Porosity Prediction and Flow Unit Identification at the Mississippian and Arbuckle Reservoirs Using Seismic AVO Analysis and Pre-Stack Seismic Simultaneous Inversion

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SUBSURFACE APPLICATION: Determination of Mississippian and Arbuckle carbonate reservoir porosity and distribution of flow units. Assessment of pre-stack seismic analysis methods (AVO, simultaneous inversion, multattribute regression) for prediction of carbonate reservoir heterogeneous properties.

STATUS: Focused-term project in progress

TIMING: Significant results to be reported

FUNDING: Partial from United States Department of Energy

Purpose
The Mississippian and Arbuckle reservoirs in the US mid-continent have been major hydrocarbon producers and are targets for enhanced oil recovery operations as well as CO₂ sequestration projects (Franseen et al., 2004; Mazullo et al., 2009; Rogers and Longman, 2001; Watney et al., 2001). Furthermore, resurgent industry interest in the Mississippi Lime play is resulting in increased interest in carbonate reservoirs. Seismic imaging is the primary industry method for exploration and development of hydrocarbon resources. However, carbonate reservoirs are heterogeneous and the distribution of properties controlling the flow of fluids is often below seismic resolution. Identifying characteristic relationships between reservoir properties (i.e. thickness, porosity, density, fracture sets, flow baffles/conduits) and seismic response (amplitude, frequency, phase, offset, azimuth) is critical to assessing hydrocarbon resources.

The objectives of this research are to: a) Assess the capability of pre-stack seismic analysis methods (Amplitude Variation with Offset – AVO, simultaneous inversion of AVO data for P- & S-impedance and density) to quantitatively predict Mississippian and Arbuckle Reservoir properties in South-Central Kansas, and b) Develop seismic data interpretation workflows applicable to the region for carbonate reservoir characterization.

Project Description
The proposed work will expand on completed work of predicting Mississippian Chert reservoir thickness and porosity distribution using 3D P-wave post-stack seismic amplitude and acoustic impedance at the Wellington field in South-Central Kansas. The proposed research will focus on the Mississippian and Arbuckle reservoirs. It will investigate 3D P-wave pre-stack seismic data analysis, Amplitude Variation with Offset (AVO) for elastic impedance inversion and fracture characterization (e.g. Aki and Richards, 1980; Li et al., 2003; Ruger, 1997). Figures 1 and 2 show results of AVO analysis and simultaneous inversion at the Mississippian and Arbuckle reservoirs. This ongoing research is resulting in a comprehensive assessment of seismic attribute analysis for characterization of two important mid-continent carbonate reservoirs which are of primary interest to KICC membership.
Key Findings
- High porosity zones in the Mississippian and the Arbuckle Group exhibit Class IV AVO response
- AVO classification can be employed to identify the porous zones at Wellington Field 3D volume using the intercept-gradient cross plotting technique
- Simultaneous AVO impedance inversion results in improved estimation of Mississippian reservoir and the Arbuckle Group properties than model-based inversion of post-stack data
- Flow units in the Arbuckle can be mapped using AVO analysis and Simultaneous AVO impedance inversion

Deliverables
i) Comprehensive assessment of pre-stack seismic attribute analysis for Mississippian and Arbuckle reservoir characterization
ii) Evaluation of AVO pre-stack seismic gather analysis methods for mid-continent carbonate reservoir property prediction
iii) Acoustic and elastic impedance inversion volumes and predicted reservoir porosity and density maps
iv) Evaluation of seismic methods for identification of flow units in carbonate reservoirs
v) Seismic determination of dominant fracture orientation and fracture density
vi) Post- and pre-stack seismic analysis workflows for Mississippian and Arbuckle reservoirs

References
**Figure 1.** (upper) Class IV AVO highlighted zones (red color) on seismic data displayed along with porosity logs at the Mississippian reservoir. AVO analysis identifies the Mississippian reservoir which has thickness below seismic resolution. (lower) Seismic prediction of reservoir porosity shown along with porosity logs.

**Figure 2.** (left) Simultaneous AVO inverted P-wave impedance ($Z_p$) cross section. Five low impedance zones are identified by the dashed lines. (right) Measured P-impedance logs (Black) from wells #15-121-22590 and #15-121-22591, and the inverted P-impedance traces (Red) at the two well locations. Five distinct low impedance zones are shaded in grey and coincide with flow units identified in well data.