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Velocity modeling in Kuwait's largest oil field

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Summary

The present work briefly describes the procedure adopted for building a velocity model in Greater Burgan, Kuwait's largest and world's second largest clastic on-land oil field. A huge wealth of hard data in the form of checkshot, well tops and large volumes of interpreted horizons were used judiciously to add precision in the model. It has added values to prepare depth maps, especially for planning a large number of horizontal wells.

Keywords: Interval velocity, Checkshot survey, Calibration

Introduction

Rock interval velocity is a very important reservoir attribute needed to convert time horizons into their depth counterparts. There is renewed urgency in quantifying precision in velocity-model building for the on-going drilling of a large number of horizontal, multi-lateral and deviated wells into the main reservoir at about 5000 ft depth, which need accurate depth prediction of bed boundaries. Since, there are also multiple reservoirs at early cretaceous and Jurassic at much higher depth, geophysical inputs from such deeper strata are also used for building a more comprehensive model. In spite of these opportunities, a number of challenges were also faced. Most of the VSP data which are pillars of the model building block, were acquired decades back from depths starting from about 300-400 ft, ignoring several shallower hard anhydrite strata, which constitutes a very complicated near-surface model. This near-surface part could be reconstructed only with large uncertainty. However, for well planning, this never stood as any hindrance. The other prominent challenge was correlation of deeper level time surfaces where, seismic data was rather poor. Verifying formation tops of a large number of older wells was also very challenging. The basin has a huge column of Stratigraphy from late cretaceous to early Jurassic, which offered a nice opportunity of correlation of a large number of surface boundaries. This added precision in the model building, since, their corresponding depth were available in the form of Formation tops. A total of 18 time surfaces were used in the model building. Time-depth data of 43 wells was available to build the model. The input velocity in the model was Prestack Time migrated RMS velocity of the 3D seismic data, at 20 ms and 500 mts interval. This velocity was refined by AOK (Amplitude-Oriented Kinematics) method (Swan, 2001) for every sample. The formation tops of the correlated surfaces were taken from database of the asset.

Theory and Method

Available commercial iterative Velocity modeling software has been used for the model building, designed with optimized 3D cellular size along in-line, trace and time axes. It takes the following data as input, (1) an input RMS velocity cube (seismic velocity), (2) Time-depth data from VSP/Checkshot survey, (3) correlated time surfaces (4) Formation tops. The working principle involved in the model building process has been shown in Fig-1. This can be summarized as follows. Seismic RMS velocity field is calibrated by the average velocity field computed from the T-D data at the well locations. Seismic velocity is low frequency velocity and lacks fineness and precision. After calibration with T-D, the layering of strata is visible when the model is viewed in 3D viewer. This resembles geology a lot. This model is further calibrated at every well location, where formation tops of markers are introduced in the model. A pseudo interval velocity is generated between every pair of surfaces. The input calibrated velocity is corrected by this pseudo velocity and spatially interpolated. The process runs in a layer-stripping manner. The final calibrated model becomes rich in precision at this stage.

Seismic PSTM RMS velocity at 500 mts by 500 mts interval was loaded in the model. Once the velocity was loaded, it was converted to interval velocity by Dix's 3D (Dix, 1955) constrained inversion method and smoothened. Here, it attempts to fit stacking velocity to a smooth bounded instantaneous velocity function in a damped least

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square sense. The seismic interval velocity was thoroughly checked in the 3D viewer slice by slice in X, Y and Z direction for possible anomalies.

