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A novel approach to improving well positioning and drilling confidence using seismic interpretation and quantitative studies on rock physics guided depth imaging and integrated pore pressure analysis: A case study from Andaman Sea fore-arc exploration.

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Summary

Deepwater exploration and drilling pose many challenges and uncertainties to both explorationists and drillers. The entire cycle from prospect delineation to drilling management needs special attention, technology and expertise. Seismic data, integrated with well information is capable of deriving comprehensive and unified model consisting of structural framework, stratigraphic understanding, reservoir model, fractures, pore pressure, fracture gradients etc. that can be utilized not only for the exploration but also pre-drill and while drilling decision making. However, the major bottleneck in utilizing the full capability of seismic till now has been the integration of suitable technologies and feasibility in terms of turnaround times so that drilling time predictions could be made. Seismic Guided Drilling (SGD), the technology of predicting ahead of bit uncertainties by integration of rock physics guided high definition seismic, suites of well logs and high-end checkshot technology like SeismicVISION* was employed in the high-profile Andaman Sea deepwater drilling campaign. One of the crucial uses of such high definition seismic data is its use for well positioning. This includes reducing uncertainties in the drilling target prognoses, drilling target locations and positioning in 3D space. Apart from this, SGD has also capability to help with structural complexity and reservoir level uncertainties. Andaman Sea fore-arc sub-basin 'pond fill' has been a 'wild cat' area with large uncertainties in understating of lithologies, depositional settings, petroleum system and fluid content. Due to lack of any deepwater wells prior to the present drilling in Andaman Sea, both deriving the subsurface model and planning/managing the drilling had high uncertainties. Seismic interpretation of 'unified model' generated through custom generated rock physics template 'guided' anisotropic depth image (both pre- drilling and while drilling) enabled bring out previously unnoticed subtle features and beyond imaging predictions like pore pressure. This unified 'baseline' earth model was further calibrated through suites of LWD and wireline logs to provide drilling 'look-ahead' and 'look-around' enabling drilling operations to take more informed decisions. This had tangible and intangible implications in optimizing the well; both in terms of cost by saving rig time and risk reduction.*

Introduction

Andaman Sea has been a high-profile exploration area with many operators having active interest in exploring the area. Several wells had been drilled in the shallower waters near the island, geologically on the accretionary wedge which showed gas. Despite fourteen wells being drilled in the area targeting the shallow water fore-arc part, the deeper waters had yet been unexplored and poorly understood. One of the shallower wells - Well 1X was reported to have produced gas. Discoveries within other parts of the Sumatra-Andaman-Myanmar belt posed as possible analogies. [Roberts, 2010]. Integrated studies using available geological information, regional 2D seismic and recently acquired high-resolution Q-Marine 3D data were done to undertake exploration of deepwater/ultra-deepwater regions of the basin, both fore-arc and back-arc areas. The present paper focuses results from SGD studies in the Andaman fore-arc deepwater exploration wells.

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Seismic data provides one of the only means for studying continuous 3D subsurface earth and forms the most important information for exploration in areas with little or no well information, like Andaman basin. Seismic data can not only be used for prospect delineation and associated volumetrics, but also for helping drilling planning and management. However, lack of suitable technologies and measurements along with turnaround time limitations due to high resource requirements had made this kind of optimum use of seismic and well data (pre-drill and while- drilling) of limited scope until now. Recent developments in model building, new rapid and more accurate imaging technologies, integrated 'beyond-imaging' workflows and availability of new well measurements are making this optimum combination more of a reality [Esmersoy, C., et. al., 2011].

Background of Andaman Geology

The Andaman Sea is a complex tectonic region located at the edge of the Sundaland Craton, where the Indian Ocean Plate is currently being subducted to the NNE below the SE Asian Plate at a rate of 6-7 cm/year (Polachan *et al*., 1991). Oblique plate convergence is accommodated by a shallow Benioff Zone below Sumatra combined with large dextral strike-slip movements along the Sagaing and North Sumatra Fault System (Curray *et al.,* 1979). Figure 2 shows the major tectonic features of Andaman Sea.

