Effectiveness of Geostatistical Method in Converting Time Map into Depth Map – A Case Study in MHS Area

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Summary

The Mumbai High L-III reservoir is a highly heterogeneous multilayered. Carbonate reservoir lying on the continental shelf of western India in the Arabian sea. The layer thickness varies between 3m to 8m. As a part of ongoing redevelopment plan, multiple horizontal wells with drain holes of the order of 500m are being drilled through these thin productive layers. It is a challenge to keep the well bore throughout in these thin layers. Detailed drilling plans are made in advance along the drain hole. The plan is made on the basis of projected well trajectory in terms of deviation in True Vertical Depth (TVD) along the drain hole. Logging While Drilling (LWD) technology is used to keep the well inside sweet zone.

Depth profile is very crucial to optimal completion of the well as drilling starts off in the direction as envisaged in the drilling plan which takes into various drilling constraints like Dog Leg severity etc. As the drilling progresses the real time LWD data, being monitored at Virtual Reality Centre in Mumbai city helps to keep the well inside sweet zone. Monitoring team intervenes as and when poor facies are encountered on the well log. The intervention is in terms of either losing or gaining the TVD for further drilling. The guidance comes from the depth map supplied to them. This depth map has been prepared for entire Mumbai High South (MHS) area which is roughly 900 sq. km. By integrating seismic time pick, well depth pick of corresponding horizon, and well driven and seismic driven velocities, it has been found that sometimes following the well trajectory based on this depth map takes the well into the over and underlying shale layers and mid course correction is applied to keep the well in the sweet zone. This deviation of the drain hole reduces its effective length and causes other drilling and well completion problems.

On closer scrutiny of such cases it was found that the deviation from actual was prominent where the model suggested deviation in terms of TVD by more than 8m. When the trajectory was superimposed on seismic time section the time map was not supporting this. This gave rise to the doubt of having wrong velocity gone into converting time map to depth map. Keeping this in mind an alternative approach using Geostatistics was applied to prepare depth map on Localized basis so as to give proper weight age to the correlation coefficients valid for that area. A small area of the order of 25 sq. km. was taken around the well bore to be drilled. The depth picks from the existing wells falling that area and corresponding time horizon was input for geostatistical analysis. Since depth conversion is a non-stationary problem, kriging with external drift was used. Based on this the depth map the well trajectory was prepared and then tested against the actual TVD profile of the well path being drilled. It was found that it was closer to it compared to the one prepared on the basis of well and seismic velocities confirming its effectiveness. It helped RTO team in taking proper decision and thereby saving valuable Rig time. The well completion also was more near to optimum.

Introduction

Mumbai High, the largest oil field in India is situated on the continental shelf of western India in the Arabian sea. There are a number of pay zones, of which L-III is most promising. The L-III layer has been considered as multi layered heterogeneous reservoir for field development. These reservoir units have been designated from the top as A, B, C,...,I layers. These layers are separated by intervening shales or impermeable carbonates. The layer A has been further subdivided as AI and A2, A2 layer containing seven sub-layers named as A2-I, A2-II, A2-III,A2-IV, A2-V, A2-VI, and A2-VII. All these layers/sub-layers exhibit differential depletion and are separated locally by intervening shale/non-reservoir steaks. Entire MH is divided into two parts namely Mumbai High North (MHN) and Mumbai High South (MHS) based on the permeability barrier running approximately West-East to the field. Development of L-III reservoir in MHS field started in 1980. The field peaked its production till 1991 and since then the field is on decline phase. To arrest this decline, redevelopment program was formulated by adopting remedial measures like zone transfer, in-fill drilling and redistribution of injected water to maintain the reservoir health and put into action. The focus is now on layer wise reservoir management and in-fill drilling is being done on large scale into various promising sub-layers by drilling high tech horizontal drain hole having length of the order of 500m on average. The large length is kept so as to expose larger area of reservoir and thereby more production. This has given favorable results and the decline has been arrested.
Drilling of horizontal well is a challenge in itself because the carbonate reservoir sub-layers are thin, having thickness ranging between 3m to 8m with interbedded shales of 2m to 3m thickness and it is a tough task to keep the drain-hole within sweet zone having good reservoir facies having good hydrocarbon saturation. Any deviations of the drain-hole from sweet zone takes drain-hole into shale and may give rise to other problems.

To ensure that the well remains within sweet zone, a detailed drilling plan is prepared in advance taking into account various drilling constraints. This drilling plan is primarily based on the structure and porosity distribution map of the target layer/sub layer. The most crucial part is the structure map which decides the course of drilling action. The variations in depth as depicted in the map are taken into account and the drilling starts of with this plan. This depth map is seismic guided and has been prepared by integrating seismic time map, well depth pick and well and seismic velocities for the entire MHS area.

