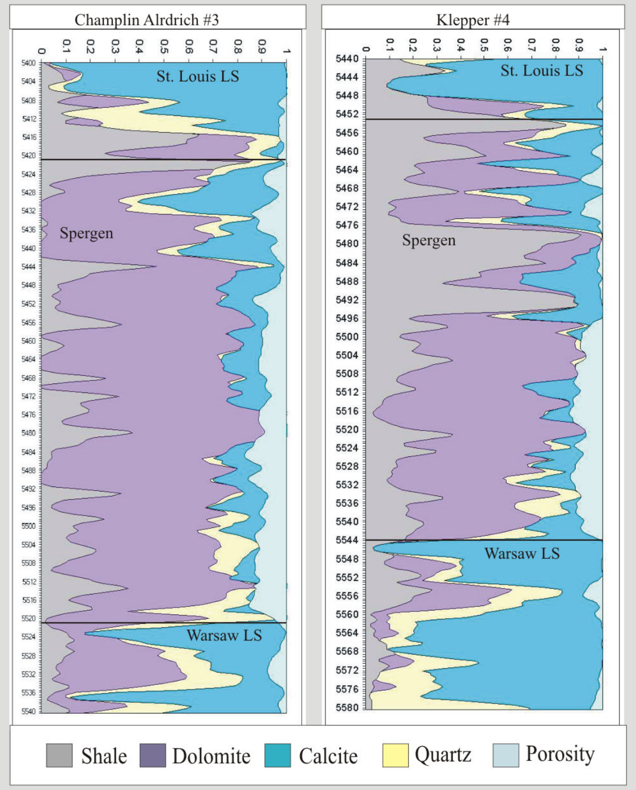
Core to Log Comparison

Composition Graph

We use an Excel spreadsheet to set up the matrix algebra solution for compositional analysis. The MINVERSE function within Excel is used to perform the operation through inversion of the matrix of the log properties of the components. The logs used in the composition analysis are: Gamma Ray, Neutron Porosity (percent), Bulk Density, and Photoelectric Volumetric Cross Section. By premultiplying the logs by this inverse matrix, we can determine the percentage of calcite, dolomite, quartz, shale, and porosity.

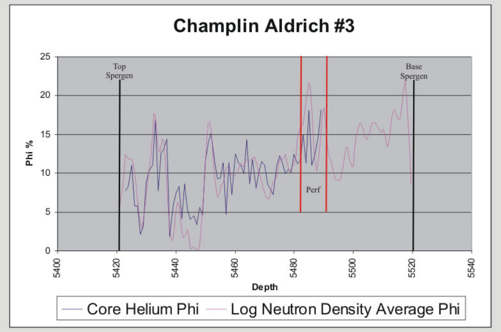
- Mineral compositions estimated from the logs show good concordance with lithologies described from core.
- The composition graph is a useful quantitative representation of lithofacies, porosity, and amount of dolomitization observed within each core.
- Porosity computed from average neutron-density porosity logs shows a fair correlation with porosity measured in core.

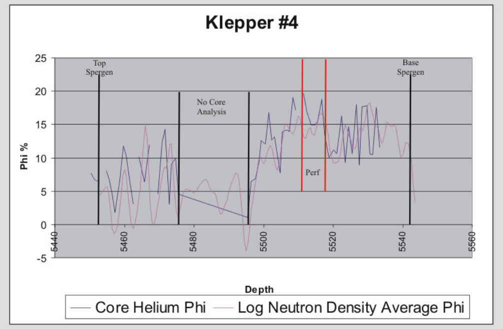


Composition graphs using GR, Neutron porosity (percent), Photoelectric, Grain Density, and Bulk Density.

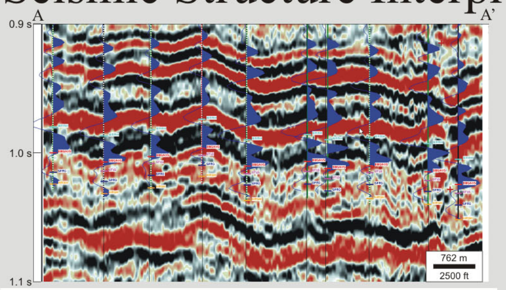
Porosity Comparison

Porosity from core analysis is plotted against Neutron Density Average porosity from logs. There is a fairly good match between the two data sets for the Spergen section.

