Seismic Acoustic Impedance Inversion in Reservoir Characterization Utilizing gOcad

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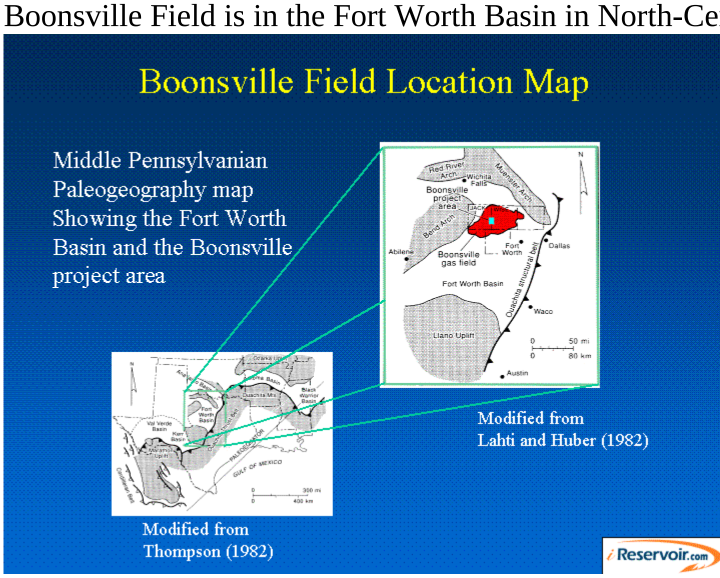
Introduction

Workflows for utilizing seismic data inverted to acoustic impedance data in reservoir characterization will be shown. We are using the public domain 3D seismic dataset at Boonsville Field in North-Central Texas for our example. This public domain dataset is fairly complete with seismic, well, and production data:

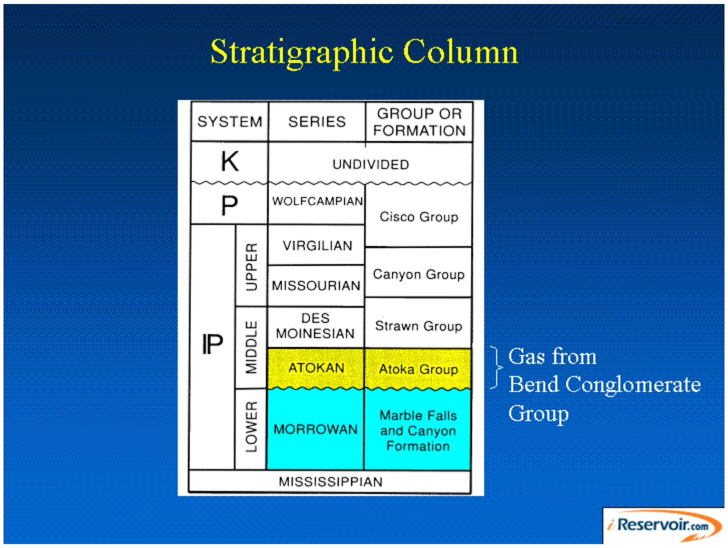
- •5.5 sq. Miles of 3D seismic data
- •Vertical seismic profile (VSP) near center of survey
- •Digital well logs from 38 wells
- •Well markers for the bend conglomerate group
- •Perforations, reservoir pressures, production and Petrophysical data for the 38 wells

We acknowledge Oxy USA, Inc., Enserch, Arch Petroleum, Bureau of Economic Geology, GRI and the DOE as contributing members for making this dataset available. This data is made publicly available as part of the technology transfer activities of the Secondary Gas Recovery (SGR) program funded by the U. S. Department of Energy and the Gas Research Institute.

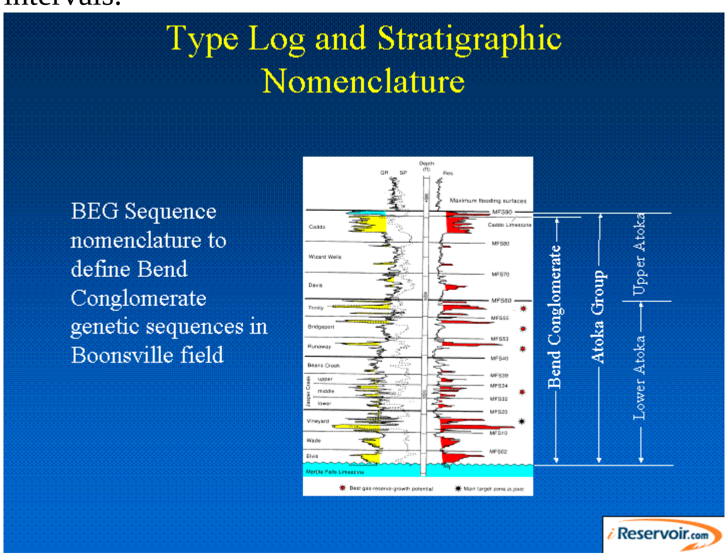
Boonsville Field is in the Fort Worth Basin in North-Central Texas.



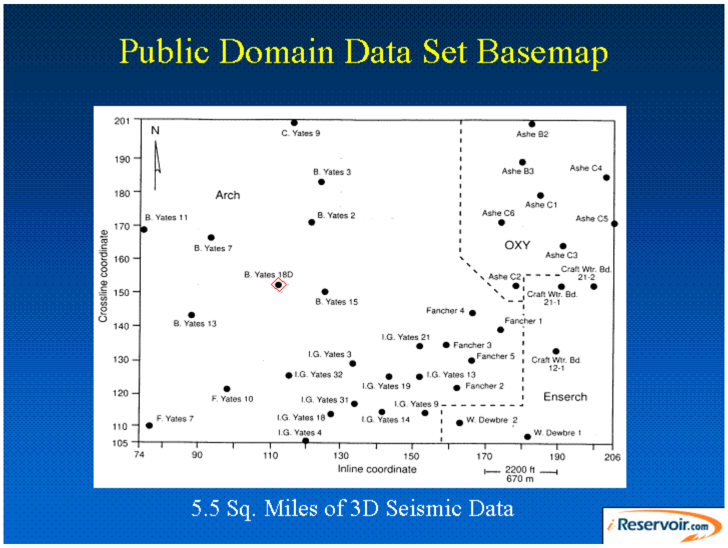
The main productive interval are clastic sandstones in the Pennsylvanian Atokan Bend Conglomerate Group.



