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Geostatistical Prestack Inversion For Sand Thickness Prediction And Porosity Estimation In Sabriyah Field, North Kuwait

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Introduction

The Ratawi formation is an unconventional clastic play in Kuwait that has been extensively studied. In the Sabriyah field only a few wells have produced oil from the sands within the Ratawi Shale. These sands are discrete but have a good porosity. Additional efforts to understand the nature of deposition, entrapment, play, etc., are required for further exploration and development. Inversion technology was used to enable us to integrate various data types to achieve a reasonable geological interpretation. The estimation of reservoir properties in the Ratawi Shale formation, based on geostatistical partial stack inversion, produced reliable results that can be used for successful exploration well planning and future field development drilling.

Geology

The Sabriyah field is located in the onshore area north Kuwait (Figure 1). The Ratawi formation is divided into two members: Ratawi Shale and Ratawi Limestone (Fig 2). In this study, we focus on the Ratawi Shale member where the upper part develops potential sandstone reservoirs.

According to the facies trends (Jackson, 2004) the distribution of the sandstones in the Ratawi Shale member is a result of a local and regional structural influence. The percentage of sand decreases from the west to the east reflecting its western provenance. The deposition of sand appears to be area-restricted by the Kuwait Arch acting as a depositional barrier/subsea topographic feature. The southern part of the Sabriyah Field has more sandstone than the northern part (Figure 3). The geostatistical inversion results demonstrate similar facies trends

Figure 1 Study area

The uppermost seal lithofacies (Ratawi Shale member and shales of the overlying Zubair Formation) were deposited as shallow marine and deltaic shales during the regressive part of a second order cycle. The shallow-water depositional environment of the carbonate platform was terminated by the deposition of the overlying Ratawi Shale Member and the Zubair Formation. The carbonate platform of the

Berriasian and Valanginian was characterized by 3rd order and higher catch-up and give-up phases. The periodic give-up phases in platform development lead to deposition of low energy argillaceous carbonate muds that formed seal rocks, (Stephen Crittenden, 2012).

The Ratawi Shale Member is interpreted to represent highstand progradation of deltaic clastics (shales, siltstones and fine grain sandstones) and transgressive sand bodies with a source hinterland located to the west and subtidal marine shales.

This unit is thought to herald the onset of deposition of the widespread “deltaics” of the overlying Zubair Formation. The nature and age of the contact with the overlying Zubair Formation, the Late Valanginian unconformity, is ambiguous and does require further work to resolve. The log data is difficult to interpret for placement of the formational boundary and in many instances is a gradational contact. The interbeds of sandstone and siltstone increase in thickness and frequency upwards within the Ratawi Shale Member and at the same time the incidence of carbonate interbeds decreases upward until the rock can no longer be defined as shale and thus becomes the Zubair Formation.

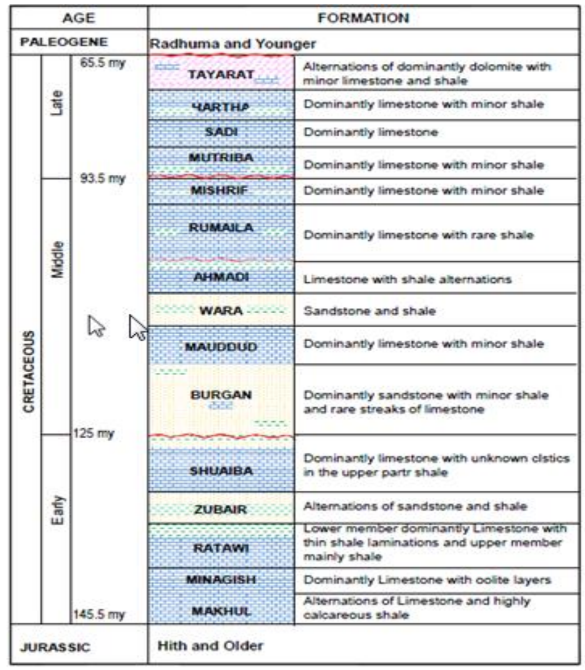

Figure 2 *Stratigraphy of Kuwait - Cretaceous age*

Conditions for geostatistical partial stack inversion

Very complex lithology of the formation is reflected in significant differences in its elastic properties. An attempt was made to differentiate between highly porous sandstones and sandstones with porosity less than 11%. Net thicknesses in the study ranges from 5 ft to 85 ft according to well data. In some wells permeable rocks are absent. The percentage of lithotypes, (ratio in the sample) in Ratawi Shale interval is as follows: porous sand -- 5%, tight sand -- 10%, carbonate -- 13% and shale -- 72%. Figure 4 shows the lithotype distribution in a field of elastic parameters. P-Impedance, Vp/Vs, and density parameterization was chosen. Rock physics modeling was done to ensure the elastic properties were physically reasonable. This led to more reliable wavelet estimation and well-ties.

