Quantitative lithology prediction of turbidite deposits, Bone Spring Formation, Delaware Basin, Southeast New Mexico and West Texas

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ABSTRACT

The Bone Spring Formation of the Delaware Basin in southeast New Mexico and west Texas consists of approximately 1,500 m (4,921 ft) alternating carbonate nd siliciclastic gravity-flow sediments deposited on carbonate slope and basin floor settings. Recent studies provide some insight into the Bone Spring sedimentary characteristics; however, the reservoir-scale structure and lithological and petrophysical heterogeneity remains illusive. This study characterizes Bone Spring turbidite systems by integrating well logs, seismic attributes, and core to predict lithologies within high-frequency stratigraphic sequences. The study included 300 km^2 (116 mi^2) of 3-D seismic data with well logs from 60 wells, and core from one well.

Petrophysical and mineralogical properties from wells were combined with 3-D seismic to quantitative predict lithology. First, the seismic-defined sequence-stratigraphic units of the Bone Spring Formation were identified based on reflection terminations and seismic facies characteristics. Corresponding well-log motifs of sequence stratigraphic units were identified and tied to the seismic to construct a high-frequency sequence stratigraphic framework. Second, multiple 3-D seismic geometric attributes and spectral decomposition, including curvature, coherence, continuous wavelet transform, were used to delineate seismic geomorphologic features of the turbidite system. Third, to determine lithology, 40 wells with the photoelectric-effect logs (Pe logs) were used to conduct the crossplot method of apparent matrix density versus apparent matrix volumetric cross-section (ρmaa–Umaa analysis). The ρmaa–Umaa crossplot method is calculated from Pe, bulk-density, and neutron logsand is used to estimate the lithology. Fourth, based on the lithology logs, the logistic regression supervised machine learning algorithm was employed to build a training model of gamma-ray, sonic, and density logs, and the lithology prediction was executed on 20 wells without Pe logs. Fifth, Bayesian inversion of the 3-D seismic data was used to predict the spatial distribution of lithology. The result is expressed as the probability of being in a lithologic class given a value of seismic impedance. The full probability of four types of lithology was achieved by their conditional probabilities and priori probability. The priori probability of four lithologies was based on the lithology estimates from the 60 wells, and the conditional probability was calculated as the probability that a certain seismic value (P-impedance, S-impedance, Vp/Vs, Lambda-Rho, Mu-Rho) corresponds to each type of lithology.

Seven major sequence-stratigraphic units of the Bone Spring Formation were deposited on the slope to the basin floor during the Leonardian stage of the Permian period.These units in stratigraphic order from the base to top include 3rd BSSS (represents Bone Spring siltstone), 3rd BSLM (represents Bone Spring limestone), 2nd BSSS, 2nd BSLM, 1st BSSS, 1st BSLM, and the Avalone Shale is within the 1st BSLM. The siliciclastic-rich members are characterized by intermittent strong reflections extending into the basin. The 2nd BSSS member with an average thickness of ~120 m (~394 ft) exhibits a multi-storey vertical stacking pattern. The turbidite system exhibits two siltstone-rich intervals above and below, each with an average thickness of 30 m (98 ft) and 50 m (164 ft), respectively. The seismic geometric attributes and spectral decomposition volumes exhibit several deepwater channel complexes that are >1 km (>3280 ft) wide, are oriented NW-SE, and developed on the low-gradient slope. They transition to fan-lobe-shaped seismic geomorphologic units on the basin. They overlap each other and are >3 km (>1.9 mi) wide. The ρmaa–Umaa analysis of the 2nd BSSS member suggests that these turbidite deposits consist of four lithologies: siltstone, limestone, dolostone, and mudstone. The accuracy of lithology prediction using the logistic regression algorithm reached >70%. The siltstone-rich layers have an average porosity of 8%, while the presence of dolomite and limestone greatly reduces porosity to as low as 1%. The Bayesian inversion reveals lateral lithology variability over short distances and provides probability distribution maps to indicate the distribution of the lithologies.

The complex lithology of the Bone Spring Formation that developed during the periods of regression formed due to allocyclic-autocyclic sedimentation processes. This study illustrates the complex lithologies of the thin-bedded turbidite deposits which can be useful for reservoir development strategies.

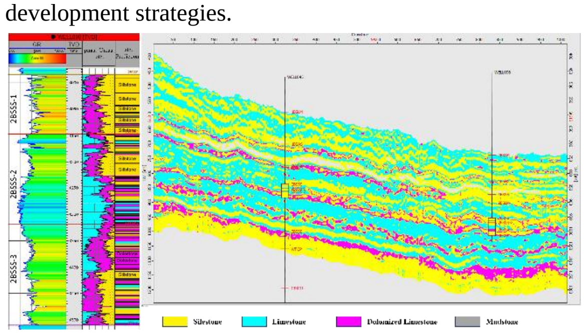

Figure 1 : Lithology prediction of the 2nd Bone Spring siltstone interval based on RHOmaa - Umaa analysis and logistic regression.