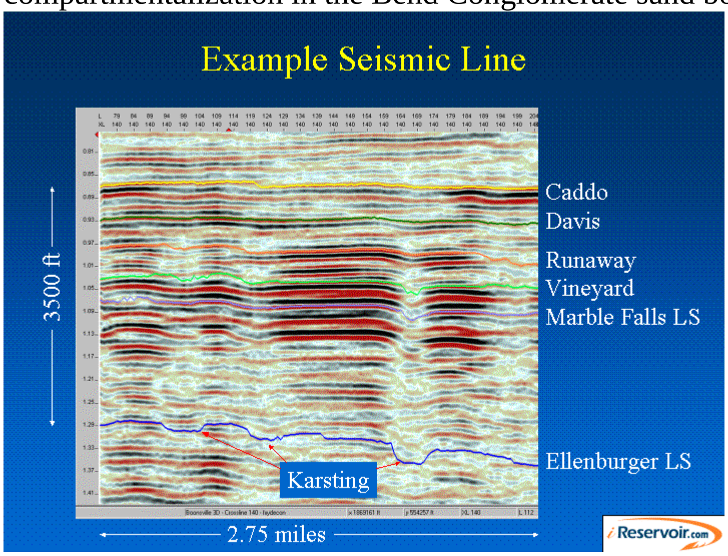
A type log shows the interbedded sandstones and shales over about 1300 feet of section. The Bend Conglomerate is underlain by the Marble Falls Limestone, a platform carbonate. The Bend Conglomerates were sourced from the northwest on the Red River Arch as the Fort Worth Basin was forming during the Oachita orogeny. These Bend Conglomerate sandstones then pinchout to the southeast, outside of this project area as they become distal to the source, prograding into the Fort Worth Basin.
Historical gas production has been from the lower most sequence in the Vineyard. Additional potential is expected in the middle sequences of the Runaway and Vineyard intervals.



This basemap shows the 5.5 square miles of 3D and the 38 wells drilled to the Bend Conglomerate Group.



This example seismic line shows the Bend Conglomerate Group structure. Most striking are the karst collapse features from dissolution of the underlying Ellenburger Limestone, some 2000 feet below the Atoka. These collapse features are seen to cause compartmentalization in the Bend Conglomerate sand bodies.



Previous conclusions from the Bureau of Economic Geology’s GRI study are:
1) Karsting from Ellenburger carbonates cause collapse features compartmentalizing the reservoir. Large range of compartment sizes exist.
2) Need 3D seismic to image the collapse features.
3) Seismic attributes can sometimes predict the reservoir facies
Upper Caddo: Amplitude
Lower Caddo: Inst. Frequency
Lower Bend Conglomerate sequences not definitive
4) Reservoirs often exist as stacked compartments of genetic sequences.

The utility of the seismic attributes derived from the amplitude data are limited and typically very dependant on the particular interval analyzed. In this project we integrate the well log data in with the seismic for a better defined reservoir model. This integration is accomplished by inverting the seismic amplitude data to acoustic impedance (AI) properties and depth converting the seismic so correlation with the well logs is possible.

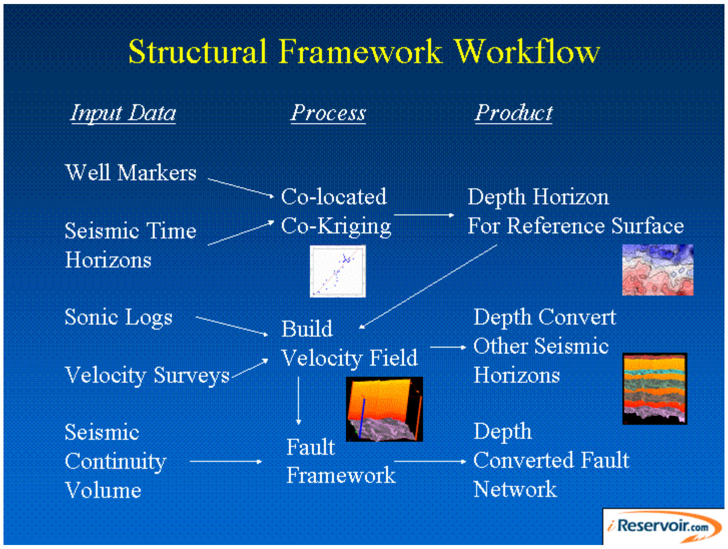
In this presentation I will only highlight the features of Structural Framework and Rock Property modeling in the overall Reservoir Modeling workflows:

> Structural Framework => Stratigraphic Gridding => Litholgy and Facies Mapping => Pressure Field => Rock Properties => Fracture Network and Stress Field => Reservoir Fluids and Dynamic Response.

Motivation for Reservoir Modeling include:
1) Integration of all relevant and available data.
2) Merge data of different scales:
(Cores, Well logs, Seismic and Production).
3) Dynamically update the model as new information becomes available.
4) Measurement of errors and uncertainty as well as expected value.
The specific workflows used are dependant on number and type of data available. In this case there is substantial well control and the seismic data is of high resolution (80Hz).