Forecasting the distribution of porous sand and tight sand can be done with only two elastic parameters, the P-Impedance and Vp/Vs. Therefore we have carried out the deterministic and geostatistical inversions based on partial seismic stacks. General principles of deterministic and geostatistical inversions are described in the article written by Filippova and Kozhenkov (2011). Due to the thin sandstone layers in the target interval (from 0.5 ft. to 22 ft.), and the limitation of seismic resolution, the result of a deterministic seismic inversion can’t be used for quantitative estimates. For example, net sand thickness. The results of deterministic inversion predetermine the necessity to use geostatistical inversion.

For each lithotype, a statistical model was created using the P-Impedance, Vp/Vs, and density data, integrated with the petrophysical interpretation and the rock physics modeling. Geostatistical inversion runs on a stratigraphic grid. It is necessary to have detailed correlations of stratigraphic boundaries in the target intervals and to define the vertical size of a cell. In this case study, the vertical cell size was set to 0.5 ms, as this corresponded to the expected size of the thin features of interest within the reservoir layers. Offset stacks were available in the following angle ranges: 0°-10°, 10°-20°, 20°-30°, 30°-40°, with 4 ms sample rate, and a frequency range of 0–60 Hz.

Results

Detailed inversion results were achieved, using multiple realizations each of which is consistent with the seismic data. The modeled elastic and reservoir properties (lithology and porosity) show a noticeable lithotype thickness trend change from north to south. This trend coincides with facies model (Stephen Crittenden, 2012) (Figure 5). Thirty realizations were conducted for geostatistical partial stack inversion. A predicted sandstone thickness map was obtained as the average of the corresponding thickness maps. A series of QC procedures were performed to check the quality of inversion results, including: 1) analysis of correlation coefficients between the input seismic data and the synthetics obtained during inversion. All partial stacks were involved in this process; 2) analysis of signal-to-noise ratio maps for each partial stack; 3) analysis of residuals, the difference between the seismic and synthetic data, both in the time and the amplitude-frequency domain, 4) comparison of the inverted elastic properties at well locations with the same parameters obtained from the wells logs; 5) comparison of predicted lithology, porosity, etc. at well locations with the results of petrophysical interpretation.

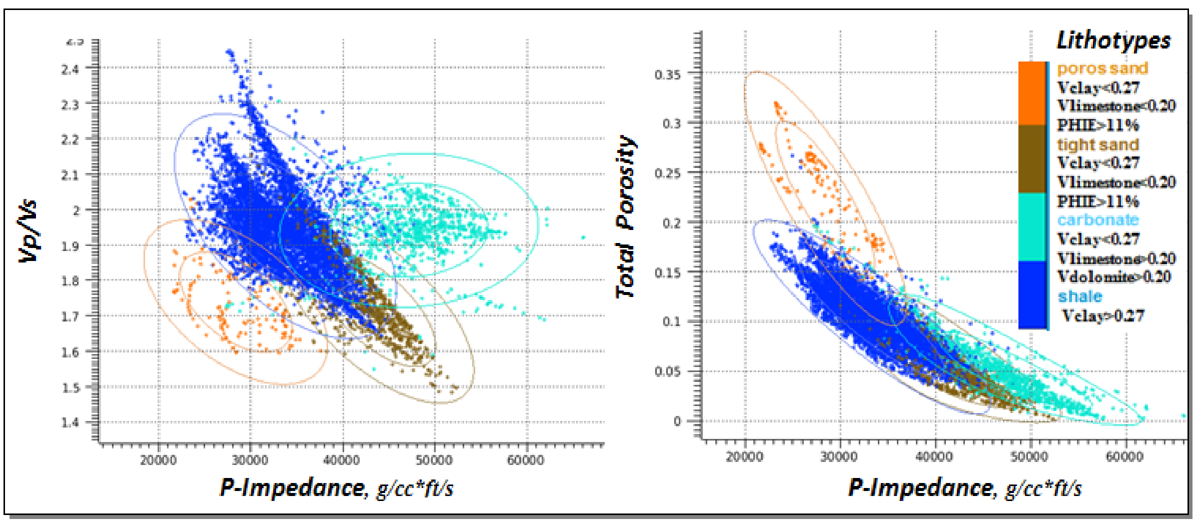

Figure 4 *Cross-plots of well log data in geostatistical scale, showing the separation of lithotypes in the field of elastic parameters.*

Tight and porous sands in the upper part of Ratawi Shale Member can have exploration potential, which is confirmed by tests in several wells. Joint interpretation of sands thickness map of the upper zone with lithology cube, geobody connectivity analyses and structure factor allows the identification of potentially productive zones (Figure 6).

