PS Structural and Stratigraphic Factors Influencing Hydrocarbon Accumulations in the Bakken Petroleum System in the Elm Coulee Field, Williston Basin, Montana*

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Abstract

The Bakken Petroleum System in the Elm Coulee field is an upper Devonian to lower Mississippian system consisting of the upper Three Forks, Bakken, and lower Lodgepole formations. The Elm Coulee Field is located at the southwest margin of the Williston Basin in Richland County, Montana, and covers over 500 mi^2. Today, the Elm Coulee Field is one of the largest oil fields in Williston Basin and has an estimated ultimate recovery of 200-250 MMBO.

This study focused on the structural and stratigraphic components of the Bakken Formation and Prairie Salt Formation in the Elm Coulee Field and addressed the basement structural trends and their influence on the Bakken pay interval and possible salt dissolution in the Prairie Salt. The latter is significant in explaining whether the anomalous thickness of the Middle Bakken Member is due to salt dissolution that may have occurred during Bakken deposition. Salt dissolution could have been initiated by basement structural faults and fractures acting as migration pathways for liquids, which could have provided an inflow of subsurface water to the Prairie Formation causing dissolution of the salt and as result collapse of overlying beds and compensation infill. The study utilized subsurface cores, well log data, and 3-D seismic.

Six distinct facies have previously been identified in the Middle Bakken: the A, B, C, D, E, and F facies. These facies have been re-examined in six representative cores from the Elm Coulee field. All facies were identified and described except for the C and D facies. The core analyses further identified the main reservoirs in the Bakken Petroleum System to be within the Bakken Formation's Upper Bakken Member and Middle Bakken Member: Facies B, E, and F. The reservoir quality in the Middle Bakken Member is enhanced by dolomitization.

Well log data analysis identified a NW-SE trending thickness anomaly of the Bakken Formation's Middle Bakken Member in the Elm Coulee Field. Whether or not this anomaly was caused by basement tectonics and/or Prairie salt dissolution was not able to be determined. Although, the presence of the Bakken Formation's Lower Bakken Member may be indirect evidence for Prairie Salt Dissolution. Ant tracking performed on the 3-D seismic data identified sub-seismic discontinuities/faults with four different trends, where the two most dominant trends were NE and NW. The laterally and vertically small discontinuities/faults are part of a large-scale, basement-driven, regional strike-slip system that

extends across the Williston basin with a primary fracture direction of ~45°NE and a secondary fracture direction of ~60°NW.

Various surface attributes were tested on the Bakken horizon to identify either positive or negative direct hydrocarbon indicators. Bakken discontinuities/faults were overlaid onto a RMS amplitude map of the Vaux 3D seismic survey. No distinct trend was observed. A production map produced by Enerplus Corporation was compared to the RMS amplitude map and no trends were identified between the amplitude brightness and production. The surface attribute maps created seem to be indicating something, but the exact interpretation is uncertain.

