



## Drilling Solutions and Overpressure Characterization for Panna Formation of Mumbai Offshore Basin

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### Keywords

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### Summary

Panna Formation was deposited during Paleocene time and is the oldest hydrocarbon bearing Tertiary sedimentary unit in the Western Offshore Basin (WOB). It is also believed to be the source rocks hydrocarbon pools in formations above.

In the recent years, exploration activity in Panna Formation has significantly increased owing to its own potential hydrocarbon pools. Primary challenge in drilling through Panna Formation includes well flows, losses, stuck pipes and limitation of LWD tools under higher temperature for real-time monitoring. Stable mud weight window becomes narrow (<2ppg). Pore pressure seems to vary considerably from near-hydrostatic to ~17.5ppg subjected to thickness of the Panna Formation and well locations in the block. Pore pressure ramp is observed to start either from bottom of Lower Bassein or Devgarh or 120m-150m inside Panna Formation itself. In addition, the transition of pressure from near-hydrostatic to overpressure zone is quite sharp. As a result, the lithology seal isolating the high-pressure compartment is broken, well flow is encountered and in the process of well control, losses due to insufficient fracture gradient starts.

To delineate the area with overpressure and identify its mechanism a comprehensive geomechanics study with lithology types has been carried out across 5 main blocks of WOB. Study integrates petrophysical, geological and drilling information to give insight into the overpressure mechanism and safe drilling solutions through this complex set-up. Pore pressure, rock mechanical properties and stress profiles have been estimated in few wells to build robust Geomechanical model and estimate stable mud weight windows.

Study establishes the Type-II overpressure phenomenon with the help of crossplots between effective stress with velocity, density with compressional slowness, and pressure with porosity.

There is a clear shift in geothermal gradient associated with the overpressure interval. Casing policies for safe drilling have been discussed in different scenarios. Analysis has also outlined the occurrence of overpressure in triangular area adjacent to Bombay High oilfield.

### Introduction

Panna Formation is oldest Tertiary sedimentary unit deposited during Paleocene time of the WOB and is important from the point of hydrocarbon exploration due to the presence of source, reservoir and seal inside it. Panna Formation shales and coals are believed to act as one of the primary source rocks in the basin. In addition, they also act as vertical and lateral seal for the coarser clastic reservoirs embedded within them (Biswas et.al, 2006).

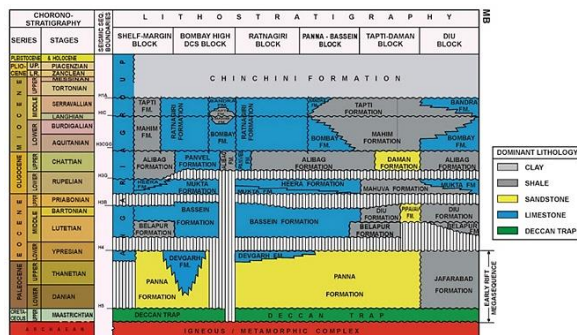
In the recent years, exploration activity in Panna Formation has significantly increased owing to its own potential hydrocarbon pools. Primary challenge in drilling through Panna Formation includes well flows, losses, stuck pipes and limitation of LWD tools under higher temperature for real-time monitoring. Stable mud weight window becomes narrow (<2ppg). There is uncertainty in drilling when well flow in one well gets stabilized with mud weight greater than 17.8ppg whereas in another field, losses are observed at 14.1ppg mud weight. In addition, the transition of pressure from near-hydrostatic to overpressure zone is quite sharp. As a result, having casing shoe at relatively with lower fracture gradient leads to gain-loss situation once the lithology seal isolating the high-pressure compartment is broken.

This inconsistent behavior is reported to vary across the basin and influence safety and cost of the exploration activity. The objective of this paper is to develop a better understanding of variation of observed in formation overpressure and characterize its mechanism. Study also aimed to discuss safe drilling solutions to minimum non-productive time.

