Fracture Interpretation in the Barnett Shale, using Macro and Microseismic Data

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Summary

The Barnett Shale of the Fort Worth Basin (Texas, USA) is potentially the largest gas field in North America. As with most tight-gas fields, successful Barnett well creation requires accurate well path placement in the gas zone: with judicious alignment of the well path relative to existing fractures and current stress orientations, followed by effective hydraulic fracturing. Previous work has established a current stress orientation of approximately 50 to 60 degrees from North.

Microseismic data recorded during hydraulic fracturing in a horizontal well in the study area exhibits a very diffuse spatial pattern and dramatic differences in microseismic activity, in adjacent fracture stages. Natural karst-related collapse chimneys are known to exist in this region, with larger structural collapses visible on auto-tracked seismic horizons. A combination of volume seismic curvature, incoherence and dip/azimuth estimates provided complementary indicators for the location, extent and magnitude of structural collapse.

Crossplot analysis of micro- and macroseismic data highlighted the correlation of induced seismicity and natural karst-related fracturing. Volume interpretation of calculated seismic attributes was used to map collapse chimneys in three dimensions. Composite depth displays of seismic horizons and kart bodies provided an ideal environment for horizontal well planning, to avoid tapping into water-bearing formations.

Introduction

The Barnett Shale of the Fort Worth (Texas, USA) Basin has emerged as potentially the largest North American gas field, with an estimated 250 tcf in place and USGS ultimate recovery expectations of 26.2 tcf. First drilled by Mitchell Energy in 1981, the Barnett Shale has become the proving ground for effective and efficient tight-gas production, with over 10,000 wells to date. As with most tight-gas fields, successful Barnett well creation requires accurate well path placement in the gas zone, judicious alignment of the well path relative to existing fractures and current stress orientations, followed by effective hydraulic fracturing, generally using slick water techniques.

The Barnett Shale was deposited during the Mississippian period in a marine setting and unconformably overlies Ordovician carbonates. In the area of this study, the underlying Viola limestone has been eroded, juxtaposing the Barnett Shale against the locally porous and water-bearing Ellenberger Limestone. The Barnett Formation ranges in thickness from about 50 feet in the south to nearly 1000 feet to the northeast. From the southwest boundary of the Llano arch, the Barnett Shale dives from a depth of 2500 feet down to 8000 feet near the Muenster Arch, the northeastern field boundary. The top of the Barnett in the study area is located at 6400 feet and has a thickness of 500 feet. Barnett shale porosity ranges from 0.5 to 6% with permeabilities as low as 70 nanodarcies. Low clay content (20-30%) makes the Barnett more "fracture friendly" than typical shales, which is verified by analyzing microseismic magnitudes and density.

Method and Examples

Investigation of available stress information (e.g. World Stress Map) and our measurement of published microseismic data all indicate a current stress orientation along a 50-60/230-240 degree azimuth. Microseismic images were collected from a handful of papers describing hydraulic fracture monitoring in the Fort Worth Basin. These images were imported and spatially registered in a modern software application. An interactive "tape measure" tool was used to determine the mean orientation angle of microseismic data, noting spatial extents of microseismic events, when possible.

Microseismic data were recorded and located for three hydraulic fracture stages of a horizontal well in the study area. The orientation of the horizontal well, from heel to toe, is approximately 120 degrees from North. Analysis of the resulting microseismic data reveals a very diffuse pattern, which is generally desired as induced fractures tie into approximately orthogonal natural fractures. What is surprising is the high variability in number of microseismic events, ranging from slightly over 500 for two stages and only 76 for the stage nearest the toe of the horizontal well. Various observations indicate that the level of local induced microseismic activity is related to natural "collapse chimneys" (Figure 1).