Structural Framework Workflow

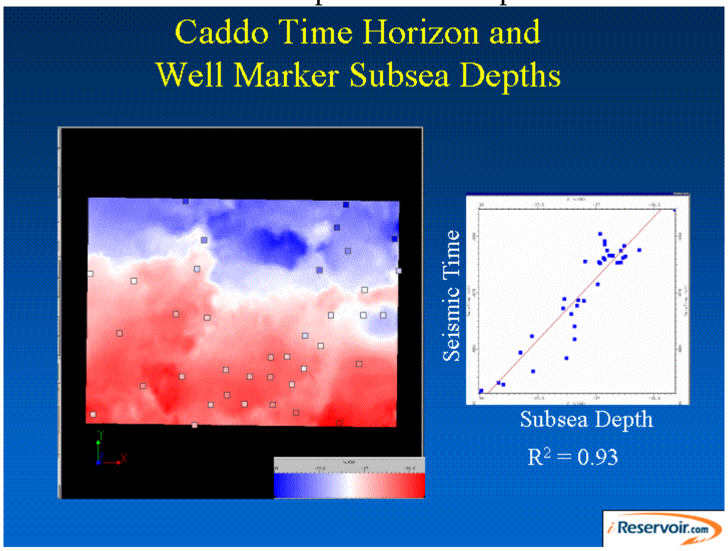
The Structural Framework Workflow is shown below:



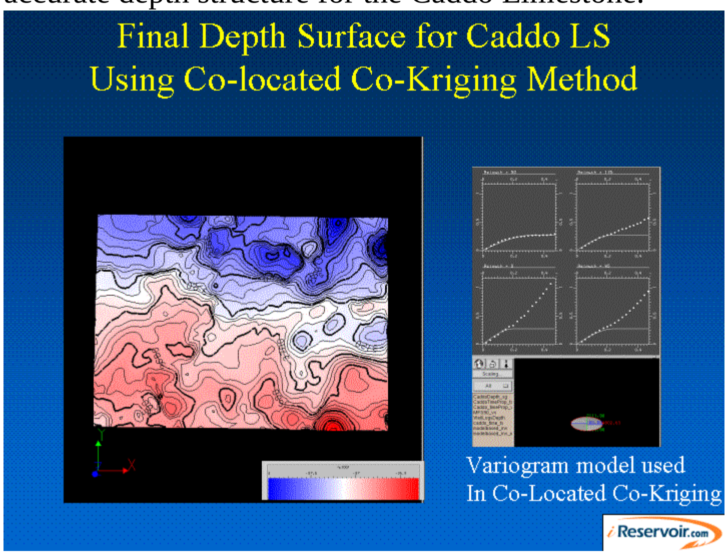
Obtaining the Structural Framework from the seismic gives a much better description than from the well control alone. The karst features were not known until the 3D seismic data was acquired.
Integration of the well marker tops and the seismic time horizons proceeds by 2 pathways:

1) A reference horizon (the Caddo Limestone) was an excellent reflector that also tied the well tops. This is depth converted by a co-located co-Kriging method.
2) Time horizons below this reference did not exactly tie the associated well markers due to tuning effects of the thin bedded Bend Conglomerate Group. For these horizons a velocity field was constructed from interpolating the sonic logs, calibrated to the seismic and checkshot survey. The depth was then created by the time and velocity relationship.
3)The fault network will be incorporated in the future using a seismic continuity analysis.

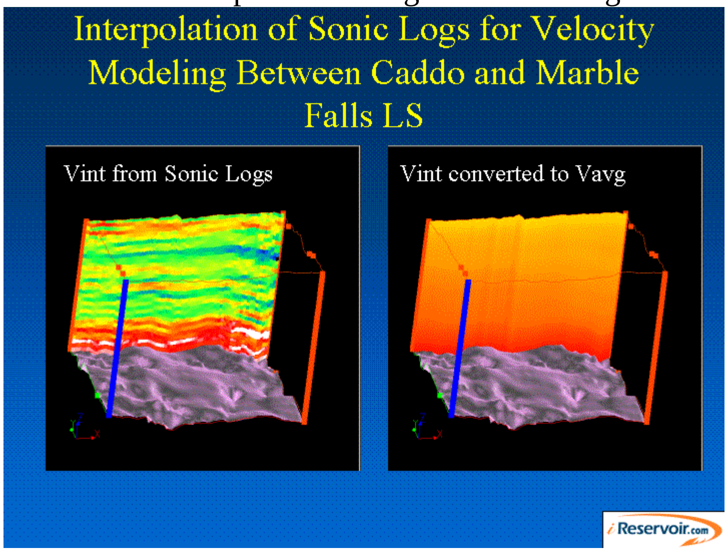
Depth conversion of the reference horizon is accomplished thru the strong correlation between the time and depth relationship at the well locations.



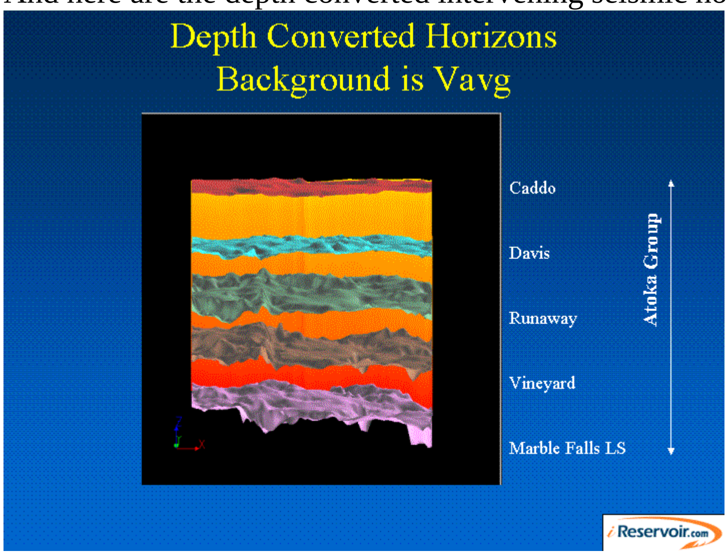
Co-located co-Kriging of the seismic time and well marker depths produces a very accurate depth structure for the Caddo Limestone.



Interpolating the sonic logs in the survey a interval velocity field is produced. Converting these interval velocities to average velocities (inverse Dix's equation) provides the information on depth converting the intervening horizons.

