First order pore pressure modeling in Naga Schuppen belt- NE India

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Summary

The pressure of fluids within the pores of a reservoir is usually hydrostatic pressure defined as the pressure exerted by a column of water from the formation's depth to sea level. The compaction of sedimentation of impermeable rocks such as shales does not always allow their pore fluids to escape and thus support the total overlying rock column, leading to anomalously high formation pressures. The computation of pre drilling pore pressure is an integral part of well planning. The estimated pore pressure and its derivative, fracture pressure, provides mud weight to be used for drilling. If the abnormal pressures are not accurately predicted prior to drilling, catastrophic incidents, such as well blowouts and mud volcanoes, may take place.

In the present study, we computed the pore pressure in Naga Schuppen belt of NE India to establish hydraulically-connection between the formations. In order to achieve the adequate spatial distribution, we used five wells corresponding to different regime. We computed pore pressure using Eaton's method with inputs as sonic log for compaction trend computation and gamma ray log for shale volume cutoff. Interpretation of pore pressure in zones, Miocene Sand reservoir unit of Supra thrust Girujan, Barail formation and Sub-thrust and sand lenses in Girujan clay shows a persistent over pressure in all the wells, deciphering a regional hydraulic connectivity.

Introduction

Pore pressure analyses include three aspects: (i) pre-drill pore pressure prediction (ii) pore pressure prediction while drilling and (iii)post-well pore pressure analysis. The pre-drill pore pressure can be predicted by using the seismic interval velocity data in the planned well location as well as using geological, well logging and drilling data in the offset wells. The pore pressure prediction while drilling mainly uses the logging while drilling (LWD), measurement while drilling (MWD), drilling parameters, and mud logging data for analyses. The post-well analysis is to analyze pore pressures in the drilled wells using all available data to build pore pressure model, which can be used for pre-drill pore pressure predictions in the future wells.

The Assam-Arakan Basin is situated in the northeastern part of India categorized as category-I basin (Figure: 1). More than 100 oil and gas fields, including Jorajan, Kumchai, Hapjan, Shalmari, Lakwa, Lakhmani, Geleki, Amguri, Charali, Borholla, Khoraghat, Baghjan, Dirok etc. have been discovered. . So far various play types, structural, stratigraphic and strati-structural, have been probed successfully.

One of producing levels in the basin is Miocene Sand. Miocene sands are basically non continuous sand bodies and bounded by large faults and thrusts. The present case study features the Pore pressure study of the five wells in the Miocene Sand reservoir unit of Supra thrust Girujan and Barail formation and Sub-thrust and sand lenses in Girujan clay.

Study Area

The study area is a part of the the Naga-Schuppen Belt of the Assam Arakan Basin (Figure:1). The study area is covered by 2D and 3D seismic data and five wells. Out of these wells, 3 wells namely Well-A, Well-B and Well-C proved to be fluid bearing (Figure: 2). The major formations encountered by the wells in the study area are Namsang formation, Girujan formation and Barail formation. Girujan Sand has gas discovery.

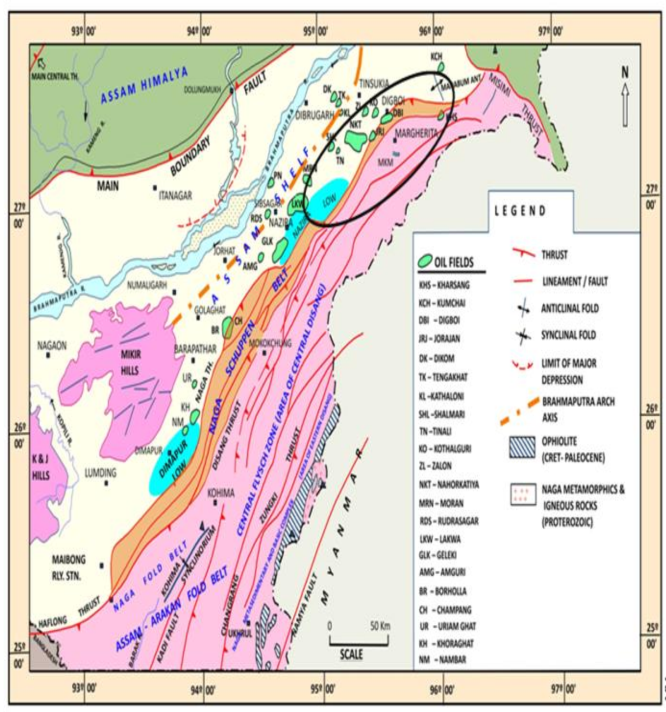

Fig.1: Study area

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Fig.2: Wells plotted within the study area

