High Resolution Characterization of Reservoir Heterogeneity with Cross-well Seismic Data – A Feasibility Study

Brad Bonnell*
Memorial University of Newfoundland, St. John's, Newfoundland, Canada
bbonnell@mun.ca

and

Chuck Hurich
Memorial University of Newfoundland, St. John's, Newfoundland, Canada

and

Rudi Meyer
Memorial University of Newfoundland, St. John's, Newfoundland, Canada

Abstract

Introduction

Characterizing reservoir heterogeneity is important for the understanding and optimization of production of oil and gas reservoirs. Reservoirs can contain impermeable lithological units and heterogeneous porosity/permeability distributions that are further affected by complex fault systems that significantly affect fluid flow paths and distribution. Reservoir heterogeneity occurs at the metre-scale, where heterogeneities are controlled by bedding, fluid changes, and diageneitc effects. Heterogeneities occur at larger scales also, but at the metre-scale heterogeneities affect fluid flow behavior the greatest (Grammer, et. al, 2004). Traditionally, well log data and surface seismic data are used to characterize reservoir features, but both lack in their resolution capabilities that limit the effectiveness of characterization. Well log data has a sufficiently small vertical sampling interval (cm scale), but samples a very small portion of the entire reservoir near the borehole. Surface seismic data resolution suffers both vertically and spatially. Large areas are surveyed in 2-D or 3-D with a spatial sampling normally around 10 – 30m (depending on acquisition geometry), and vertical sampling typically 30 – 50m at the reservoir interval (Yilmaz, 1999). Between well log data and surface seismic data a resolution gap exists, hindering reservoir characterization methods.

Appropriate temporal and spatial resolution necessary for characterization of reservoir heterogeneities can be achieved through cross-well seismic imagining. Cross-well seismic data avoids near surface effects that drastically attenuate high frequencies, allowing high resolution sampling (~1m) at the reservoir interval (Lazaratos, 1993). Bridging the resolution gap between seismic and well log data provides reservoir engineers the opportunity to more accurately define reservoirs using flow simulations.

This study aims to evaluate the effectiveness of borehole to borehole seismology for providing high resolution reservoir images and extraction of geostatistical information that can be used in reservoir simulation. Two synthetic cross-well seismic datasets are created using velocity models derived from an offshore petroleum reservoir, built to simulate lithologic detail and reservoir heterogeneities at detectable cross-well seismic scales. The geostatistical information extracted from the processed cross-well seismic data adds new information for reservoir characterization.

The Reservoir Models

Two models were derived from sonic log data and several cores from the Whiterose Field on the Grand Banks, offshore Newfoundland and Labrador (Figure 1). The Whiterose Field is the third largest field in the Jeanne d'Arc Basin with expectations to produce 100 000 barrels per day with an expected production life of 10 to 15 years (Husky Energy, 2005). This study incorporates a 250m section of Ben Nevis Formation sandstones that constitute the reservoir.

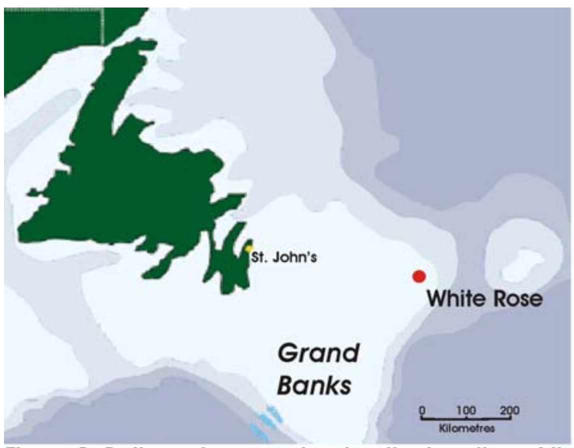

Figure 1: Bathymetry map showing the location of the White Rose Field offshore Newfoundland. (Modified from website www.budget.gov.nl.ca/budget2001/economy/whiterose.htm)

The models address two issues affecting reservoir production. The first issue deals with highly impermeable calcite concretion zones impeding the flow of hydrocarbons (Husky, 2000). The lateral extents of these concretionary intervals are poorly understood due to the sparse sampling of drill cores and they are below the resolution of surface seismic data, but appear laterally discontinuous in drill cores. In the models, their lateral extent was randomly varied throughout the reservoir interval to evaluate the effectiveness of cross-well seismic data to resolve the concretion layers (Figure 2).