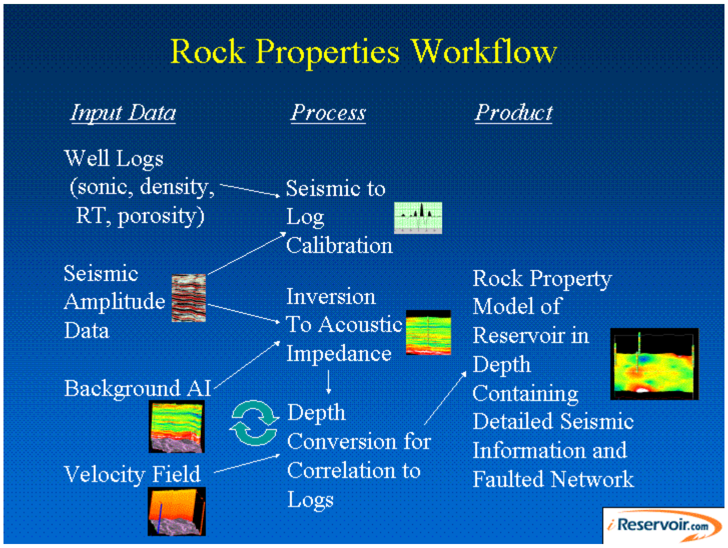


And here are the depth converted intervening seismic horizons.

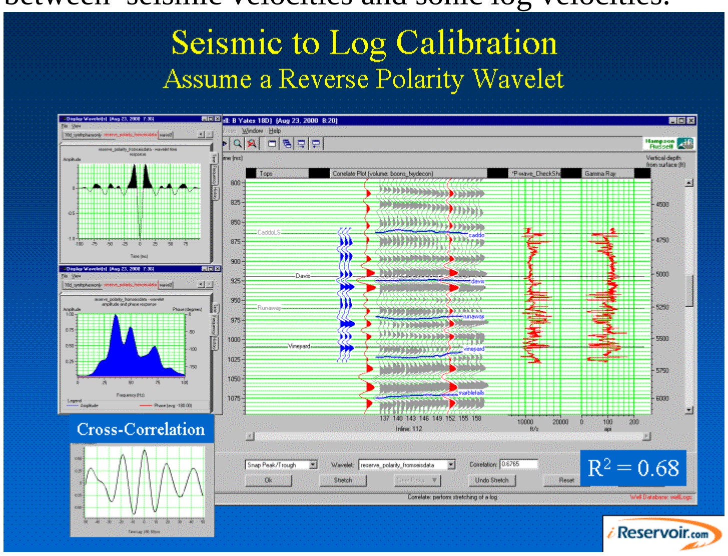


Rock Properties Workflow

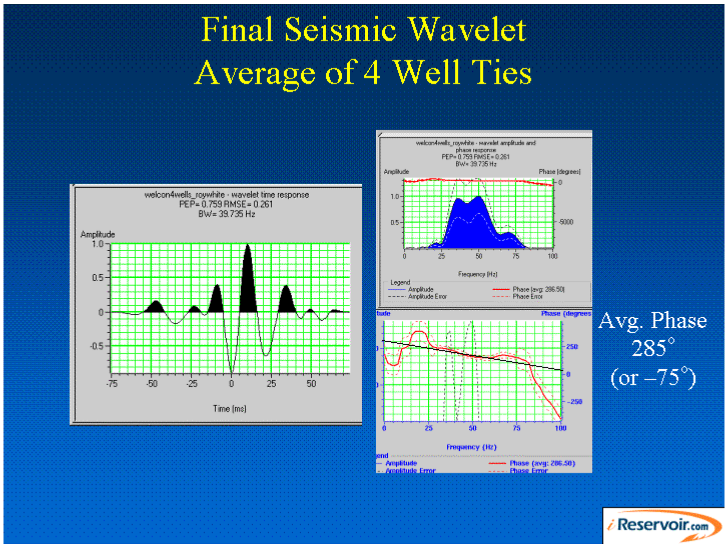
This rock property modeling workflow utilizes the seismic information obtained via inversion to acoustic impedance to better control the well log interpolation of rock properties. This is also accomplished with the accurate structural information that the seismic provides. This workflow is necessarily iterative due to the dependency of one data on another and the iteration between time (on the seismic data) and depth (for the log data) referencing.



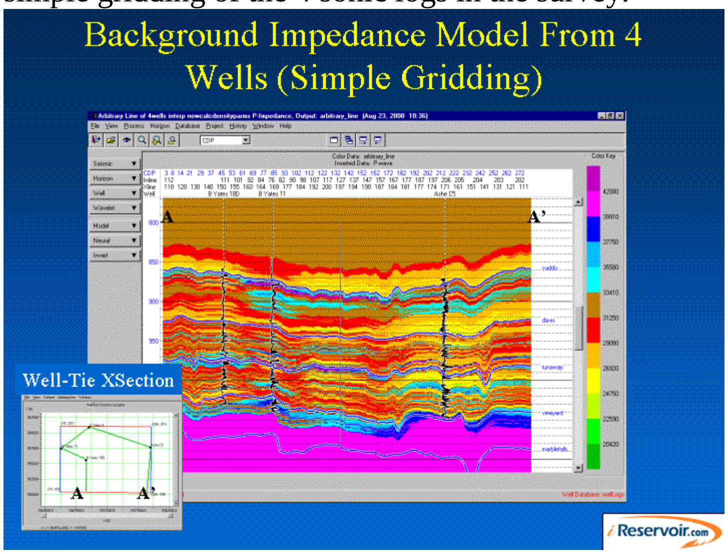
Seismic to Log Calibration is the first step in integrating the seismic amplitude data with the log properties. Starting off one may not know other than by qualitative correlation what the seismic wavelet is. In this case a reserse polarity wavelet is assumed. The synthetic is then tied to the seismic data, performing a constrained stretching and/or squeezing to fit major events. This stretching/squeezing is primarily due to dispersion between seismic velocities and sonic log velocities.