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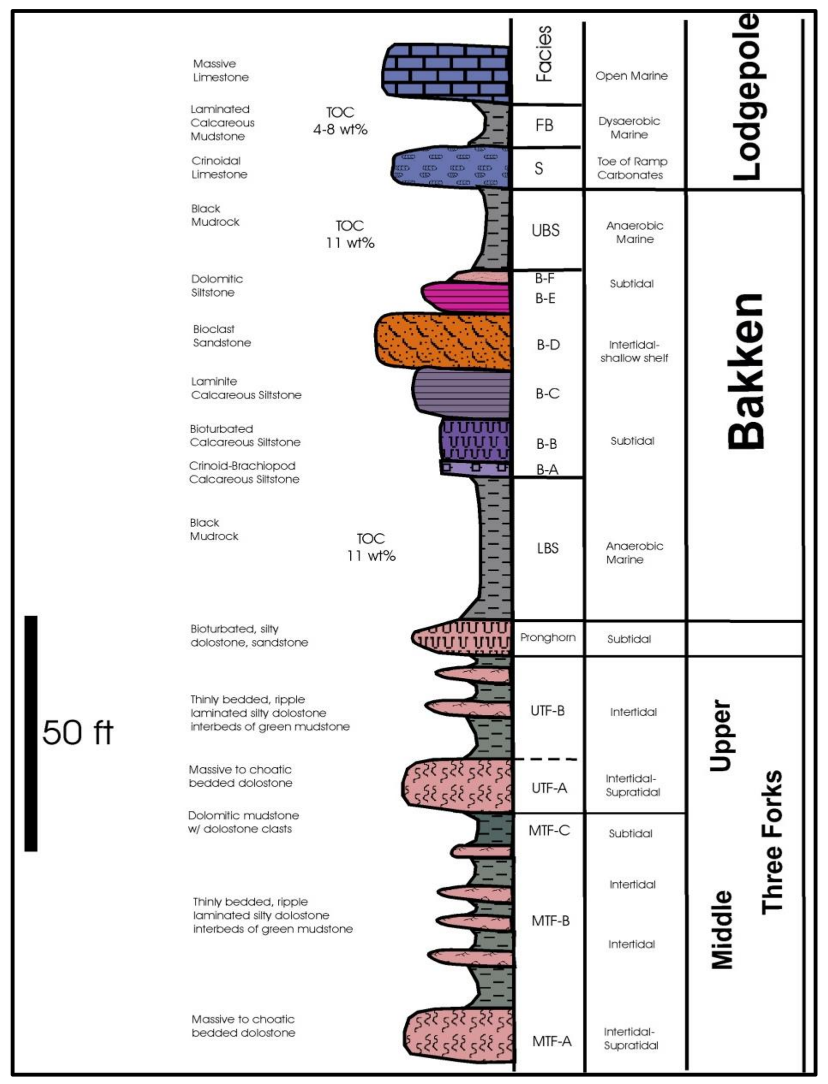
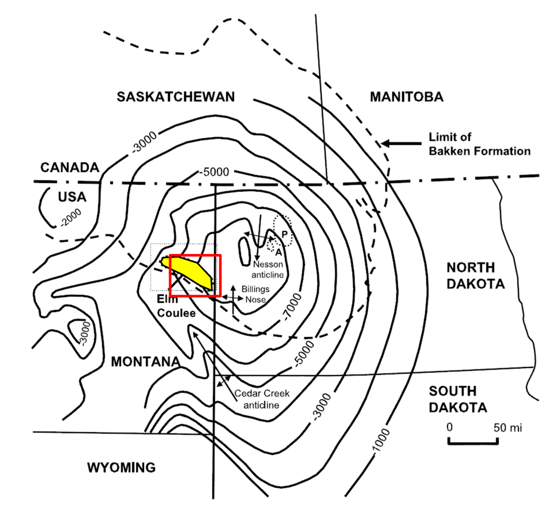
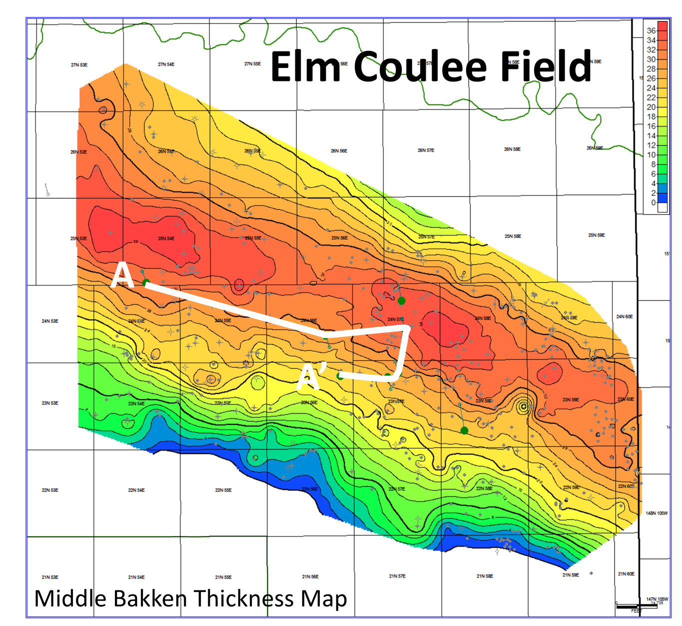
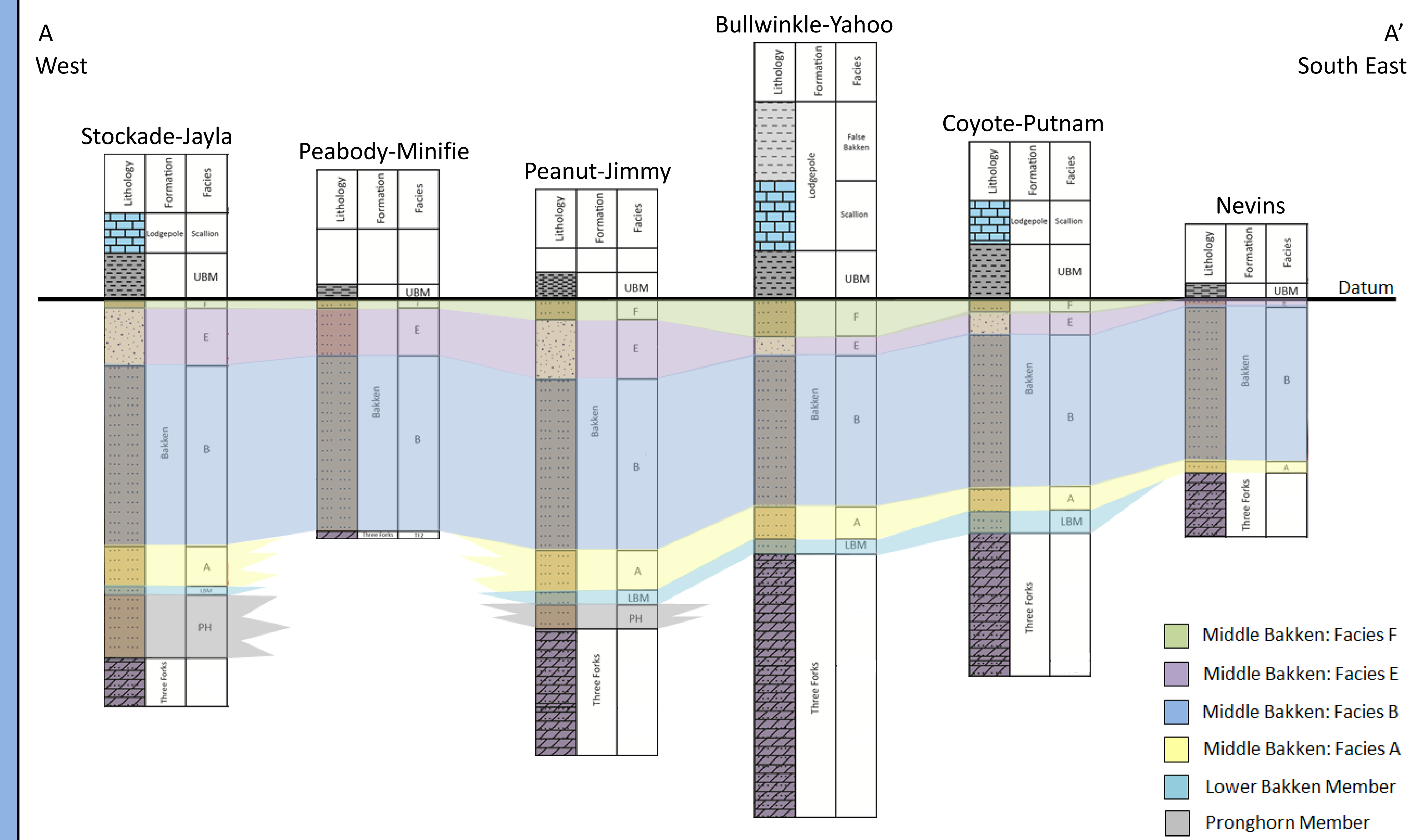
BAKKEN PETROLEUM SYSTEM



