Summary

In this study, we present the results of using Ant-tracking to identify faults in the vicinity of five horizontal wells drilled in the Barnett shale. In these five wells, Long Period Long Duration (LPLD) events were observed during multi-stage hydraulic fracturing. LPLD events are believed to be caused by relatively large faults slipping slowly and stably. By utilizing Ant-tracking, we were able to identify a steep fault dipping to the north which intersects the middle of the five wells exactly where the largest density of fractures was found in FMI images. Moreover, the local orientation of the fault has the same strike as the observed fractures. This fault appears to be located in the source of the LPLD events produced during hydraulic fracturing. It is also coincident with a distinct gap in microseismicity. Thus, it appears that slip on this relatively large scale fault is responsible for the LPLD events observed.

Introduction

Long Period Long Duration (LPLD) events are bursts of seismic energy observed during multi-stage hydraulic fracturing (Das and Zoback, 2013a,b). As the events are similar to tremors occurring due to slow slips of large tectonic plates, the LPLD events are thought to be caused by relatively large mis-oriented faults slipping slowly and stably (Zoback et al., 2012).

The importance of LPLD events lies in that they signify a process (stable slip of large faults) that can account for a substantial amount of the increase in permeability associated with hydraulic fracturing. Das and Zoback identified LPLD events on recordings of micro-earthquakes induced by hydraulic fracturing in what they referred to as Barnett data 1 in the Barnett Shale. Five sub-horizontal wells A, B, C, D and E (shown in Figure 1) with well separation of 150m were fractured sequentially from toe to heel and the resulting seismic events were recorded. Wells A and B were fractured simultaneously with a horizontal recording array of nine three-component (3C) geophones placed in well C (geophone separation of about 12m). Wells D and E were fractured with zipperfrac (one fracture stage carried out in a well and the following fracture stage carried out in the neighboring well) and monitored in well C with ten 3C geophones. Well C was subsequently fractured, with a recording array of twelve 3C geophones placed in the vertical section of well B. Around 4500 microseismic events were located by the contractor with magnitudes ranging between -1.5 and -3 (Das and Zoback, 2013a).

A pre-fracturing (baseline) 3D reflection seismic survey was acquired to identify important subsurface features for well and process design purposes. The acquisition geometry used in this 3D seismic survey principally involved 3C geophones deployed in lines parallel to the wells shown in Figure 1. A sampling interval of 2 ms was used, and the record length was 4s. The Figure shows hypocenters of micro-earthquakes displayed as dots, with dot size representing magnitude and color representing fracture stage. FMI fracture strikes from well C are also displayed, as well as the range of angles from which LPLD events emanated (shown as a yellow wedge), which is discussed below.
Das and Zoback reported that most LPLD events originated close to the heels of wells A, B and C, where the highest density of pre-existing fractures was detected by an FMI survey in well C with an average strike of ~N100°E (Das and Zoback, 2011; Johri and Zoback, 2013).

**Fault Identification with Ant-tracking**

The 3D reflection seismic data provided to us by ConocoPhillips Company was the form of a post-stack migrated volume. To locate fault(s) in this area, we calculated the variance attribute of the seismic data to detect discontinuities and followed it by two passes of Ant-tracking (developed by Schlumberger) for discontinuity/edge enhancement. The variance of each voxel in the data is a measure of local amplitude dissimilarity which indicates discontinuities such as faults (Randen et al., 2001). Discontinuities are enhanced when the variance volume is used as input to Ant-tracking which improves edge definition in the data by tracking consistent discontinuities that are likely to be faults.

Figure 2 shows the result of the second Ant-tracking pass, showing a large apparent fault interesting well C where the highest density of natural fractures was observed on the FMI log, and having their same strike orientation of approximately N100°E.

The Figure also shows the constraints on the location of LPLD events calculated by Das and Zoback. Since it is difficult to identify P and S waves on LPLD events, Das and Zoback were able to find the general angular range from which LPLD events originated by analyzing event move-outs from well B and C recording arrays. With the monitoring array deployed in the vertical section of well B, LPLD events located during fracturing of well C were found in the range of angles between the broken line green circles in Figure 2. The wedge located within the orange broken lines indicates the angular range from which LPLD events were emitted during fracturing of wells A and B and recorded with a geophone array in well C. The fault we identified is clearly located in the range of angles from which LPLD events emanated.
The fault identified here seems to be the most likely source of LPLD events, as it matches the dense natural cluster of fracture orientations found in well C in both location and strike direction and it is located within the range of angles from which LPLD events were emitted.

**Microseismic Gap along a Slowly Slipping Fault**

To visualize the locations of the microseismic events relative to the fault discussed above, we used the Automatic Fault Extraction feature of Petrel E&P Software Platform (from Schlumberger) to create a three dimensional representation of the fault identified through Ant-tracking. To display only the fault under consideration, we limited the azimuth and dips of the extracted patches to that of the slowly slipping fault. We then plotted the hypocenters of the microseismic events in the same 3D window as the fault.

By examining the locations of the microseismic hypocenters, we identified a region near the fault in which microseismic events from stages 7-9 of the simulfrac treatment of wells A and B are almost nonexistent, as shown in Figure 3.
Figure 3: A 3D plot of hypocenters of micro-earthquakes from stages 7-9 of wells A and B simulfrac and the extracted slowly slipping fault showing a significant drop in microseismicity near the fault.

Moreover, the microseismic events from the last 3 fracturing stages of the nearest well to the left, well D, also seem to be dropping significantly in number near the fault, as shown in Figure 4, leaving another microseismic gap to the left of the LPLD source.

Figure 4: A 3D plot of micro-earthquake hypocenters from stages 8-10 of well D fracturing and the slowly slipping fault showing a significant drop in microseismicity near the fault.


**Discussion and Conclusions**

We were able to identify a large fault using the variance attribute of the 3D reflection seismic data and enhance it with Ant-tracking. The fault matched the strike direction and position of the highest density of natural fractures seen on the FMI log of well C. The fault also lies in the angular range from which LPLD events were emitted, suggesting that slow stable slip of this fault is the cause of the LPLD events recorded during the hydraulic fracturing treatments.

A microseismic gap (a region where microseismic events are scarce) was also found for events recorded during the hydraulic fracturing stages of wells A, B and D close to the fault. The microseismic events seem to drop significantly in number close to the area of the slowly slipping fault from which LPLD events emanated. It seems that as the activated fault slips stably emitting seismic energy in the form of LPLD events, microseismic events near the fault become almost nonexistent.

**Acknowledgement**

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**References**