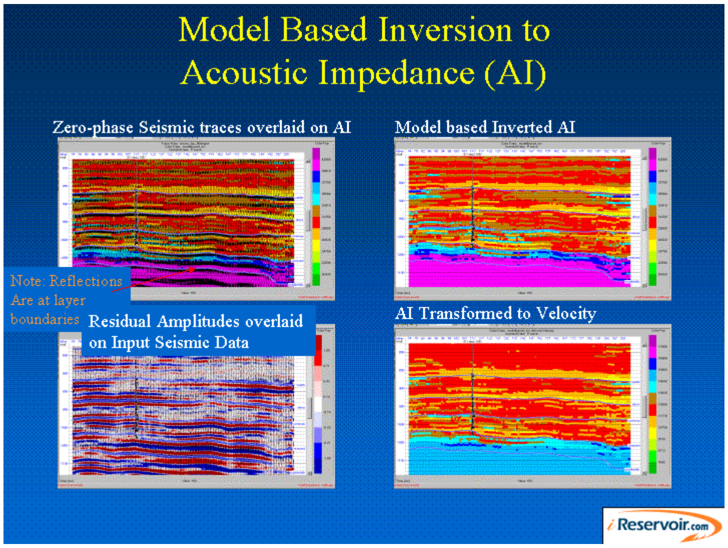
A final seismic wavelet is then extracted. Always use more than a single seismic to log calibration tie. In this case 4 well ties were averaged for a consistent wavelet showing that the seismic wavelet is nearly –90degrees out of phase and slightly ringy. The ringing suggests that the deconvolution was not sufficient to collapse the source wavelet. The seismic bandwidth is very good (20-80Hz).



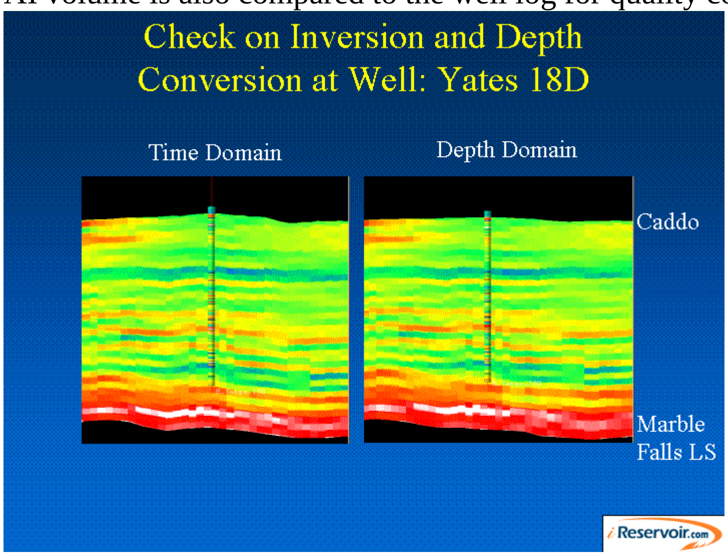
A background acoustic impedance model is needed to supply the low frequency component missing from the seismic trace data in the inversion. This first iteration uses a simple gridding of the 4 sonic logs in the survey.



A model based inversion using Hampson-Russell Software's Strata program shows the transform of the qualitative amplitude data into rock property information. The result is very dependant on the background model used and later we'll see an improved background model for a better result.

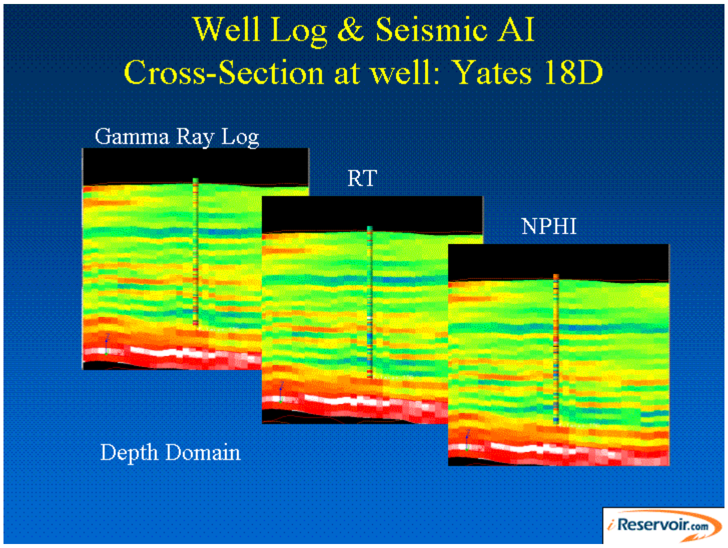


Checking this inversion at our key well: B Yates 18D the seismic inverted acoustic impedance ties well qualitatively with well log acoustic impedance. Depth converting this AI volume is also compared to the well log for quality control.

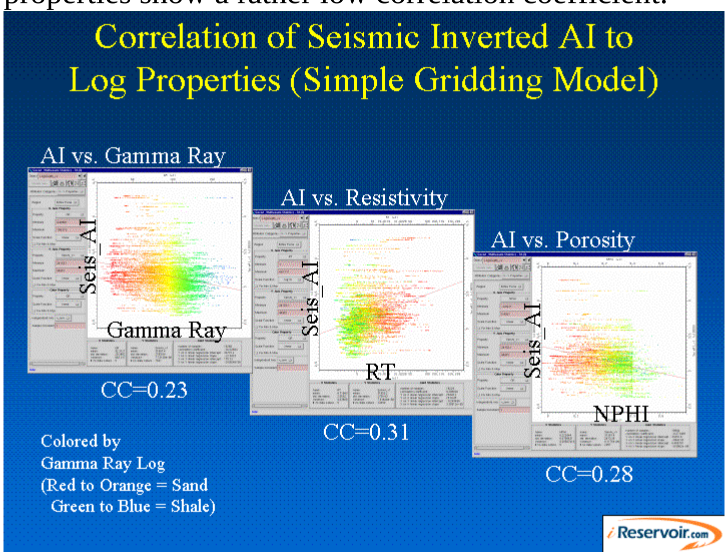


Now that we have seismically derived rock properties from the seismic in depth, let's see how they correlate to the well logs. In general we see that:

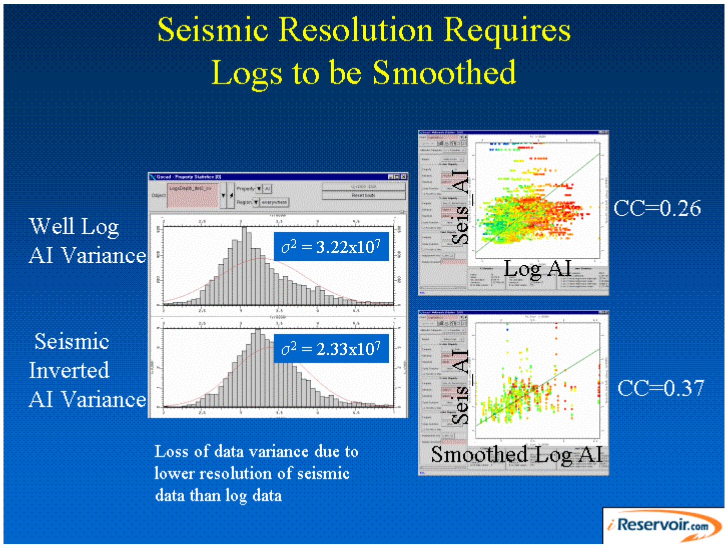
1) Low AI relates to shales from the gamma ray log.
2) High AI relates to resisitve sandstones from the RT log.
3) Correlation of AI to the porosity is more complicated since the shales measure a high porosity with low AI and the more porous sandstones are in an intermediate range of AI, while the tight sandstones are resistive and also high AI.



