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THE IMPORTANCE OF GEOLOGICAL AND HYDROGEOLOGICAL KNOWLEDGE IN JUSTIFYING PORE PRESSURE PREDICTION: THE CASE STUDY OF THE PECIKO FIELD, LOWER KUTAI BASIN

PENTINGNYA PEMAHAMAN GEOLOGI DAN HIDROGEOLOGI DALAM MENJUSTIFIKASI HASIL PREDIKSI TEKANAN PORI: CONTOH KASUS DARI LAPANGAN PECIKO, CEKUNGAN KUTAI BAWAH

Agus M. Ramdhan
Insitut Teknologi Bandung, 10 Ganesha Street, Bandung, Indonesia
E-mail: agusmr@gc.itb.ac.id

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ABSTRAK

Salah satu faktor yang mempengaruhi prediksi tekanan pori adalah pemilihan metoda dalam kalkulasi tekanan pori tersebut. Jika kita memilih metoda yang tidak tepat, hasil estimasi tekanan pori tersebut mungkin bukan hanya tidak merefleksikan kondisi tekanan pori sesungguhnya di suatu daerah, tetapi juga tidak mencerminkan kondisi geologi yang bekerja di keseluruhan cekungan. Dalam penelitian ini, dua metoda diaplikasikan untuk menghitung tekanan pori dari log talikawat di Lapangan Peciko: Metoda Eaton dan Metoda Mekanika Tanah. Perhitungan tekanan pori yang dihasilkan dari kedua metoda tersebut menunjukkan perbedaan yang sangat signifikan. Metoda Eaton menghasilkan perbedaan tekanan reservoir dan serpih (over-prediksi tekanan reservoir) pada kedalaman dangkal dan kesamaan tekanan reservoir dan serpih pada interval yang lebih dalam. Berbeda dengan hal tersebut, Metoda Mekanika Tanah menghasilkan kesamaan tekanan reservoir dan serpih pada kedalaman yang dangkal dan underprediksi untuk interval yang lebih dalam. Dilihat dari proses yang bekerja pada lapangan ini yang mempengaruhi tekanan pori, yaitu aliran fluida reservoir secara lateral dan kecepatan sedimentasi yang tinggi, sepertinya Metoda Eaton memberikan hasil yang lebih mencerminkan tekanan pori di lapangan ini dibandingkan dengan Metoda Mekanika Tanah. Penelitian ini juga menghasilkan kesimpulan yang cukup penting: jika terdapat perbedaan tekanan antara reservoir dan serpih, maka sepertinya kondisi hidrodinamika berlangsung secara aktif.

Kata Kunci: *overpressure, eaton, soil mechanics, hidrodinamika, perbedaan tekanan.*

ABSTRACT

One significant factor affecting pore pressure prediction is choosing a method of calculation. If we choose the inappropriate method, the result may not reflect not only pore pressure condition in an area, but also geological processes operating in the whole basin. In this research, two methods are applied to wireline-based pore pressure calculation in the Peciko Field: the Eaton Method and the Soil Mechanics Method. The results of the calculation show a significant difference between these methods. The Eaton Method resulted in reservoir-shale pressure discrepancy (by over-predicting the reservoir pressure) at shallower depth, and reservoir-shale pressure equilibrium at depth. On the contrary, the Soil Mechanics Method resulted in reservoir-shale pressure equilibrium at shallower depth and an under-predicting at depth. It seems that, in terms of processes operating in this field which affect pore pressure regimes, i.e. lateral reservoir drainage and rapid mud-dominated deltaic sedimentation, the result of the Eaton Method is more plausible than that of the Soil Mechanics Method. This research also reveals an important inference: if there is a pressure discrepancy, then it is likely that a hydrodynamic condition is present.

Keywords: overpressure, eaton, soil mechanics, hydrodynamics, pressure discrepancy.

I. INTRODUCTION

The Peciko Field is located in the lower part of Kutai Basin, Kalimantan, Indonesia (Figure 1). The Kutai Basin is a Tertiary sedimentary basin with the thickness of its Neogene section possibly reaching about 14 km in its depocenter area (Allen and Chamber 1998). Sedimentologically and stratigraphically, the Peciko Field is very much affected by the development of the Mahakam Delta. The Mahakam Delta is a fluvial-tidal mud dominated delta, and it has been prograding from the Lower Miocen period to the present day (Allen and Chamber 1998). The present average sediment supply of the delta is about 8 x 106 m3 per year (Allen and Chamber 1998). With respect to these conditions, overpressure is a common phenomenon in the Mahakam Delta area, as reported by Oudin and Picard (1982), Ungerer et al. (1990), Burrus