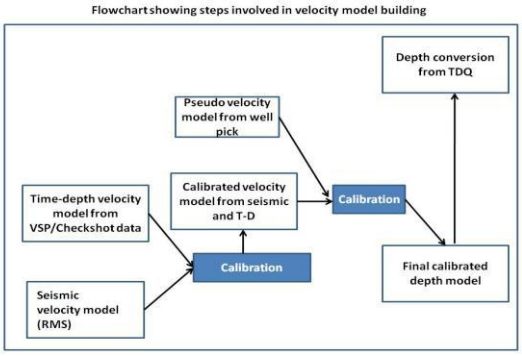

Fig-1: Flowchart showing model building sequence

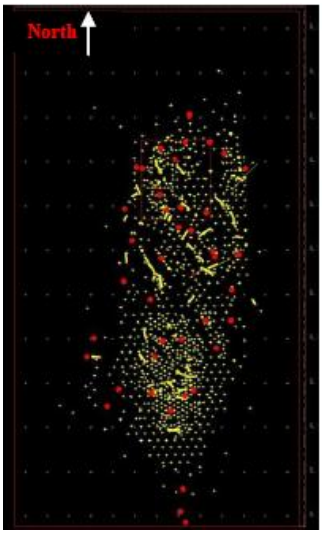

Figure-2 shows cluster of wells considered for the model building. The red dots show wells with VSP/Checkshot and the yellow show other wells, considered for tying their formation tops.

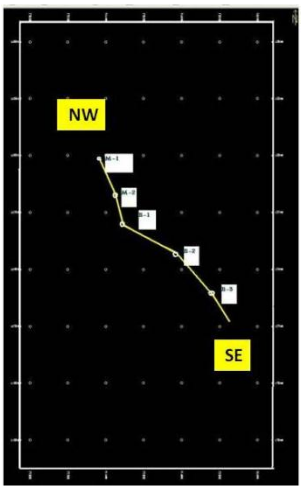

Figure 3: A random 2D line through wells from the 3D volume.

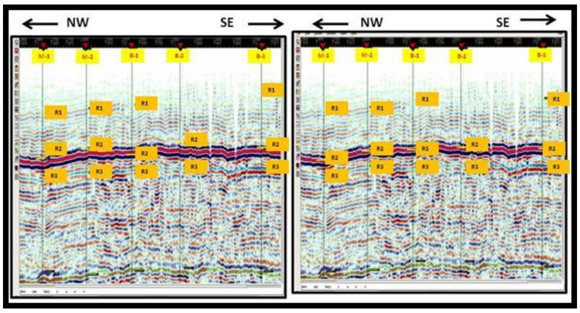

Figure-4a and 4b: seismic line with applied unedited (left) and edited(right) Time-depth function in the shallowest zone.

Formation tops. Due to the absence of shallower data from zero to about 300 ft in most of the wells, the T-D curves were manually adjusted slightly in the shallower region to align the top shallowest marker to its respective cycle. Figure-3 shows a random line passing through a few wells and figure-4a shows misalignment of the strong topmost marker from its respective cycle, when the unedited Checkshot Time-depth pair was activated and posted on the seismic data of the random line. Figure-4b shows alignment after minor tuning of the shallowest part of the time-depth curve, which was devoid of data. This process was continued for all Checkshot wells. The edited Time-depth pair was checked at all formation boundaries by posting it on seismic section at the cross-point to see, if there was complete agreement between the tops and their respective cycles. At this stage, the model based on seismic velocities becomes updated with well T-D functions. QC of the well- calibrated model was continued by viewing in 3D layer- wise as usual

The next job was to load the surfaces. Two way time surfaces starting from the shallowest to the deepest markers were correlated, de-spiked and median filtered and checked for intersection with nearby horizons, if any. Due to the irregular shape of the live data, horizons from 2D lines from the neighbouring area were merged with 3D horizons to get an accurate extended surface for model building. Without this merging, the time surfaces would have been extrapolated till the 3D area boundary without any realistic data. The respective horizon from 2D and 3D data were merged after creating mapping file. Figure-5a, 5b, 5c respectively show the map containing 2D lines common to the 3D area, a horizon map with 3D seismic alone and one with merging of horizons from 2D and 3D data.

18 formation tops, starting from shallowest to the deepest from 955 wells were loaded into the model. These tops were meticulously checked with logs by Petrophysicists.

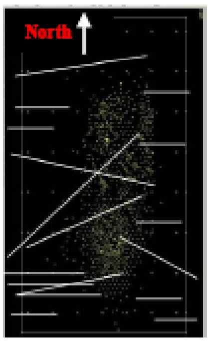

Figure- 5a: 2D lines common in the 3D area.

