Am I Really Predicting Natural Fractures in the Tight Nordegg Gas Sandstone of West Central Alberta? Part II: Observations and Conclusions

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Summary

This two part effort is concerned with understanding and predicting fracture density in the Nordegg of West Central Alberta. In particular we are concerned with fractures that might be encountered by horizontal drilling of this tight gas reservoir. The ultimate goal of these efforts is to build the fundamental knowledge of fracture density that will help in the planning of the most prolific horizontal wells from this formation. The key fundamental step- and our goal in this work- is a quantitative analysis of fracture prediction techniques for the Nordegg using objective and scientific validation data. To aid us in this effort, we have validating data from FMI logs and from a microseismic survey shot over one of three horizontal wells in the area. We also have extracted attributes such as AVAz, VVAz, Curvature and Coherence from the 3D surface seismic data that covers the area. In part one of this effort we used the FMI data to illustrate that the fractures are almost uniformly vertical and aligned. This satisfies key theoretic requirements of AVAz and VVAz.

In part two of this work, we analyze the correlations that exist between FMI fracture density, microseismic events, and our seismic attributes. The data correlations illustrate that some of the surface seismic attributes correlate strongly to FMI fracture density and microseismic event moments, while others correlate weakly or not at all. The AVAz crack density showed the best correlation with all validating data, while low resolution most positive curvature and VVAz anisotropy showed weaker but statistically convincing correlations to the validating data. Coherence data did not correlate to any of the validating fracture data in this experiment. Correlations were also carried out between the surface seismic attributes themselves, showing vast differences in behavior depending on what sample statistic was employed in the comparison. This experiment provides conclusive support to the assertion that AVAz, Curvature, and VVAz do indeed predict fracture density in the Nordegg in this area. The best results for predicting fractures were arrived at by using these three methods of prediction together in a complimentary solution.

Introduction: part I demonstrated the theory may be valid here

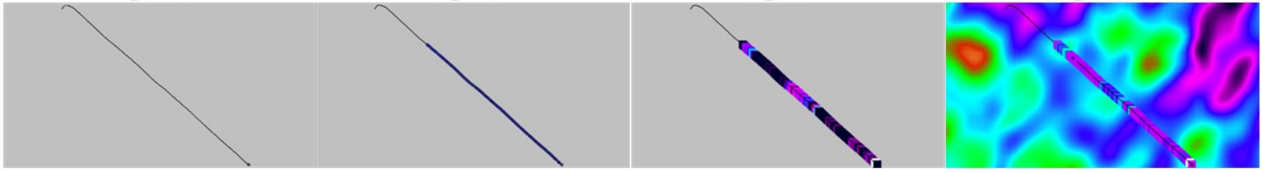
The FMI fracture density data from part I of this study illustrated that the observed fractures were vertical and aligned in a preferred orientation. This observation was made with over 1800m of horizontal log data from Wells A and B, and the statistical behaviors observed were compelling. Some 85 percent of the fracture angles were at or greater than 80 degrees to horizontal. The azimuthal data was just as clear with the FMI data having an unequivocally dominant strike azimuth of about 50 degrees east of north. The AVAz fracture density data illustrated similar azimuthal content along wells A and B. This evidence suggests that the key theoretic requirements for AVAz and VVAz are met in these wells.

Experimental set-up and procedure

The 3D surface seismic data (3D) used to produce the seismic attributes is the same 3D discussed in Hunt et al's (2008) interpolation and AVO case study. This study illustrated that pre-stack interpolation filled in offsets and azimuths missing from an irregular land geometry. This support allowed pre-stack migration to produce superior imaged gathers for subsequent AVO analysis. This same interpolated data was migrated in azimuthal sectors to produce data for AVAz and VVAz attribute estimation. Volumetric Curvature and Coherence attributes were produced from specially processed and conditioned migrated stacks at high and low resolutions by Chopra and Marfurt following methods they described in 2007. Attribute values were extracted from each of these processed volumes at the Nordegg level and were gridded in a consistent manner for each volume.

Our experimental hypothesis regarding the FMI fracture density data is this: if these 3D attributes predict fractures, they should correlate with the FMI fracture density values along the wellbores. In order to test the hypothesis, we need to extract the FMI data with the 3D data at the same locations. This presents challenges regarding scale and support. The FMI data is recorded with resolution on the centimetre and millimetre scale, and is sampled with average values at a fraction of a meter. The bins that the 3D attributes are extracted from are 30m by 60m in size. In order to bring these data together, we created a new binning scheme for the FMI data, where we created FMI data bins at every 10m along the horizontal wellbore paths. FMI data was averaged within the bins. Each FMI data bin was dubbed as a pseudo vertical well with the FMI fracture density given as a formation top value. FMI and gridded 3D attribute data could then be extracted together at each of the dummy well locations and exported as ascii data for analysis. The FMI bins were still much smaller than the 3D bins, which allowed us some flexibility in further averaging of FMI data later on. Figures 1 to 4 illustrate this element of the procedure.