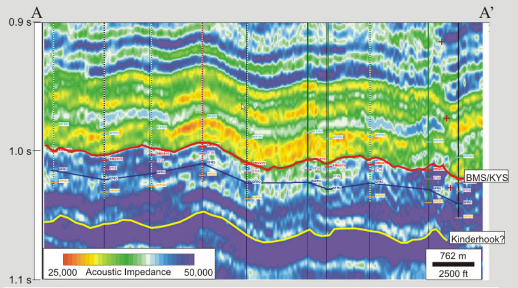




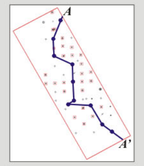
Seismic Structure Interpretation



Vertical seismic section through wells with sonic logs from a 5.5 sq. mile 3-D seismic survey in Cheyenne Wells and Smoky Creek fields. Peaks are black and troughs are red. Synthetic seismograms generated from the sonic logs are superimposed in blue. The following formation tops are displayed: Morrow (cyan), BMS/KYS (red), Top Mississippian St. Louis (violet), Spergen (dark blue), Warsaw (gold).

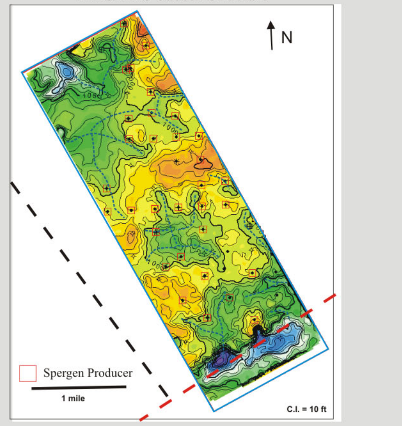


Section through model based inversion volume corresponding to the seismic section at left. The BMS/KYS horizon (red) is visible as a sharp impedance increase. A deeper continuous horizon corresponding to another impedance increase is tentatively interpreted as the top of Kinderhook (yellow).

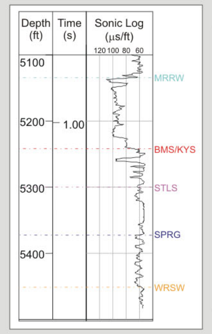


Location map for seismic sections.

BMS/KYS Subsea Structure



BMS/KYS subsea depth structure map derived from seismic data. Orange indicates structural highs and purple indicates structural lows. Interpreted drainage patterns are indicated by blue dashed lines. The red dashed line is a Precambrian shear zone and the black dashed line is a high angle basement fault from Sims et al. (2001).

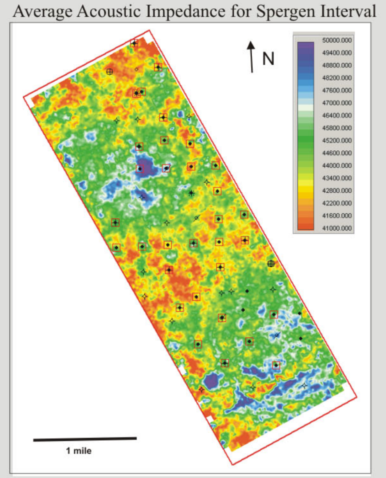


A sonic log for a well in the Smoky Creek field shows that the top Mississippian (STLS) and top Spergen (SPRG) do not correspond to significant acoustic impedance contrasts. The closest seismic horizon to the reservoir interval that can be reliably interpreted across the entire dataset is the BMS/KYS.