## Drilling Solutions and Overpressure Characterization for Panna Formation

### Geology of Panna Formation

Panna formation overlies Deccan Trap or crystalline basement and is overlain unconformably either of Devgarh or Bassein or Belapur or Pipavav Formation. The formation is spread over the entire WOB except in the paleo-highs and is composed of sandstone and claystone at the bottom, overlain by a section of coal-shale alternation in the middle and succeeded by shale unit at the top. The development of the reservoir facies throughout the basin is undefined because of the lenticular nature of the sand deposition. Hence understanding the distribution of the reservoir facies within the formation is essential for fulfilling the exploration requirements. Gross lithology of reservoir facies in Panna formation is lithic/quartz wacke composed of quartz, rock fragments of granite & schist, heavy mineral like siderite, pyrite and iron oxide and clay minerals. Dominant clay minerals are chlorite, montmorillonite and illite (Kumar et.al, 2004). Panna Formation belongs to fluvial to shallow marine depositional environment. Boundary of Panna Formation is characterized by change in lithology from clastics to carbonates. **Figure-1** shows the general lithostratigraphy of Western Offshore Basin highlighting details of Panna Formation. This study has considered multiple wells drilled across the shown 5 primary blocks having Panna Formation.



**Figure 1:** General lithostratigraphy of Western Offshore Basin (after Zutsi et al., 1993)

### Workflow

Drilling complications in Panna formation, acquired drilling and logging data is gathered from all different blocks of the basin. Geomechanical models incorporating petrophysical, geological and drilling information is constructed to give insight into formation pressure profile, vertical and horizontal

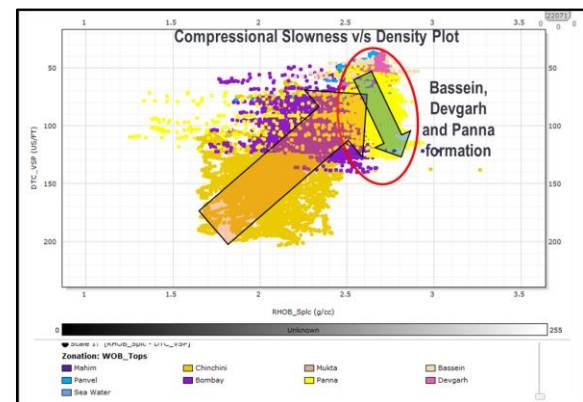
stresses, elastic and strength properties. Crossplots between compressional slowness versus density (Hoesni, 2004), velocity versus effective stress (Bower's, 1994) and pore pressure versus porosity has been utilized to establish the mechanism leading to this overpressure. Wells are correlated on a regional scale to ascertain the variation of lithofacies in correspondence to overpressure. Variation of geothermal gradients is also studied for Panna and associated formations above.

Different casing polices have been evaluated in exploration blocks having varied lithological setup.

### Analysis Overview

In this section, details of the adopted workflow and analysis summary based on our key observations is discussed.

To ascertain the origin of high pore pressure, compressional slowness versus density crossplot is prepared for multiple wells shown in **Figure-2**. Different colors on the plot indicates different Formations (refer legend). Data points belonging to Bassein, Devgarh and Panna Formation indicate that the overpressure mechanism is of hybrid nature which is also classified as Type-II mechanism (Kumar et.al, 2015). Crossplot suggests no relation or inverse relationship between density and compressional slowness which is usually seen in formations having normal pressure or have underwent undercompaction phenomenon.