Figure 1 **Figure 2** **Figure 3** **Figure 4**



Figures 1 to 4, respectively. Figure 1 shows horizontal Well B. Figure 2 shows Well B with the vertical wells created as FMI data bins. Figure 3 shows the bins with FMI fracture density values. Brighter colors represent higher values of fracture density. Figure 4 shows the FMI data located over a gridded 3D attribute (the attribute is a scaled average of AVAz crack density and Curvature).

The experimental hypothesis regarding the microseismic event moment data is this: if the microseismic event moments correlate with pre-existing fractures and in situ stresses on the rock, and if the 3D attributes predict fractures, then there should be some correlation between the surface seismic attributes and the microseismic event moments. As the microseismic data is affected by a variety of mechanisms, the correlations may be expected to be weaker, and we must be cautious of our confidence in the conclusions from this experiment. Events from four different completion stages were accumulated into one microseismic event moment horizon that we could locate and bin within the 3D volume. Bins with no events were given a moment value of zero. Correlations with surface seismic attributes were carried out by extracting the microseismic horizon data and the 3D attribute data at the same bin locations. This extraction was limited to a small area where the microseismic data was observed, so that the no event data meaningfulness could be maintained. Figures 5, 6 and 7 illustrates these data together.

Figure 5 **Figure 6** **Figure 7**

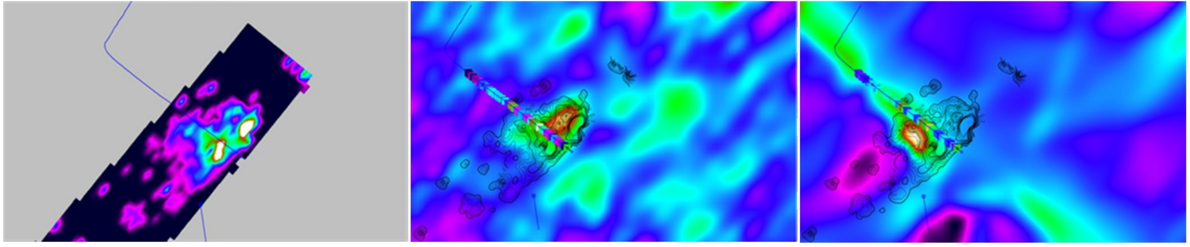


Figure 5 illustrates the microseismic cumulative event moments at Well A. Figure 6 illustrates the contoured event moment data overlain upon AVAz crack density data. Figure 7 shows the same comparison for low resolution most positive curvature data and the microseismic moment data contours. In all cases, brighter (yellow) colors represent higher values.

FMI Data correlations with surface seismic attributes

3D attributes were extracted at the FMI data bins along the horizontal trajectories of Well A and Well B. These data were correlated with the FMI fracture density values in three ways: a simple regression of seismic bins to FMI bins, a regression where the FMI bins were smoothed by a seven point smoother, and a regression where a potential second population within the attribute data was excluded. The smoother was employed to consider further the effect of the different levels of support between seismic and log data. The second population was identified in part I of this work, and was thought to potentially be the result of a difference in the scale of observation, or even a breakdown in the attributes themselves at or near a major discontinuity (possibly a fault). The anomalous population was separated in the same way for each attribute through a resorting of the data by Curvature values. Table I summarizes the correlation coefficients that result from these regressions. The AVAz and Curvature attributes had strong correlations, while the VVAz attribute had a correlation that was not as strong, but still statistically convincing. The Coherence attributes did not show a meaningful data correlation; in fact, these correlations were counter to theoretic expectations and hence were coloured yellow.

Correlation Coefficient	AVAZ	VVAz	Curvature		Coherence
	(B ani) RMS	Velocity Anisotropy	Maximum	Low Resolution Most Positive	Energy Ratio
Raw	0.484	0.426	0.602	0.510	0.175
Averaged FMI	0.612	0.539	0.739	0.628	0.215
Averaged FMI, Low Curvature Population	0.742	0.541	0.676	0.355	0.184

Table I: Correlation coefficient summary for the 3D attributes regressed against the FMI fracture density data.

These regressions can be used to create fracture density prediction maps from the attributes. Figures 8, 9, and 10, below illustrate three such maps near Well B. The best map is found in figure 10, which employed a multi-linear regression of AVAz and Curvature attributes. This map uses the attributes in a complimentary fashion.