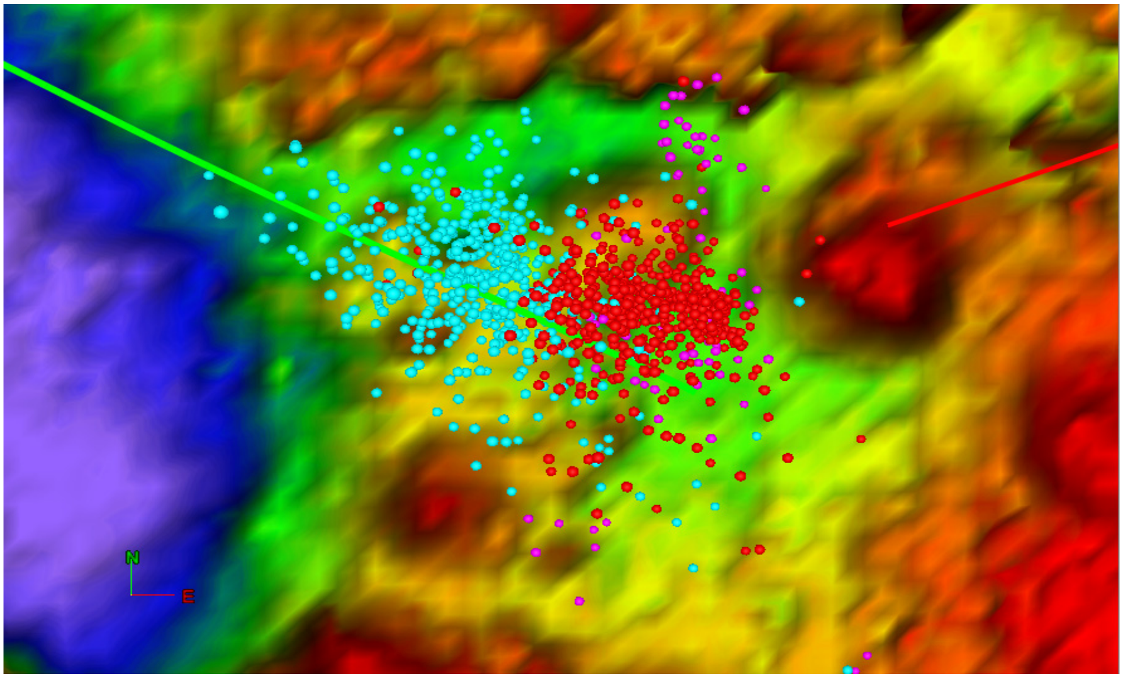

Figure 1: Diffuse microseismic patterns (blue/red/magenta) relative to karst chimneys (redder zones)

Circular "collapse chimneys" of fractured rock pockmark much of the study area and range from the Ellenberger upward thousands of feet to the Pennsylvanian Caddo (Atoka) Limestone. While opinions vary on the relative influence of karsting and basement faulting upon the creation of these fractured columns, they can be water conduits, tapping into the wet Ellenberger. Seismic attributes, in particular minimum curvature, have proven useful for identifying the location and extent of collapse chimneys (Sullivan 2006). In this study, a range of seismic attributes including volume curvature, incoherence and azimuth/dip were used as complementary indicators of the spatial and vertical extents of collapse chimneys and the corresponding degree of rock structural collapse (Figure 2).

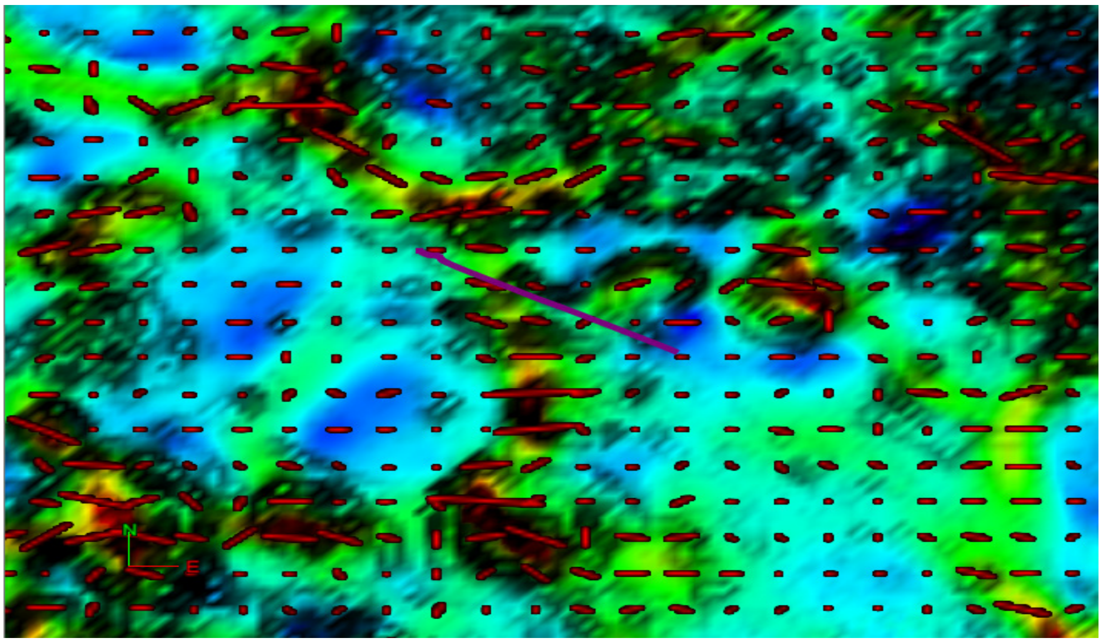

Figure 2: Negative curvature (red), incoherence (black patterns) and dip/azimuth (red arrows) all provide diagnostic indicators of the location and amount karst-related collapse chimneys, relative to actual (purple) and planned wells. .