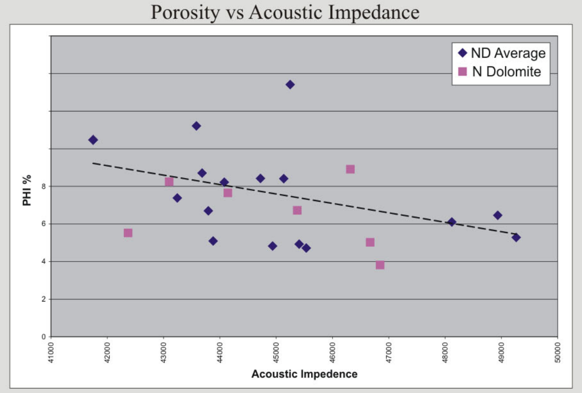
- Synthetic seismograms have been used to tie formation tops to seismic reflections and to guide a model-based acoustic impedance inversion of the seismic data.
- St. Louis, Spergen, and Warsaw tops do not correspond to strong impedance contrasts. The Base Morrow Shale / Top Keyes (BMS/KYS) is the closest continuous seismic reflector.
- The drainage pattern interpreted on the BMS/KYS structure map is reminiscent of karst drainage consisting of blind valleys. Local topographic depressions as small as 20 acres in size may be sinkholes.
- A down-to-the-south fault at the southern end of the seismic survey aligns with a Precambrian shear zone.

Acoustic Impedance Interpretation

Average Acoustic Impedance for Spergen Interval



Porosity vs Acoustic Impedance



- Average acoustic impedance has been extracted from the model-based inversion volume for the interval between the top and base of the Spergen. (The positions of the top and base of the Spergen in the seismic data volume have been approximated using the BMS/KYS horizon and isochron maps calculated from isopach maps and interval velocities from wells with sonic logs.)
- The Spergen acoustic impedance map shows spatial variation with broad NE trending bands of high and low impedance.
- Acoustic impedance may be an indicator of porosity variations.
- The crossplot of acoustic impedance and average Spergen porosity shows considerable scatter, but in general, higher acoustic impedance corresponds to lower porosity.

Log Petrophysical Analysis

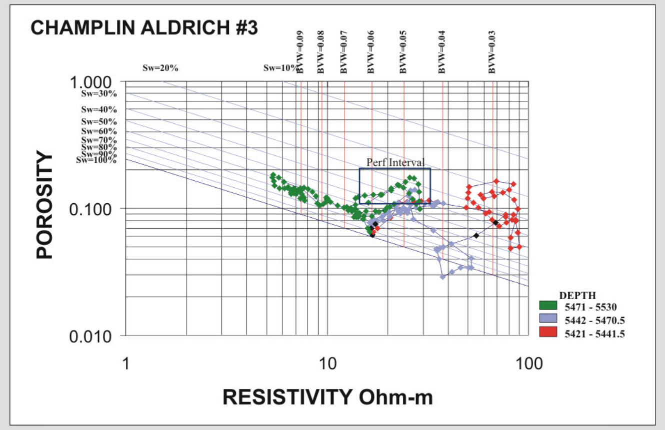
A modified Pickett crossplot (PfEFFER) was used to analyze patterns in porosity, resistivity, and saturation in the reservoir. Each data point on these plots represents a half-foot interval and points are linked together in sequence by depth to reveal trends through the reservoir. From the Archie relations, saturation contours and bulk volume water contours are superimposed. Details of the methodology in using the modified Pickett plots are described in Doveton et al. (1996).

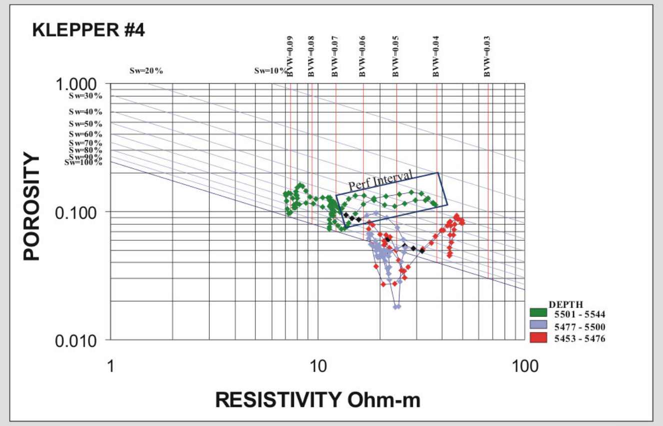
Inputs - wireline log resistivity and porosity, water salinity, Archie parameters (m and n). Porosity, BVW, and permeability cut-offs were used to identify the net pay at each well.