STUDY AREA





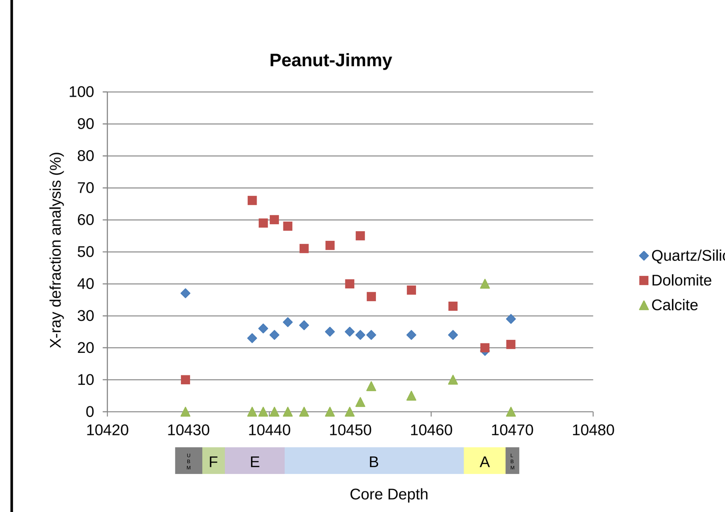


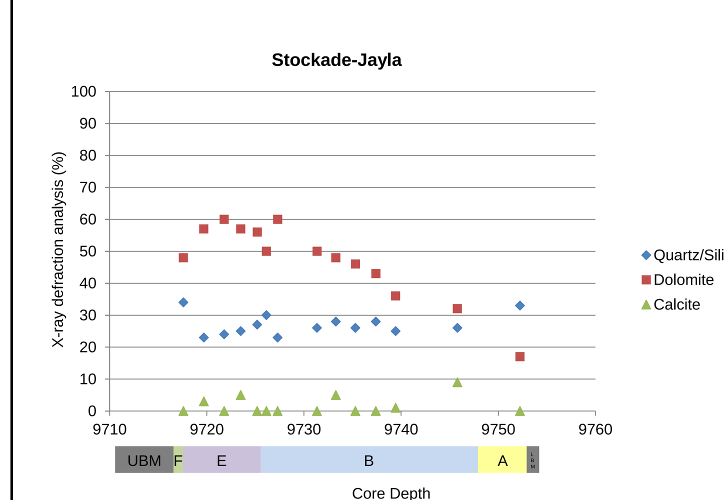
LITHOFACIES

Formation	Facies	Photo	Description
Lower Lodgepole	False Bakken		Brownish-black **mudstone** with open fractures
	Scallion		Grey **limestone** with crinoids and dark irregular layers (stylolites)
Bakken	Upper Bakken Member		Dark **organic-rich shale** with silty laminations, fractures, and occasional pyrite
	MB: Facies F		Dark grey **dolomitic siltstone** with brachiopods, crinoids, lighter grey wavy and planar laminations
	MB: Facies E		Grey **dolomitic siltstone/sandstone** with wavy and planar laminations and occasional bioturbation
	MB: Facies B		Brownish-grey **dolomitic siltstone** with abundant clay-rich Helminthopsis and Scalarituba burrows
	MB: Facies A		Dark grey **dolomitic siltstone** with brachiopods and occasional bioturbation
	Lower Bakken Member		Grey **dolomitic siltstone** with occasional bioturbation
	Lag		**Pyritized fossil lag** surrounded by black mudstone
	Pronghorn		Grey **dolomitic siltstone** with lighter colored storm deposit layers
Upper Three Forks	Three Forks 3		Tan to green laminated/layered **dolomitic siltstone**
	Three Forks 2		Reddish-brown **dolomitic siltstone** with laminated and mottled subfacies
	Three Forks 1		Reddish-brown **dolomitic siltstone** with breccia clasts

