Guided Facies Modeling using 3D Seismic and Well Data: Soft-Conditioning to Geomorphologic Objects

Mohamed N. Bushara  
*Petroleum Development Oman (PDO), PO Box 81*  
Postal code 113, Muscat, Sultanate of Oman  
Mohamed.Bushara@pdo.co.om

Roy F. Cox  
*Schlumberger Overseas S.A., Rasa Tower, 17th Floor*  
555 Phaholyothin Road, Chatuchak, Bangkok 10900, Thailand  
geotrek@gmail.com

Abstract

Greater geologic realism is obtained when simple interpreted trends from 3D seismic were used for litho-facies modeling. Images slices from 3D seismic attributes provided soft-guidance to lateral arrangement of depositional reservoir facies. These are calibrated to wells establishing a relationship from which litho-facies distribution is predicted between well and extrapolated away from wells. It was observed that although well data was faithfully honored, as were trends in the 3D seismic data, all the simulation outcomes generally lacked geological meaning & realism. We applied principles of seismic sedimentology of (Zeng & Henz, 2004) to interpret & map geomorphic & depositional features from 3D seismic data over Tobaz field. The geology of reservoirs comprises deposits of lower coastal plain, fluvial with minor marine influence of sub-tidal to inner shelf environment of Upper-middle Miocene age. Correlation of reservoir sand packages between logs, core and seismic signatures was severely hampered by core limitation and coal masking of reservoir rocks on seismic. The litho-facies model of BB field is obtained using object modeling of deterministic geomorphologic expressions on seismic attribute images to guide facies trends. This approach is more geologically meaningful, and it shifts emphasis from the orthodox methods of analyzing vertical seismic sections & well logs to a more lateral area-wide synoptic characterization of geologic features controlling reservoir rocks. It leads to reduction of uncertainties associated with estimates of reservoir hydrocarbon in-place & production potential.
Interpretation of Sedimentological and Depositional Features

Brown et al. (1981) first illustrated that 3D seismic data could be used to produce high-resolution satellite picture-like images of depositional facies by means of seismic horizon slices. Since then there have been numerous examples (Liu et al., 2004; Zeng, 2004; Zeng & Henz, 2004) of this technique for imaging of subsurface depositional facies. These depositional images have proved to be useful to illustrate the spatial arrangement of various depositional elements that are often directly related to lithofacies. The primary objective of this technique is to define depositional fairways & distribution of key reservoir elements away from well control.

Reservoir rocks in BB field are interpreted as fluvial channel, distributary channel, crevasse splay, shoreface and delta front deposits that tend to be discontinuous over short distances. Channels created by flood cuts and floodplain subsidence may be filled with fine-grained material, occasionally intermixed with coarser crevasse splay sediments. This places a serious challenge to define reservoir architecture around well control and to accurately predict reservoir distribution in areas where there is not well control.

In this field, we began with horizon interpretation & the seismic volume is flattened or datumed to remove lateral effects of structure. Seismic slices were generated several milliseconds above or below the coal markers based on whether reservoir sands sit on top of coal or coal overlies sands, respectively. In doing so, horizontal seismic images were produced through the sandbodies to help delineate geometries of sand-prone features. Several attribute horizon images were produced including acoustic impedance, variance, iso-frequency at different frequency contents, AVO & full stack seismic ((Figure 1). Horizon, stratal & time slices have been used directly to infer litho-facies in seismic data but these results are often not always successful. This is particular true where the depositional fabric of the horizon slice is poorly imaged or there is low impedance contrast between rock layers. Under these conditions, horizon slices result in very poor quality 3D litho-facies models. There was no single image that was best describes the preserved morphological information, but a collage of the images used together can elucidate first order depositional features that can be used to condition facies 3D models. Therefore, more supplementary seismic images were constructed at different time windows above & below known geologic markers so as to provide wider range of vertical information on depth of valley incisions & channel cuts.

