CHAPTER 6

Discussions and Conclusions

Geostatistical seismic inversion was carried out to detect thin sand layers in Arthit Field, offshore Thailand. The applied methodology was a joint geostatistical inversion, using well logs and multiple pre-stack time migrated (PSTM) angle stacks as inputs. The geostatistical inversion process generated multi-realizations of lithofacies and elastic property volumes based on Bayesian Inference and Markov-Chain Monte Carlo methods. The results showed that the applied methodology worked efficiently to improve delineating sands and their range of uncertainty below seismic resolution.

The initial stages of the study consisted of data preparation prior to the inversion process, comprising well log data conditioning, shear wave velocity (Vs) prediction and rock physics analysis. In general, the quality of the well log data was affected by bad borehole conditions. The conditioning included bad data and spike removal, interpolation of missing data and depth shift correction. The application of these operations improved the data quality and the consistency of the measured log data. To optimize the geostatistical model for simulation and inversion process, shear wave velocity data was required for all input wells. Since two of the four input wells (Well-A and Well-D) were missing such measured log data, shear velocity prediction was carried out based on a multi-linear regression (MLR) methodology, using the measured shear sonic logs in Well-B and Well-C as inputs.

Elastic properties (AI, Vp/Vs and density) were cross plotted using well log data from all four input wells (Well-A, Well-B, Well-C and Well-D). The crossplot analysis showed that sand could be distinguished from shale, while discrimination of gas and brine sands would be very challenging due to the significant overlap of the elastic properties for these facies types. The cross plots also suggested that well log data classified as coal were widely scattered for all properties. However, and as expected according to common knowledge, most of these data points showed low AI and low density related to coal layer. Based on this elastic properties analysis, three lithology types consisting of shale, sand and coal were considered for geostatistical modeling and inversion.

Seismic to well ties were carried out for all input wells starting with an initial time-depth relationship derived from checkshot data. The ties were further optimized through careful application of time shifts and followed by careful use of stretch-squeeze which was QC'ed using cross-correlation between synthetic and seismic traces. At each well location, wavelets were extracted for each angle stacks within a window defined by an interval between the horizons H20 to H50. The wavelet length was 120 ms, also considering the general frequency range of the seismic dataset. For each angle stack, the extracted wavelets from Well-A, Well-B and Well-D provided good quality wavelets that were used to estimate multi-well wavelets, and also used as the input for geostatistical inversion. Consequently, the final time-depth relationships were simultaneously calibrated for all angle stacks and at each well considering the final angle-dependent multi-well wavelets. The best correlation was achieved at Well-B, mainly due to the good seismic data quality in this area. The final well correlations for Well-A, Well-D and Well-C were considered to be moderate to poor, respectively. The variable seismic data quality observed in the target zone was mainly explained by imaging issues unresolved by PSTM, such as fault shadows and near surface amplitude anomalies.

Geostatistical model fitting was carried out within two reservoir layers in the solid model. The solid model was constructed with a vertical resolution of 0.5 ms in order to model thinly bedded layers, such as sand and coal layers. Based on data from the four input wells, the prior PDFs and variogram settings of each lithology type and their respective elastic properties were determined. In general, the reliability of PDF and variogram fitting of each lithology type was affected by the number of available data samples. The rich amount of data samples for shale (89%) contributed to reasonable PDF and variogram for this lithology type. On the other hand, the PDF and variogram fitting for sand and coal were more uncertain due to the significantly smaller amount of data samples (10% and 1% respectively) for these lithology types. To optimize the geostatistical parameters, three simulation models with different variogram ranges were tested. Simulation model 2 was designed with medium variogram range (400m, 4 ms), and provided the best results in term of posterior proportion, posterior PDFs of elastic properties and reasonable shape and distribution of each lithology type.

Based on the results of the inversion parameters testing, the most sensitive parameters were vertical/lateral variogram range, prior proportion, prior PDFs and S/N ratio. Facies thickness was associated with the vertical variogram range, while facies distribution was related to the lateral variogram range. Increasing values of the vertical and lateral variogram ranges resulted in thicker and wider sand bodies in the lithofacies section and caused the posterior sand proportion to be overestimated. However, such overestimates of posterior proportions could be reduced by decreasing the prior proportion. Due to the variable seismic data quality for each angle stack, the parameters for seismic S/N ratio were set individually for each angle stack. Decreasing the S/N ratios for near and far angle stacks caused reduced posterior proportions of sand and coal.

Consequently, ten realizations of geostatistical inversion were produced based on the parameter set from Test 18. Analysis of the resulting realizations showed similar distributions of thick sand reservoirs, which were directly obtained by the vertical resolution of the seismic data. The distribution of thinner sand bodies and coal layers below seismic resolution were variant for each realization, and mostly driven by input geostatistical parameters. In general, AI and lithofacies sections showed reasonable sand thickness and distribution with high correlation to well data, while the resulting Vp/Vs and density sections showed moderate to poor correlation to well data. Since inverting for Vp/Vs, and especially density, relies on good quality far offset seismic data, this resulting variability of the inverted data quality was mainly explained by lack of sufficient far offset data in the seismic dataset. It should be noted that the 3D seismic survey in this study was acquired in 1998 with a maximum offset of only 3,100 m.

The QC analysis of the inverted results included comparisons with deterministic inversion results, visual inspection of stratigraphic slices (lithofacies and probabilistic volumes) and blind well tests. The comparison of the results achieved by deterministic and geostatistical inversion methods showed that the latter method utilized in this study provided results with significantly higher vertical resolution. As such the results helped better definition of thin sand and coal distribution that was conforming with the well log data. The stratigraphic slices of litholofacies and probability volumes also provided improved ability to identify channel features, especially in reservoir layer 1 (H30). The results of the geostatistical inversion method also provided more accurate sand prediction in term of thickness and distribution found at a blind well, and thereby showed good predictive ability of identifying thinner geobodies of economic interest beyond seismic resolution prior to drilling additional development wells in this area.

The geostatistical inversion method jointly honors input wells, input seismic data and input geostatistical parameters. Access to a complete set of log data is also crucial for reliable geostatistical parameterization of the elastic values, so this study benefited from having two of four input wells with complete sets of geophysical logs. On the other hand, it is also reasonable to conclude that the results achieved here could have been even better with access to a better, and more modern seismic dataset.

Most of the reservoir structures in this area are defined by combined structural and stratigraphic traps, and most wells have been drilled close to fault planes. The structural style of these reservoirs in combination with a limited hydrocarbon column height explains the reasoning behind such well placements. In general, the seismic data quality is poor near such faults and interpreted fault planes were not available as part of the input data. It is very likely that having access to interpreted fault planes, and by using these when constructing the solid model could have improved the quality of the inversion results further.