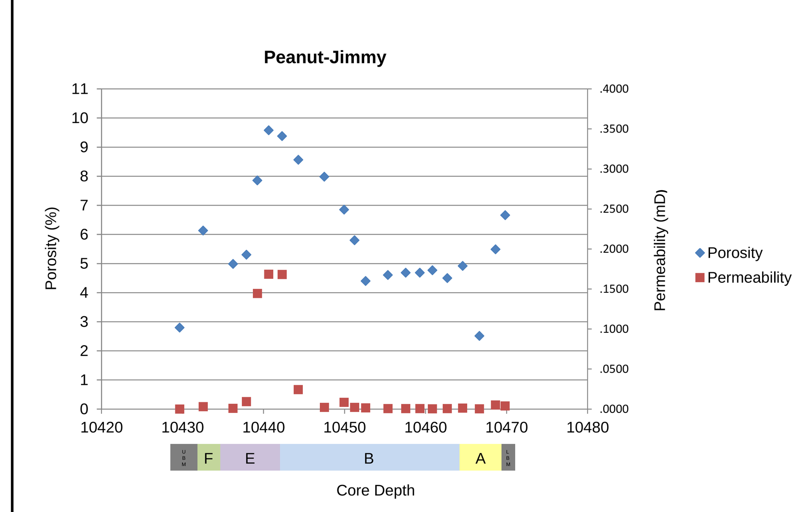
RESERVOIR PROPERTIES

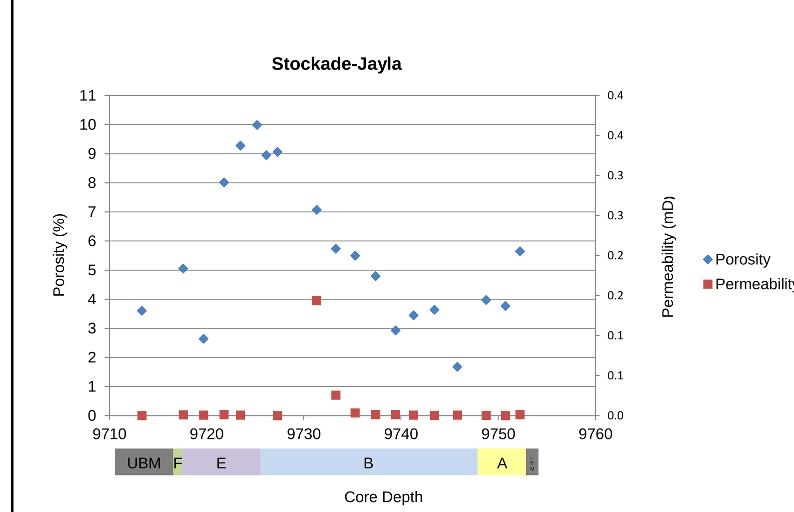
Dolomitization Trends



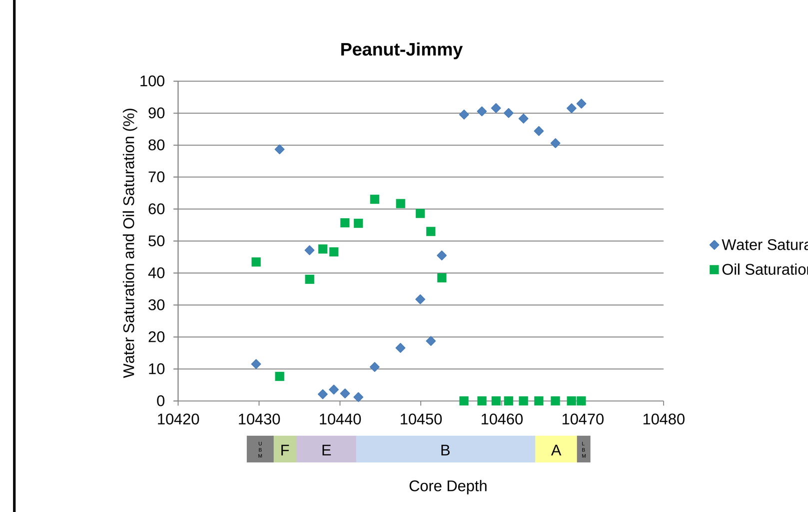


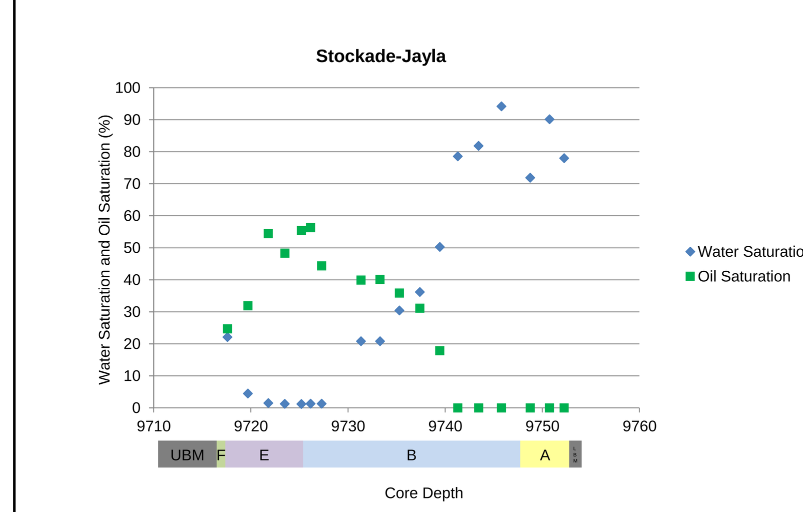
Porosity & Permeability Trends