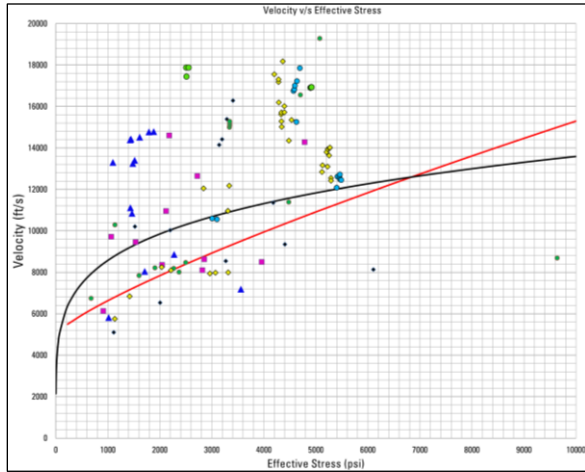


**Figure 2:** Well-A: Overpressure mechanism analysis using compressional slowness and density crossplots (Hoesni, 2004)

**Figure-3** shows another multiwell crossplot between effective stress and velocity which is also called

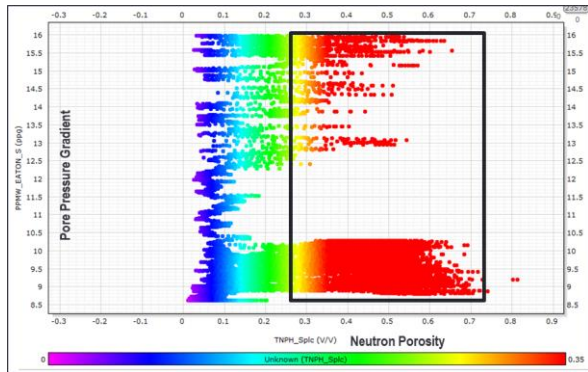
### Drilling Solutions and Overpressure Characterization for Panna Formation

Bower’s plot. Effective stress is estimated for points of measured pressure or from SIDP pressure corresponding to a well flows/influx. Velocity is based on wireline compressional slowness acoustic log. In the crossplot, both loading and unloading trends are visible. Bower’s parameters ascertained from the analysis were A~6.5, B~0.8 and U~5 respectively.



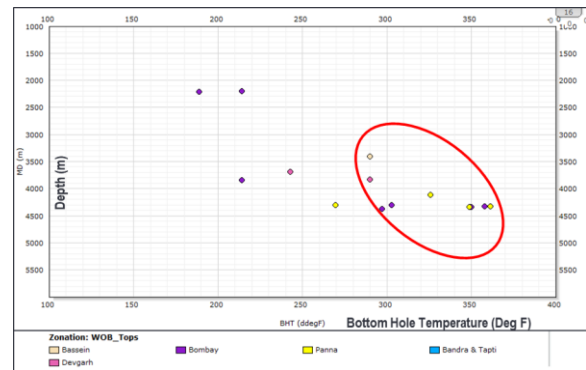
**Figure 3:** Bower’s velocity versus effective stress crossplot to characterize A, B and U parameters of Bower’s Type-II Equation

To confirm Type-II mechanism, pore pressure gradient was plotted against neutron porosity (Figure-4). It is observed that pore pressure is independent of neutron porosity. Increase in pore pressure for shale facies (neutron porosity above 28% pu.) does not correlate with the proportional increase in neutron porosity.



**Figure 4:** Porosity dependance of shales in high pressure zones.

To further understand the overpressure origin, bottom hole temperatures from different measurements (from wireline, LWD, well test etc.) were plotted against different formations (Figure-5). It is found that geothermal gradients in the high-pressure Formations are higher as compared to normal pressure Formations. Higher temperature values for Bassein, Devgarh and Panna Formations are observed. This sudden increase in geo-thermal gradient might be because of presence of hotter volcanic rocks below Panna Formation and can also be attributed to the fact that Panna is the kitchen for hydrocarbons.



**Figure 5:** Increase in geothermal gradient inside high pressure Bassein, Devgarh and Panna Formations

Figure-7 shows the pore pressure modelling performed at the southern side of the basin by using Eaton’s method (Eaton et. al, 1975) and modifying its parameters based on drilling events encountered. Bower’s Type-II equation has also been used with estimated parameters obtain match the well behavior and calibration data points. Based on the analysis in this well, it is found that pore pressure ramp starts from the bottom of Bassein Formation and increases up to 15.8ppg inside Panna Formation. In this well, Lower Devgarh carbonates are acting as a seal for underlying overpressure region. Similar analysis is conducted for multiple wells in different exploratory blocks of WOB and a summary is shown in Figure-8. Red dots indicate wells having overpressure (>10.5ppg) in Panna Formation whereas white dots are for normal pressure wells. These overpressured wells lie adjacent to Bombay High oilfield in triangular area.