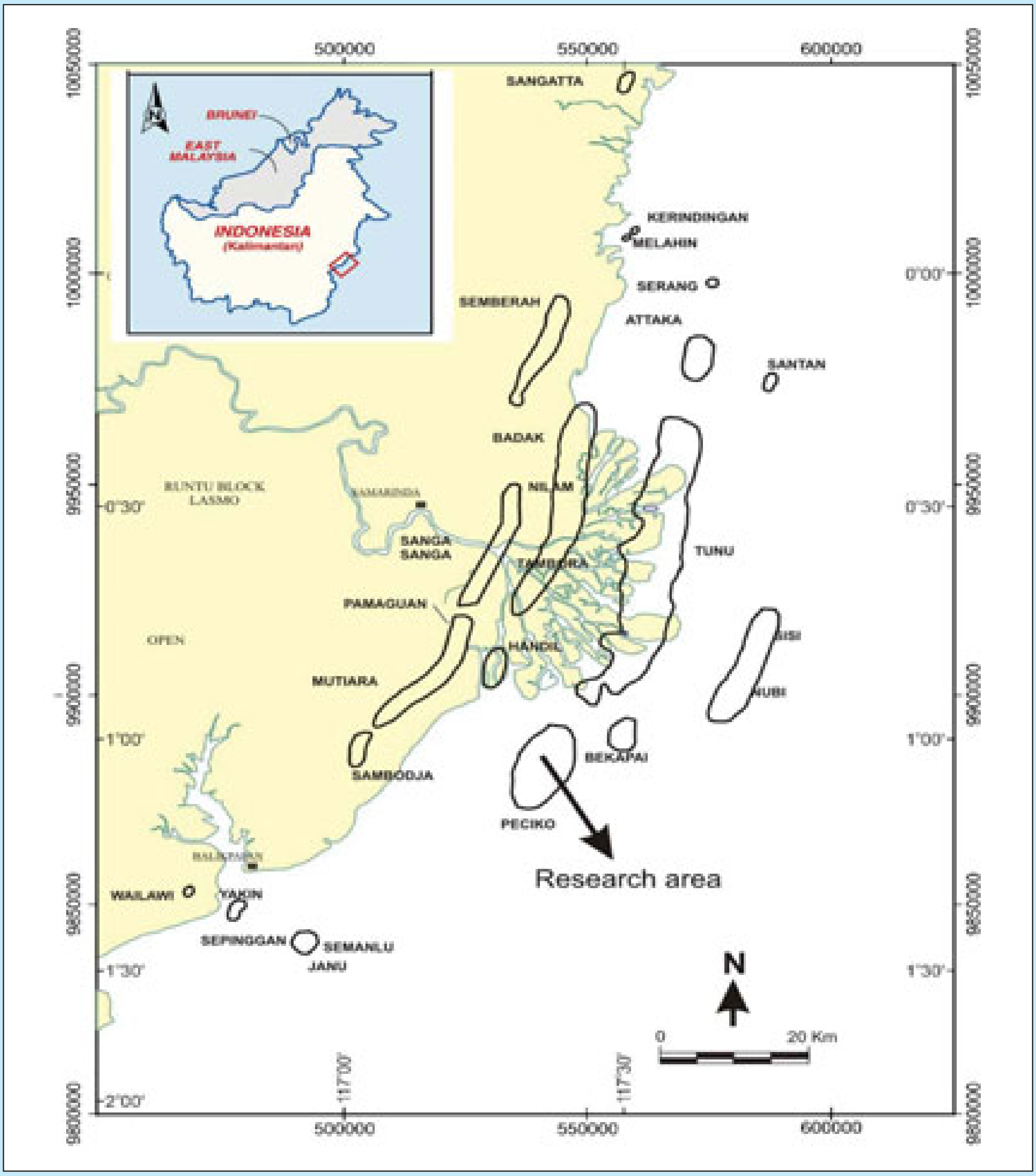

Figure 1
Research area.

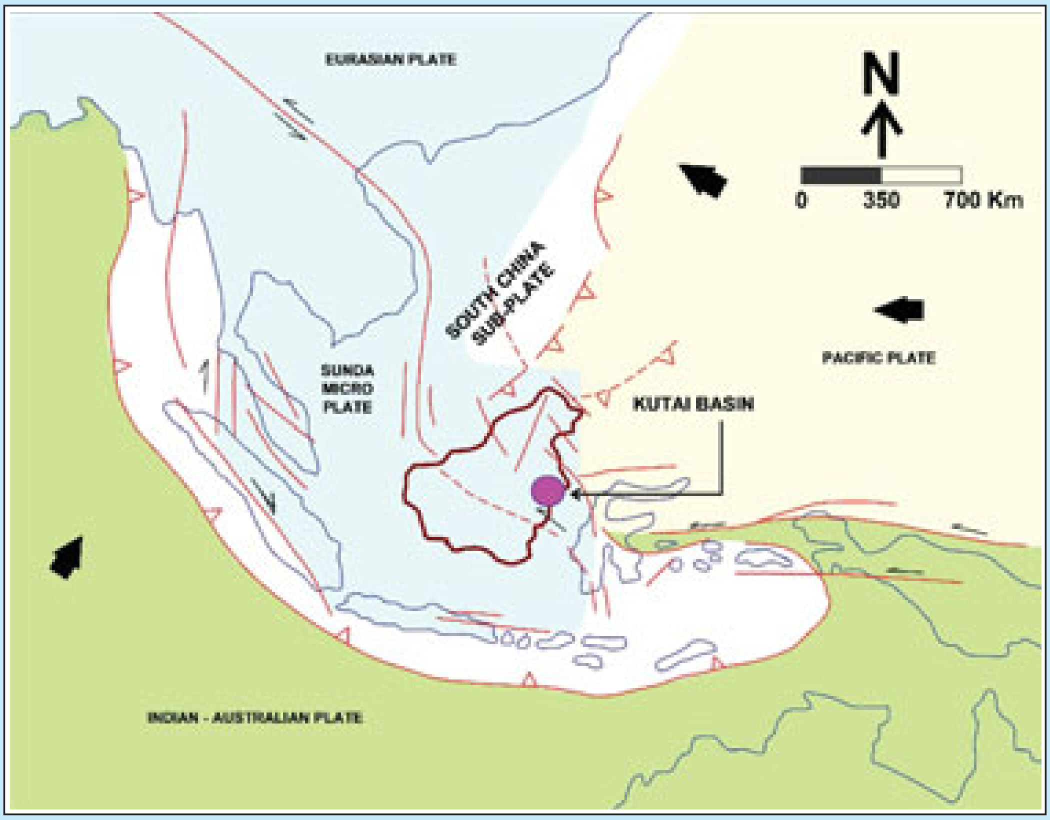

Figure 2
Tectonic framework of Kutai Basin.

et al. (1992), Bois et al. (1994), Bates (1996), and Burrus (1998).

