

# **Geophysical Insights into the Bakken: Secrets from a Sleeping Giant Elm Coulee Bakken Field (Sleeping Giant), Montana USA\***

Elaine Honsberger<sup>1</sup>

Search and Discovery Article #20187 (2013)\*\*

Posted January 29, 2013

\*Adapted from oral presentation given at Rocky Mountain Association of Geologists and the Denver Geophysical Society 18<sup>th</sup> Annual 3D Seismic Symposium, Denver, CO, March 2, 2012.

\*\*AAPG©2012 Serial rights given by author. For all other rights contact author directly

<sup>1</sup>Chief Geophysicist, Enerplus, Calgary, Alberta ([EHonsberger@enerplus.com](mailto:EHonsberger@enerplus.com))

## **Introduction**

"Explosive development" is an understatement to describe the pace of recent drilling in the North Dakota Bakken play, yet given the wealth of seismic being shot, it is unclear to what degree this data is impacting development. Enerplus shot a 48mi<sup>2</sup> 3D over a portion of the Elm Coulee Bakken field in Montana in 2007 for a deeper target. With about 100 horizontal Bakken wells drilled and producing over the 3D area, this dataset provides a useful database for integrating geophysical, geological and engineering data to determine what relevant development information can be derived from seismic for the Bakken play in Montana. While depositional details and tectonic setting may vary, concepts deduced from the 3D seismic over Elm Coulee may provide methods that could be used to highlight areas with potentially higher EUR's and OOIP's in less developed Bakken fields in Montana and North Dakota.

## **Background**

The Elm Coulee field resides along the SW rim of the Williston Basin in NE Montana. This field, also known as Sleeping Giant, covers an area of over 500mi<sup>2</sup> and has just under 700 horizontal wells producing from the Bakken Formation. Production sits at an impressive 115 MMbbls and 94 BCF as of year-end 2011. The play concept was initially tested in 1996 as a follow-up to shows on a mud log through the dolomitic middle member of the Bakken in the Albin FLB 2-33 well, originally drilled for a deeper target. Instrumental to the discovery of the field and the move to commercial development was the testing of the effectiveness of horizontal drilling in May 2000 of the Burning Tree State well, which marked the beginning of a remarkably successful horizontal development strategy that continues to evolve today.

Another productive zone in the area is the Ordovician Red River Formation. In January 2007, Enerplus acquired a 48mi<sup>2</sup> 3D dataset to map Red River targets. The 3D was acquired with a Vibroseis source and a brick layout. In late 2010 and early 2011, Enerplus embarked on a project to evaluate concepts for optimizing Bakken oil recovery in Elm Coulee. It seemed fitting to reprise the 3D dataset that had been used solely to map the Red River, to evaluate if any information could be extracted about Bakken productivity and resource potential in Elm Coulee that could apply to the Bakken elsewhere in the Williston Basin.

## **Processing Methodology**

The 3D was reprocessed with the goals of optimizing the Bakken while enhancing the seismic image of the entire geologic section from surface to basement. Surface topography and near-surface layers were variable and required static corrections ranging from a few milliseconds (msec) to +/- 40msec. Velocity analysis showed significant multiples that, when removed from the dataset, significantly improved the output data quality. The data was migrated with both a post-stack and pre-stack methodology, with unremarkable differences between the two. The data was not depth migrated due to the absence of layers with highly variable velocities or complex structure above the Bakken. Testing for evidence of azimuthal anisotropy is currently underway.

## **Stratigraphic Mapping**

Production in Elm Coulee is from the clean middle dolomite member, located at a depth of about 10,000ft (3000m) with pay values typically from 15ft to 20ft (5 to 6m), average porosities of ~9% and permeabilities of .02 to .04md. In seismic terms, this zone is very thin. The Bakken seismic interval covers only ~7 msec at 10-80Hz, which is less than the thickness of one seismic peak, even when the upper, middle and lower members are included. The thickness, or rather thinness, of the Bakken in Elm Coulee does not make this zone suitable for extraction of rock properties through seismic inversion, as it is at high risk of being contaminated with the reflectivity effects from zones both above and below. I did use synthetic seismic modeling to examine if there was any possibility of detecting qualitative changes in Bakken pay from seismic character. Modeling indicated a very weak drop in amplitude when pay thickness and porosity were significantly increased within a package of constant thickness. This observation will be re-visited briefly in the upcoming discussion of resource potential.