Figure-6 shows a multi-well plot belonging to a different block in the northern side of the basin. Plot includes basic logs (gamma ray, resistivity, density-porosity and pore pressure with MDT/RFT

### Drilling Solutions and Overpressure Characterization for Panna Formation

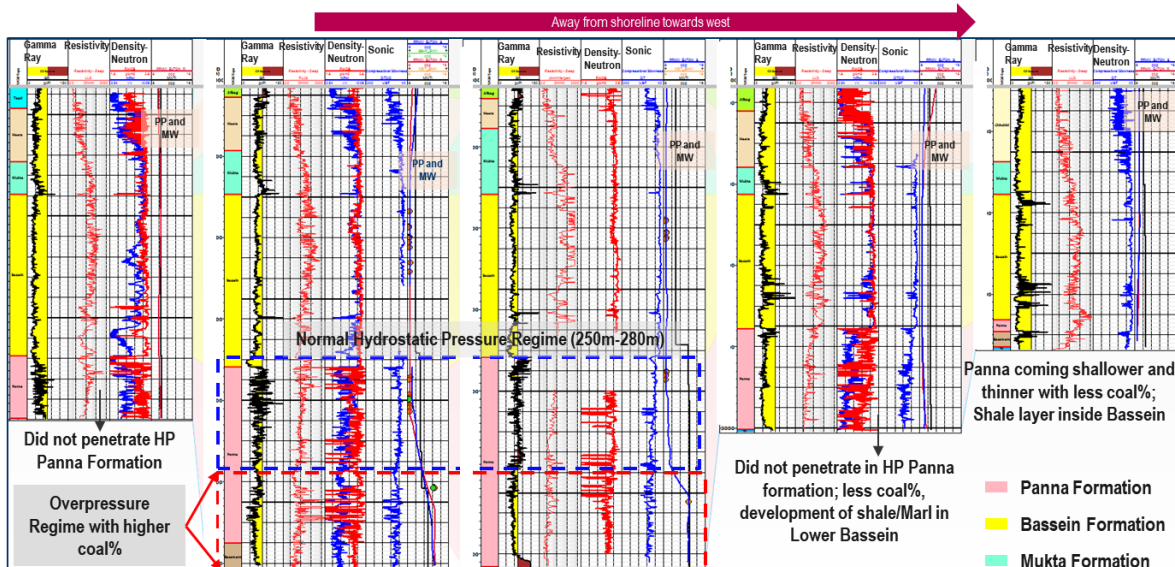


Figure 6: Multiwell plot showing pore pressure variation with thickness and lithology

measurements and mud weight. In this field, Panna Formation is found to have dual pore pressure. Initial 250m to 280m show hydrostatic pressure gradient and it increases upto 14.2ppg inside Panna Formation. From this multiwell analysis, it is also evident that overpressure region has higher percentage of coal lithofacies marked with fall in density and porosity. Also, the overpressure compartment is separated by shale lithology which is acting as a seal and is holding nearly 3000-4000psi excess pressure (Shaker, 2001). These observations are consistent across the region, with transition zone lying either in Devgarh, Bassein or Panna Formation.

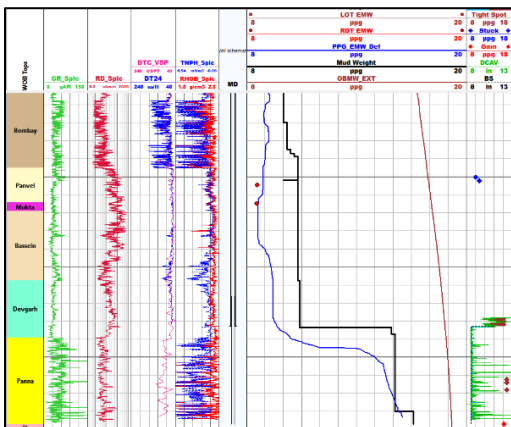


Figure 7: Porosity dependence of shales in high pressure zones.

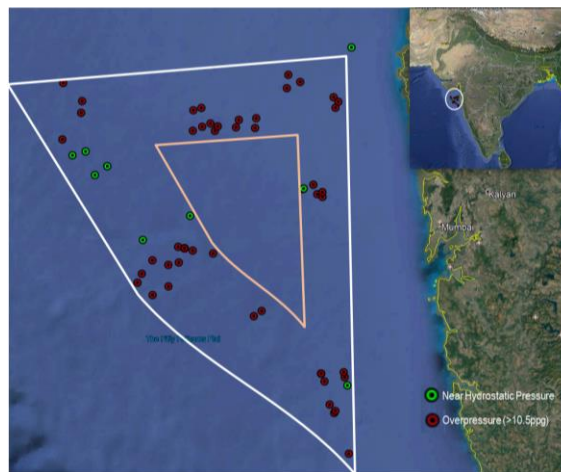


Figure 8: Overview of Pore pressure variation in Panna Formation across Mumbai Offshore.