Tectonically, the basin has experienced several rift-sag-inversions as the result of interaction between the South China Sea Sub-Plate to the north, the Pacific Plate to the east, and the Indian-Australian Plate to the south (Moss and Chambers 1999) (Figure 2). One interesting tectonic process is inversions, causing almost all sedimentary layers, including the reservoirs, in the Kutai Basin crop or sub-crop on the surface. In terms of overpressuring, at some points, depending on the degree of reservoir connectivity, this condition may cause overpressure bleed-off. This process is also known as lateral reservoir drainage.

The lateral reservoir drainage was found to present in the Peciko Field (Grosjean et al, 1994 and Lambert et al. 2003), and it forms a hydrodynamic trap in the field. In this research, overpressure values in the reservoir are systematically re-analysed and re-mapped for every stratigraphic layers. An example of reservoir a overpressure map in one stratigraphic layer in this field, together with its pressure – depth plot is shown in Figure 3. In the figure, it can be seen that gas pressures (represented by red dots) lay on a common gas gradient, indicating good reservoir connectivity. However, water pressures (represented by blue dots) do not lie on a common water gradient. This is very indicative of lateral reservoir drainage. The spatial distribution of the ovepressure in the water legs is then mapped as shown in the right figure. The overpressure gradient in this layer is about 75 psi/km, which is considered high if it is compared to other published ovepressure gradients, as can be found in Dennis (2000). For example, the North Sea Paleocene overpressure gradient is only 5 psi/km. In the map, it can be seen that direction of the reservoir lateral drainage is to the north.

In a lateral reservoir drainage environment, a reservoir bounded by the shale will posses lower overpressure than its shale. It is referred to as pressure discrepancy in this research. However, theoretically, since the shale is not impermeable, there should also still be a pressure continuity between shale and sand. O'Connor and Swarbrick (2008) coined the

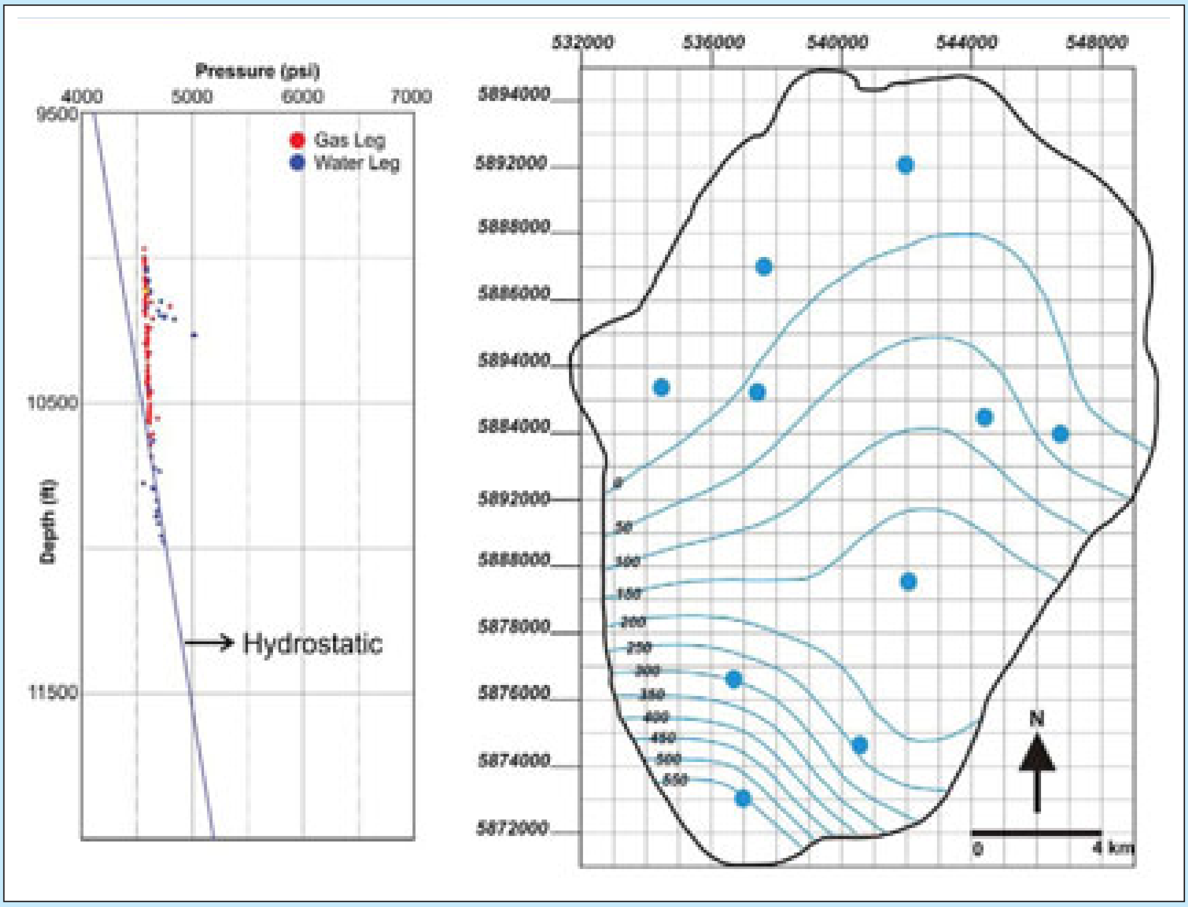

Figure 3
Lateral reservoir drainage in the Peciko Field.

term of "shoulder effect" to describe this continuity. An illustration of the pressure discrepancy and its shoulder effect is shown in Figure 4.

