Post-drill Analysis of Pore Pressure and Fracture Gradient from well logs and Drilling Events – An Integrated Case Study of a High Pressure Exploratory Well from Panna East, Mumbai Offshore Basin, India*

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Abstract

Pore pressure studies have now become an integral part of almost all drilling campaign to better understand downhole pressure anomalies and drilling mud window information to minimize non-productive times (NPT). Here we present a post-drill analysis of an offshore vertical exploratory well from Panna east area, Mumbai Offshore Basin, western India, drilled to the Cretaceous basement. Interpreted pore pressure was in good agreement with pre-drill estimates from seismic and offset wells down to mid Eocene. Lower Eocene Panna shales showed prominent deviation from normal compaction trend on resistivity and sonic logs with top of overpressure interpreted at 2670m. During drilling the final section (Panna Shale), well took four kicks and Kill mud weights helped to calibrate the pore pressure interpretations precisely. Continuous high background gas, connection/pump-off gas, tight spots throughout the 8 ½" section (2850-4100m) confirmed overpressure in Paleocene to lower Eocene shale-dominated section with maximum pore pressure reaching 17.75 ppg. Drilling events, downhole formation pressure measurements, leak off tests were integrated to finalize the pore pressure and fracture gradient estimated from LWD and wireline data in the studied well.

Introduction

As E&P activities focus more on difficult environments and reduction of drilling cost comes into picture, pore pressure analysis becomes an integral part of well planning and drilling process. Overpressure, one of the important drilling hazards seen globally, is mainly associated with narrow operating mud windows resulting in severe well control incidents and significant nonproductive times (NPT), sometimes even leading to early abandonment. Accurate knowledge of pore pressure is fundamental to any safe and economic well construction. Here we present a detailed post-drill pore pressure analysis of a high pressure offshore exploratory vertical well from western India integrating geophysical logs, downhole pressure measurements and drilling-event-based interpretations. Eaton's method (Eaton, 1975) have been used to compute pore pressure from resistivity and sonic logs, while both Eaton's and Mathews & Kelly method (Mathews and Kelly, 1967) have been utilized to calculate fracture gradient (Ganguli et al., 2017).

Geological Setting

Mumbai Offshore Basin is a divergent passive continental margin basin, located on the continental shelf off the western coast of India, covering about 148,000 km^2 from coast to 200-m isobath. The basin was formed due to the extensional tectonics during rifting of Indian plate from Madagascar in Late Jurassic - Early Cretaceous (Basu et al., 1982). It accounts for nearly two-thirds of the annual hydrocarbon production of India. The basin is divided into six tectonic blocks (Tapti-Daman, Diu, Heera-Panna-Bassein, Mumbai high-Deep Continental Shelf [DCS], Ratnagiri, and Shelf Margin), and the sedimentary fill ranges from 1100-5000m (Basu et al., 1982). Several large oil and gas fields have been discovered in this basin, and the presence of hydrocarbons has been established in the multiple pay zones belonging to various limestone reservoirs of Miocene age (in Mumbai high), Mukta (early Oligocene), Bassein (middle Eocene), Panna (Paleocene to early Eocene), and Daman (early Miocene-late Oligocene) and Mahuva (early Oligocene) in Tapti Daman block (Basu et al., 1982).

Pore Pressure and Detailed Drilling Events

The studied vertical exploratory well has been drilled in the Panna East area of Heera-Panna-Bassein tectonic block to explore the Panna Formation (Figure 1). The well has been drilled to the Cretaceous basaltic basement, has a TD of 4100m with 33m water depth. Pre-drill pore pressure analysis from seismic velocity and offset wells estimated a pressre ramp in the interval 2500-3000m (10.2-13.5ppg), followed by a gradually overpressured shaly section of Panna Formation till basement, with maximum pore pressure reaching 14.7ppg.

17 ½" Section

Up to 1840m were drilled, covering the mid-Miocene to lower Oligocene shales and intermittent sandstone-siltstone horizons of Bombay and Mahim formations. In the lower part of this section, lower Miocene shales show deviation from Normal Compaction Trend on resistivity and sonic logs (Figure 2) with calculated pore pressure ranging between 8.8-10.8ppg. This section was smoothly drilled with 9.7-12.8ppg KCl-based mud. 13 3/8" shoe was set at 1839m.