Archie Parameters and cut-offs:

$a = 1$	$m = 2$	Phi = 0.1	$S_w = 0.6$
$n = 2$	$R_w = 0.06$	GR = 40	$V_{sh} = 1$ BVW = 1

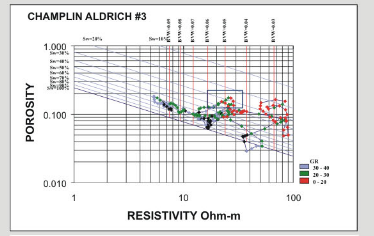
- Pickett plot analysis results are consistent with the three intervals of Spergen (A, B, and C) observed in logs. PfEFFER also locates potential bypassed pay within the wells for which the analysis has been completed.



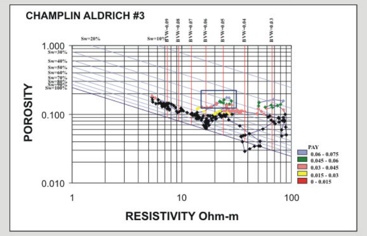


Pickett Plot for Spergen Interval A (red), B (blue) and C (green).

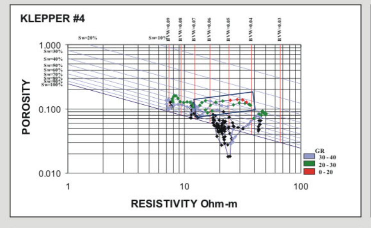
Pickett Plot for Spergen Interval A (red), B(blue) and C (green).



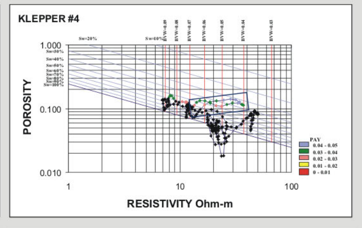
Pickett Plot illustrating ranges of Gamma Ray values: 0-20 (red), 20-30 (green), 30-40 (blue), >40 (black).



Pickett Plot illustrating ranges of Net Pay Feet based on the formula: Thickness (0.5 ft.)*Phi*(1-Sw).



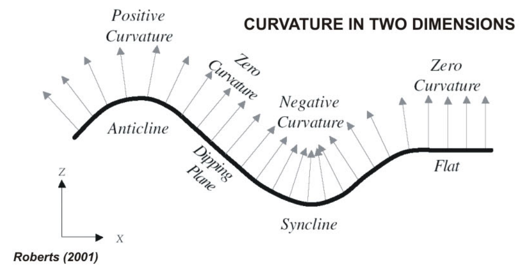
Pickett Plot illustrating ranges of Gamma Ray values: 0-20 (red), 20-30 (green), 30-40 (blue), >40 (black).



Pickett Plot illustrating ranges of Net Pay Feet based on the formula: Thickness (0.5 ft.)*Phi*(1-Sw).

Seismic Volumetric Curvature Interpretation

Curvature describes how bent a surface is at a particular point and is closely related to the second derivative of the curve defining the surface. The more bent a surface is, the larger the value of the curvature attribute. Positive curvature refers to an antiform feature, negative curvature refers to a synform feature, and zero curvature refers to a planar feature.

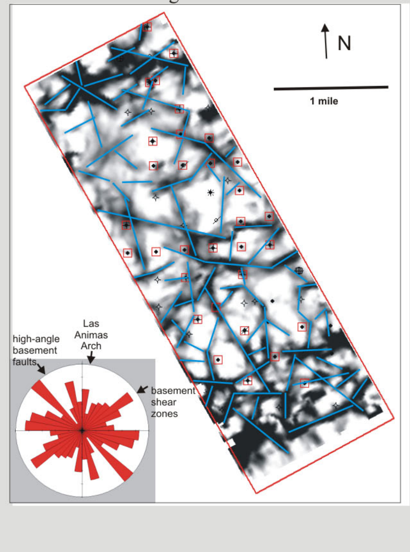


Various curvature attributes reveal useful information relating to folds, faults, and lineaments contained within the surface (Roberts, 2001). Most published work of curvature analysis applied to 3-D seismic data has been limited to calculations based on gridded interpreted horizons (e.g., Hart et al., 2002; Masaferro et al., 2003; Sigismondi and Soldo, 2003). However, recently, a suite of volumetric curvature attributes has been developed, where reflector curvature is calculated directly from the seismic data volume, with no prior interpretation required (Al-Dossary and Marfurt, 2006).