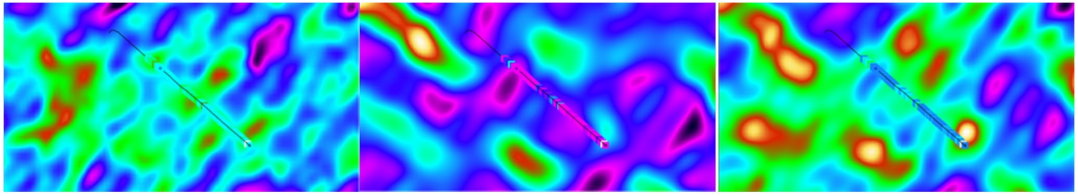


Figure 8 Figure 9 Figure 10

Figure 8 illustrates the fracture density predicted from AVAz data. Figure 9 illustrates the fracture density predicted from low resolution most positive curvature data. Figure 10 illustrates the fracture density predicted from AVAz and Curvature data.

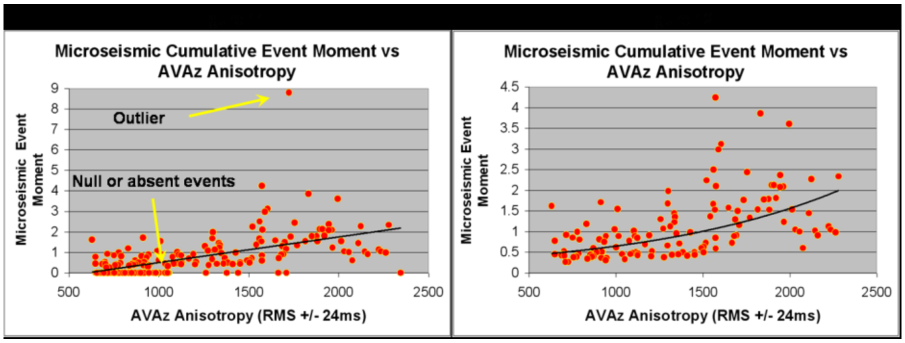
Microseismic event correlations with surface seismic attributes

The microseismic event moment data was regressed with the 3D attribute data binned at the same locations. This was done in four different ways: a simple regression utilizing all the data, a regression with a single outlier point culled, a regression with the null or non-events culled, and a regression where both the null events and the outlier were culled. Table II below, summarizes the correlation coefficient values of those regressions. The AVAz attributes were clearly the best, followed by Curvature and VVAz attributes. Statistically meaningful correlations for the amount of data points used were arrived at regardless of the sample statistic used. The Coherence attribute was again correlated counter to theoretical expectations, and is hence coloured yellow.

Correlation Coefficient	Microseismic Cumulative Moment (# of data points)			
	All Data (196)	All data, 1 cull (195)	No null events (124)	No null events, 1 cull (123)
AVAz (B ani) RMS	0.567	0.638	0.452	0.541
VVAz anisotropy	0.257	0.310	0.214	0.290
Maximum Curvature	0.284	0.353	0.194	0.285
Low Resolution Most Positive Curvature	0.294	0.370	0.092	0.166
Coherence	0.076	0.065	0.276	0.319

Table II: Correlation coefficient summary of the 3D attributes regressed against microseismic event moments.

Two example cross plots from the regression work are shown in Figures 11 and 12 below. The null or non events and the data outlier are identified. We present these observations carefully since the absence of a microseismic event is clearly important information, but our handling of that information is less sure. Figure 12 shows a strong correlation, which may fit better to an exponential curve.



Figures 11 and 12 respectively are the microseismic event moments cross plotted against an AVAz crack density attribute. Figure 11 uses all data while Figure 12 has the null events and an outlier event culled.

Conclusions

These experiments illustrate that the AVAZ, VVAz, and Curvature attributes are correlated strongly with FMI fracture density, and should be valid predictors of fractures in the Nordegg of this area. Similar observations were made using the microseismic data, which is a less direct validator of fracture prediction, but also exhibited strong correlations. It appeared from this work that AVAz was the best single predictor of fracture density, although Curvature attributes were almost as good. We also found that these attributes predicted the fractures in different ways, and that superior results were arrived at by using both types of attribute. A surprising conclusion from this work was that the Coherence attribute did not predict fracture density or microseismic event moments for the Nordegg in this area.

The full presentation will focus more on the choices used in data handling within this work, and will examine the attribute relationships with each other in more detail, attempting to observe just how the attributes may or may not be seeing different kinds of fractures and therefore compliment each other. The analysis with a potential second data population may be significant, and is investigated further. The possibility that this population represents a breakdown in the validity of some of the attributes and why will be discussed. The puzzling lack of predictive capability of the Coherence attribute will also be discussed. We will consider if we have been putting the correct hypothesis to this attribute, particularly in regards to the type, scale, and resolution of features we expect Coherence to address.

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