12 ¼" Section

This section covers the lower Oligocene shales of Mahim formation (to 2050m), mid-Eocene Bassein Formation (2121-2657m) and the top of Panna Shale. Downhole pressure measurements (MDT) show sub-hydrostatic pressure condition against the depleted Bassein limestones, which was the primary established target. It was drilled with 10 ppg mud. Underlying lower Eocene Panna shales show increasing deviation from Normal Compaction Trend (Figure 2), resulting in an increase of pore pressure from 9-11ppg in the interval 2670-2850m, drilled with 10.3-11.5ppg mud. 9 5/8" shoe was set at 2848.5m, and LOT recorded 17ppg at 2852m.

8 ½" Section

Paleocene to lower Eocene Panna Shale section was drilled with 8 ½" bit, drilling started with 11.5ppg mud. However, at 2862-2864m, increase in return flow had been observed, well was killed with 12.5ppg mud. Operator started carrying-out fingerprinting prior to every connection beyond this point to check influx trend and early kick detection. High background gas and connection gas continued in 2872-2919m interval, and mud weight was increased to 12.7ppg. At 3061m, gas increased to 30% and well started flowing; BOP was closed; initiation of well-killing used drillers' method, with 14.2ppg mud weight. After two days of continuous endeavor (NPT), well was killed with 15.5ppg mud; average flow was reduced to 0.3bbl/min. Further drilling continued with 15.5ppg mud to 3750m. This section recorded flow rate of 18-24bbl/hour at several depth points (3172-3736m interval). 3750m onwards. The Paleocene shales show clear indication of further increasing pore-pressure trend on resistivity and sonic-log responses, high background and connection gases, influx (recorded 7.5-12bbl/hour at 3850-4078m interval), cavings, and multiple tight spots were encountered while reaming; these led to the increase of drilling mud weight from 15.5-16.8ppg. Upon reaching TD at 4100m, fingerprinting carried out and flow check in trip tank recorded a 7.5bbl/hour influx with 10-13% background gas and 23% connection gas. Well finally was killed by drillers' method with 18 ppg mud prior to final POOH to surface.

Conclusions

Geophysical logs have been the primary tool to compute the post-drill pressure profiles, while the direct downhole measurements (MDT, Kill MW and LOT/FIT) have been instrumental to calibrate (Ganguli et al., 2017; Sen et al., 2017) and finalize the pore pressure and fracture gradients (Figure 2). In terms of pressure-related issues, this well had been very critical against the overpressured Panna shales, as actual pore pressure was quite high with respect to the pre-drill estimate. Consistent influx caused drilling the 8 ½" section very challenging and resulted in significant NPT, although fingerprinting method was adapted for EKD. Top of overpressure has been interpreted at 2670m; pressure ramp in the interval of 2670-3061m with pore pressure rapidly increasing from 9ppg to 15.5ppg in lower Eocene shale, followed by a long continued Paleocene to early Eocene overpressured-shale-dominated section to TD with pore pressure 15.5-17.75ppg, resulting a narrow mud window of 1.5ppg at TD.

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Selected References

Basu, D.N., A. Banerjee, and D.M. Tamhane, 1982, Facies distribution and petroleum geology of Bombay Offshore B asin, India: Journal of Petroleum Geology, v. 5, p. 57-75.

Eaton, B.A., 1975, The equation for geopressure prediction from well logs: SPE 50th Annual Fall Meeting, SPE paper 5544, 11 p.

Ganguli, S.S., S. Sen, and M. Kumar, 2017, Geomechanical analysis for feasible CO_2 storage in an Indian mature oil field:12th Biennial International Conference & Exposition, SPG India, Nov 17-19, 2017.

Matthews, W.R., and J. Kelly, 1967, How to predict formation pressure and fracture gradient: Oil and Gas Journal, v. 65, p. 92-106.

Sen, S., J. Corless, S. Dasgupta, C. Maxwell, and M. Kumar, 2017, Issues faced while calculating overburden gradient and picking shale zones to predict pore pressure: 1st EAGE Workshop in Pore Pressure Prediction, 2017, Pau France (abstract of presentation): EarthDoc, DOI 10.3997/2214-4609.201700042. Website accessed September 24, 2018, http://www.earthdoc.org/publication/publicationdetails/?publication=87623.

