

Microseismic Monitoring of a Multi-Stage Frac In the Bakken Formation, SE Saskatchewan

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Summary

Downhole microseismic monitoring was used to measure the azimuth, length and height of a multi-stage hydraulic fracturing (frac) program in the Bakken Formation of the Williston Basin in SE Saskatchewan. The microseismic results confirm that the minimum horizontal stress direction is approximately N20W and that the frac will propagate at an azimuth of approximately N70E. Furthermore, the frac height can be controlled through injection rates and monitored using these downhole microseismic techniques. A frac half-length of between 75 and 100m was also measured.

The experiment also proved that shallow (12m) seismic shot holes could be used for the orientation of the downhole 3C geophones at a greatly reduced cost compared to downhole sources.

Introduction

Petrobank Energy and Resources is involved in a multi-well program in SE Saskatchewan drilling for light oil from the Bakken formation of the Williston Basin. Early drilling into the Bakken was with vertical well bores, typically for deeper targets. Few of these wells tested the Bakken and fewer still resulted in economic production. However, recent activity using horizontal drilling technology and improved fracture stimulation has resulted in surprisingly good results.

The Bakken formation in SE Saskatchewan is made up of an upper organic rich shale, a middle siltstone member and a lower organic rich shale (Exshaw) (Figure 1). The middle siltstone member ranges from 13m in the Benson area (Twp 6 Rge 8W2) to 5m in the Corning area (Twp 11 Rge 6W2). To the south and west there is a 1 to 3m thick, sometimes porous sandstone at the top of the siltstone. This sandstone is productive only in the south Midale area (Twp 7-11W2). The majority of the recent drilling and production comes from the siltstone updip from the sandstone edge. Petrophysical logs in vertical wells indicate a range in net pay (1 to 5m) and resistivities (1 to 3 ohms).

2D and 3D seismic data indicates the Bakken surface can be structurally complex in various areas. The seismic and well control indicate salt collapse features, faulting and structural roll-overs play a key role in pool segregation. Through reprocessing of the older data or by using new acquisition/processing, we are able to image the Bakken siltstone and to geo-steer the horizontal wellbore (Figure 2).

The ideal hydraulic fracture would be one that stays in the Bakken and that did not penetrate into the upper water-bearing Lodgepole interval. By drilling the well parallel to the minimum horizontal stress field and hence hydraulically fracturing the well perpendicular to the minimum horizontal stress field we are able to better control the height and length of the frac. The world stress map (www.world-stress-map.org) indicates that the minimum horizontal stress for this area is approximately N-

S. Further analysis of engineering and breakout data indicate a minimum horizontal stress direction of about N20W. The downhole microseismic data was acquired to confirm this direction that in turn dictates the azimuth of the horizontal wellbore.

Theory

Microseismic technology borrows from many of the well established theories that were originally developed for earthquake seismology and in particular from the work done in the late 1960's near Rangely, Colorado (Gibbs et al, 1973). As the name suggests, microseismic events have very small amplitudes and very high frequencies (200 – 2000 Hz). Both passive and active microseismic activity can result from pore pressure increase and formation stress increase. Maxwell and Urbanic (2001), Caley et al (2001) and Maxwell et al (2002) have identified the many applications of microseismic monitoring: fracture characterization (azimuth, length and height) during hydraulic fracturing; sweep efficiency for secondary recovery (SAGD, CO₂, THAI, etc); and production induced anisotropy.

Accurate velocity models for both the compressional and shear wavefields are necessary for accurate event locating. A control source, in this case a shallow seismic charge (1/4 Kg at 12m), is used to calibrate the velocity models. The origin of individual microseismic events can be calculated from the polarization of the shear waves and from the travel time differences between the weaker P-waves and the stronger S-waves and also from hodogram analysis.

Method

Multi-stage horizontal hydraulic fracturing techniques, such as the StackFRAC™ design (Figure 3) are designed to expose a larger amount of drainage area to the wellbore as compared to a hydraulically fractured vertical well, a non-stimulated horizontal well or a single treatment horizontal hydraulic fracture.