Tectonics and Basin Evolution

The Assam-Arakan Basin is a polyhistory basin that evolved simultaneously with other East-Coast basins of India, concomitant with the rifting and subsequent drifting of the Indian Plate from eastern Gondwanaland. The basin was initiated in an extensional phase and later was modified by different episodes of compressive phases. The basin covers an area of 116000 Sq.Km.
The Assam Arkan Basin is divided into three major tectonic elements. They are:

- Upper Assam Shelf
- Naga Schuppen belt
- Assam-Arakan Fold belt.

The Naga Schuppen belt is sandwiched between two prospective and petroliferous zones viz the Upper Assam Shelf and the geo-anticlinal belt (Assam-Arakan Fold Belt). The occurrence of commercial hydrocarbon pools in both these zones speaks of the potentiality of the Naga Schuppen belt.
This belt is densely forested with complex geological framework and logistic limitations. There are oil fields such as Kharsang, Manbhum and Digboi in the NE part of the belt in upthrust block and Geleki, Kumchai and Changpang fields in the sub-thrust block. This provides an indicative prospectivity of the block from NE-SW-W part of the belt. Geological Section exhibits the presence of Tipam and Girujan sequences in the up thrust block and sylhet (Eocene) to Neogene sequences below the Naga thrust in the Naga-Schuppen belt. Some of these sequences hold Hydrocarbon pools in the northern part of the belt. Therefore, this inadequately explored prospective belt is of great interest for finding good sized pools in the south-western part of belt in fault controlled traps.

Methodology and Results

In this present study, post drill pore pressure analysis is done for five wells in Naga Schuppen belt region of Assam Arakan Basin.

Abnormal pore pressure and drilling incidents:

Abnormal pore pressures, particularly overpressures, can greatly increase drilling non-productive time and cause serious drilling incidents (e.g., well blowouts, pressure kicks, fluid influx). Overpressures can be generated by many mechanism, such as compaction disequilibrium (under- compaction), hydrocarbon generation and gas cracking, aquathermal expansion, tectonic compression (lateral stress), mineral transformations (e.g., illitization), and osmosis, hydraulic head and hydrocarbon buoyancy (Gutierrez et al, 2006; Swarbrick and Osborne, 1998). In nearly all cases where compaction disequilibrium has been determined to be the primary cause of overpressuring, the age of the rocks is geologically young.

Pore pressure and pore pressure gradient:
Pore pressure is one of the most important parameters for drilling plan, geomechanical and geological analysis. The pore pressure gradient is more practically used in drilling engineering, because the gradients are more convenient to be used for determining mud weight (or mud density).
Pore pressure varies from hydrostatic pressure, to severe overpressure quatified as 48% to 95% of the overburden stress. If the pore pressure is lower or higher than the hydrostatic pressure (normal pore pressure), it is abnormal pore pressure resulting in under and overpressure.
The fundamental theory for pore pressure prediction is based on Terzaghi's and Biot's effective stress law (Terzaghi et al., 1996; Biot, 1941). The theory indicates that pore pressure in the formation is a function of total stress (or overburden stress) and effective stress. The overburden stress, effective vertical stress and pore pressure can be expressed in the following form:

$$p = (\sigma_v - \sigma_e) / \alpha \quad \ldots\ldots\ldots\ldots(1)$$

Where p is the pore pressure, σ_v is the overburden stress; σ_e is the vertical effective stress; α is the Biot effective stress coefficient, which is generally assumed unity in geo-pressure community.