Figure-6 also shows wells with thin Panna Formation (<50m) have near-hydrostatic pressure. However, saying that thickness of Panna is not directly proportional to formation pressure. Study say examples, from southern tip of the triangulated area (Figure-8) where thickness of Panna was higher, but pressure was limited to under 11ppg. Hence the statement, thicker Panna Formation has chances of encountering high pressure will be valid.

## Drilling Solutions and Overpressure Characterization for Panna Formation

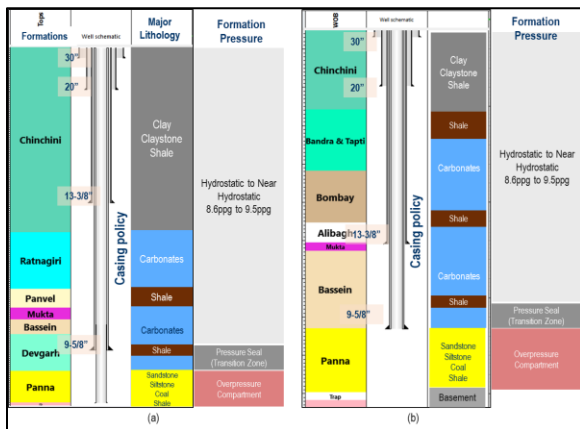
### Casing Policy Scenarios

Pore pressure modelling reinforced with actual field experiences in WOB establishes that overpressure exists in Panna Formation, whereas Devgarh has shown signatures of both normal and high pressure. Considering all the scenarios of pore pressure profile, a suitable casing policy has been discussed below.

**Figure-9** shows depicts two separate cases of PP variation in Bassein, Devgarh and Panna Formations. It also shows the relatively safe location of 9-5/8” casing shoe to prevent breaching of seal. Both (a) and (b) cases are commonly observed in WOB.

In Case(a), transition zone to overpressure starts from the middle of Devgarh Formation. Distinct signature of shale and carbonates lithology is evident on the basic logs. Wells with casing shoe at the start of Transition zone were drilled without any major drilling difficulties.

In case(b) scenario, Devgarh Formation is absent, and this transition lies in Lower Bassein Formation, having similar shale and tight carbonates lithology. In such a scenario, 9-5/8” casing shoe has been placed in Lower Bassein transition interval. Drilling deeper in the transition zone increases the risk or well flow and loss situation as its thick is not uniform.



**Figure 9:** Case-(a) and (b) Decision of Casing Policy Based on Lithofacies and position of sealing compartment for overpressure in Panna Formation

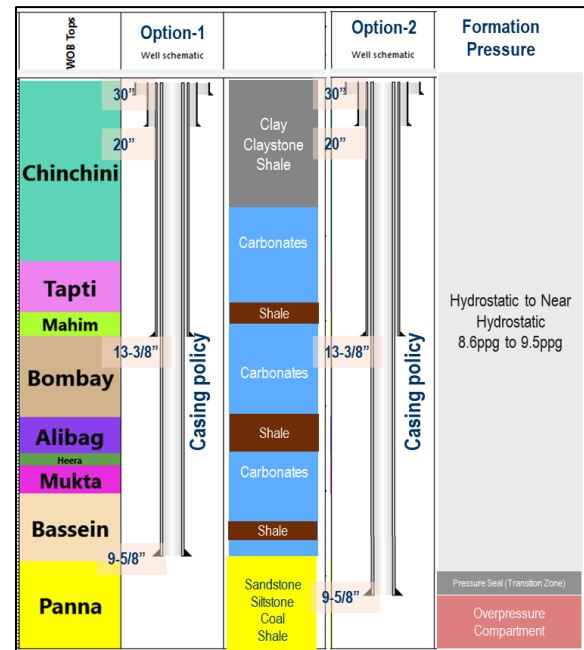
Third case (c) is peculiar and most challenging as, here Panna Formation shows dual pressure regime i.e. both near hydrostatic and overpressure exists inside Panna Formation. Here, transition zones further shift inside Panna Formation, making it challenging to take

decision over casing policy. **Figure-10** shows two options of 9-5/8” casing policy. Option-1 is usually adopted in the region with challenge of losses in coal and low-pressure sands.