## **Structural Mapping**

The main objectives for embarking on this evaluation were to determine if 3D seismic could be used to understand Bakken fracture networks, and how these might relate to resource and performance indicators, such as Original Oil In Place (OOIP) and Estimated Ultimate Recovery (EUR). Through this stage of the project, the approach has been to understand the structural framework and tectonic history as it impacted the generation and locale of natural fracture networks. This is in contrast to alternate methods that aim for direct fracture detection, which may be worthwhile to pursue as a complementary next step.

The two most critical seismic picks used to characterize the relevant structural history and tectonics are the Ordovician Winnipeg Formation immediately below the Red River and the Bakken. A Bakken depth structure map was created by deriving a velocity grid to depth convert the Bakken time structure at all vertical well points and at the entry point for each horizontal well. Given the large number of well-control points (~100) and the high degree of similarity between the Bakken time and depth structure maps, the Bakken seismic depth map was made with high confidence and is considered suitable for detailed structural analysis. The Winnipeg surface was examined, using time-structure mapping, due to lack of deep well control for depth conversion at this formation.

The most remarkable structural features observed are small vertical-offset but laterally extensive faults at the Winnipeg level. Both major and minor lineaments have been interpreted from the Winnipeg seismic event, with orientation in two key directions:  $\sim 50^\circ\text{NE}$ , and  $-50$  to  $-60^\circ\text{NW}$  (Figure 1 left). The methodology used to detect these faults included a 3D visualizer to enhance their subtle expression, coupled with the examination of 3D seismic profiles. Once the key Winnipeg faults were defined confidently, it became apparent that two other attributes were exceptionally good at highlighting these faults: Dip/Azimuth and Crossline/Inline Difference (SeisWare).

Interpretation of Bakken faults and lineaments was initially not as straightforward. However, when the above-noted attributes were calculated on the Bakken depth map, lineaments became far more interpretable (Figure 1 right). I interpreted only major lineaments to avoid over-interpretation of the dataset and cross-checked interpreted lineaments on seismic profiles. Orientation of the Bakken lineaments are consistent with what was observed at the Winnipeg:  $45^\circ\text{NE}$  and  $-60^\circ\text{NW}$ . Given their similarity, I conclude that the interpreted lineaments are related to the same tectonic system.

The next phase of the interpretation was to put these interpreted lineaments into the regional framework. The fault system observed at both the Winnipeg and the Bakken has the characteristics of a NE/SW left-lateral strike-slip system that is driven by basement tectonics. Faults/lineaments aligning in the NW/SE direction appear to have occurred earlier, as they provide evidence for direction of the left-lateral slip motion. The NE/SW lineaments could certainly be related to the Brockton-Froid left lateral strike-slip system that cuts across the Williston Basin to the north of Elm Coulee all the way to the NE side of the basin in Canada. To confirm this hypothesis, deep lineaments have been mapped using 3D seismic 100's of miles north in the Freda Lake area of SE Saskatchewan, Canada, that align remarkably with features observed on the 3D in Elm Coulee.

To complete the characterization of these lineaments, I had the benefit of using the 3D seismic volume--to evaluate for features commonly associated with strike-slip faulting such as "flower" structures. Once the seismic was viewed in the regional structural context, it became apparent that the changes in structure at shallower levels provided very strong evidence for strike-slip motion. I conclude that:

- Lineaments interpreted from the Winnipeg and Bakken seismic events are representative of a very large left-lateral strike slip system that extends approximately  $45^\circ\text{NE}$  across the Williston Basin with secondary cross-cutting features extending  $\sim -60^\circ\text{NW}$ .
- The portion of the Elm Coulee field over the 3D area is located on and adjacent to this significant strike-slip system.

### **Reservoir Performance**

The next step taken was to evaluate if seismically mapped lineaments exhibited any relationship to reservoir performance. Key to understanding reservoir performance was developing a methodology to compare EUR's for horizontal wells drilled over a 10-year period. Some variables that can impact well EUR's include: horizontal well length, completion style (with/without packers, number of stages), location of production along the horizontal path, number and spacing of horizontal legs, and drilling order in each section. Inter-well connectivity is evident but variable and can also impact EUR's, with complex behavior observed on production data during and after fracturing operations. The one near-constant was well orientation within the 3D area, with most wells drilled at  $\sim 160^\circ\text{SE}$  ( $-20^\circ\text{NW}$ ) with numerous orientations outside the 3D area.