Fracture pressure and fracture gradient:
Fracture pressure is the limiting pressure required to fracture the formation and cause mud loss from wellbore into the induced fracture. Fracture gradient can be obtained by dividing the true vertical depth from the fracture pressure. Fracture gradient is the maximum mud weight.

Pore pressure computation:

Eaton (1975) presented the following empirical equation for pore pressure gradient prediction from compressional sonic transit time:

$$P_{pg} = OBG - (OBG - P_{ng})\,(\Delta t_n / \Delta t)^3 \quad \ldots\ldots\ldots(2)$$

Where Δt_n is the sonic transit time or slowness in shales at the normal pressure; Δt is the observed sonic

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transit time in shales obtained from well logging, and it can also be derived from seismic interval velocity. This method is pervasively applicable in petroleum basins. To apply this method, one needs to determine the normal transit time Δt_n.

The proposed methods have been applied in Naga Schupam belt region of Assam Arakan basin to verify the applicability. Five examples of wells in the Naga Schupam area are presented in the following section.

Results:

The vital requirement for pore pressure computation is overburden gradient and overburden pressure. These profiles are computed beforehand by using simple model obtained from Newtonian compaction relationship. The overburden gradient profile for wells A, B,C,D and E is shown in Fgiures 3,5,7,9 and 11. The overburden gtadient and pressure does not show any abnormality and does not merit a detailed discussion. We will present here a step by step analysis of pre pressure profile in detail, which is as follows:

Well-A:

- The pressure profile (Figure:4) with depth in this well is similar to many geologically young sedimentary basins where overpressure is encountered at depth.
- At relatively shallow depths (less than 500m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth.
- Deeper than 500m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from shallower ones.
- By 1190 m, pore pressure reaches to a value close to the overburden stress, a condition referred to as hard overpressure.
- The increase in overpressure causes reduction in the effective stress.

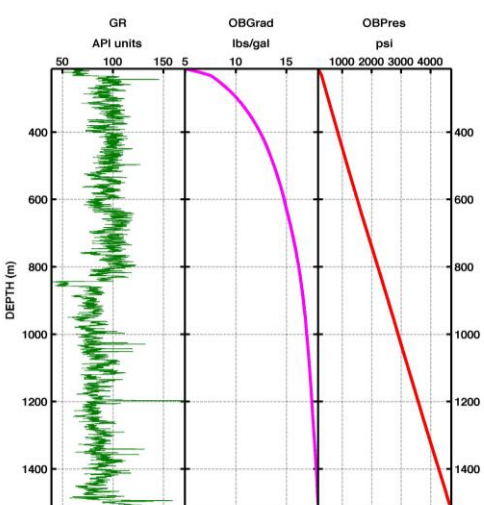

Fig.3: GR Vs Overburden gradient Vs Overburden Pressure

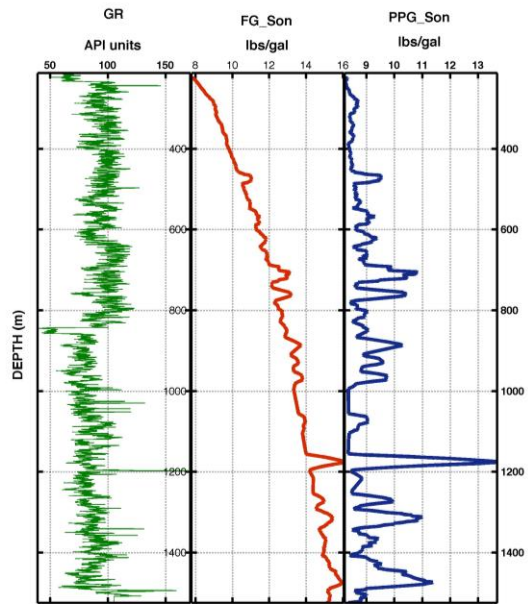

Fig.4: GR Vs Fracture gradient Vs Pore-Pressure gradient

Well-B:

- The pore pressure profile (Figure:6) at relatively shallow depths (less than 500m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth.
- Deeper than 700m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from shallower ones.
- By 1000m, pore pressure reaches to a value close to the overburden stress, a condition referred to as hard overpressure.