Since there is no direct pressure measurement in the shale, the pressure in the shale is commonly calculated by using wireline data. In such calculation, one factor that largely affects the result is the choosing of a method of calculation. Two methods that are widely used in shale pore pressure calculation are the Eaton Method and the Soil Mechanics Method. It is demonstrated in this research that, in the Peciko Field, results of pressure calculation by using the Eaton Method seems more plausible than that of the Soil Mechanics approach. Results of the Eaton calculation show reservoir-shale pressure discrepancy which captures the hydrodynamic condition in this field, and the fluid retention point with sub-parallel to lithostatic gradient pressure profile below that point which captures rapid deltaic sedimentation causing disequilibrium compaction. This research shows that the understanding of geologic and hydrogeologic processes operating in the basin is an important factor in justifying the results of the pore pressure calculation. Moreover, this research also shows that hydrodynamic condition could also be inferred from a reservoir – shale pressure discrepancy, or in other words: if there is a pressure discrepancy, then a hydrodynamic condition (lateral reservoir drainage) is present.

II. METHODOLOGY

A. The Eaton Method

The Eaton Method is widely used by companies operating in the Kutai Basin for predicting pore pressure. For example, Bois et al. (1994) analysed shale pressure in the Sisi-Nubi by using this method. Using the Eaton Method, shale pore pressure could be calculated by using a resistivity log, sonic log, or d'exponent. In this research, a sonic log is used for such calculation. Eaton's equation for the sonic log is (Eaton 1975):

$$\frac{P_f}{z} = \frac{S_v}{z} - \left(\frac{S_v}{z} - \frac{P_{f\,hyd}}{z}\right)\left(\frac{\Delta t_n}{\Delta t_{\log}}\right)^3 \qquad (1)$$

where:

P_f = fluid pressure in shale (psi)

z = depth (ft)

S_v = vertical stress (psi)

P_{fhyd} = fluid pressure at hydrostatic condition (psi)

Δt_n = sonic travel time at normal compaction trend (μs/ft)

Δt_{log} = sonic travel time read directly from sonic log (μs/ft)

Bowers (1995) wrote Eq. 1 in form of effective stress as:

$$\sigma_v = \sigma_{v_{hyd}}\left(\frac{\Delta t_n}{\Delta t_{\log}}\right)^3 \qquad (2)$$

where:

σ_v = vertical effective stress (psi)

σ_{vhyd} = vertical effective stress for normally compacted sediments (psi).

As the equation relating pore pressure and effective stress is (Eq. 3) (Terzaghi, 1967):

$$P_f = S_v - \sigma_v \qquad (3)$$

then, by combining Eq. (2) and Eq. (4), it can be obtained:

$$P_f = S_v - \sigma_{v_{hyd}}\left(\frac{\Delta t_n}{\Delta t_{\log}}\right)^3$$

or (4)

$$P_f = S_v - \left(S_v - p_{f\,hyd}\right)\left(\frac{\Delta t_n}{\Delta t_{\log}}\right)^3$$

If Eq. (5) is written in terms of pressure gradient, then it will have the same form as Eq. (1). Therefore, it can also be said that, as noted by Bowers (1995), the Eaton Method is an effective stress method, and it should be taken into consideration in determining a normal compaction line as discussed below.