Models of reservoir properties were generated through geostatistical simulation using the inversion outputs as secondary trends (cosimulation). Given the 3D models of elastic property and lithology, the cosimulation process produces highly detailed 3D models of porosity and other petrophysical reservoir properties exploiting the relationships between the different reservoir properties.

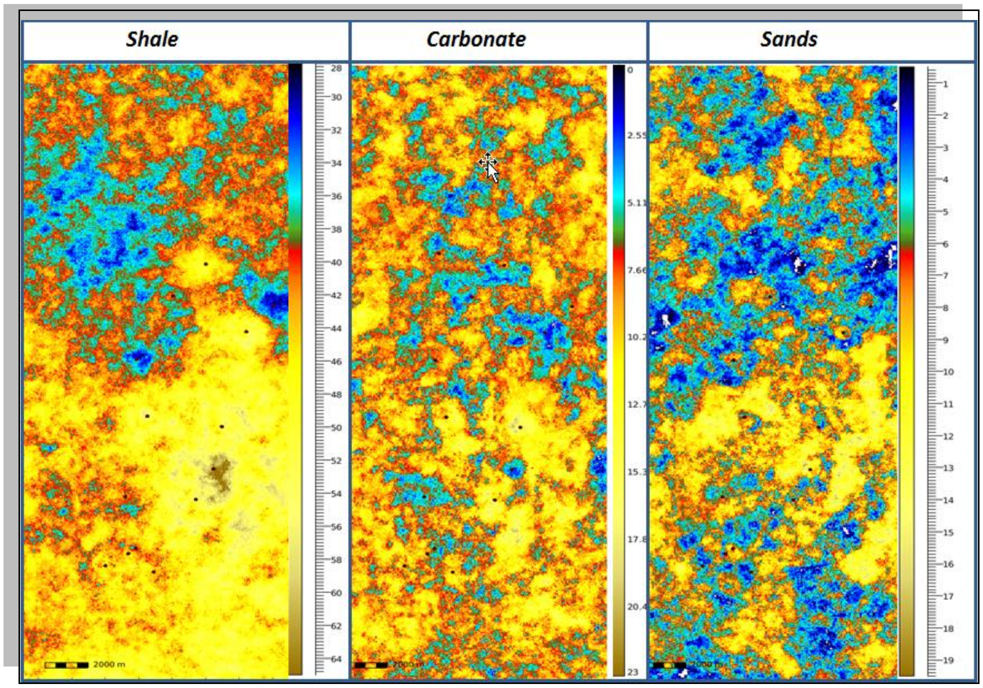

Figure 5 *Lithotype thickness maps (in time, ms)*

Conclusions

The geostatistical inversion of the seismic partial stacks is the most advanced method for clastic reservoir characterization. Two key factors should be considered for this methodology: 1) seismic resolution compared to reservoir thickness and 2) the availability of high quality petrophysical and core data. In our case study a detailed model of a reservoir is needed, the geostatistical inversion of partial stacks enabled us to obtain elastic parameters and lithology/porosity cubes. Thickness maps were calculated based on the inversion results. The distribution and connectivity of sands bodies has been mapped, and the prospective zones identified (Figure 6). The results will help in the planning new wells.

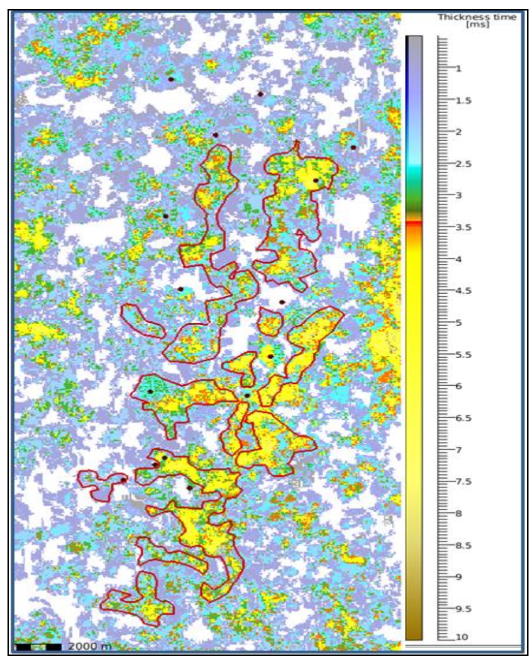

Figure 6: *Sandstone time thickness map with prospective areas*

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