To evaluate reservoir performance across much of the field independent of seismic, whole-life well EUR's derived using decline analyses were normalized for horizontal well length, plotted at the midpoint of each horizontal well path in units of bbl/ft, then gridded. While the EUR data exhibited well-to-well variations, once values were gridded and color-blocked by bbl/ft, it became apparent that EUR's were clustering in what I have defined as potential "regions" of similar EUR. In particular, I observed region boundaries on the gridded EUR data (Figure 2) that mimic the regional Bakken structural trends interpreted from seismic. One of the most significant features observed on the normalized EUR map is a possible boundary between regions of higher versus lower normalized EUR along a 45°NE trend through the middle of the 3D, that mimics the significant 45°NE strike-slip feature mapped from seismic. This high EUR area is also bounded by a significant NW/SE trend to the south, just off the 3D, that parallels the -50 to -60°NW secondary lineament orientation mapped using seismic.

These data are complemented by observations from a 2010 microseismic survey acquired for two wells in Elm Coulee approximately 10 miles west of the 3D. Results from the microseismic survey were published in SPE paper 139774 (O'Brien et al., 2010) and will not be elaborated further here, except to note that fracture azimuth averaged 63°NE direction, with one outlier at 40°NE. The fracture orientation observed on the microseismic survey is interpreted to represent natural fracture orientation in the area where the wells with microseismic data were located, and while slightly rotated from the 3D area, this data lends credibility to the large-scale trends interpreted from the EUR map.

When the structural lineaments derived from seismic were overlain onto the normalized EUR map, it was apparent that the possible boundaries mapped strictly from EUR data are very similar to the lineaments mapped at the Bakken level from seismic. I postulate that the Bakken structural lineaments derived from seismic:

- may be useful in defining regions of similar reservoir performance when some well control is available to calibrate the regions;
- are representative of natural fracture orientation in an area which may be useful to select a preferred drilling orientation;
- highlight subtle faults that may act as fracture propagation barriers and partially compartmentalize the Bakken reservoir.

### **Resource Potential**

Next, geologically derived OOIP per section estimates were plotted on a map with both the Winnipeg and Bakken-derived lineaments. Observations based on comparing the Winnipeg-derived lineaments to OOIP per section show potential regions bounded by major lineaments that have similar OOIP's. These OOIP regions range from an average of 4.6MMbbls per section up to 6.4MMbbls per section.

This observation is similar to the relationship observed with normalized EUR values, where regions or compartments exhibit similar reservoir performance. In the case of OOIP's, I found a better fit between similar OOIP's and lineaments defined from the Winnipeg level, as opposed to those lineaments from the Bakken level. This could be due to having very under-sampled OOIP data with only one OOIP value plotted in the middle of each section. That said, the observation of common values mapping into regions defined by structural lineaments is worth noting. I infer that mapping Winnipeg faults is an excellent proxy for defining major structural influences at the Bakken level. This may be important on data where defining Bakken lineaments is difficult.

One last observation is also worth noting, albeit it is weak. When seismic amplitudes at the Bakken level were compared to the OOIP/section data, there was directionally an indication of higher OOIP's with lower seismic amplitudes. This observation is consistent with the seismic modeling that showed a drop in Bakken amplitude with thicker/better reservoir.

### **Conclusions**

Analysis of the Sleeping Giant 3D indicates that 3D seismic is a useful tool for interpreting structural lineaments at the Bakken and Winnipeg zones. These lineaments appear to represent laterally extensive but small vertical-offset faults. Further, faults at the Winnipeg appear highly relevant to subtle faults at the Bakken, where both sets are part of a large-scale, basement-driven, regional strike-slip system that extends across the Williston basin with primary fracture directions of  $\sim 45^{\circ}$ NE, and secondary fracture directions of  $\sim 60^{\circ}$ NW. The Elm Coulee Field is located on this major strike-slip system in the 3D area, with potential for other strike-slip faults elsewhere in the field. There appear to be regions or compartments within the Elm Coulee field that produce similarly, where distinct NE/SW and NW/SE faults may act as baffles and possibly fracture propagation barriers between compartments. Prediction of compartments with better versus poorer reservoir performance (EUR's) may be possible by combining lineament mapping from seismic with some well production for calibration. Deep structural lineaments defined from seismic also appear to be related to resource potential (OOIP), where some regions bounded by small-scale faults have higher OOIP's than other regions. Perhaps these relationships are an indication of similar diagenetic processes within these regions, and/or similar natural fracture characteristics. It is important to note that conditioning of the seismic through processing is highly impactful in enabling lineament detection. In Elm Coulee, optimizing basic processes such as statics and velocity derivation is imperative to achieve the optimal input for migration, which can then be used to predict Bakken depth and the structural framework. While depositional details and tectonic setting may vary, concepts deduced from the 3D seismic over Elm Coulee may provide methods that could be used to highlight areas with potentially higher EUR's and OOIP's in less developed Bakken fields in Montana and North Dakota.