Logging While Drilling (LWD) technology is used to keep the well within sweet zone by real time monitoring of LWD data by RTO team at Virtual Reality Centre in Mumbai. Mid course correction in well path is applied when the well strikes non-reservoir facies. Continuous monitoring of well using LWD data ensures the well from being diverted from sweet zone. Nevertheless it causes loss in effective length of drain-hole and invites other drilling related and well completion problems. If we have correct depth map perhaps no such problem will occur. But converting time to depth has always been a problem area and it was the same here also especially in the area where depth map suggested sharp change in depth values of target layer over 500m length of the drain-hole. LWD data showed things differently and depth profile of drain-hole showed not much variation in TVD of layer. This warranted some insight into it. Surprisingly the time section along the well trajectory did not show much changes whereas the depth profile indicated a change of about 10m meaning thereby that the velocity information was not correct. Though the method which went into depth creation is very robust a different approach was adopted to convert time map into depth map purely on Geostatistical basis to keep away unwanted velocity influence on a sectorial basis. The study area was around 25 sq. km. around the well bore. The depth picks and corresponding time horizon were input for geostatistical analysis. Since depth conversion is non-stationary problem, hence kriging with external drift was applied for converting time into depth. Horizon time was integrated with well depth based statistical correlation at well locations. this is a spatial method analysis to a trend and residual mapping where the deterministic trend is the seismic time grid. The seismic time grid is treated like a polynomial function of depth. There remains a depth residual or random component. The degree of polynomial that gives an average tie to the wells are tested. Then the whole procedure is solved at once as kriging with external drift. When such prepared depth was tested against the actual well depth profile being drilled it was found to be more closer to the reality. This data helped RTO team in taking decision about well maneuvering for keeping the well inside sweet zone and resulted in increase in effective length of drain-hole.

Theory

Statistics is a tool of all sciences indispensable to research and intelligent judgments. In general Geostatistics means to find out unknown at a place using some other known values of same kind at other location or some other kind of values at that location or combining both by finding out some kind of relationship among them and thus interpolating them.

The technology of interpolation may be divided into two large parts - general and local analysis. In both approaches the goal is to calculate the unknown coefficients by minimizing as usual the square sum of the error of estimation on the set of measured observations i.e. the minimum which provides the best solution.

When the interpolation coefficient is dependent on the distance between known values then the method used is known as kriging (after its developer, Daniel G. Krige). Kriging is based on the assumption that there is a spatial dependency between geological properties at separate points. The statistical measure that expresses the rate of change in point values in relation to a distance is the semi variance. Semi variances are calculated for different distances between points and plot the result in a variogram which is then used for calculating the weighting coefficients for kriging interpolation. The semi variogram determines the extent of variance of an unknown value of one point from a known value of a different point depending upon its distance from known point. There are different forms of kriging of which kriging with external drift was used for the purpose of creating depth map. We use kriging with external drift when the regionalized variable is considered to consist of two elements: the trend and residuals. In a non stationary case trend represents the global variability of the region. From a statistical point of view, trend is a conditional average in each point location where
the condition is supplied set of measured values. The trend is the average or expected value of the variable within the range in which all locations have a relationship to each other (also called the neighborhood).

The residual is the difference between the real value at a point and the trend and can be considered to be stationary. Once the effect of the trend is removed, changes in residual values are considered to result from the effect of velocity variation. In this method the following operations are performed:

Semivariogram calculation: Trend is estimated from the time map and removed from between each pair of control points (depth points) and the semivariogram is estimated. In FIG.-1; A illustrates map values exhibiting trend. B shows the map values with trend removed. C represents the semivariogram resulting from A. D represents the semivariogram resulting from B.

Thus essentially the method comprises of two steps:

a. Stationary values are kriged to calculate estimated values for all grid points.
b. Depth is restored to obtain estimates of the actual surface.

Kriging steps a and b are performed together as a unified operation. The expression for drift is incorporated as additional constraints into the system of simultaneous equations used to find the kriging weights. Solving the expanded set of equations produces a set of weights for the kriged estimates that includes the effect of the specified drift within the local neighborhood.

Examples

An area of 5km by 6.25 km was taken for preparing depth map around the place where a new well was to be drilled with two laterals of 500m and 400m into A2-VII layer in two different directions from the landing point. The area had 21 wells already drilled from which depth picks were used. Fig.-2 shows the time interpretation of A2-VII layer.

Figures -3 and 4 show the projected trajectory into A2-VII layer along the drain hole based on the depth map prepared by integrating time map, depth picks, and well and seismic velocities. These trajectories indicated continuous loss in TVD along the drain hole.

Well trajectories were projected on arbitrary traverse seismic time section which reveal the trajectory to be near horizontal in time as shown in Figure 5.

To find out TVD variation along the well trajectory depth map was prepared using kriging with external drift in which the trend was taken from the interpreted time map.
The output map was tied with depth picks by distributing the error over area. The result is shown in Figure 6 and 7 where the drilled well locations are shown as red circles along with their depth values of the layer. The well trajectory is shown as thin red line over the map.

The results show variations of the order of 2m to 3m in TVD which was found to be close to reality as discovered after drilling the lateral.

Conclusions

Geostatistical approach for converting time map into depth map in an area having good number of well controls has been found useful and needs attention. Further study of its effectiveness needs to be done in other parts of the MH Area on sectorial basis as well as on entire MHS Area. The results will give further insight into its utility.

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