Considering each of the chosen seismic attributes in turn:

1) minimum curvature responds to subtle collapse, with largest response at the core of collapse chimneys

2) incoherence responds most to the circumference of the collapse chimneys, with greatest vertical change

3) dip/azimuth responds most to the greatest amount of chimney collapse, with vectors pointing to the core

Time-lapse analysis of microseismic data, in conjunction with depth-converted seismic attributes, indicates a high level of seismicity occurs early in fracture stages located near high karsting features. A lower level of seismicity occurs later in time for a fracture stage initiated in a region with low natural fracturing, with apparent breakthrough to karsting features at the later times. Crossplot analysis of micro- and macroseismic data provides insight into the correlation of induced seismicity and natural karst-related fracturing.

Crossplotting of minimum curvature and incoherence seismic data provides a means to delimit values and visually identify potential water-tapping collapse chimneys. Volume interpretation of calculated seismic attributes was used to map collapse chimneys in three dimensions. These feature not only dominate the Barnett Shale zone, but extend well above the Marble Falls and below the Ellenberger and down to the basement, in some cases. Optimal horizontal well designs will avoid karst bodies and track sufficiently above the Ellenberger interface to avoid direct or indirect contact with water aquifers during drilling and subsequent well completions (Figure 3).

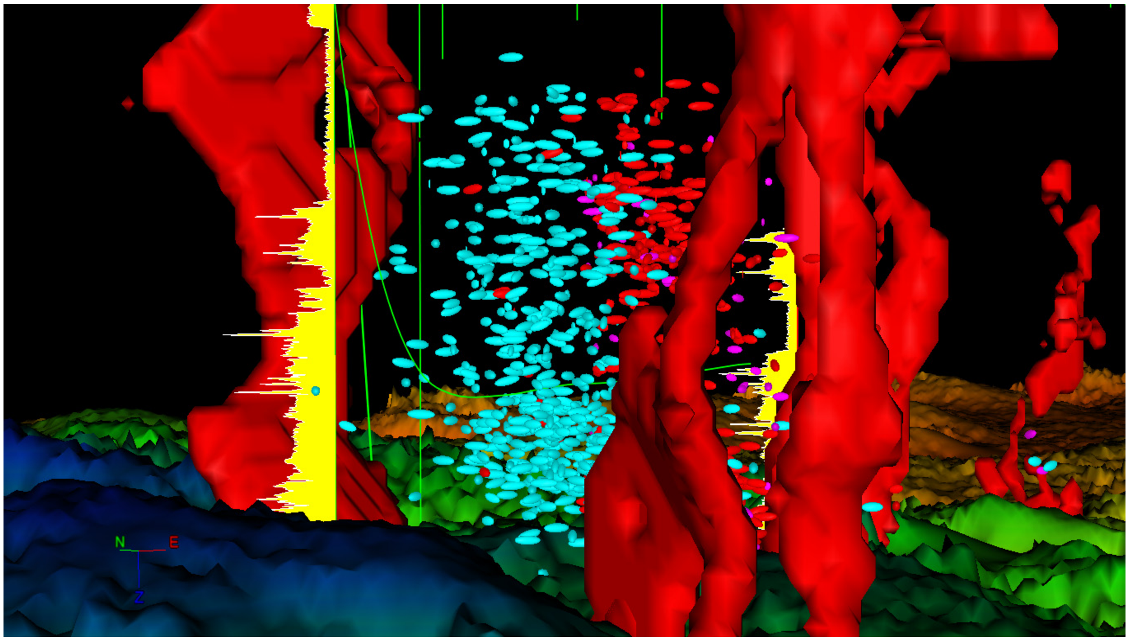

Figure 3: Volume interpretation of collapse chimneys (red) displayed with other depth data, including interpreted seismic horizons, provides a backdrop for horizontal well planning

Conclusions

Hydraulic fracturing in the Barnett Shale, as monitored with microseismic data, can be shown to interact with naturally fractured collapse chimneys, with the potential for tapping into water from the underlying Ellenberger limestone. Volume seismic attributes, including minimum curvature and incoherence, were used to identify collapse chimneys and map them using volume interpretation tools. A composite depth scene was designed to combine seismic surfaces, seismic attributes and karst bodies for optimizing well trajectories and completions strategies.

Acknowledgements

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