BB-1 Reservoir Sands

Amplitude & variance horizon slices across the middle of the sand package, and above a coal marker were generated (Figure 2). The amplitude image of the BB-1 sands depicts two channel systems trending northeast. The concave & curvilinear features bounding this channel belt are regarded as scours & point bar deposits flanking an approximately 4-5 km wide channel belt. A larger channel consisting of subtle channel threads is observed extending across the northern part of the image in a NE-SW orientation. The other channel system with subtle channel threads is about 500m wide & emanates from around the center of the image & bifurcates into two
branches to the west. It has a dispersed appearance as the edges become unclear & diffuse. On the variance image, both channels can be observed but difficult to trace with certainty in some places. The edges of this low stand channel progressively become obscure as one moves southward. A segment of another N-S-trending channel boundary can be seen on the variance image in the north, which was difficult to follow on the amplitude map. The western extent of this channel can only be mapped on the full stack reflection slice showing accreted meander point bars or early migrating meander loops lying west of the arcuate fault zone. Even though it is difficult to discern complete geologic features on a single image, meaningful depositional features can be mapped by integrating all images. The variation in the reflection energy of the fill along the mapped channels can be attributed to different depositional facies depending on location in the valley (fluvial sediments, channel bars, estuarine sands & mudstones). Structural lineaments of different lengths are traceable having preferential NW-SE orientation. Whether these lineaments mark small sub-seismic faults or channel boundaries remains enigmatic.

**Figure 1:** 3D seismic attribute types of BB field: a) fullstack seismic, b) AVO cube, c) acoustic impedance, d) seismic variance, and e) iso-frequency cube.

**BB-2 Reservoir Sands**
Horizon slices were also generated across BB-2 reservoir sands as shown in Figure 3. Looking at these slices, different geologic & geomorphologic features can be observed. They brought out remarkable geologic & geomorphic characteristics of sedimentation that are presumably contemporaneous in time domain. On the fullstack amplitude image 8-ms above the center of the reservoir, there is clear depictions of a meander channel about 1.2 km wide appearing on the lower right part of the image. Traces of the channel are also seen on the 7-ms below. This channel is virtually absent on the RMS amplitude & variance maps. Only the middle segment can barely be seen
on the 15 HZ iso-frequency image. It is noteworthy that two channel systems are observed comprising dendritic pattern (chicken-foot-like) of narrow tributaries coming from the northwest.

**Figure 2:** Sedimentological & geomorphic features delineated by various horizon slice images of BB-1 reservoir which define broad depositional fairways or channel belts containing reservoir sands: a) maximum amplitude, b) variance, c) slice 9 ms above coal layer, and d) slice 5 ms above coal layer.
Figure 3: Sedimentological & geomorphical features shown by from various 3D sesimic horizon slicing of BB-2 reservoir: a) iso-frequency at 15Hz, b) full stack slice at 7ms below mid-sand, c) full stack slice at 8ms above mid-sand, d) variance, and e) RMS amplitude. Note how different slices depict different geologic features which are seldom repeated on the other.
Figure 4: Simplified geomorphologic facies interpretation merged from different images: I) BB-1 reservoir interpretation showing line-drawing and flow lines of depositional fairways used for litho-facies modeling, II) BB-2 line-drawing & flow lines. 1) accreted point bar deposits or meander loops, 2) possible channel bar, 3) Point bar complex incised by later channels. Flow lines were drawn on top of amplitude maps of the reservoirs.
These tributaries appear to have paleo-flow direction from the northwest feeding into larger channels that are generally flowing to the southwest. It is also possible to interpret these channels as resulting from channel overbank avulsion forming frontal splay complex & another farther out from the avulsion node. Many other small sedimentological features such as point bars & crevasse splay sands were observed but difficult to ascertain their precise location in reference to larger features in this low-resolution work.

**Figure 5:** Litho-facies realizations of BB-2 reservoir produced from SIS. Even though the two SIS realizations have the same facies percentages & probabilities, their spatial distribution & proportions are different. For example, because sand occurrence has 50-60% probability, based on seismic-facies correlation, it is more abundant in realization-1. In realization-2 it is partially replaced by shale & marginal sands facies.