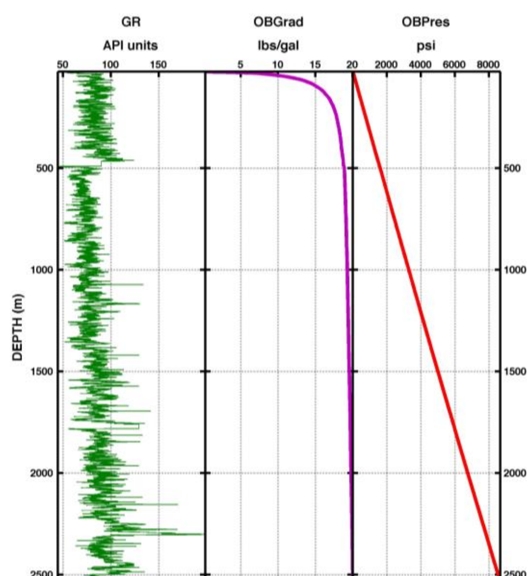

Fig.5: GR Vs Overburden gradient Vs Overburden Pressure

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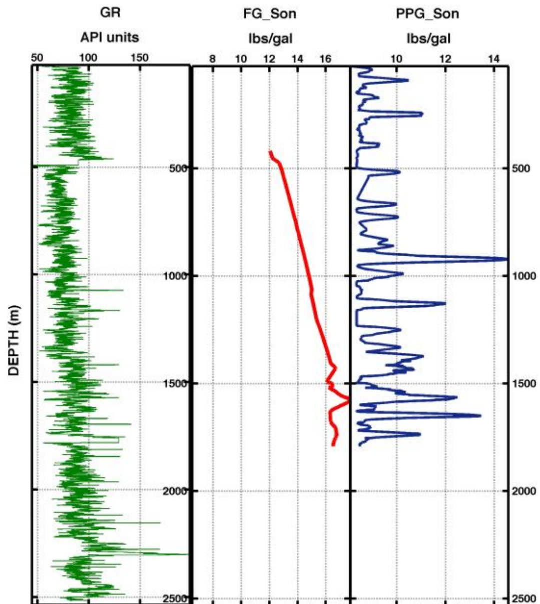

Fig.6: GR Vs Fracture gradient Vs Pore-Pressure gradient

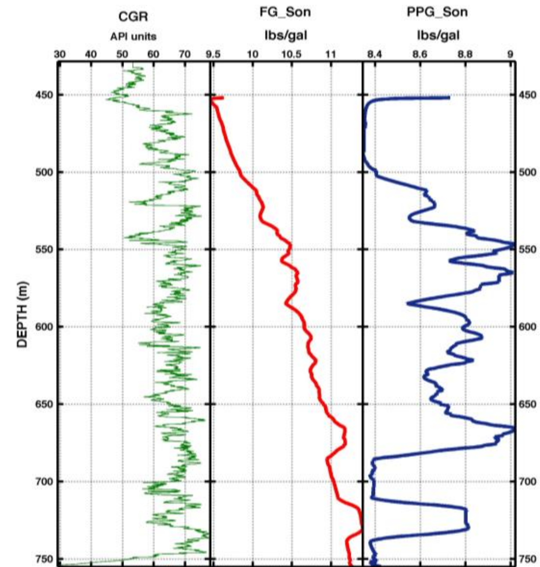

Fig.8: GR Vs Fracture gradient Vs Pore-Pressure gradient

Well-C:

- The pore pressure profile (Figure:8) at relatively shallow depths (less than 550m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth.
- Deeper than 650m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from shallower ones.

Well-D:

- The pore pressure profile (Figure:10) at relatively shallow depths (less than 1000m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth.
- Deeper than 1200m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from shallower ones.
- Beyond 1600m, pore pressure reaches to a value close to the overburden stress, a condition referred to as hard overpressure.