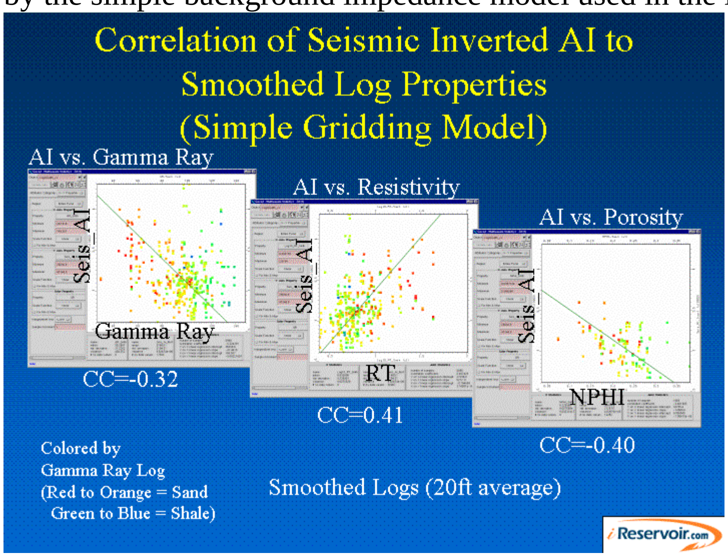
More quantitatively these cross-plots of the seismically derived AI and the well log properties show a rather low correlation coefficient.



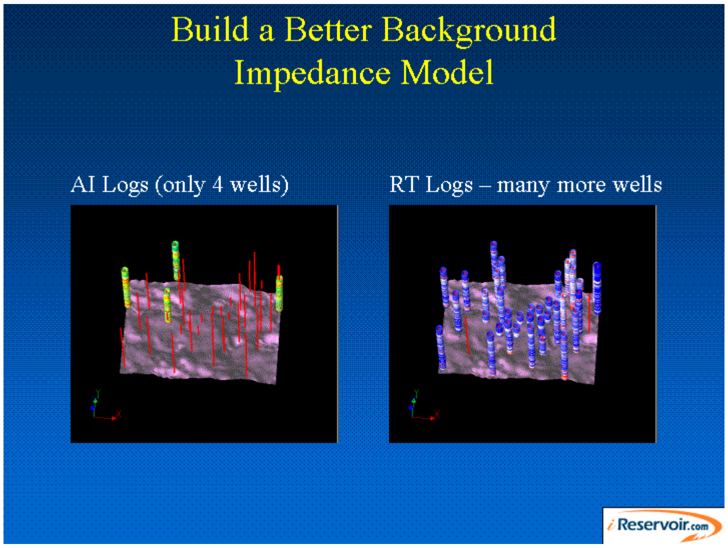
An observation of the relative scales of information is needed. The well logs of course are of higher resolution than the seismic data as shown in the lower variance of AI derived by the seismic data than that represented in the well log data. Smoothing the log curves is required to be able to statistically correlate the respective information. This correlation is also stongly influenced by the exact depth conversion of the seismic information to tie the wells. Due to the thin bedded nature of the Bend Conglomerate Group a mistie of only a few feet will severely effect the correlation.



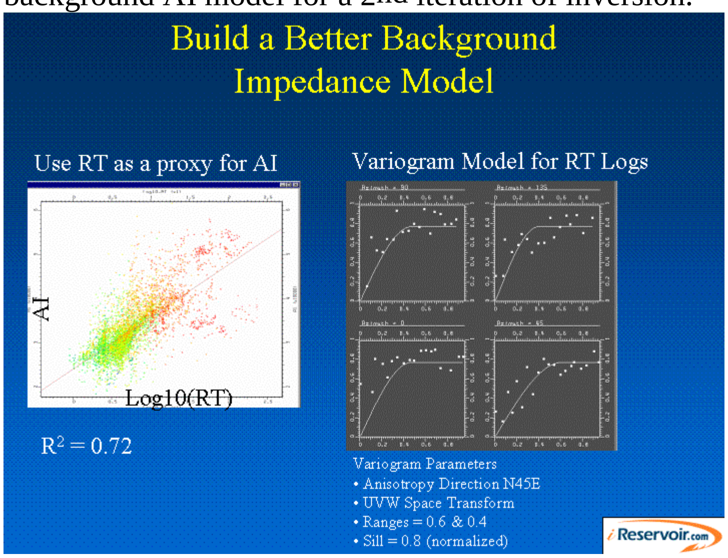
Cross-plotting the seismically derived AI to the smoothed well logs (20 feet averaging) increases the correlation, as now the data are on a more equal sample support resolution. These correlations are still low. These seismically derived AI values are also influenced by the simple background impedance model used in the inversion.