Water and Oil Saturation Trends





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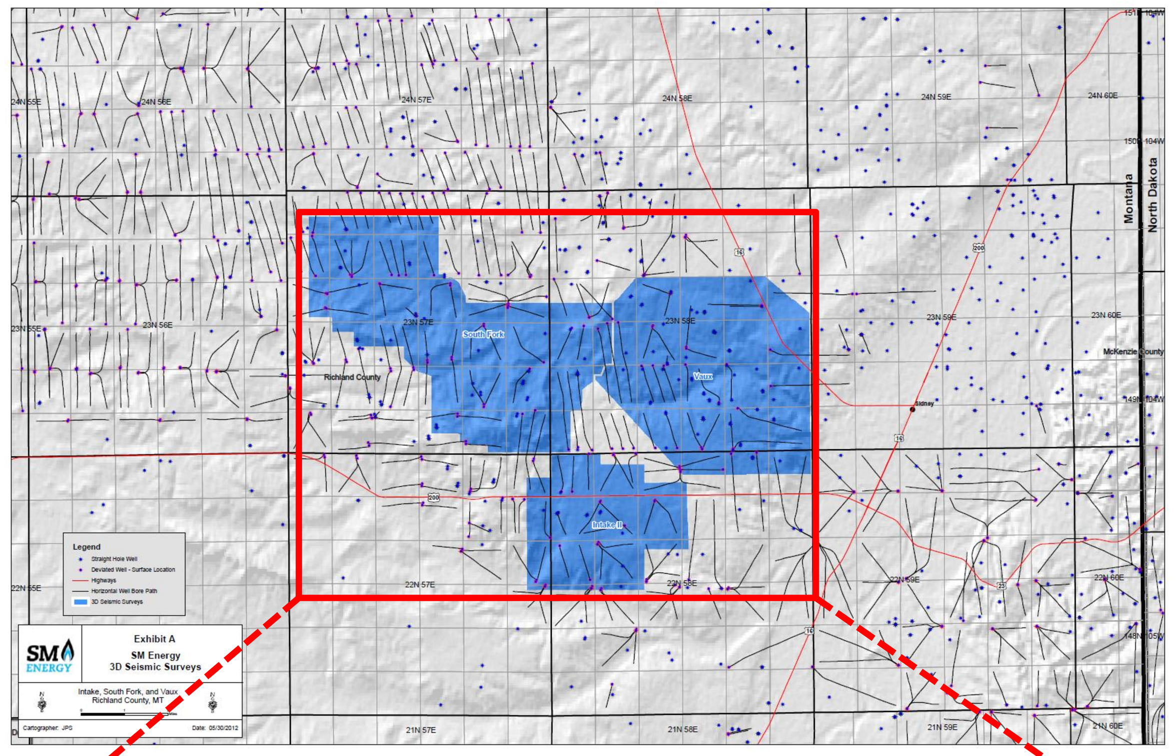
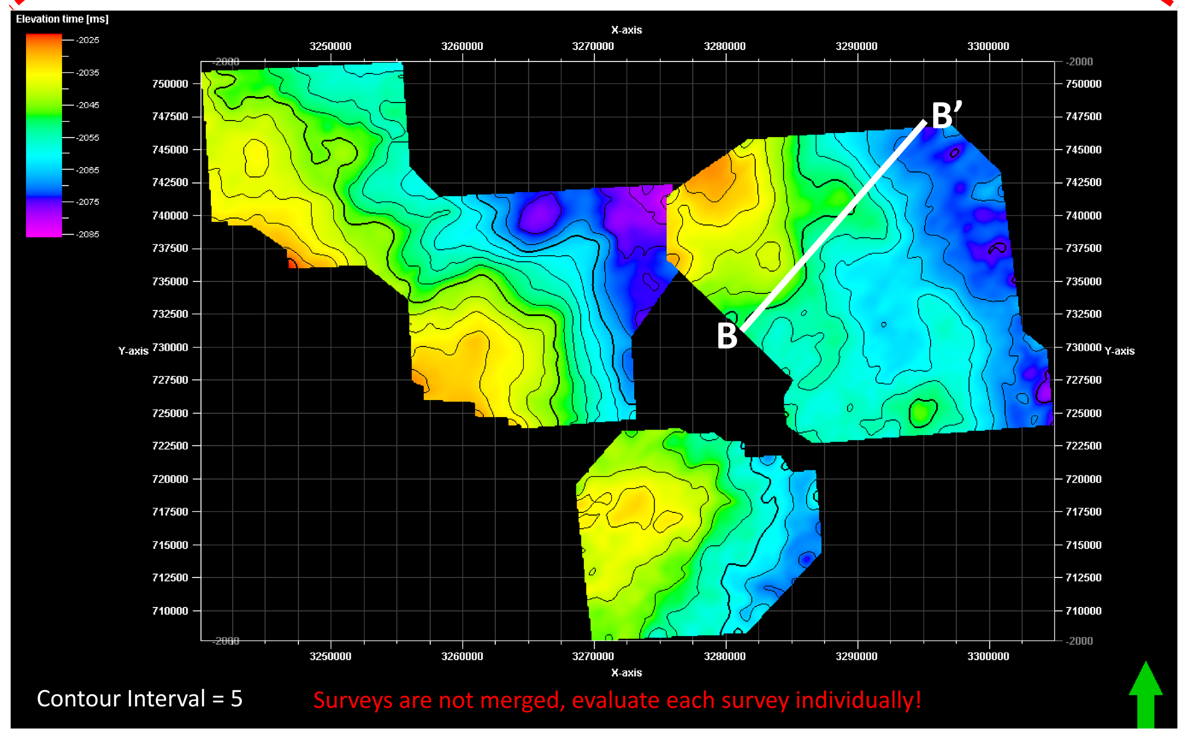
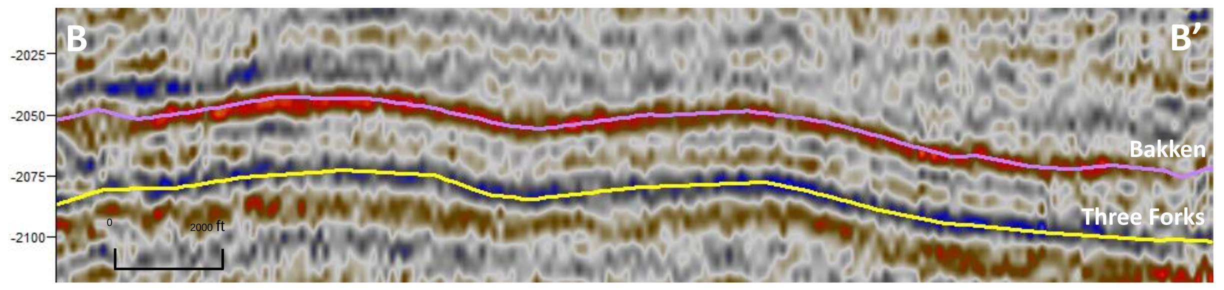
3-D SEISMIC SURVEY AREA