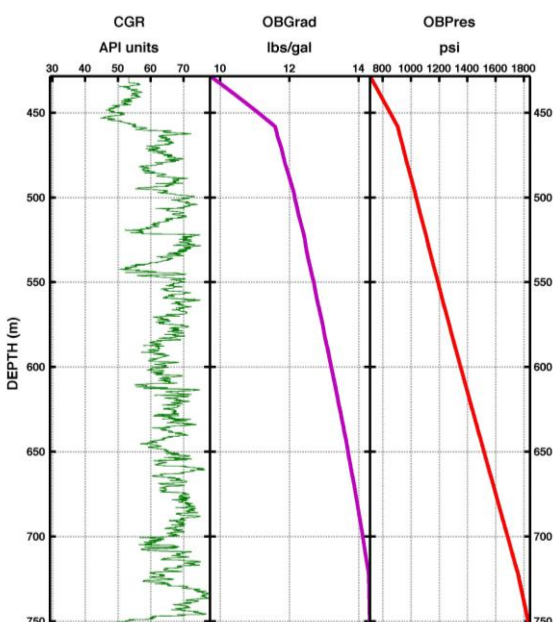

Fig.7: GR Vs Overburden gradient Vs Overburden Pressure

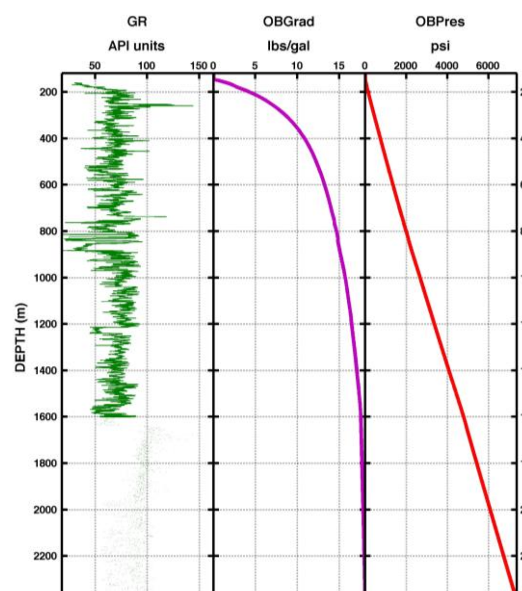

Fig.9: GR Vs Overburden gradient Vs Overburden Pressure

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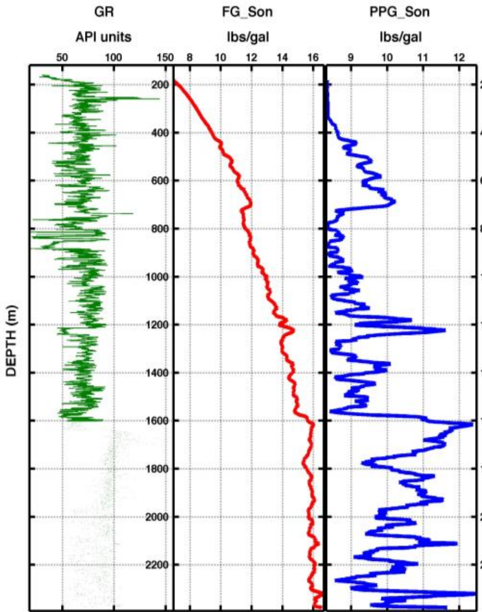

Fig.10: GR Vs Fracture gradient Vs Pore-Pressure gradient

Well-E:

- The pore pressure profile (Figure:12) at relatively shallow depths (less than 1000m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth.
- Deeper than 2000m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from shallower ones.

Conclusion

We compute the first order pore pressure profiles in Naga-Schuppen belt by adopting Eaton's method. Since Eaton's method suffers with the problem of unloading effect, which we circumvented by computing an accurate compaction trend using sonic-log. The first order pore pressure modeling in the present study area shows a consistent overpressure zone varying from 9.5-12.5ppg in formation Miocene. The consistency of this abnormal pressure shows presence of fluid and more importantly a hydraulic connection among the fluid bearing formation across the area. This analysis provides an important input to the dynamic and static reservoir modeling as well. The pore pressure gradient computed can be used as drilling inputs for future drilling or an initial input to the detailed pore-pressure modeling using seismic velocity cube. A second order map with seismic velocity input will be our next challenge with more inclusions of well and LOT data.