Active sea-floor spreading in the Andaman Sea and rifting of the Mergui-North Sumatra Basin may be related to the displacement of crustal blocks along these faults (Curray *et al.,* 1982; Tapponnier *et al.*, 1982). Plate reconstructions suggest that subduction in this region began in the Early Cretaceous (Fitch, 1972; Suensilpong *et al.*, 1981). The Andaman island arc, a part of the Burma Java subduction complex, comprises marine sequences ranging from Late Cretaceous to Recent. These rocks are exposed in the Andaman Nicobar Island chain which is an uplifted subduction complex [Sandip K. Roy *et al.,* 2011]. Seismic data show that the basin has a thick pile of post-rift sediments (reaching up to 2500 m at places), deposited since Middle Miocene in shallow and deep marine environment under a restricted/ ponded setting. Seismic data in the area have reported to show presence of channel-levee complexes, incised valleys, canyon cuts, gullies, sheet sands, slumps, fan/lobes, gravity flows/ mass transport complexes etc. which can be directly associated with regional tectonic events. [Jha, P., *et al.,* 2011].

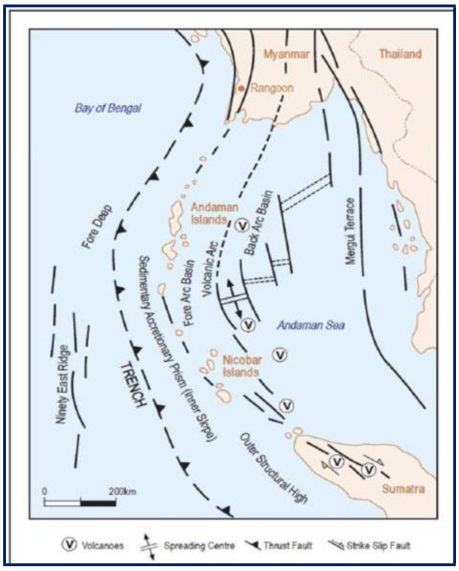

Figure: 2: Major tectonic feature in Andaman Sea (from Gary Scaife et. al., 2011)

SGD Theory

Seismic Guided Drilling is a state of art technology suite aimed at arriving at a 'unified earth model' through realizing full potential of seismic, in order to minimize exploration/drilling uncertainties and make drilling scale decisions. Figure 3 shows the different stages of SGD. The first step of feasibility study starts with understanding the exploration and envisaged drilling challenges and data adequacy for formulating the solutions. This is followed by one of the most crucial stages of Baseline Imaging and generation of a 'unified earth model' to facilitate subsequent updates in terms of time depth functions, velocity models and other attributes. The baseline model is generated though proprietary technologies like RPG MIG which aims at deducing geologically meaningful velocity along with high definition structural image.

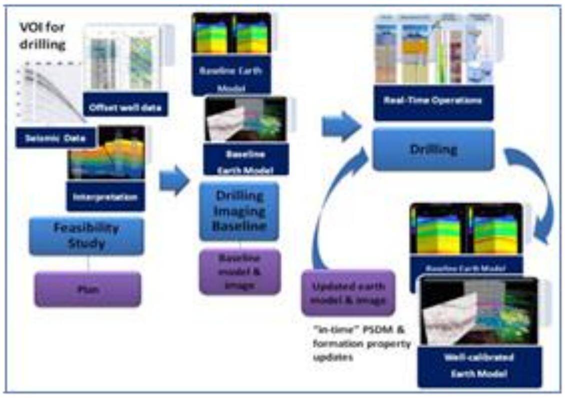

Figure 3: Stages of seismic guided drilling (SGD).

The baseline is then calibrated using real time logs and updated through re-imaging and re-tomographic model building 'in drilling time' during the SGD 'while drilling' update phase. The 'baseline' pre-drill model and while drilling updates help take more informed decisions like avoiding geo-hazards, proper fault positioning, salt bodies, intrusions, sub-basalt scenarios, casing points, well placement, predicting pore pressure and landing at proper target reservoir locations, to name a few. For case of ONGC Andaman Sea exploratory drilling, SVWD data was used to calibrate the time-depth of the SGD model and generate drilling updates.