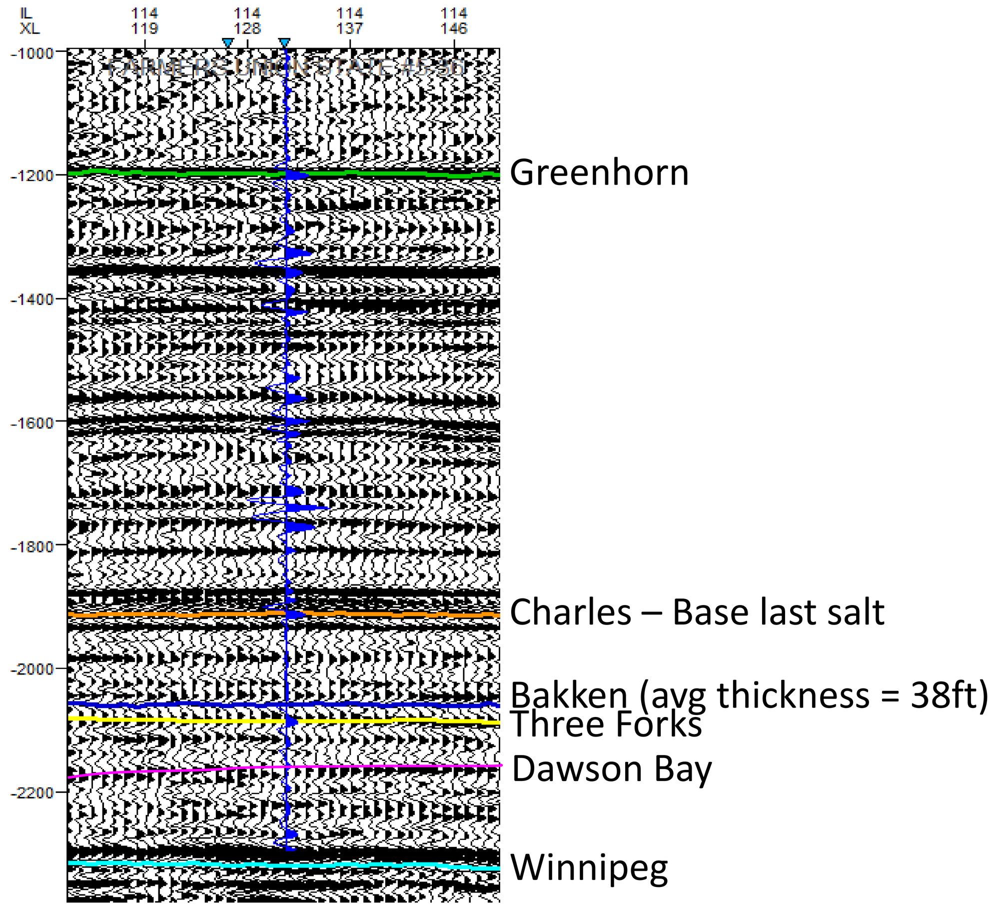
BAKKEN TIME-STRUCTURE MAP



SEISMIC PROFILE



SEISMIC WELL TIE



VOLUME ATTRIBUTES

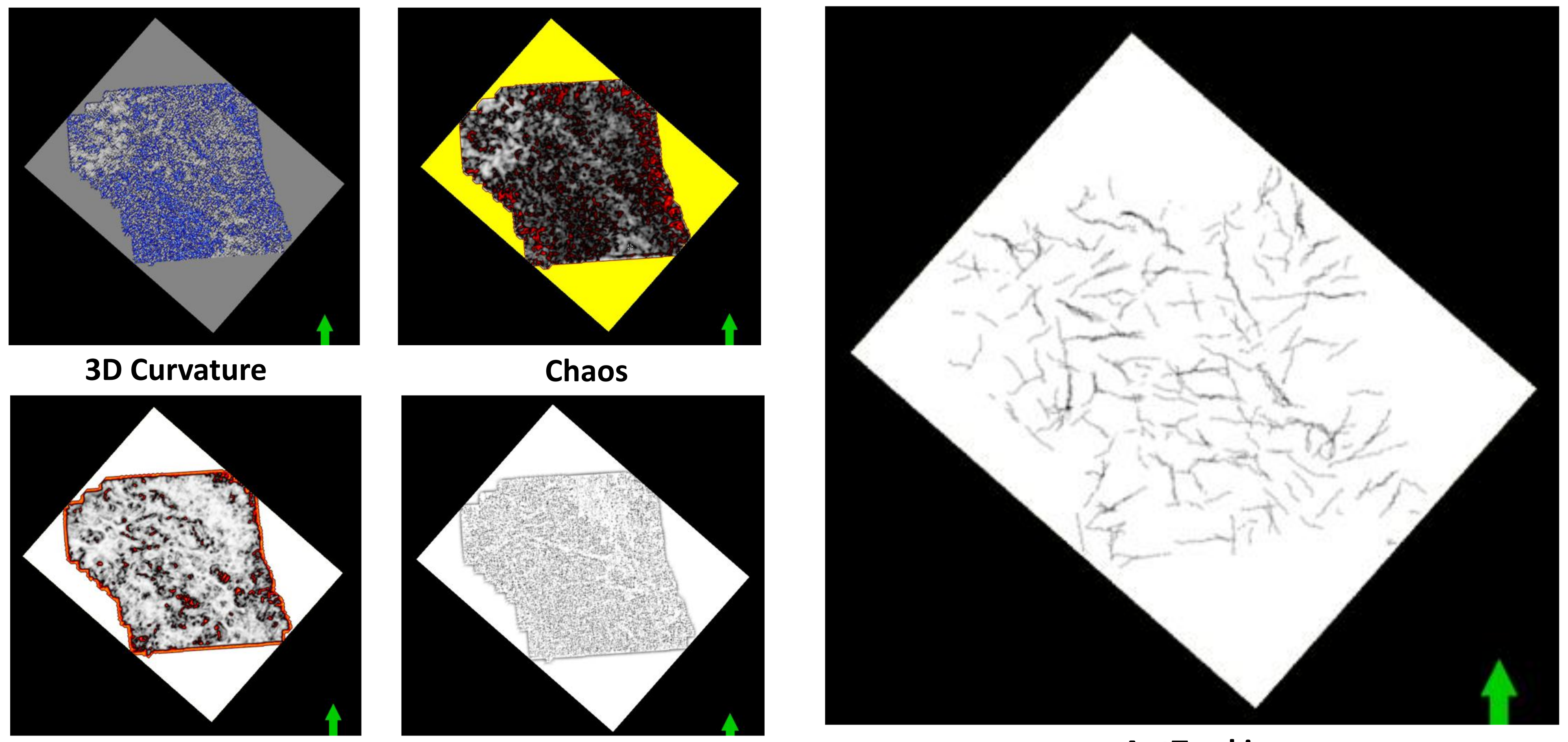
Ant Tracking – used to automatically extract faults from a pre-processed seismic volume. The pre-processing can be performed in Petrel. The result is an attribute volume that displays fault zones in great detail and sharpness.

3D Curvature – for a particular point of curvature, it is defined as the rate of change in the curve direction. It can be used to bring out stratigraphic features in sedimentary environments, karst features or structural discontinuities.

Chaos – measure of the "lack of organization" in the dip and azimuth estimation method. It can be used to illuminate faults and discontinuities and for seismic classification of chaotic texture. Chaos can be related to local geologic features as it will be affected by gas migration paths, salt body intrusions, reef textures, channel infill, etc.

Variance – the estimation of local variance in the signal. Useful for edge detection. It can be used to isolate edges from the input data set. By edge, this means discontinuities in the horizontal continuity of amplitude. Variance is applicable as a stratigraphic attribute.

Dip deviation – the difference between the dip trend and the instantaneous dip. Creates an edge volume from the input seismic volume. By tracking rapid changes in the orientation field, edges and subtle truncations become visible. The edge attribute has been found to work successfully for low-angle fault illumination.