The second issue addresses the distribution of reservoir heterogeneity within the reservoir interval. Again, sparse sampling of wells and the poor resolution of surface seismic data does not provide the necessary information to examine small-scale heterogeneous characteristics of the reservoir. The porosity distribution is assumed to control the heterogeneities within the reservoir formation, controlled, in part, by the bedding of the sedimentary layers, diagenetic processes, and fracturing.

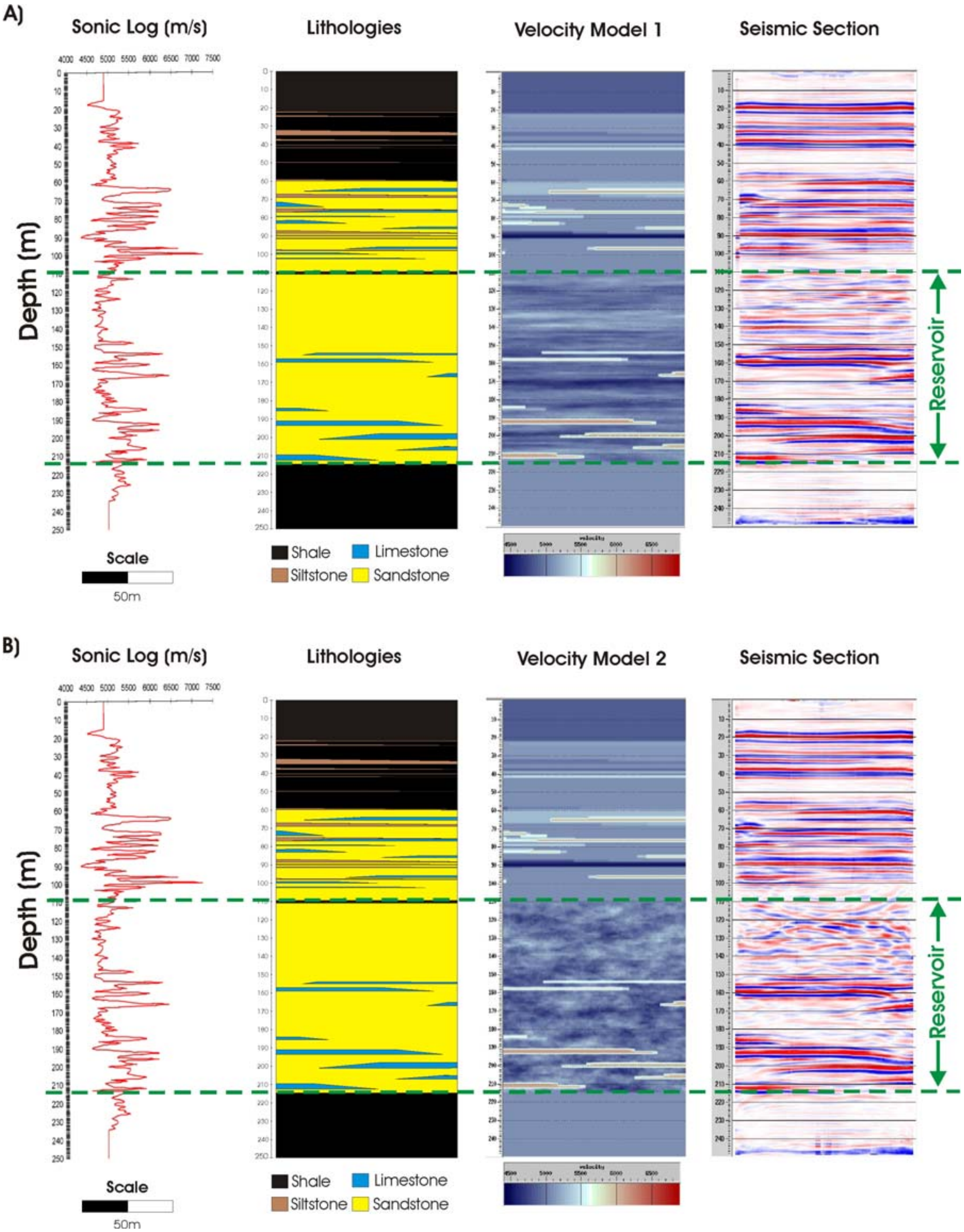

Figure 2. Display of the sonic log and lithologies taken from drill cores used to create velocity models 1 (A) and 2 (B). The seismic sections are the processed result from the cross-well seismic surveys acquired through the velocity models.