Wandrey, C.J., 2004, Bombay geologic province Eocene to Miocene composite total petroleum system, India: U.S. Geological Survey Bulletin 2208-F, 26p.

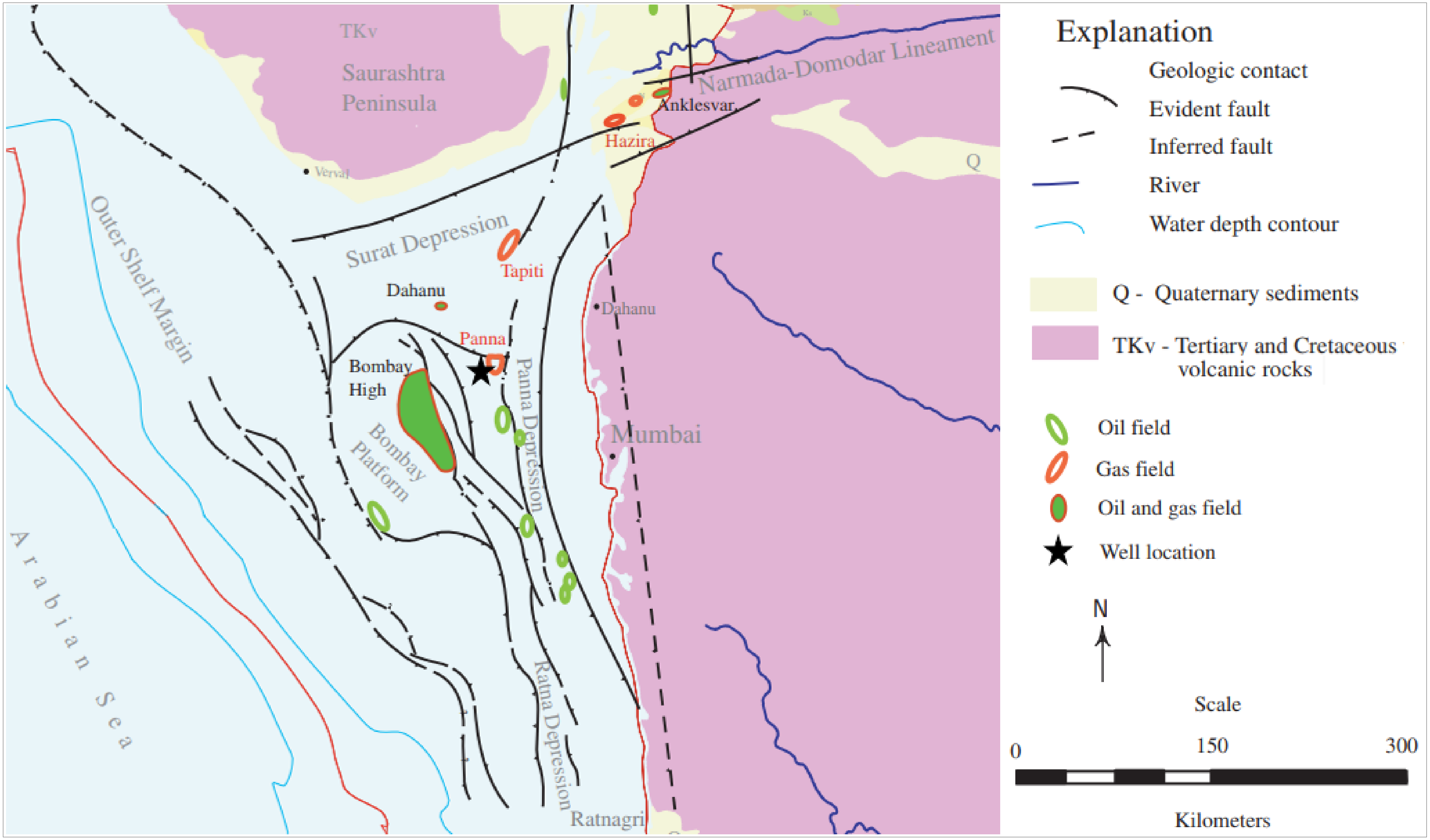

Figure 1. Regional structure and selected oil and gas fields of Mumbai Offshore Basin (Wandrey, 2004), along with the location of the studied well marked by black star

