Modeling Pore Pressure, Fracture Pressure and Collapse Pressure Gradients in Offshore Panna, Western India: Implications for Drilling and Wellbore Stability

Article *in* Natural Resources Research · February 2020

DOI: 10.1007/s11053-019-09610-5

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Natural Resources Research (© 2020)
https://doi.org/10.1007/s11053-019-09610-5

Original Paper

Modeling Pore Pressure, Fracture Pressure and Collapse Pressure Gradients in Offshore Panna, Western India: Implications for Drilling and Wellbore Stability

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Received 3 June 2019; accepted 18 December 2019

Pore pressure modeling has proven and direct implications in oil and gas exploration and development. Abnormal pore pressure leads to drilling complexity and well control issues because of reduced mud window, contributing to major non-productive times and steep drilling cost. A comprehensive pore pressure–fracture pressure model plays a critical role in successful well drilling. This work caters to the pressure modeling of Panna area in Mumbai offshore basin, western India. Two offshore wells, drilled through 4 km of Tertiary sedimentary succession down to Cretaceous basaltic basement, were analyzed to interpret the vertical stress, pore pressure, fracture gradient and collapse pressure. Vertical stress profile was generated from density logs; pore pressure was estimated using Eaton's method by employing resistivity and sonic logs. Calculated pore pressure was calibrated with various direct downhole measurements and various well events. Compaction disequilibrium was inferred as key mechanism for generating mild overpressure in Oligocene to early Miocene shales (14–15 MPa/km), while it increases sharply against early Eocene sediments, and hard overpressure with near-lithostatic gradient (22 MPa/km) was detected in the underlying Paleocene shales. The mid-Eocene Bassein formation, the primary hydrocarbon reservoir, reveals sub-hydrostatic condition (7.5 MPa/km) resulting from production-related depletion. Estimated fracture pressure was calibrated with available leak-off test data. Mohr–Coulomb rock failure criterion was employed to estimate collapse pressure and validated with the observations from caliper log to address the wellbore stability issues. This study provides insights on downhole pressure behavior across stratigraphy, to achieve optimum drilling mud designing as well as safe and successful operational planning.

KEY WORDS: Pore pressure, Pressure gradient, Overpressure, Fracture gradient, Collapse pressure, Panna offshore.

INTRODUCTION

Pore pressure characterization has established proven and direct implications in any field development cycle, right from wildcat exploration to abandonment phase (Sayers et al. 2002; Tingay et al. 2009; Tingay 2015; Meng et al. 2011; Ramdhan and Goulty 2011; Hoesni 2004). Accurate evaluation of pore pressure is critical for geomechanical model

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Published online: 01 January 2020

building, which leads to safe drilling fluid design, casing emplacements, enhanced wellbore stability and hydraulic fracturing optimization (Swarbrick and Osborne 1998; Zoback et al. 2003; Tingay et al. 2005; Zhang 2011; Gholami et al. 2014; Rajabi et al. 2016; Ganguli et al. 2017). With growing energy demand in India, exploration activities have seen a surge targeting new frontiers as well as finding more opportunities in proven fields. Many researchers are presently working on the pore pressure and geomechanical modeling aspects of these new potential target areas, which include Krishna Godavari Basin, Mahanadi basin, Upper Assam Basin and Mumbai High-Deep Continental Shelf (DCS) area (Chatterjee et al. 2011, 2012; Kumar and Rao 2012; John et al. 2014; Dutta and Kumar 2015; Dasgupta et al. 2016; Kumar et al. 2016; Chatterjee and Singha 2018; Das and Chatterjee 2017; Alam et al. 2019). Mumbai offshore basin (MOB) in western India has many proven oil and gas fields (middle Eocene to upper Eocene pay zones) contributing to the majority of the domestic hydrocarbon production, and operators presently are looking for deeper prospects in Paleocene–Eocene Panna sediments. Latest studies by Kalpande et al. (2018) and Bandyopadhyay et al. (2108) in the MOB interpreted overpressure in upper Miocene Chinchinni formation, early Eocene top-Panna Formation and Devgarh formation in the Mumbai High-DCS area and Tapti-Daman block, operated by Oil and Natural Gas Corporation (ONGC). However, these wells were not drilled to the basement and therefore the pore pressure behavior of deeper Paleocene (Panna) sediments could not be established. Recently, discovered oil occurrences in Paleocene sands in Vasai area have increased exploration interest.

In this study, we investigated two recently completed offshore exploratory wells, which were drilled up to the Cretaceous basaltic basement. It provided us the opportunity to study the 4000 m thick Tertiary sediments in the Panna region. The studied wells experienced several formation fluid influxes/kicks at regular interval, and the mitigation process contributed to significant non-productive times (NPT) with cost implications. The prime objective of this work was to integrate all available dataset to model the vertical pore pressure distribution within the entire Tertiary sequence. This work also focuses on the fracture pressure and collapse pressure gradient estimation to address the wellbore stability issues. The inferred 1D pore pressure–fracture pressure–collapse pressure gradient model enhances the understanding subsurface pressure behavior in Panna area and enables the operator to better plan the drilling mud and casing policies.

GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY OF TARGETED AREA

The MOB, situated in the western continental shelf of India, is a pericratonic rift basin (Goswami et al. 2007) with a cumulative sedimentary lithologic column of 1100–5000 m (Basu et al. 1982). It covers approximately 148,000 km^2 from coastline to 200 m isobath. Zutschi et al. (1993) interpreted six prominent tectonic blocks within the MOB, named as Tapti-Daman, Diu, Heera–Panna–Bassein, Mumbai High-DCS, Ratnagiri and Shelf Margin. Figure 1 depicts the major/prominent regional structures along with the proven hydrocarbon discoveries in surrounding areas. The MOB was opened as a result of rifting in late Jurassic to early Cretaceous. After the Deccan volcanism, trap wash sediments mark the first deposition in Panna depression followed by clastic deposition (Panna Formation) in fluvial to transitional setting during Paleocene to early Eocene (Wandrey 2004). Panna Formation is a proven source rock (2.3–14.5% total organic carbon content), containing Type II–III quality kerogens (Goswami et al. 2007). At the end of early Eocene, a major regression took place, ceasing this syn-rift sedimentation with an unconformity at Panna top (Naik et al. 2006; Kumar and Rao 2012). During middle Eocene, as a result of transgressive event, shallow marine Bassein limestones were deposited with great lateral extent (Goswami et al. 2007, Barnett et al. 2010). These have been the primary hydrocarbon reservoir in the MOB (Barnett et al. 2010). Shallow marine shales and shelf carbonates were deposited during Oligocene–lower Miocene time, followed by extensive terrestrial clastic sedimentation late Miocene onward (Wandrey 2004; Naik et al. 2006).

Our study area lies in the Heera–Panna–Bassein tectonic block (Fig. 2), bounded by N/NNE trending normal faults on the east and west sides. The Heera–Panna–Bassein block is situated east of the Mumbai High-DCS and south of Surat depression. This has three main tectonic units trending nearly N–S to NW–SE, which lose their identity in

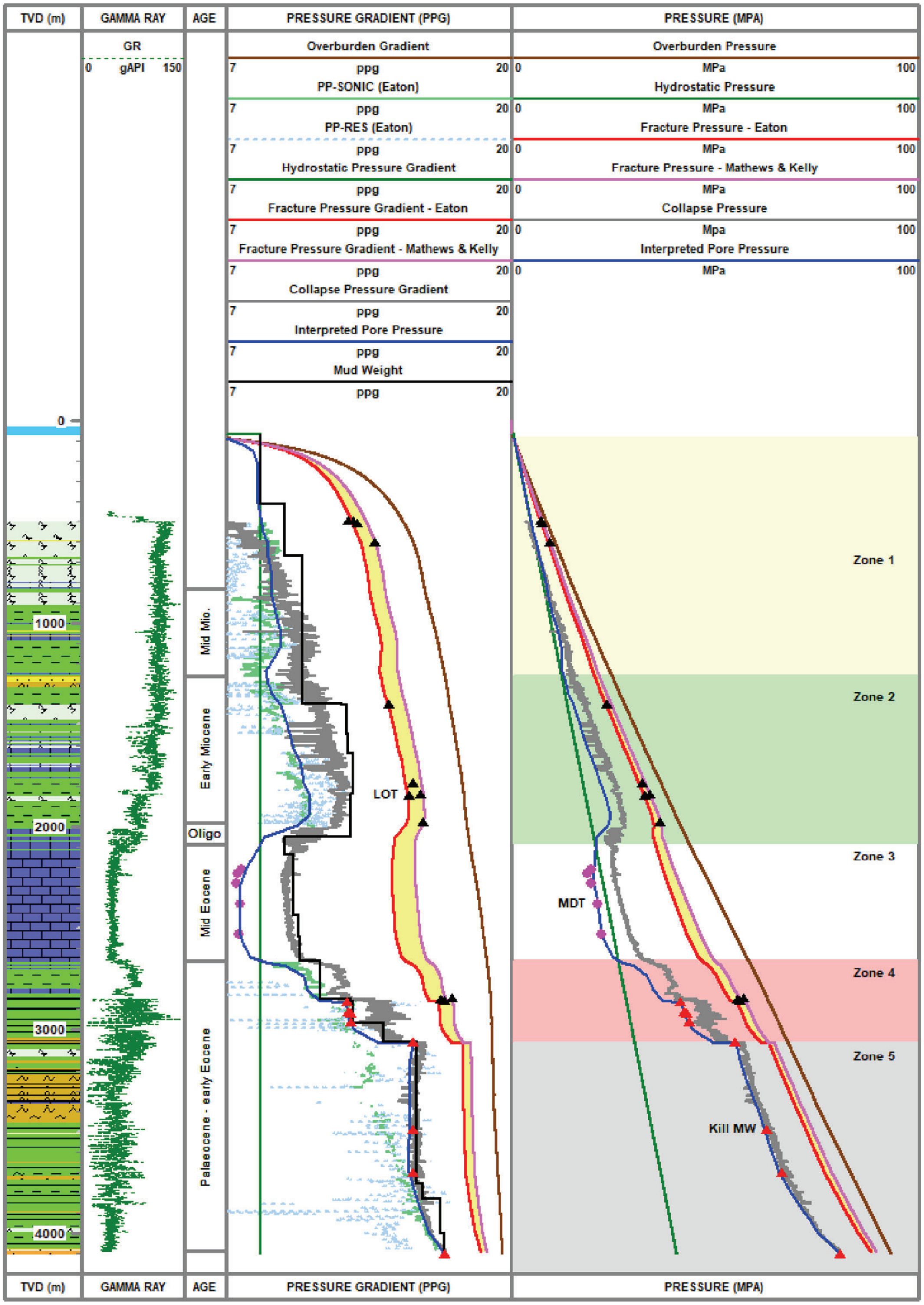

Figure 8. Interpreted pore pressure, fracture pressure and collapse pressure in Panna, along with downhole measurements, i.e., MDT (pink dots), LOT (black triangles)) and kill mud weight (red triangles) from influx events. Various pore pressure regimes have been demarcated based on the PP gradients and marked as Zones 1–5.

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