### **Acknowledgements**

The author gratefully acknowledges: Enerplus for granting permission to present these findings; the support and assistance of Bruce Slevinsky, Enerplus' Chief Reservoir Engineer in collecting and providing scores of decline analyses and general reservoir food for thought; Robert (Bob) Larson, Jr., Geological Engineer, for his geological insight; Denise Lytle, Reservoir Engineer for more decline analyses; and Dr. Jim Applegate, Geophysical Consultant for his encouragement to present the findings at the 2012 RMAG/DGS 3D Seismic Symposium.

### **Reference Cited**

O'Brien, D.G., R.T. Larson, Jr., R.C. Parham, B.L. Thingelstad, W.W. Aud, R.A. Burns, and L. Weijers, 2012, Using real-time downhole microseismic to evaluate fracture geometry for horizontal packer-sleeve completions in the Bakken Formation, Elm Coulee Field, Montana: SPE #139774, 17 p.



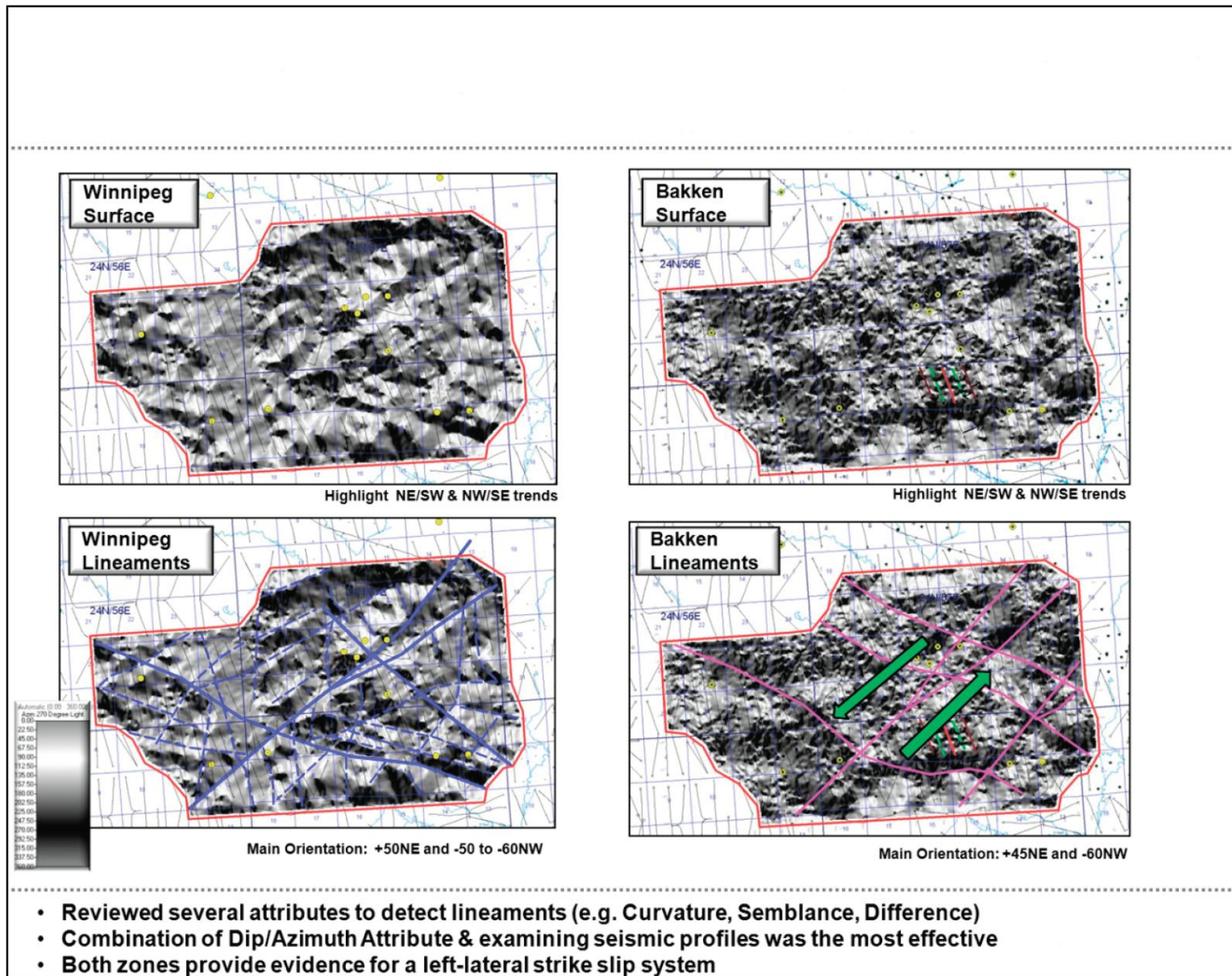


Figure 1. Faulting/lineaments interpreted from seismic. Left: Winnipeg surface and lineaments; Right: Bakken surface and lineaments.