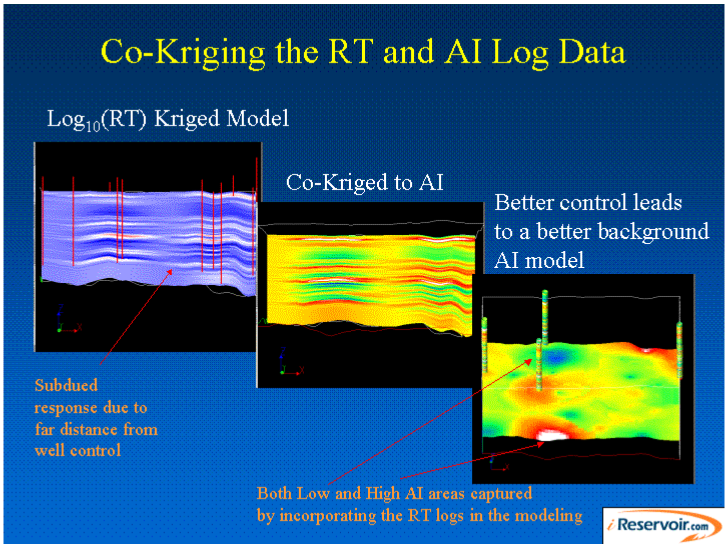
Building a better background model will utilize the many more resistivity logs available in the survey.



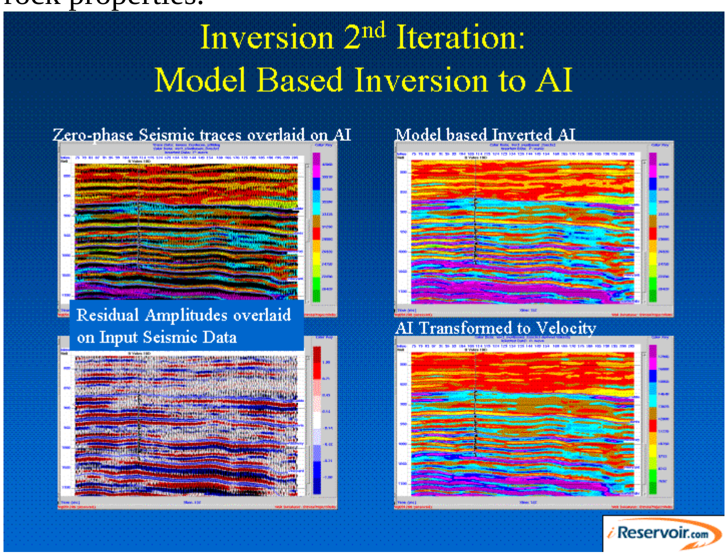
The well log acoustic impedance (AI) is highly correlated to the Log_{10}(RT). The spatial variogram shows a fairly long range to the correlation in order to provide a good background AI model for a 2nd iteration of inversion.



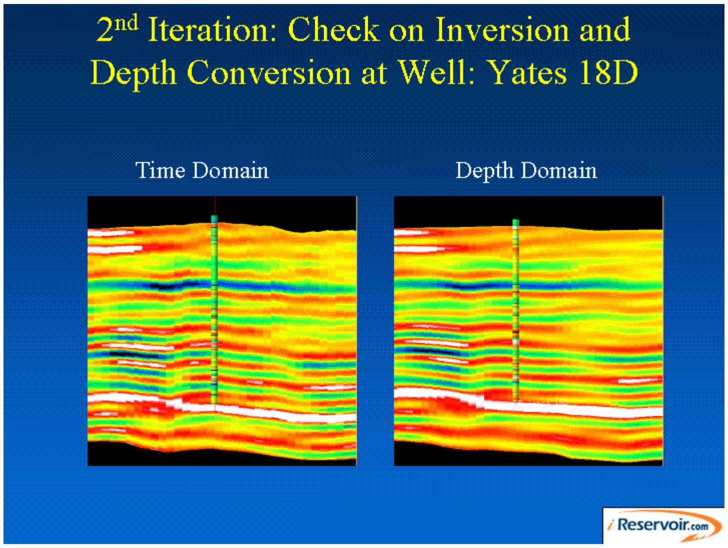
First Kriging the Log_{10}(RT) logs is performed. Next co_Kriging the 4 wells with acoustic impedance information is run. Spatially this new background impedance model is shown to provide spatial features not available with just the 4 wells with sonic logs. Areas near the well control have very high frequency information content. While away from well control the response is subdued towards an average from the Kriging system. Since the seismic is principally used for interpolating the interwell region this background impedance model is low pass filtered to 20Hz. This way the well control is only adding the very long wavelength trends to the inversion result. And the interwell region should be justly controlled by the seismic data.



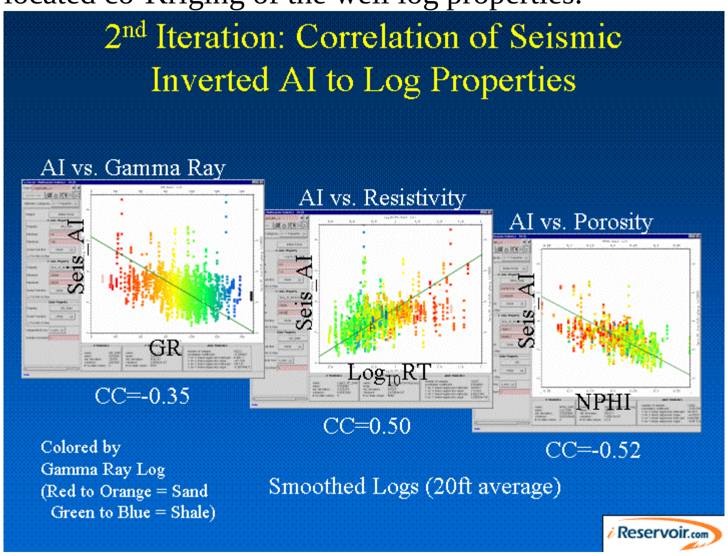
This 2nd iteration of inversion shows the transformation of the seismic amplitudes to rock properties.