We used a nearby vertical wellbore as a monitor well for the horizontal frac. Figure 4 shows the geometry of the acquisition from both a top view and a side view. Typically the orientation of the 12 levels of 3-component geophones is done using a coil-tubing-deployed string charge. However, we were concerned that the string charge may damage the frac assembly. So we tested a compressed nitrogen source that would be similar to a marine air gun. The energy from this "nitrogen gun" was very weak and the use of coil tubing very expensive. A third alternative is shallow dynamite charges (1/4 Kg at 12m) similar to those used in conventional land seismic acquisition. This technique proved to be cost-effective and provided adequate signal for geophone orientation.

Results and Conclusions

The results from the downhole microseismic monitoring indicate that: the minimum horizontal stress and resultant fracture direction will be N20W and N70E respectively; the fracture half length for the frac rates used on this project will be between 75 and 100m; and the fracture height can be monitored using microseismic recording and hence controlled by varying the injection rates (and other fracture parameters) (Figure 5).

Furthermore, the experiment also proved that shallow (1/4 Kg at 12m) seismic shot holes could be used for the orientation of the downhole 3C geophones at a greatly reduced cost compared to downhole sources. The conventional geophone orientation technique is a coil-tubing-conveyed string charge deployed at a known location in the treatment well. This is not an option when using slotted liners as the charge may damage the frac assembly. We also tested a downhole coil-tubing-conveyed nitrogen pulse, like an air-gun, that ultimately proved inadequate and expensive.

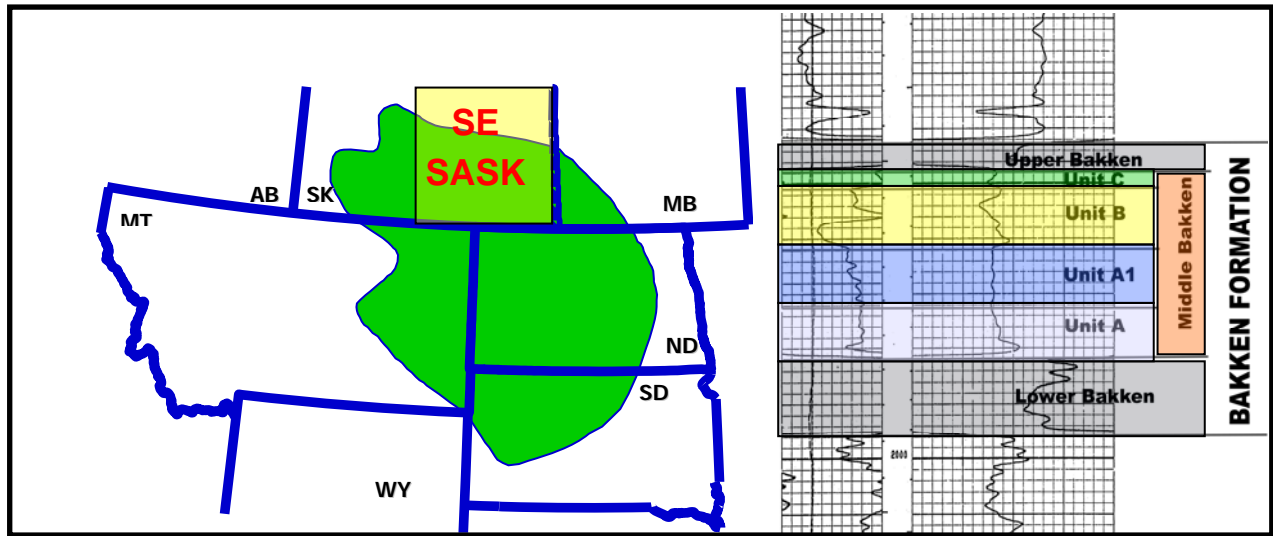


Figure 1: Location of Williston Basin and type log for Bakken Formation showing Upper Bakken, the three units of the Middle Bakken and the Lower Bakken (sometimes called the Exshaw).