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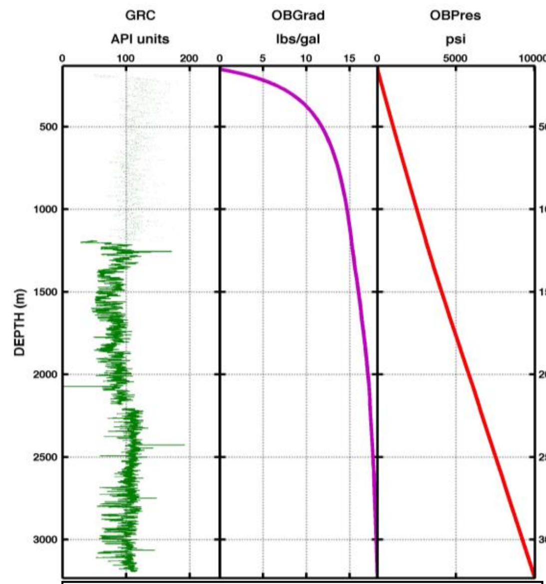

Fig.11: GR Vs Overburden gradient Vs Overburden Pressure

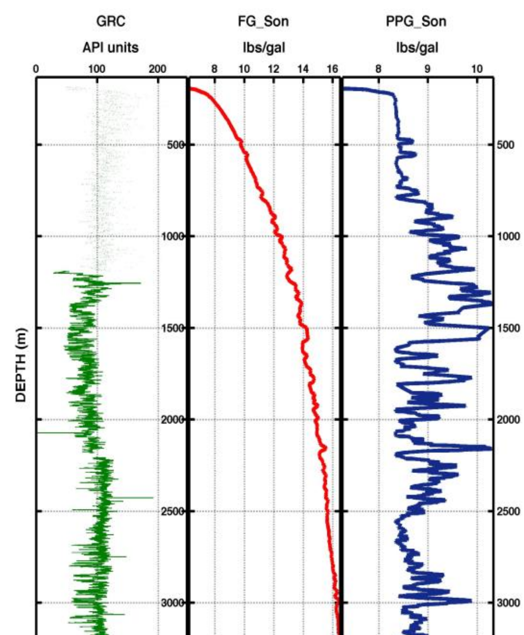

Fig.12: GR Vs Fracture gradient Vs Pore-Pressure gradient

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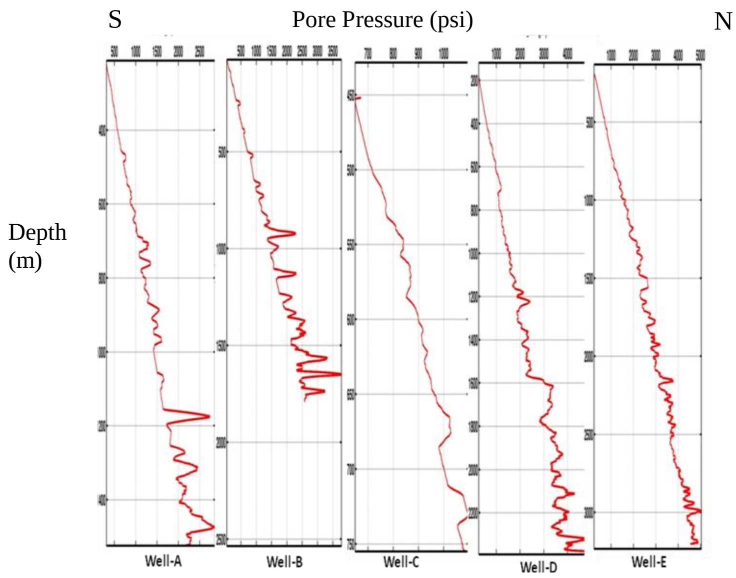

Fig.13: Comparison of Pore-Pressure between the wells

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