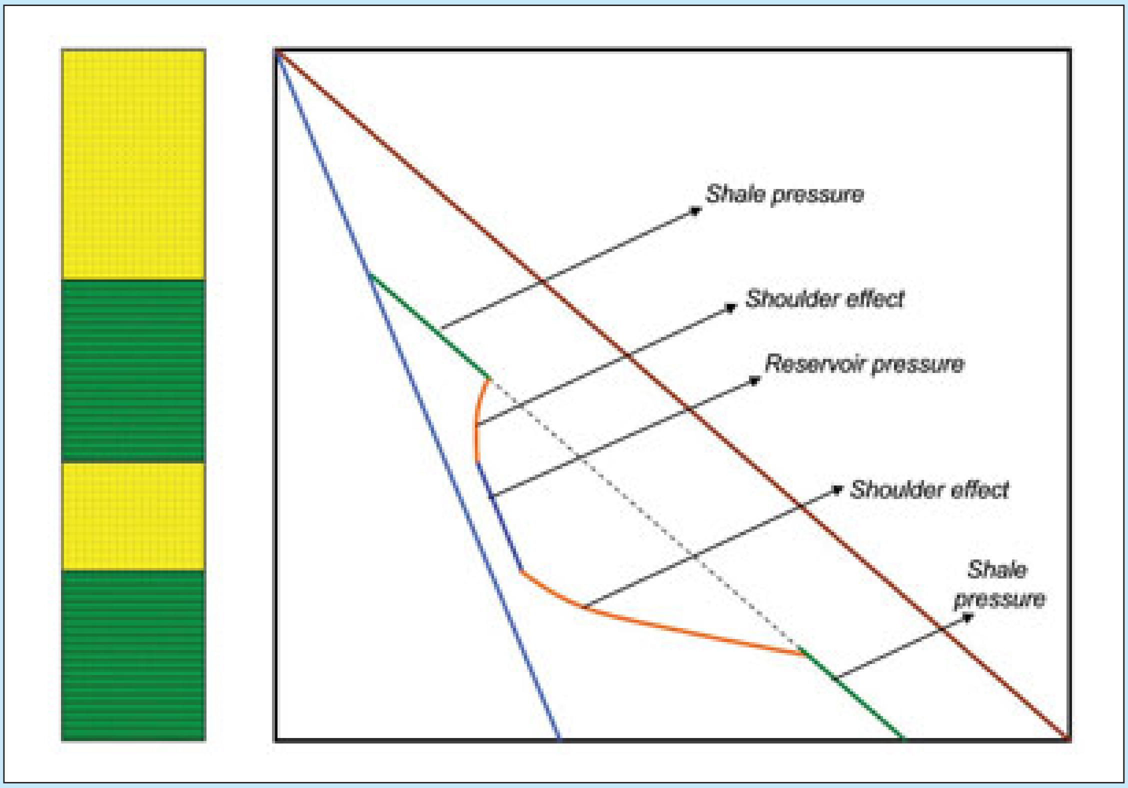

Figure 4
Illustration of reservoir – shale pressure discrepancy and its shoulder effect.

It can be seen in Eq. (1) that the parameters required to calculate shale pressure are vertical stress and normal compaction trend. Vertical stress can be obtained directly from a density log by using the equation:

$$S_v = \sum_{i=1}^{n} \rho_i g \Delta z_i \qquad (2)$$

Where:

ρ_i = bulk density at the interval (gr/cc)

g = gravity acceleration (cm/sec²)

Δz_i = depth interval (ft)

The normal compaction trend determination is both an academic and a practical discussion. It is usually constructed by extrapolating a shallower section, which is thought to be normally pressured, to depth. The problem is that there is no calibration measurement point which can be used to verify the normal trend at depth.

Bouchet and Mitchell (1[illegible]) op cit Chiarelly & Serra (1[illegible]) stated that for a tectonically inactive subsidence basin, velocity, as a proxy for porosity, could be related to depth with the exponential equation of:

$$v = ae^{bz} \qquad (3)$$

Where:

v = interval velocity (us/ft)

a = constant, obtained from best fit equation

b = constant, obtained from best fit equation

This exponential relationship is also used by Magara (1[illegible], 1[illegible]). Wahr et al ([illegible]) has proven that this relationship could be justified physically and empirically. Zahann ([illegible]) also used this exponential relationship in determining normal compaction trends both for shallower interval (smectite line) and deeper interval (illite line).

However, Bowers (1[illegible]) argued that since the Eaton Method is a vertical effective stress method, the normal trend should be in the form of a functional relationship between velocity and vertical effective stress rather than velocity vs depth. If it is done so, instead of an exponential relationship, he found that for a virgin curve (i.e. the normal compaction trend to be used for counting overpressure caused by dis-equilibrium compaction), the data exhibit power law relationship as described in the following equation could be used:

$$v = v_0 + A\sigma_v^B \qquad (4)$$

Where:

v_o = surface velocity

Mondol et al ([illegible]) pointed out that, based on a comparison of their laboratory experiments and the results from previous researchers, there is no single, simple curve that fits all the data by using exponential or log functions. In this research, both exponential and power law relationships are compared and analysed, based on measured pore pressure in the reservoir.

A. Soil Mechanics Method

The work of soil mechanics suggests that compaction behaviour of fine-grained sediments should be analysed by relating void ratio and vertical effective stress with the following equation (Burland, 1[illegible]):

$$\log\left(\frac{\sigma_v}{\sigma_{100}}\right) = \frac{e_{100} - e}{Cc},$$

or $\qquad$ ([illegible])

$$\sigma_v = \sigma_{100} \times 10^{\frac{e_{100}-e}{Cc}}$$

Where:

e = void ratio (complement of porosity)

σ_{100} = effective stress at some arbitrary vertical stress, taken here to be 1[illegible] kPa ([illegible]a)

e_{100} = the intercept of the best fit line at 1[illegible] kPa effective stress ([illegible]a)

Cc = compaction coefficient, determined from slope of the best fit line at semilog scale

Pore pressure is then calculated by combining Terzaghi's equation (Eq. [illegible]) with Eq. ([illegible]):

$$P_f = S_v - \sigma_{100} \times \frac{10^{e_{100}-e}}{Cc} \qquad ([illegible])$$

Unlike the Eaton Method, the Soil Mechanics Method requires porosity values, to be converted to void ratio. In this research, the porosity value is derived from a sonic log by using the equation of (Raiga-Clemenceau et al (1[illegible]):

$$\phi_s = 1 - \left(\frac{\Delta t_{ma}}{\Delta t_{\log}}\right)^{1/x} \qquad (1[illegible])$$

where:

ϕ_s = sonic-derived porosity

Δt_{ma} = interval transit time in the matrix, taken here 220 us/m (Issler, 1992)

Δt_{fl} = interval transit time in the fluid in the formation

x = empirical exponent used to fit the porosity and sonic transit time, taken here 2.19 (Issler, 1992)

In analysing overpressure in the study area, we used data coming from 16 exploration wells.

III. RESULT AND DISCUSSION

A. Eaton Method

Vertical stress profiles in the Peciko Field, obtained directly by applying Eq. (5) is shown in Figure 5. As can be seen in the figure, down to the depth of 14,000 ft, the vertical stress in this field is still less than 1 psi/ft.

Typical sonic vs depth profile in semi-log profile in the Peciko Field is shown in Figure 6. Bois (1994) suggested that threshold depth for normally compacted sediments is assigned if, visually, the data no longer falls into a straight line. As can be seen in the Figure, this situation happens at the depth of 6000 ft.

The normal compaction trends are then constructed until the depth of 6000 ft for each GR class. Both exponential and power equations of the normal compaction trends are shown in Table 1. An example of the application of this normal compaction trend for the class of 70 ≤ API GR < 80 to the actual sonic velocity measurement is shown in Figure 7.