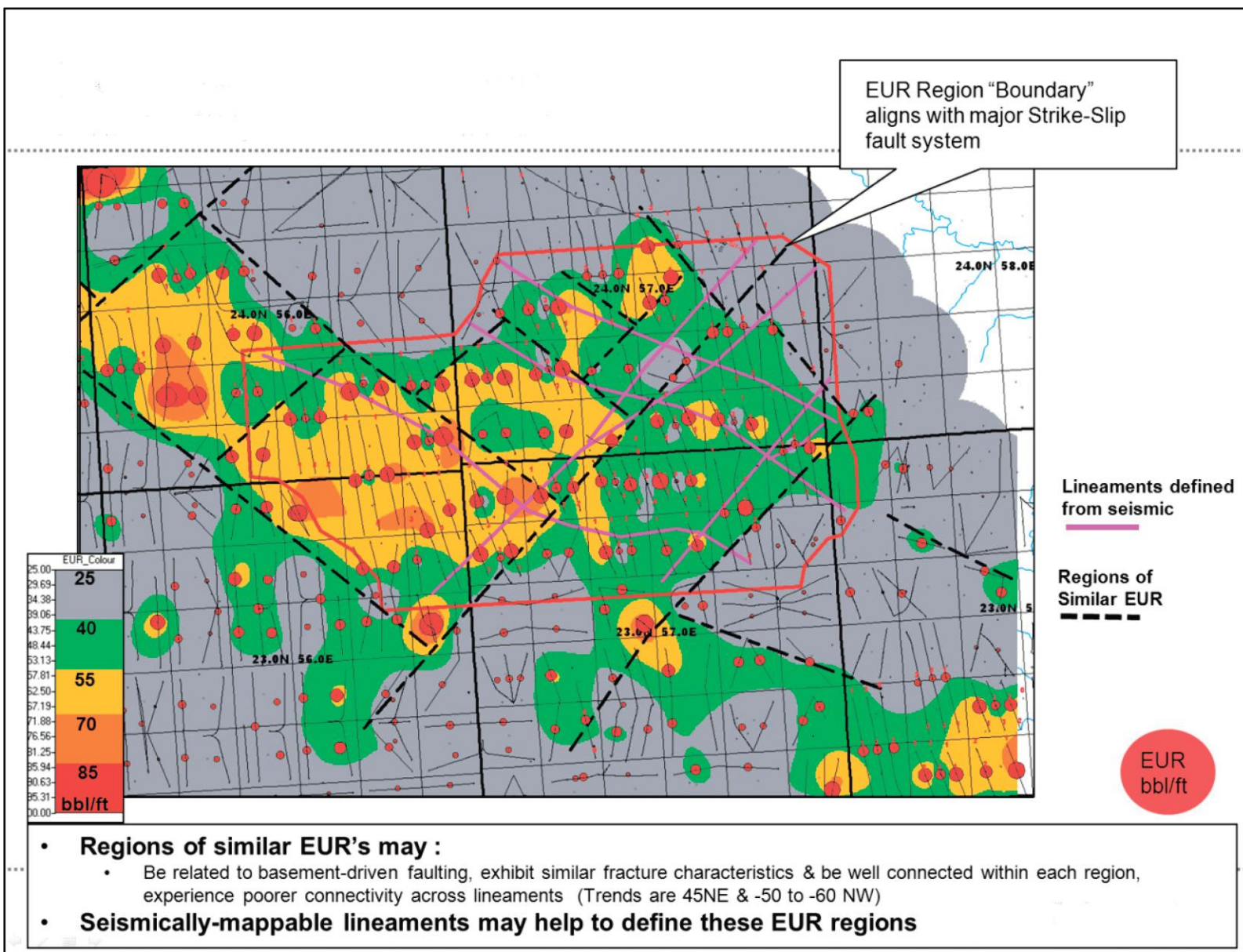


Figure 2. EUR data (normalized)--plotted at midpoint of horizontal path.