Well placement challenges arise mainly because of uncertainties in both location of structural elements like faults, major horizon of interest etc. while drilling the overburden and the actual location of the target itself while landing the well. SGD helps in such cases by building a high definition velocity model which is not only data driven, but is also 'guided' using rock physics to ensure closeness to the geology of relevance, and depth migrating using these velocities. Seismic data for SGD is conducive to accurate prediction of drilling hazards through shallow hazard identification improvements, pore pressure and fracture gradient estimates, and identifying other regional hazards such as tar and gas hydrates. [Esmersoy C., *et al.*, 2011].

It has been observed that purely data driven velocity analysis in seismic data processing using results in higher trends of velocities, especially in the deeper parts. Although a tomographic solution enables a fairly accurate depiction of the subsurface structure, it often is not adequate for 'beyond imaging' studies like pore pressure, fracture gradient etc. However, in order to be effective for drilling purposes, SGD workflows employ proprietary seismic imaging workflows named RPG MIG incorporating specific rock physics constraints.

Case study Results

Andaman Sea deepwater has been a yet unexplored area with the present deepwater drilling being the first deepwater wells in the area. SGD suite of technology was employed by Schlumberger along with other services during the drilling operations for the Andaman wells.

To start with, during SGD, a rigorous pre-drill baseline 'unified earth model' was generated which was conducive to drilling scale decision support. This baseline was to be further updated 'while drilling' to aid drilling operations decision making.

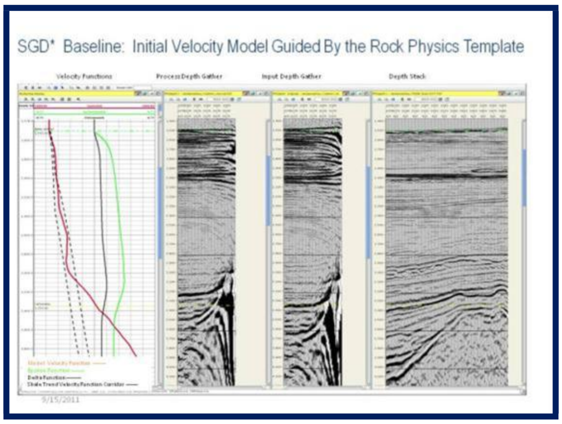

Figure 4: RPG MIG modeling and depth imaging view.

SGD baseline study involved understanding the geology of the area and generating a specific 'rock physics template' targeted to the area. This RPT was then used to constrain the tomographic velocity estimation during anisotropic depth imaging. Figure 4 shows a typical rock physics guided migration (RPG MIG) anisotropic model building.

Area specific rock physics template (RPT), which forms the core of RPG MIG, ensured that the velocities thus derived were geologically meaningful and feasible from a geomechanical point of view. As new information became available during drilling, the RPT was calibrated and updated for further effectiveness in the look-ahead (Figure 5).

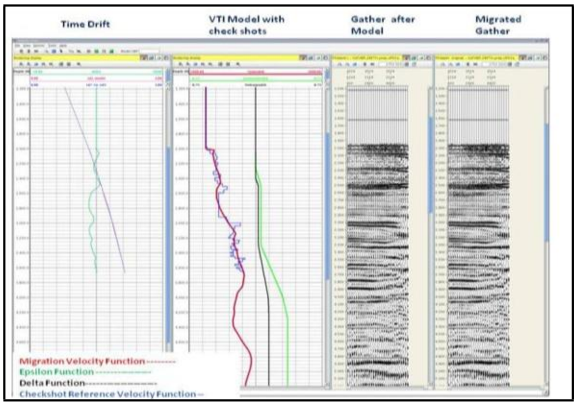

Figure 5: RPG MIG analysis 'while-drilling' incorporating SVWD checkshots. Left most panel shows time drift between model velocity and checkshots.

Structural positioning forms one of the most crucial steps of well placement. SGD provided an accurate 3D model that could be used for drilling decisions relevant to trajectory. As seen from the figure 6, SGD workflows generate results that can change the earlier interpretations and generate more accurate target tops. This in turn can help in accurate landing of the well and avoid missing the structural play.