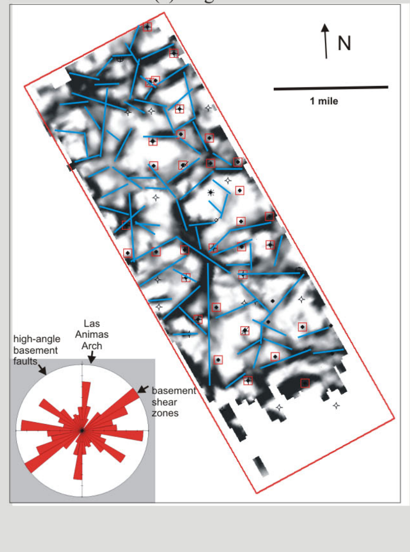
Of the numerous volumetric curvatures calculated, the most positive and most negative curvatures, which measure the maximum positive and negative bending of the surface at a given point, are the most useful in delineating faults, fractures, flexures, and folds (Al-Dossary and Marfurt, 2006; Blumentritt et al., 2005; Nissen et al., 2005; Sullivan et al., 2005).

- In the study area, slices through the most negative and most positive curvature volumes extracted along the BMS/KYS and Kinderhook horizons show several sets of large-scale high curvature lineaments.
- Curvature lineaments are aligned along orientations that parallel basement structural orientations, as well as the Las Animas Arch.
- Interpreted curvature lineaments may reflect subtle structural features, fractures, or reservoir compartment boundaries that are the cause of the production inconsistencies in the Cheyenne Wells and Smoky Creek fields.

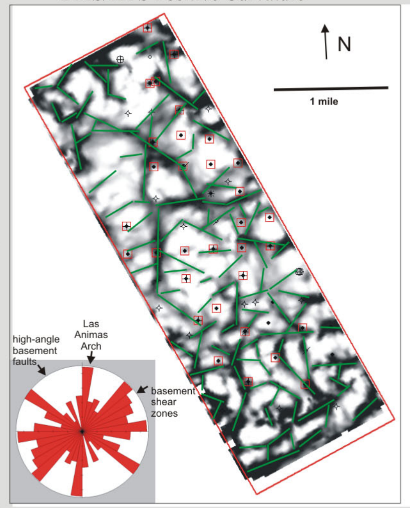
BMS/KYS Negative Curvature



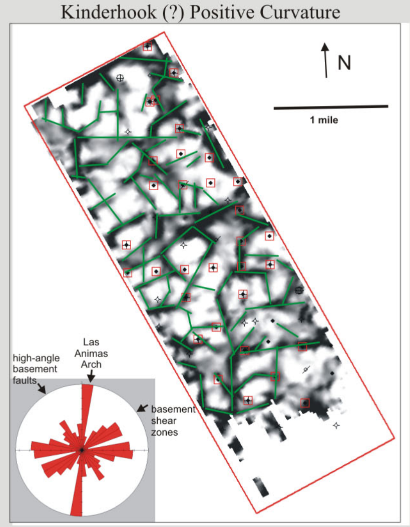
Kinderhook (?) Negative Curvature



BMS/KYS Positive Curvature



Kinderhook (?) Positive Curvature



Most positive and most negative curvature extractions along the BMS/KYS and Kinderhook horizons. Tighter curvature is shown in black and dark gray. Orientations of interpreted negative curvature (blue) and positive curvature (green) lineaments have been analyzed using length-azimuth rose diagrams (red).

Conclusions

Core, log, and seismic data provide complementary information about the Spergen reservoir in Cheyenne Wells and Smoky Creek fields. Core and log data show that productive Spergen exhibits a variety of lithofacies and a wide range of matrix porosities. Production is not well correlated with matrix porosity, suggesting that another parameter controls well performance.

The detailed structure map of the BMS/KYS horizon obtained from the seismic data along with the Keyes isopach map from well tops indicates a drainage pattern suggestive of karst. While production is not directly related to overall structure and thickness of the Spergen, subtle karst features, such as solution-enhanced fractures aligned along structural trends, may impact production. Various oriented lineaments have been identified on seismic curvature maps and these lineaments may relate to compartment boundaries, closed fractures, and/or open fractures.

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