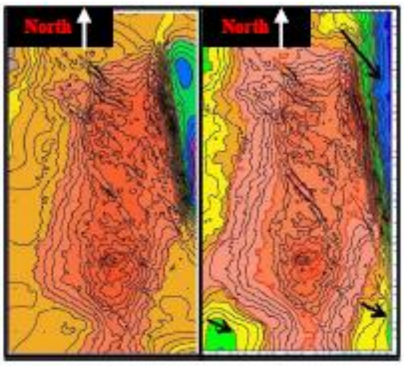

Figure-5b and 5c shows respectively, the time surface and contour without and with merging with 2D data.

Calibrating the model: The seismically derived interval velocity was calibrated in three stages, namely, with well VSP/Checkshot velocity, across time surfaces, and lastly, with the pseudo velocity produced from the known depths of well tops and their timings. The model was decimated before running the final calibration to save time. After each step, the model was checked visually for any gross error by observing slices along X, Y and Z directions in the 3D viewer. The quality was also checked from the calibration score card, which gives the error in depth and also velocity. The errors were controlled by deactivating some formation tops, which did not fit the model. This could be due to some error in picking the formation top depth or proximity of such tops, falling close to major faults. Figure-6a and 6b show the model at the last two calibration stages.

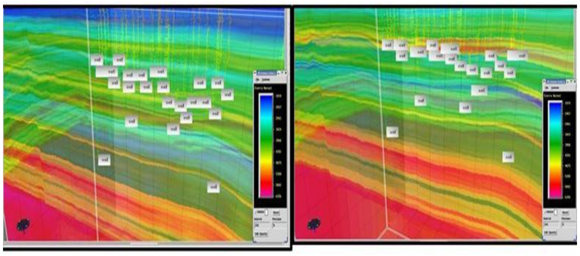

Fig-6a and Fig-6b: Model instantaneous velocity in two stages: without (6a) and with (6b) considering well tops.

Predicted depth of various formation tops at well positions were compared with their true depth. Wells showing errors of more than 15 ft at Burgan level or shallower and more than 40 ft at deeper levels (Jurassic), were excluded from the model. Although, well control was weak at very deeper level, it was very good at the main reservoir level due to large number of wells. Figure-7 shows a plot between predicted vs. actual depth of all the formation tops taken in the model. The quality is judged by cluster of points on the 45 degree line, except a few falling outside. The ultimate test of the model was carried out by comparing the depths of the main seismic marker, of Burgan sand (top) with the predicted depth from the model, drilled in 2009-10, not considered for model building, as in Figure-8. A good match is obtained for most of the wells, except a few, which are either closer to faults or quite away from any VSP well.

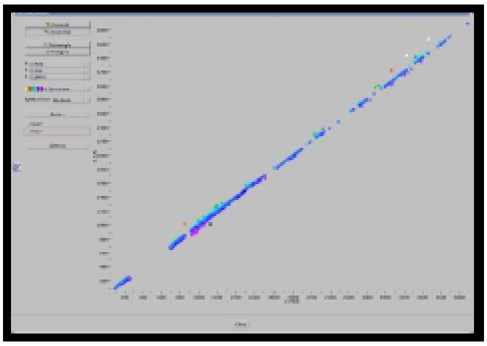

Figure-7 : Predicted (X axis) vs. actual depth (Y axis) of various formation tops at well positions.

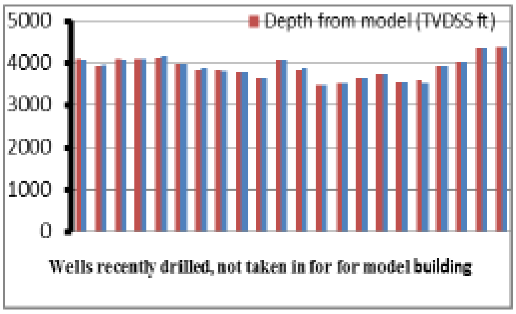

Figure-8 : Blind test of Model-predicted vs. actual depth

Conclusion

Very few wells penetrated till Jurassic rocks. VSP and formation tops of limited number of wells for these depths could be available for model building. As a result, the model has got some limitation of precision at the deeper levels. Another major problem is a few high velocity layers (evaporates) in the shallower part of about 300 ft, for which, no checkshot data is available

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