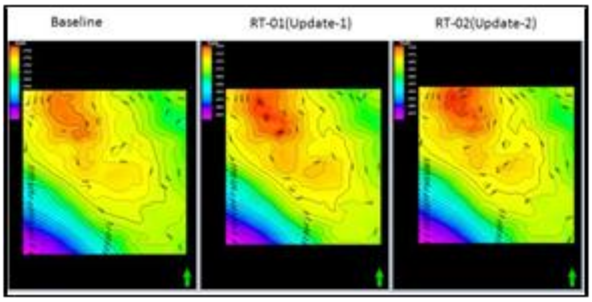

Figure 6: a) Target top map from SGD baseline interpretation. b) From SGD 'while drilling' update 1 c) the same map from 'while drilling' update 2.

This opens the possibility of tweaking the trajectory within allowable limits, for optimum well placement through all the vertically stacked prospect levels. SGD provides improved target maps that could be utilized for the purpose (figure 7).

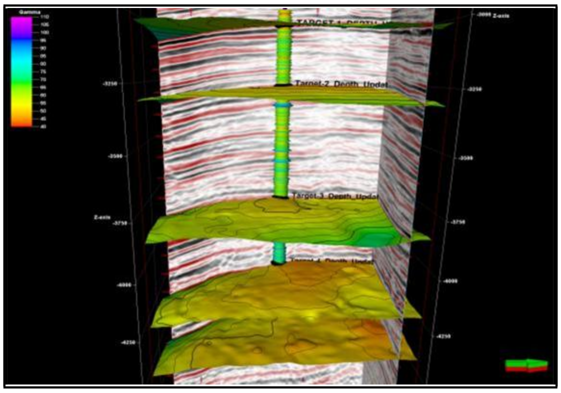

Figure 7: Improvement in structural positioning through seismic interpretation of SGD enhanced image.

SGD helped detect subtle features like faults that could have posed risk during drilling. Figure 5 shows the prediction of high angle fault that enabled the operations team be well informed of the event well ahead of bit.

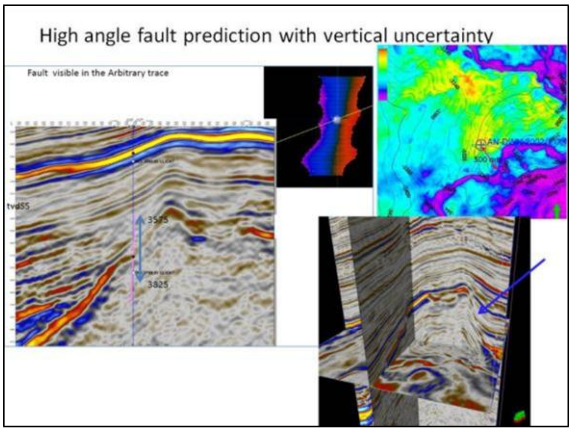

Figure 5: Prediction of location of a high angle fault through the trajectory enhanced confidence for drilling decisions.

SGD provides 3D 'look-around' capability that helps drilling/operations teams to judge the need for actions such as side-track, deviation within acceptable drilling limits etc.

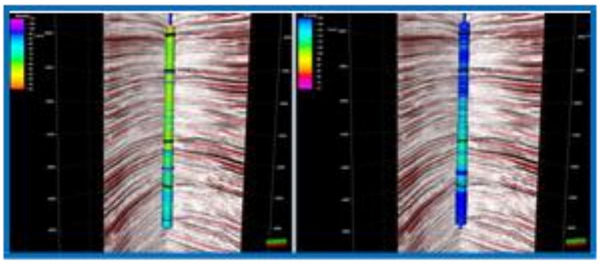

Figure 6: Gamma and sonic logs posted on the background of SGD seismic during drilling. This is an example of the 'look-around' capabilities of SGD provided during Andaman campaign.

Velocities, rock physics template and subsurface geo-models achieved through SGD baseline study prepare the fundamental framework for the pre-drill pore pressure predictions.