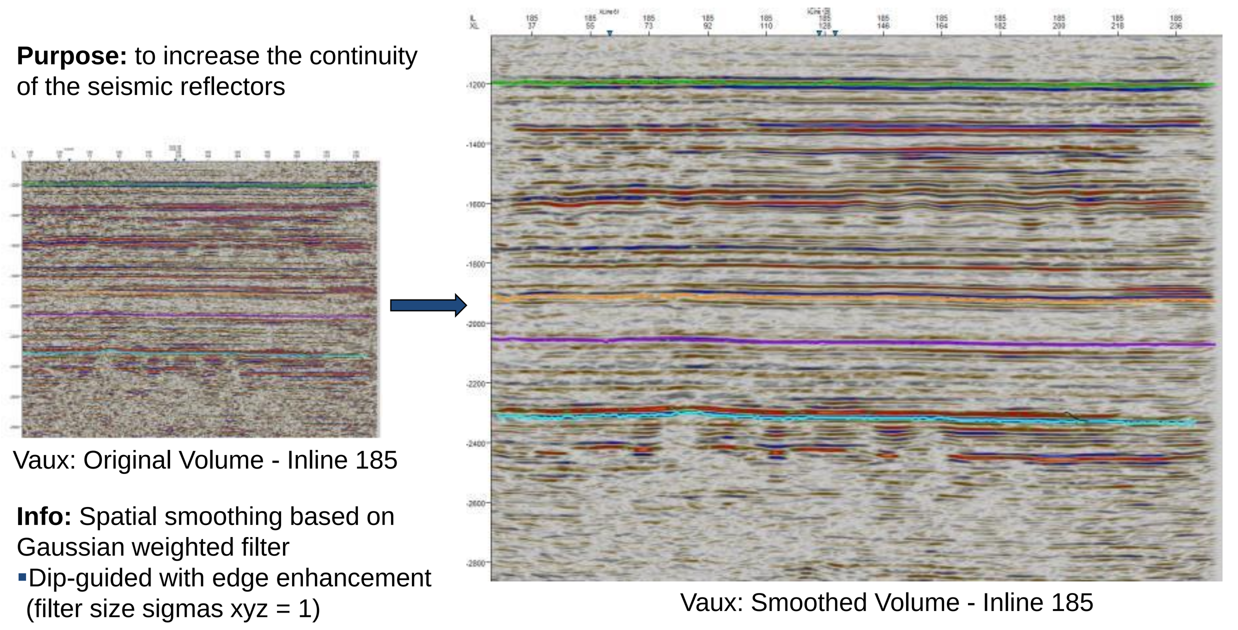
3D Curvature | Chaos | Variance | Dip Deviation | AntTracking

ANT TRACKING

AntTracking emulates the behavior of ant colonies in nature and their use of pheromones to mark their paths in order to optimize the search for food. The result is an attribute volume that shows fault zones in sharp detail. Using AntTracking to extract faults requires multiple steps and the AntTracking workflow used for this study included:

Step 1: Structural Smoothing

Purpose: to increase the continuity of the seismic reflectors



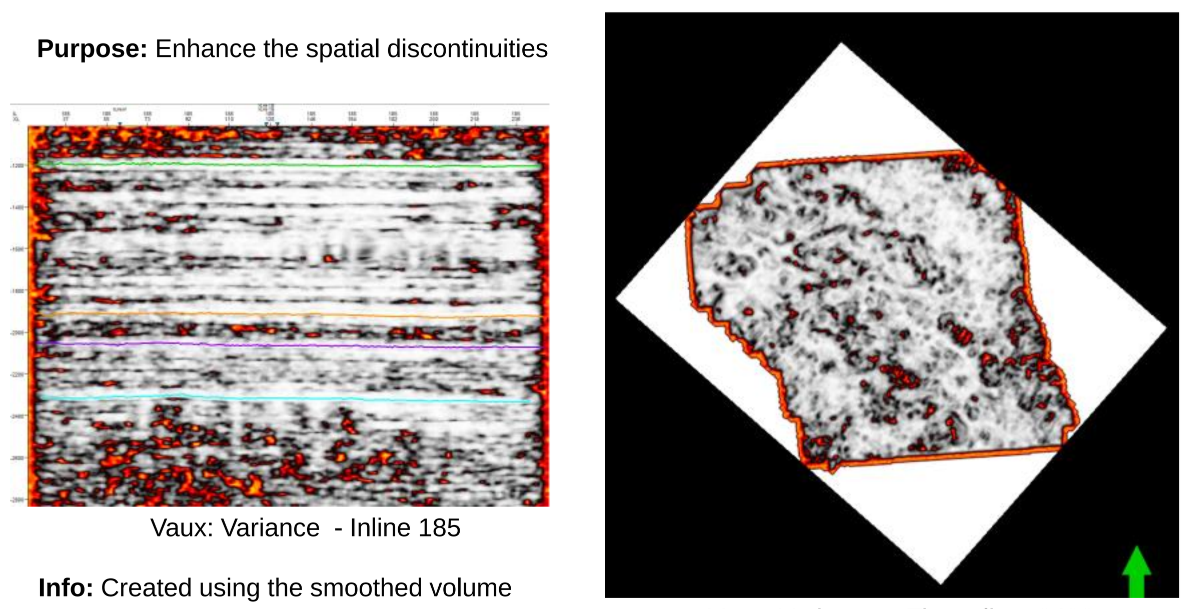
Vaux: Original Volume - Inline 185

Vaux: Smoothed Volume - Inline 185

Info: Spatial smoothing based on Gaussian weighted filter
- Dip-guided with edge enhancement (filter size sigmas xyz = 1)