Bedding creates thin and lenticular porosity distributions as different sorting and grain sizes define the porosity of each bedding plane. Diagenetic processes and fracturing creates a more globular porosity distribution via fluids percolating through formations, either enhancing porosity by dissolving minerals, or reducing porosity by stimulating growth of minerals. Fractures influence the porosity distribution by providing a path for fluid migration through the formation. A stochastic velocity field was introduced to the reservoir interval, representing two different end-member porosity distributions. Long and low aspect ratio velocity variations were included in the first model to represent bedding controlled porosity, and short and high aspect velocity variations were included in the second model representing porosity controlled by diageneitc effects and fracturing (Figure 2).

Shooting and processing of cross-well data

Synthetic cross-well seismic data are acquired using the reservoir models described above as input to the finite difference modeling algorithm in *ProMAX®*. The recorded wavefield contains a suite of arrivals consisting of direct arrivals, upgoing and downgoing reflections, and multiples. Only the reflected waves are used to produce an image of the subsurface, while the other arrivals are removed. The remaining upgoing and downgoing reflections are separated and transformed to the CDP domain to create CDP gathers. The gathers are transformed again so traces are represented by incident angle for editing and stacking to produce an image of the subsurface (Lazaratos, 1993).

Statistical analysis

Statistical methods are used to analyze the scattered portion of the wavefield. The spatial statistics are determined by fitting the autocorrelation of a sliding window of seismic data to the autocorrelation of the von Karman model (Hurich, 1996). The von Karman model is defined by the correlation length, Hurst number, and variance (Hurich, 2000). Correlation length defines the point at which the scaling of lithological units, with constant physical parameters, is no longer represented by a power law function, and the Hurst number estimates the scaling properties of lithological units.

Statistical analysis performed on the two seismic sections, between depths of 110m to 150m, provided correlation lengths and Hurst numbers similar to the stochastic descriptions used to create both velocity distributions. Correlation between the input and derived stochastic description validates the effectiveness of the technique on cross-well data, which can be used to provide parameters for reservoir characterization.

Conclusions

The deterministic and statistical information gained through cross-well seismic data can improve reservoir characterization. The scale at which lithological layers are resolved is considerably enhanced, and is more suitable for reservoir studies. In this study, cross-well seismic data effectively imaged the lateral and vertical distribution of concretion zones, which could not be achieved through surface seismic techniques. The distribution of concretion zones can be deterministically added to reservoir flow simulations to improve production forecasts. They can also be used during reservoir completion to ensure perforations are strategically placed.

The statistical information extracted from the cross-well seismic data provides new, high frequency constraints for reservoir flow simulations. The addition of correlation length and Hurst number as constraints on the flow model, should more accurately concentrate simulation results on the correct answer. Further improvement during reservoir simulations occur because information gained through cross-well seismic data is closer to the resolution of well logs.

References

Grammer, G. M., Harris, P. M., Eberli, G. P., 2004, Integration of outcrop and modern analogs in reservoir modeling: Overview with examples from the Bahamas, *in* Integration of outcrop and modern analogs in reservoir modeling: AAPG Memoir 80, 1-22.

Harris, J.M., Nolen-Hoeksema, R.C., Langan, R.T., Van Schaack, M., Lazaratos, S.K., Rector, J.W., 1995, High-resolution crosswell imaging of a west Texas carbonate reservoir: Part 1 – Project summary and interpretation: Geophysics, **60**, 667-681.

Husky Energy, 2005, White Rose Project and Facts, http://www.huskyenergy.ca/whiterose/overview/downloads/FS_WR_Project.pdf

Husky Oil Operations Limited. 2000. White Rose Oilfield Project Description. Prepared for Canadian Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL.

Hurich, C.A., 1996, Statistical description of seismic reflection wavefields: a step towards quantitative interpretation of deep seismic reflection profiles: Geophys. J. Int., **125**, 719-728.

Hurich, C.A., Kocurko, A., 2000, Statistical approaches to interpretation of seismic reflection data: Tectonophysics, **329**, 251-267.

Lazaratos, S.K., 1993, Cross-well reflection imaging. Ph.D. Thesis. Stanford University.

Yilmaz, O. (1987). *Seismic Data Processing*. Tulsa, OK: Society of Exploration Geophysicists.