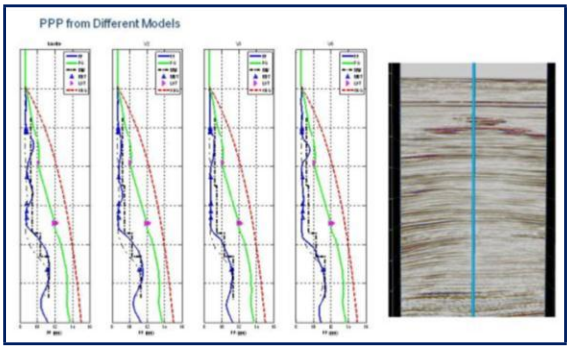

Figure 7: Pore pressure predictions from different 'while drilling' SGD models.

These pre-drill PPP models are then calibrated 'while-drilling' and can be used for crucial drilling decisions like casing, mud weights etc. Figure 7 shows the pore pressure functions for consecutive SGD updates using drilling and logging information from the well.

In figure 8, an example is provided for the velocity effectiveness achieved in understanding the target top from SGD and SVWD technologies. The four panels describe velocity vs depth profiles. The first update with calibration from SVWD checkshot and subsequent velocity model building, tomography and migration show a gradual increase in velocity and hence the exact formation top of concern is difficult to ascertain at the initial stages.

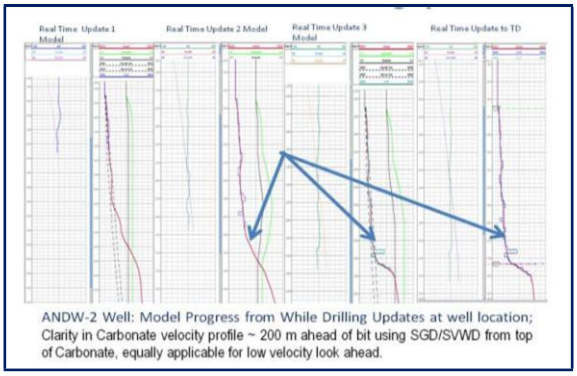

Figure 8: SGD velocity and anisotropy vs SVWD checkshot data (upto last used while-drilling) and actual velocity encountered in the well.

The update in panel B was done incorporating more amount of SVWD data, which showed improve the look-ahead. Panels C & D further sharpened the picture adding more resolution to the top where exact onset of the formation of interest was encountered. Arrows show the position of SVWD levels during the look-ahead was provided. The results were verified after drilling. The consecutive updates thus sharpened the look-ahead to the target top. Moreover, this could also have easily been a geo-hazard during drilling that SGD coupled with SVWD helped bring out.

Andaman Sea fore-arc endeavor observed tangible and intangible benefits from SGD technology, calibrated using SVWD data. In the second Andaman deepwater well, uncertainties in depth to targets while drilling were reduced. At one instance, accurate estimate of depth to basement top helped operations team to continue drilling and avoid 13-3/8'' casing. Thus, the target depth to top basement was achieved ~13 days before plan.

During the third Andaman deepwater well, at a depth level of 3725m, SGD second updated earth model suggested a pressure ramp ~4000 m. Moreover, based on the look-ahead and confidence on time-depth information from SGD, the well was drilled to 4725 m, 200 more than the planned total depth. All this was achieved ~7 days before plan. Therefore, a tangible benefit of around 20 cumulative days of saving was observed during the operations, while keeping operations well informed to avoid potential complications.

Conclusions

Schlumberger has been associated with the exploration and drilling activities of ONGC for their Andaman exploration campaign. Andaman Sea deepwater drilling had many uncertainties and drilling challenges due to the 'wild cat' nature of the area. Seismic Guided Drilling incorporating seismicVISION* and other well log data helped to predict vital clues 'ahead-of-bit' that facilitated more informed decision making by the ONGC drilling operations teams and optimizing well cost. Acquiring checkshots real time provided with real time T-D calibration at the bit level, while 'in-time' SGD brought in full analysis of subsurface information to understand drilling risks and target locations with reduced uncertainties 'ahead-of-bit'. At one instance by realizing the drilling targets zone shallower than expected, ONGC was able to continue drilling pilot section without the need to enlarge the hole and thus eliminating the planned casing, saving considerable drilling time and reduction in risk. SGD also helped predict the depths pore pressure ramps with increased confidence, hence aiding decision making for requisite mud weight profile and other drilling decisions.

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