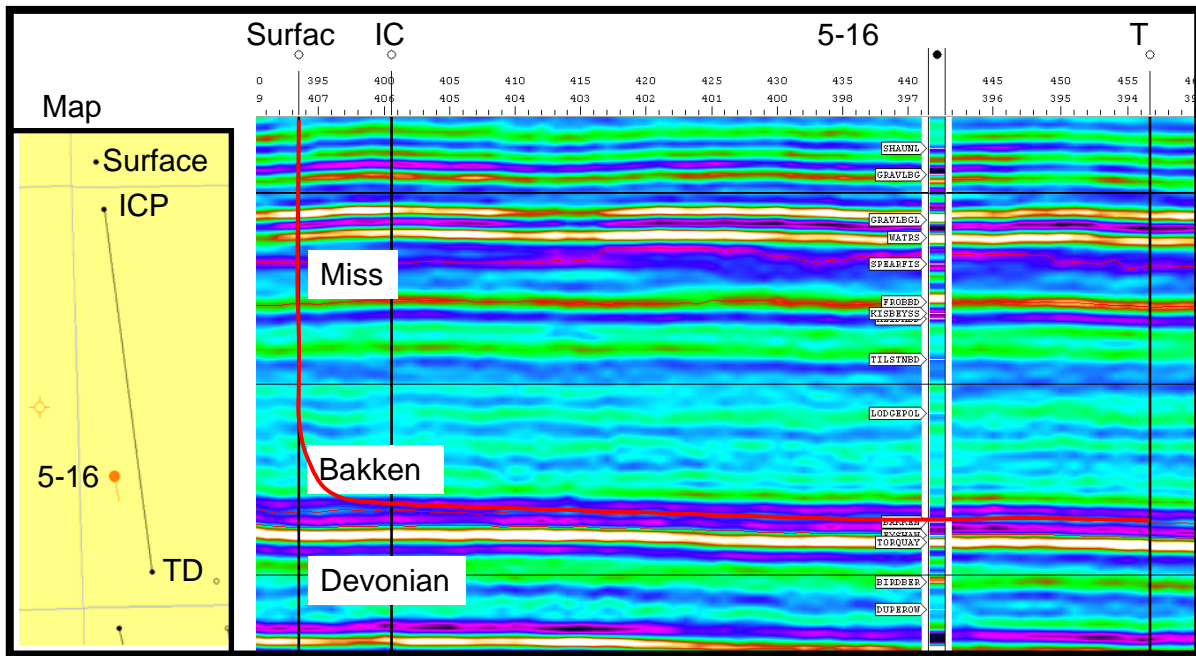


Figure 2: 3D-Seismic extraction along 4-16 horizontal wellbore and the Map View of the acquisition.

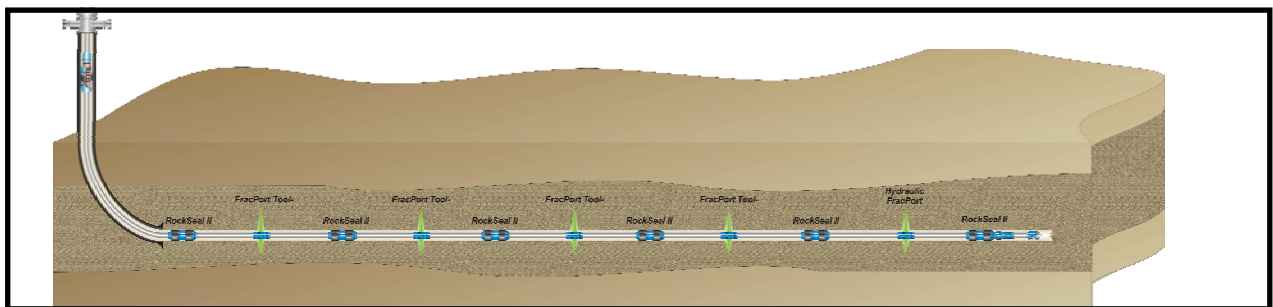


Figure 3: StackFrac™ system design showing the different ports that are isolated by pairs of packers.