In Figure 7, it can be seen that compared to the exponential equation of sonic velocity vs depth, the power equation of sonic velocity vs vertical effective stress give a lesser overpressure at shallower interval and higher overpressure at deeper inteval. A comparison between results from the both normal compaction trends for NWP-9 well is shown in Figure 8. The lowest point of pressure measurement is used as a calibration point, since this point is geologically interpreted as an isolated reservoir implying that shale pressure is in equilibrium with sand pressure. In the figure, it can be seen that the exponential trend could predict this point perfectly, while the power trend over-predicts this point. Based on this fact, it is decided that the normal compaction trend to be used in this research is the exponential trend.

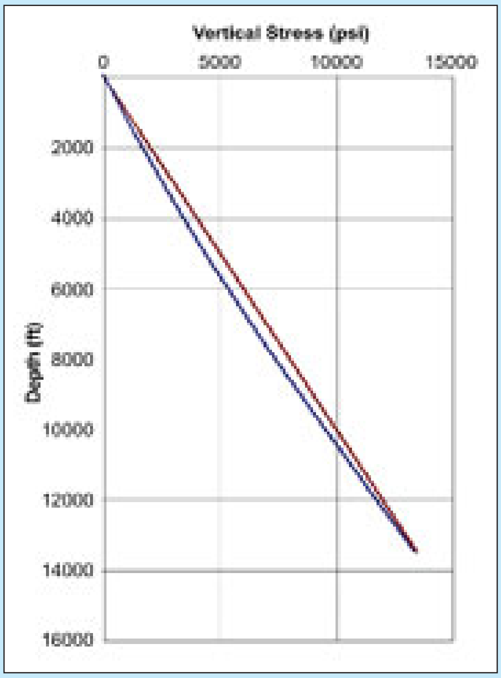

Figure 5
Typical vertical stress in the Peciko Field (blue line) and 1psi/ft line (dark red line) for comparison.

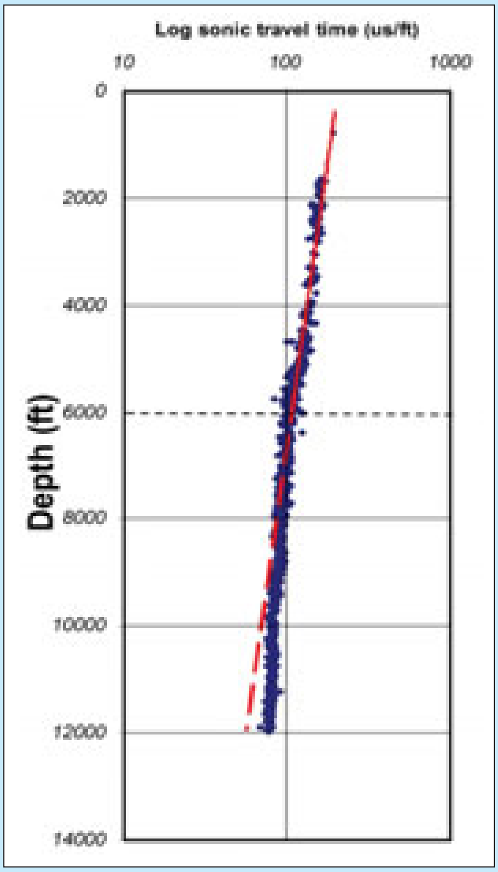

Figure 6
Typical log sonic – depth plot in the Peciko Field.

Table 1
Normal compaction line equation

No		Relationship	Normal trend equation
1		**Velocity vs depth**	**Exponential**
	a	70 = API GR < 80	$v = 182e^{-9x10^{-5}z}; R^2 = 0.7456$
	d	80 = API GR < 90	$v = 186.136e^{-9x10^{-5}z}; R^2 = 0.7513$
	c	90 = API GR = 100	$v = 190.038e^{-9x10^{-5}z}; R^2 = 0.7864$
2		**Velocity vs vertical effective stress**	**Power**
	a	70 = API GR < 80	$v = 200 - 1.337\sigma_v{}^{0.5308}; R^2 = 0.7651$
	b	80 = API GR < 90	$v = 200 - 0.83084\sigma_v{}^{059}; R^2 = 0.7927$
	c	90 = API GR = 100	$v = 200 - 0.5874\sigma_v{}^{0.6318}; R^2 = 0.8375$

Exponent "3" in the Eaton Method is an empirical constant used to fit the calculation with the data. Prior to directly applying the Eaton Method to all wells used in this research (16 wells), the exponent used in the Eaton Method is changed systematically in order to know the sensitivity of the equation to the exponent.

The well to be used for the sensitivity analysis is also NWP-9 for the same reason as in analysing the normal compaction trends. Verification cannot be referred to the other measurement points in this well since the reservoirs are in good connectivity which raises a possibility of the presence of lateral reservoir drainage as discussed previously.

The first step in the sensitivity analysis is changing the exponent "3" into the value in between 2 and 3 (2, 2.2, 2.4, 2.6, and 2.8). Results of the sensitivity analysis are shown in Figure 9. In Figure 7, it can be seen that reservoir pressure in the lowest part could be approximated reasonably not only by exponent 3, but also by the exponents of 2.6 and 2.8. The exponents of 2, 2.2, and 2.4 give an underestimation in predicting the reservoir pressure. Figure 10 shows the sensitivity analysis for the exponent greater than 3, i.e. 3.5 and 4. In the figure, it can be seen that exponents greater than 3 cause an overestimation of reservoir pressure prediction.

