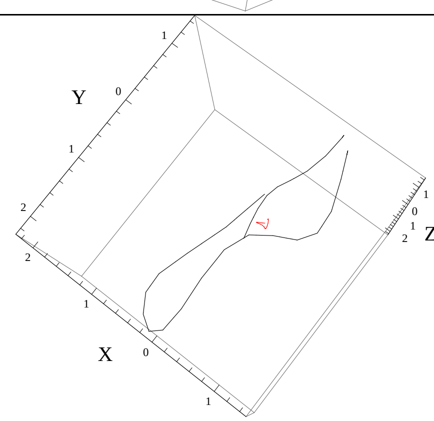
<tr><td>1310</td><td>
</td><td>
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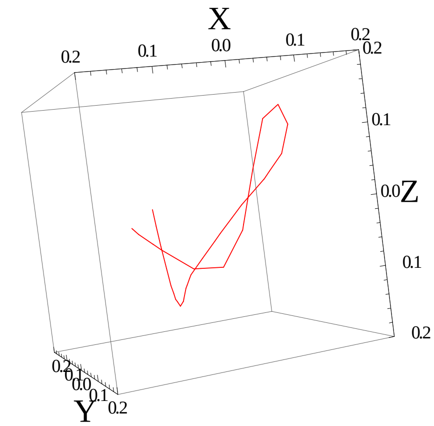
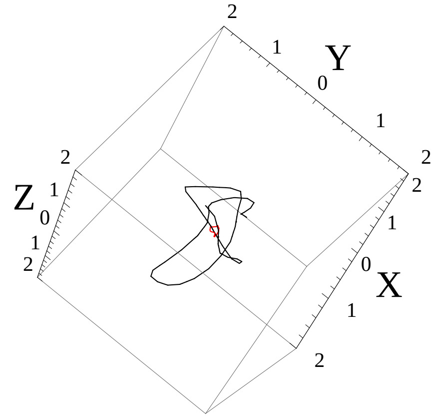
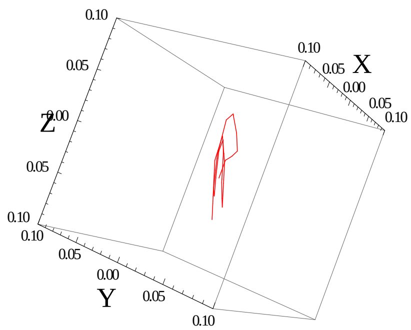
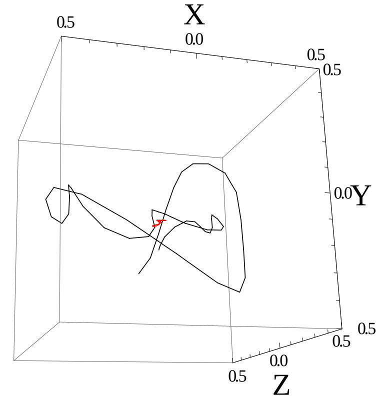
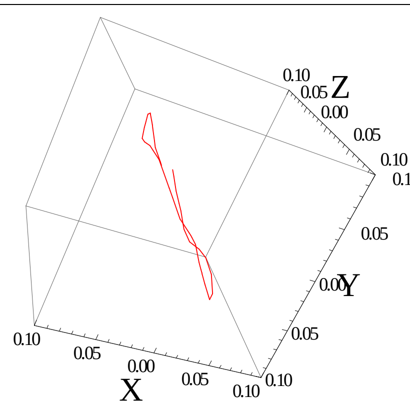
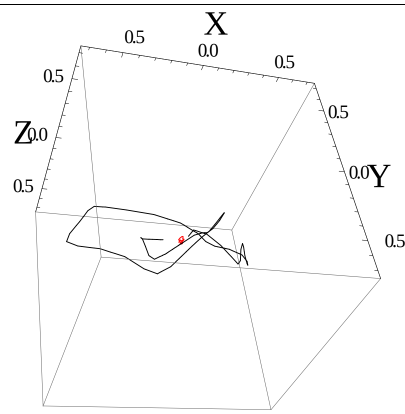
Table III. Example 3D plots of Nonlinear S wave Particle Motion (Type 2)

	P wave motion	S wave motion Looking through Propagation Dir.
1602		
1599		
1600		

In table II, the nonlinear motion patterns are clear to observe. They indicated anisotropy structures at their corresponding travel path while the linear S wave motion patterns indicated no anisotropy effects through the travel path.