Step 2: Generate Variance Cube

Purpose: Enhance the spatial discontinuities



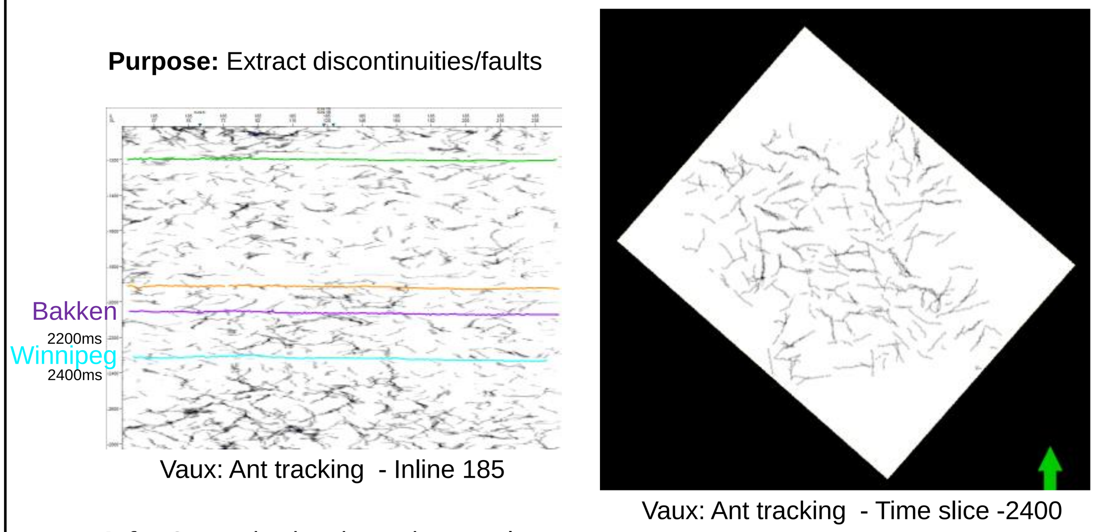
Vaux: Variance - Inline 185

Vaux: Variance - Time slice -2400

Info: Created using the smoothed volume

Step 3: Generate AntTracking Cube

Purpose: Extract discontinuities/faults

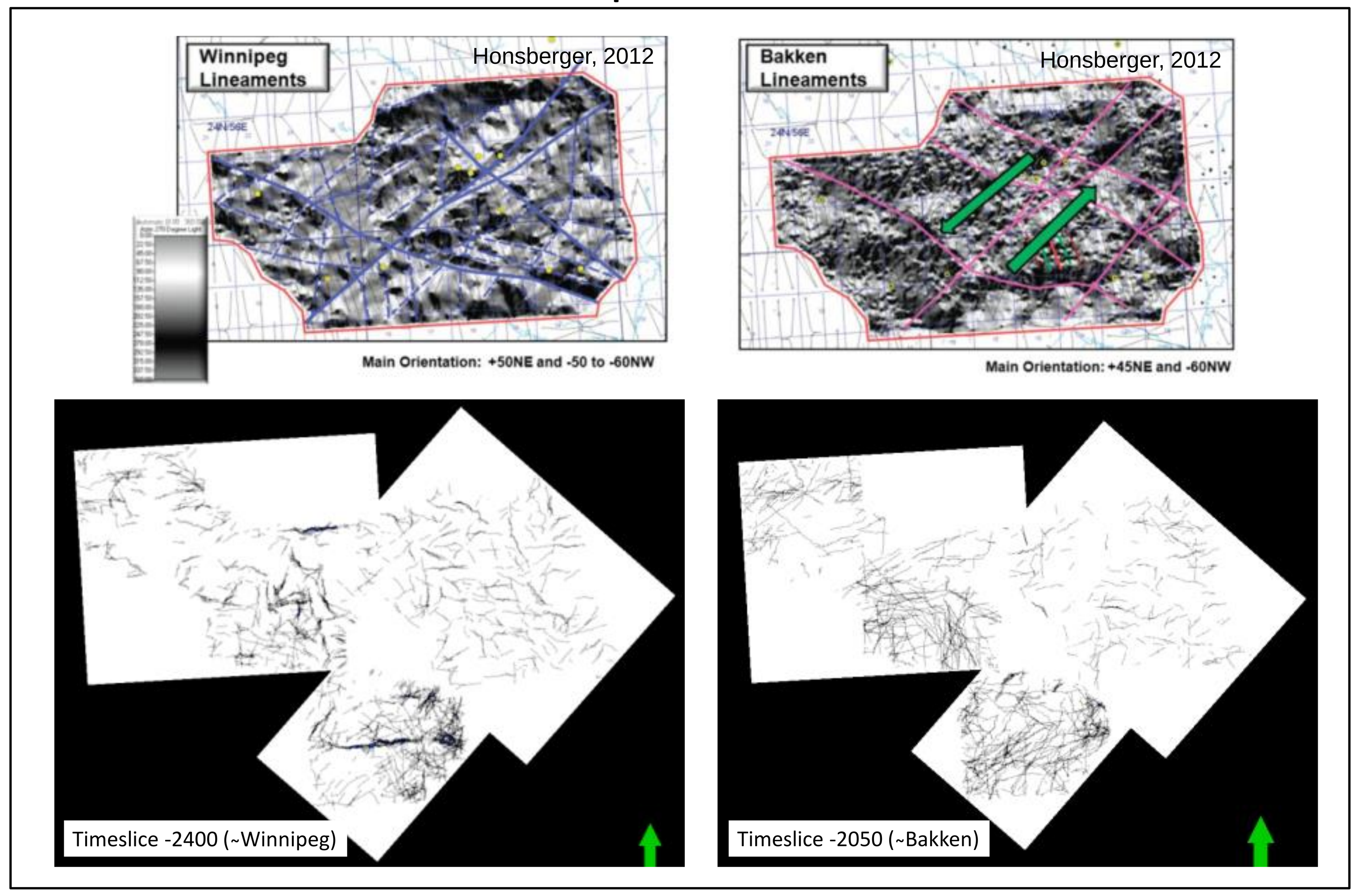


Vaux: Ant tracking - Inline 185

Vaux: Ant tracking - Time slice -2400

Info: Created using the variance volume

Step 4: Validation



SURFACE ATTRIBUTE

RMS Amplitude – the square root of the sum of the squared amplitudes, divided by the number of live samples. It may map directly to hydrocarbon indications in the data and other geologic features which are isolated from background features by amplitude response.