### Conclusions

Based on the comprehensive analysis conducted at different fields of WOB, key take away points are summarized below:

- Overpressure in Panna Formation exists in a triangulated area adjacent to the Mumbai High Oilfield area.
- Panna Formation shows dual pressure regime with variation from hydrostatic (~8.6ppg) to maximum of 17.5ppg. In majority of the areas, pore pressure variation is related to the thickness and presence of coal inside Panna Formation. In general, areas with thicker Panna Formation has shown high pressure. Having said that, exceptions has been observed in the exploration blocks located in the south-east direction located towards the shore where coal% is lower.



**Figure 10:** Case-(c)-Decision of Casing Policy Based on Lithofacies and position of sealing compartment for overpressure in Panna Formation

- Initiation of pressure ramp is variable and is observed in both overlying Lower Bassein and Devgarh Formations as well as inside Panna Formation.



## Drilling Solutions and Overpressure Characterization for Panna Formation

- In some of the wells, high pressure in Panna Formation is observed after thick shale and carbonate marker. The sealing capacity of this zone is observed as high as ~4500psi.
- Trend of density versus velocity and effective stress versus velocity crossplots indicates overpressure is caused by hybrid mechanism which is categorized as Type-II. It suggests that the formation is recharged with extra fluid without a substantial increase in porosity.
- Bower's velocity versus effective stress crossplot suggests overpressure points lie in the unloading zone where porosity based PP estimation doesn't work.
- One possible phenomenon undergoing inside Panna is thermal cracking of hydrocarbons. This hydrocarbon Maturation in a "closed" environment could lead to overpressure. Literature indicates presence of montmorillonite and illite clays indicating all smectite might have been converted to illite at this temperature conditions.
- Higher geothermal gradient is observed while entering the high-pressure Panna Formation.
- At few well locations in proximity to faults, panna seems to be over pressured at shallower depths possibly being charged through faults with maximum PP~14ppg-15ppg.
- High pressure Panna Formation is isolated from overlying normal pressure formations by setting a casing to prevent any losses.
- Coals inside Panna formation are prone to losses due to lower fracture gradient under higher ECD values. Sealing agents can be used to strengthen and avoid losses.

## References

1. Eaton, B. A., 1975, the equation for geopressure prediction from well-logs: Society of Petroleum Engineers Paper 5544.
2. Bowers, G. L., 1994, Pore pressure estimation from velocity data: accounting for overpressure mechanisms besides undercompaction: International Association of Drilling Contractors/Society of Petroleum Engineers Drilling Conference, Society of Petroleum Engineers paper 27488, p. 515–530.
3. Kumar, P., Rai, K., Sangeeta, Verma, R. P., An Innovative Approach for Formation Evaluation of Complex Panna Formation in Heera Field, Mumbai Offshore: 5th Conference & Exposition on Petroleum Geophysics, Hyderabad-2004, India PP 106-110
4. Hoesni, M. J. 2004. Origin of Overpressure in the Malay basin and its effect on the petroleum System (PhD thesis), University of Durham
5. Ghosh, A., Zacharia, J., Majithia, P. S., Saxena, R., Nirala, A. K., & Narla, S. (2019, April 8). Petrophysical Characterization of Mineralogically Complex Panna Formation: An Alternate Approach. Society of Petroleum Engineers. doi:10.2118/194639-MS
6. Kumar R.R., Talreja R., Kakrania A., Roy S., "Integrated Pore Pressure Prediction for Successful Drilling of a HP Deep Exploration Well, North-East India", presented at the GEO-INDIA conference, 2015 (Paper ID: 2011835).
7. Zutshi, P.L., A. Sood, P. Mohapatra, K.K.V. Ramani, A.K. Dwivedi, and H.C. Srivastava, 1993, *Bombay offshore basin lithostratigraphy of Indian petroliferous basins (documentV)*: Unpublished document, KDMIPE, ONGC Dehradun.
8. Biswas, S.K., Lal. H, 2006, Sand Dispersal Pattern within Panna Formation in Central Graben, Bombay Offshore Basin: A Model Based Approach, INTEG, GEOPIC, ONGC, GEOHORIZONS PP 38-42
9. Shaker, S., 2014, Reservoir vs. Seal Pressure Gradients: Calculations and Pitfalls, AAPG 2014, Annual Convention; ID# 1834685

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