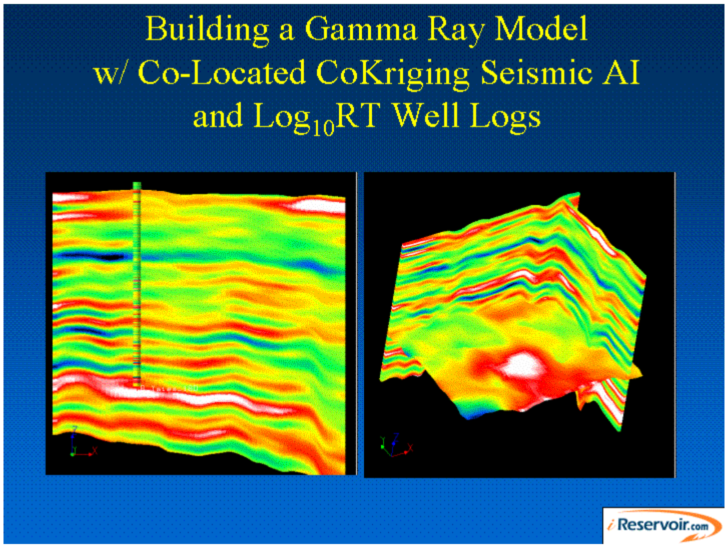
Qualitative correlation to the key well: B Yates 18D yields similar results as before.

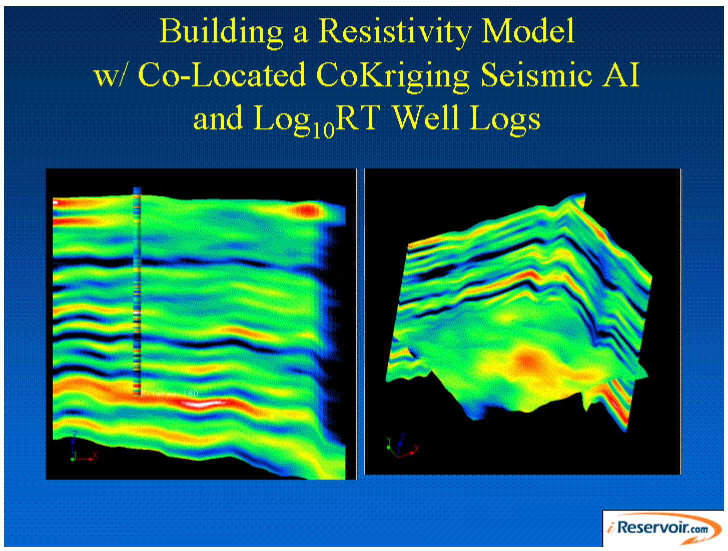


Now cross-plotting the seismically derived acoustic impedance and the log properties in depth shows a better correlation. These correlations are good enough to use in a co-located co-Kriging of the well log properties.

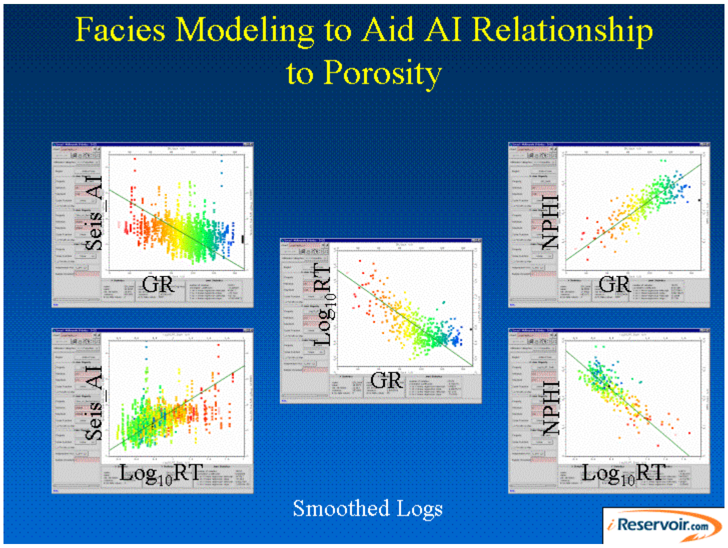


Rock property models are now generated by co-located co-Kriging of the gamma ray logs for lithology discrimination and resistivity logs controlled by the seismically derived AI properties.

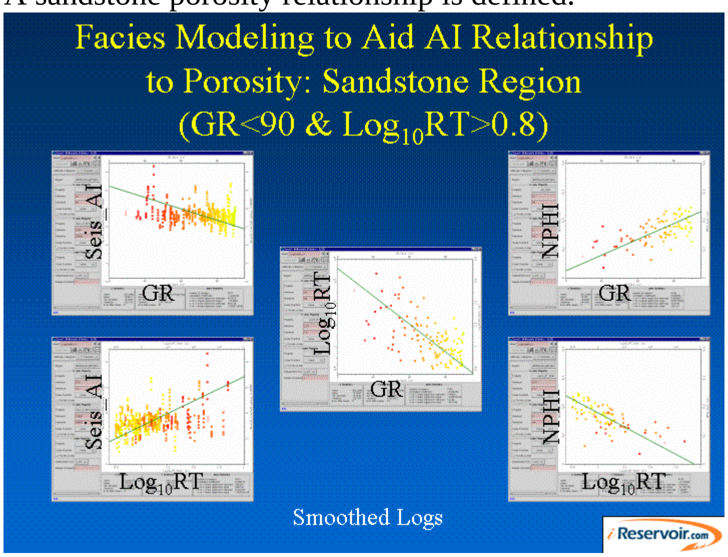




A reservoir model of sandstone porosity can be derived by the relationships of lithology to gamma ray and resistivity. Where these models of gamma ray and resistivity are related back to the seismically derived acoustic impedance.

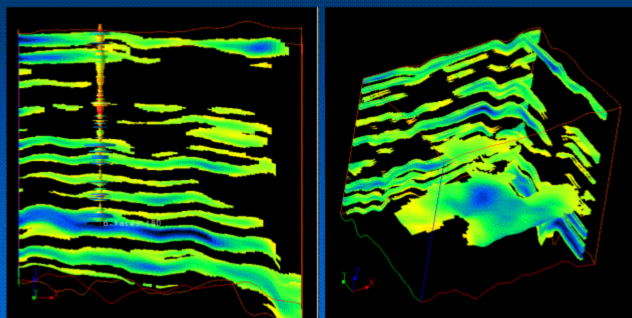


By segmenting the data into a sandstone region defined by where:
Gamma ray is less than 90 and
Log10(Resistivity) is greater than 0.8
A sandstone porosity relationship is defined.



Constructing the density model in the sandstone facies then is represented here.

Building a Porosity Model With Control from the Seismic Inverted AI and CoKriging of RT & Gamma Logs



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