From the above sensitivity analysis, it can be concluded that the original Eaton exponent of 3 is the upper limit that can be used for pressure prediction in this basin. The lower limit for the pressure prediction is the exponent of 2.6. It can be stated that any exponents greater that 3 or lower than 2.6 will cause overestimation or underestimation of pressure

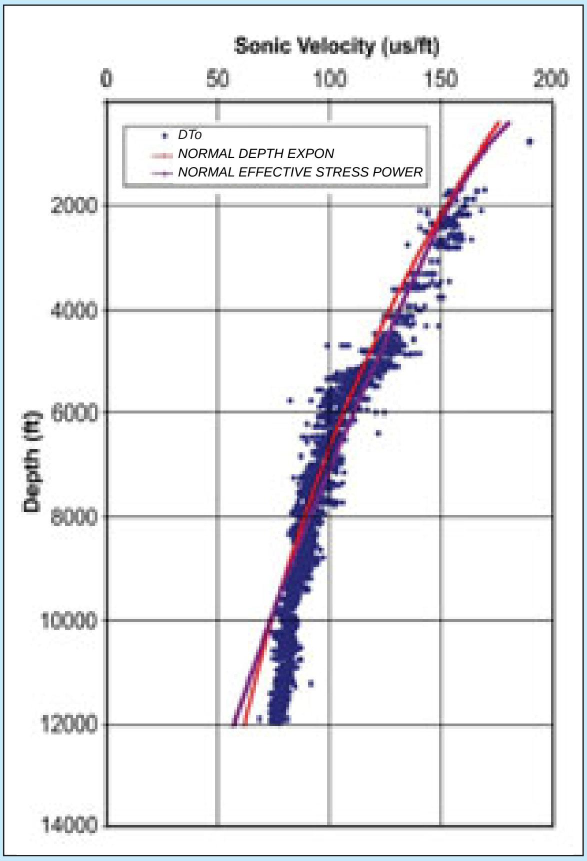

Figure 7
Application of normal compaction trends to actual data in the Peciko Field.

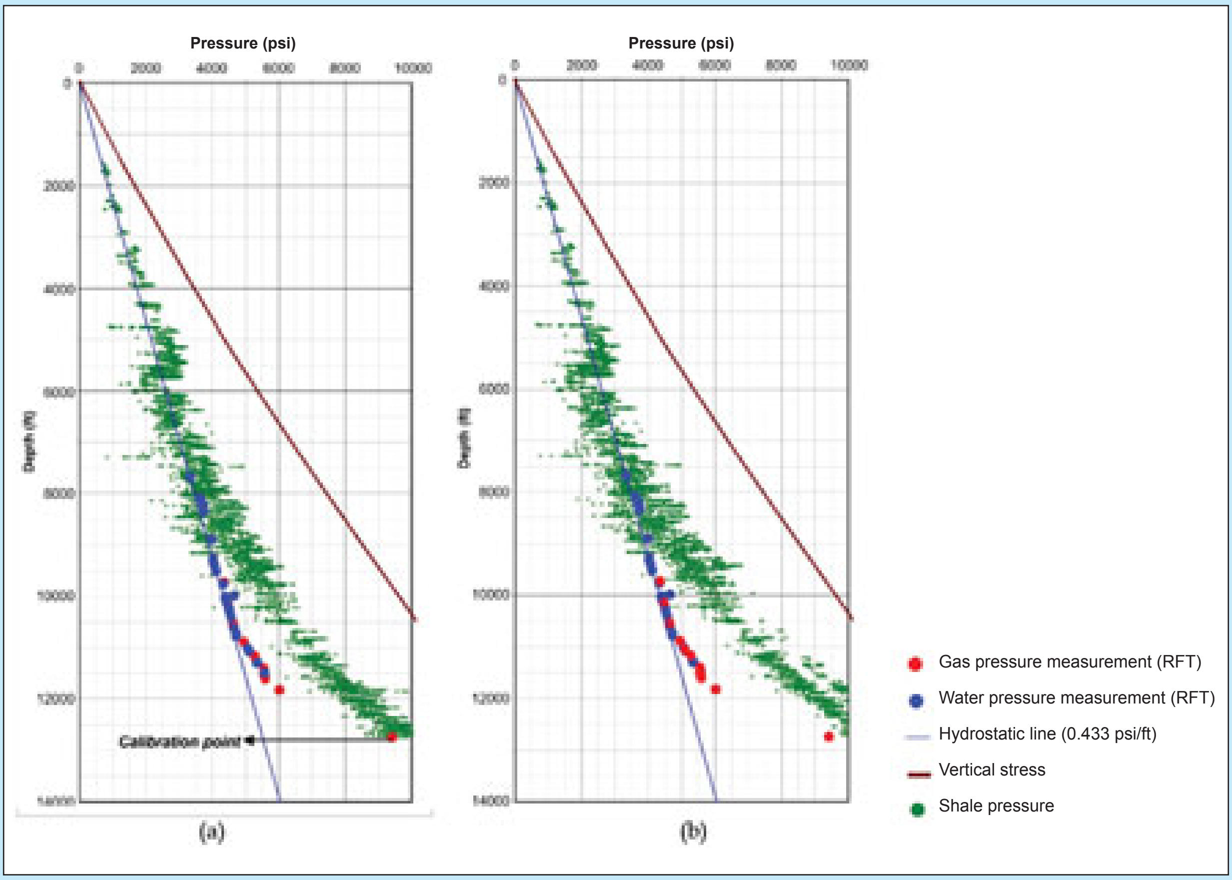

Figure 8
Comparison of pore pressure in NWP-9 well resulted from a) exponential normal compaction trend, b) power normal compaction trend.

prediction, respectively. An interesting point that could also be observed from the sensitivity analysis is that all reliable exponents (2.6 ≤ exponent ≤ 3) show reservoir-shale pressure discrepancy in the shallower section.