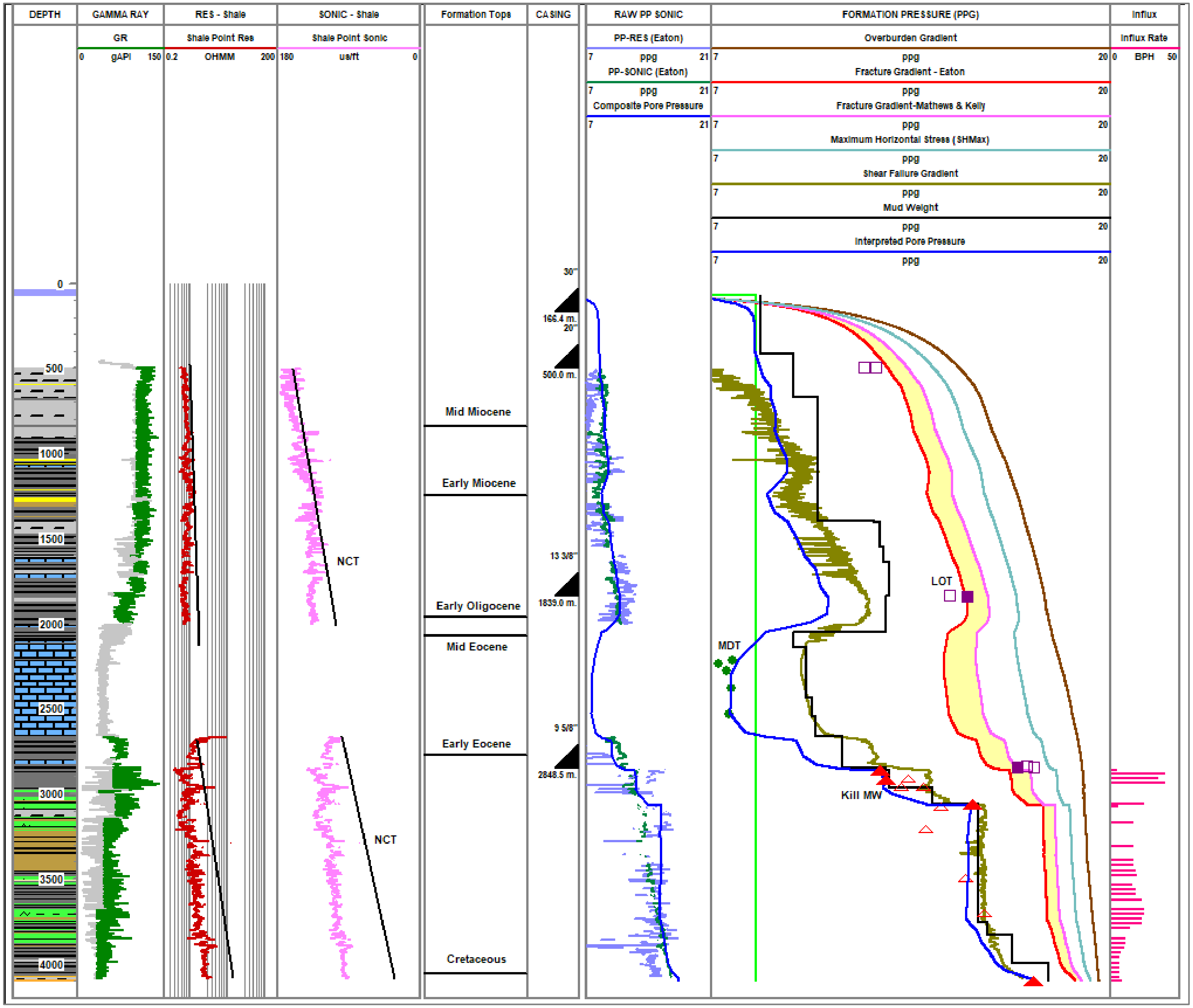

Figure 2. Post-drill pore pressure analysis of the studied well using Pore Pressure module, GEO Suite of software. (MDT as green dots, LOT as solid and hollow violet squares from studied well and offset wells, Kill MW as solid and hollow red triangles from studied well and offset wells).