Combining their hypocenter locations, we could see their position concentration area.

The hypocenters of 9 biggest events at Naught Well Stage 2 are shown in Fig IV.

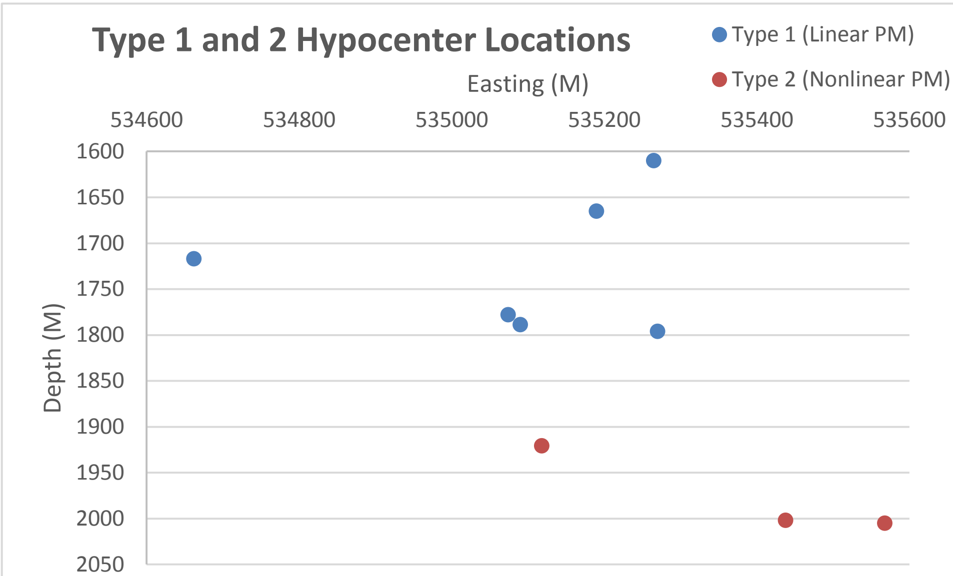


Fig IV. Hypocenter positions of different event types

By looking at the hypocenter positions of type 1 and type 2 events respectively, the position of anisotropy structures could be further inferred.

CHAPTER IV

CONCLUSION AND FUTURE WORK

We have relocated the hypocenters of the microseismic events caused by hydraulic fracturing based on arrival delays between S waves and P waves. It revealed the propagation paths of the seismic waves from the hypocenter to the recording geophones deployed underground. The P wave signals showed regular linear shape which could be inferred to the propagation directions when they arrived at the geophones. Oppositely, the corresponding S wave signals showed various irregular circular patterns. They were the evidences of the shear wave splitting mechanisms in the sedimentary rocks where the waves were propagating through. These were shown more clearly in the 3D plots of particle motion caused by the arriving S waves. After categorizing sources by different S wave motion pattern (linear or nonlinear), we could find the concentrated area of different types of sources. This information can further infer the different subsurface structures regarding seismic anisotropy.

In the next steps of this study, we will apply the method into more events and focus on finding the regularity among the anisotropy variations at specific space and time sequences. Since one hydraulic fracturing stage (one liquid injection) can cause a series of microseismic events for a long period of time compared with the time of the stage itself. The regular pattern can increase the predictability about how hydraulic fracturing will quiver the sedimentary rocks surrounding the wellbore in a specific period of time.

To explore this potential regularity, more study of 3D particle motion plots of microseismic events with close hypocenter locations need to be covered. We will try to systematize the variation as time starts from the hydraulic fracturing event.

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