**Mapping Geologic Features**
Geomorphologic & depositional features interpreted on images were grouped for each reservoir and traced to show key sedimentary trends and establish the spatial arrangement of reservoir architecture. Because of the fuzziness in the 3D seismic horizon slices in depicting complete deposition entities, channel belts other sedimentological features are treated as depositional fairways elucidating sand distribution trends. As such, for each reservoir a hand-drawn template is generated to broadly represent these geologic features. Then flow-lines were drawn using
modeling software demarcating depositional fairways or bounding channel belts within which specific geo-bodies (channel, crevasse splay, shoreface, off-shore bar etc can be modeled against a background facies. Figure 4 shows the hand-drawn interpretation along with flow lines rendition, which presumably influence how litho-facies are distributed. Flow-lines are open polygons and are taken into the modeling platform as trends. So a channel fairway would represent an area where channel threads are sweeping & swinging depositing reservoir sands at different settings.

Figure 6: Litho-facies realizations using object modeling guided by the sedimentological features & facies trends. The trends are visible on both realizations: 1) BB 1 reservoir, 2) BB 2 reservoir. It must be noted that the object trends impose only soft conditioning to litho-facies distribution and not hard-wired constraints. Therefore, these realizations show only partial imprints of input geological objects. Channel boundaries may also appear or disappear on top surfaces depending on the prevailing topography of the area.
Facies Modeling

The starting point has to be with a well-defined understanding of litho-facies in the well data. Clearly electro-facies calibrated with core descriptions will provide the best starting point from which a 3D litho-facies model derived. At the wells, Artificial Neural Networks (ANN) classification module was used so as to predict facies along the wellbore. The ANN used Vshale, Phie, Dt, Rhob well log suite as input variables and the neurons were trained (supervised) with several points on the wells with known facies either interpreted from logs or from core description.

We first used Sequential Indicator Simulation (SIS) algorithm using the four facies classes from wells input as probability curves. This process can be supplemented by co-krigging with fullstack seismic (secondary variable) property in order to provide guidance on the areal distribution of facies. The impact of the co-krigged property strictly depends on the degree of local correlation. The secondary variable will modify the mean probability of the facies such that only at the well probabilities can remain at 1 (unity), elsewhere will depend on the cross-covariance function between well data and seismic. Figure 5 illustrates two realizations from BB-2 reservoir. The most significant shortcoming of this ‘hands-off’ approach is that the results are often geologically implausible, even though realizations match the well data, and statistically the percent facies in the model match the percentage in the well. This is because seismic data was noisy & had no direct litho-facies related data, so reflection information on its own was not a useful constraint on litho-facies modeling. For this reason, litho-facies proportions are unrealistic and inconsistent between these realizations. For instance there is too much more sand captured on realization 2 than realization 1.

Stochastic object modeling algorithm is used to simulate lith-facies using flow line trend maps generated from 3D seismic. The simulation employed the guidance provided hand-drawn interpretations of depositional elements as shown in Figure 4. Facies geobody characteristics were specified in the model as depositional objects and parameters for each interpreted object within flow lines (i.e. channel width, thickness, sinuosity, frequency etc.) were provided from analog data. The geobody objects were then modeled against background non-reservoir facies (mudstone/siltstone and coal facies association) and conditioned to wells. Figure 6 illustrates resulting facies realizations of the two reservoir units. Clean reservoir sands & marginal shaly sands are superimposed on top of the background facies. The results have shown greater geologic realism in terms of sand distribution as contrasting to Figure 5 realizations. 3D seismic image interpretation using geomorphologic features, texture, appearance and albedo variations can be further developed & merged with some seismo-facies classification may help generate realistic geological facies models. Porosity & other reservoir properties can now be simulated constrained by the more meaningful 3D litho-facies model which improves predictability of reservoir quality & fluid content.

Conclusion and Recommendations

1. From the abovementioned, modeling results of both Sgcosim & SIS lacked realistic geological meaning and consistency. The spatial arrangement of sand
facies does not bore discernible depositional geometries & morphologies. This is particularly true where control points are scarce. The resulting deterministic facies & porosity simulations guided by geomorphologic maps conditioned to the well data showed greater realism than using seismic & wells alone.

2. To better ascertain mapping the sedimentological features, a chronology of depositional episodes can be established from careful analysis of crosscutting relationships observed on seismic time slices at different times.

3. Seismic image interpretation using texture, appearance albedo variations can be further developed & merged with some seismo-facies classification, which help generate realistic lithologic facies maps that can complement geomorphologic facies.

References