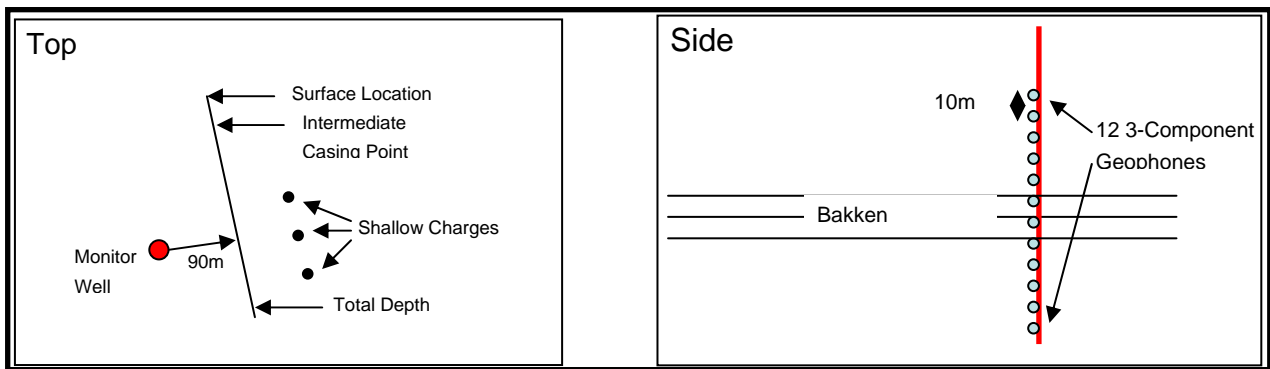


Figure 4: Acquisition geometry. The top view is on the left showing the horizontal wellbore, the monitor well in red and the three shallow dynamite charges (1/4 Kg at 12m). The side view shows the 12, 3-component array centered on the Bakken.

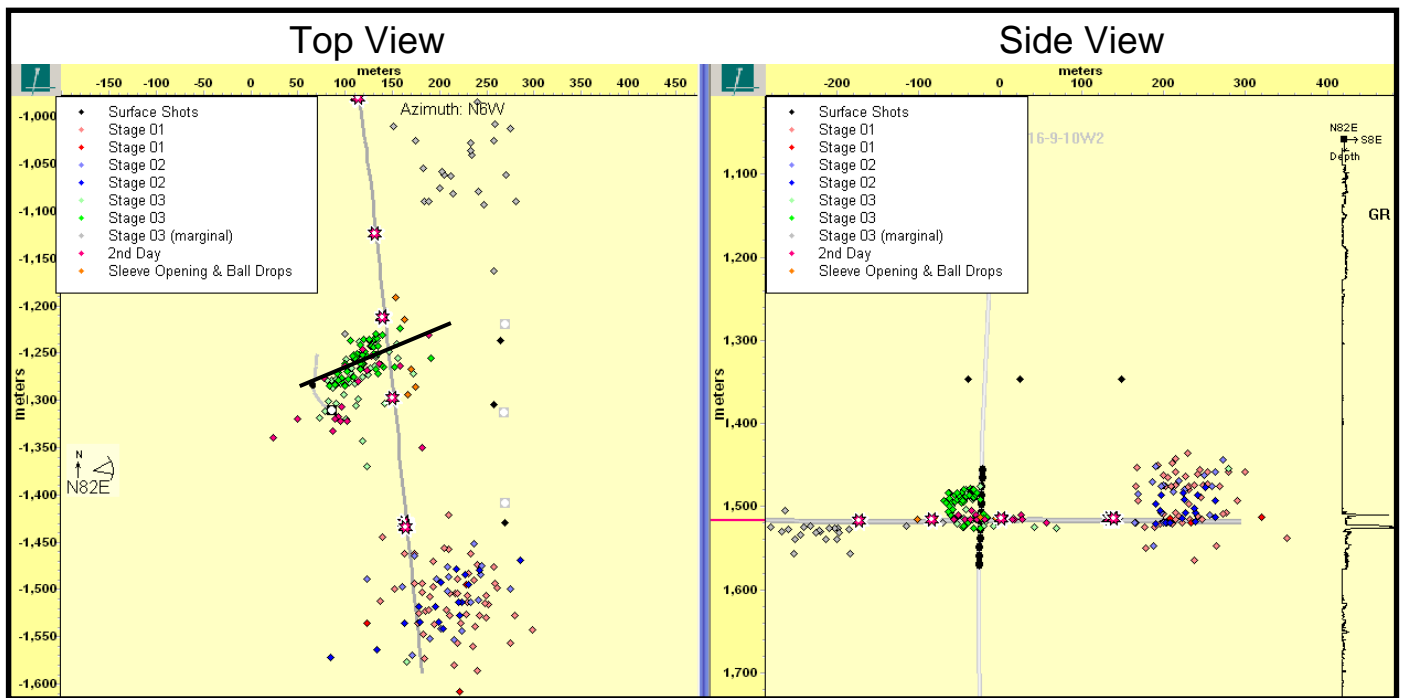


Figure 5: Microseismic events as shown in top view (left) and side view (right). A least squares regression on the strongest events suggests an azimuth of approximately 70 degrees and a frac half-length of between 75 and 100m. The green point represents the stage 3 frac and illustrates the relationship between a lower frac rate and the frac height.

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