In this research, exponent 3 is used in shale pressure calculation. The choice of using this exponent is to make consistency with the previous works using this method in this basin, so that, in the future work, the result could be compared.

We have applied the Eaton's method to 16 wells in the study area. Typical results are shown in Figure 11. Several observations that could be drawn regarding the result are the following:

1. reservoir – shale pressures show discrepancy at shallower interval and reservoir – shale pressure equilibrium at depth as observed in NWP-9 (figures 8, 9, and 10).
2. the maximum pressure discrepancy is observed in NWP-16, i.e. about 4000 psi (Figure 11).
3. the presence of sub-parallel pressure profile to lithostatic stress could be well observed both from the exponential and power normal compaction trends.
4. the departure depth of the sub-parallel pressure profile (fluid retention depth/ Swarbrick et al, 2002) varies in every well, from about 6500 ft to 7500 ft.
5. several wells could be grouped based on the relative amount of pressure-discrepancy:
   1. higher pressure discrepancy: NWP-8, NWP-13, and NWP-16 (Figure 11)
   2. lower pressure discrepancy (close to shale – reservoir pressure equilibrium): NWP-11, NWP-14, and NWP-15 (Figure 11).

B. Soil Mechanics Method

Compaction parameters for each GR class obtained from vertical effective stress – void ratio plot are shown in Table 2. As can be seen in the table, for each GR class, the compaction parameters do not vary very much. An example of the vertical effective stress – void ratio plot to determine the compaction parameters is shown in Figure 12.

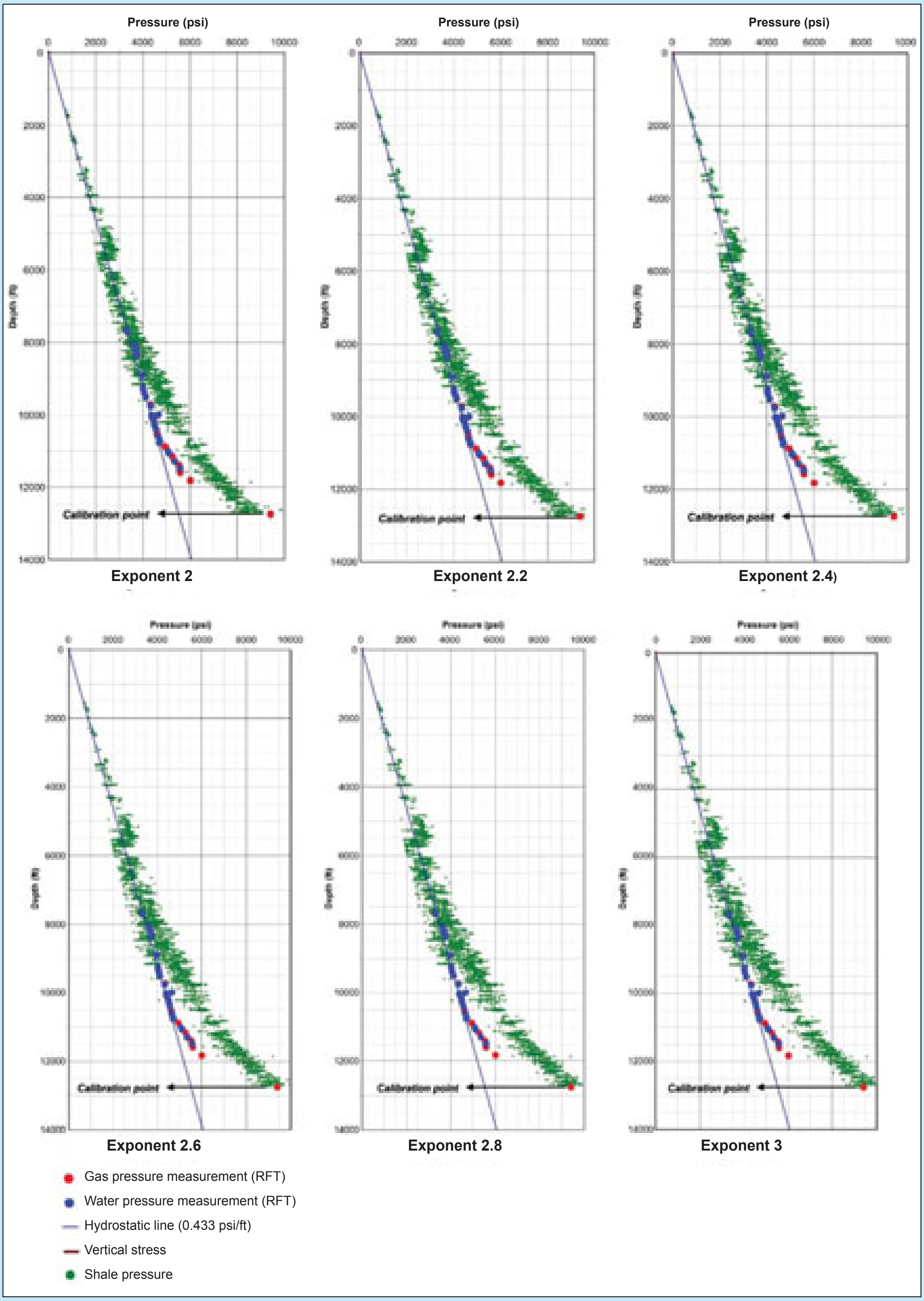

Figure 9
Sensitivity analysis of Eaton Method to the exponent with the exponent in between 2 and 3 in NWP-9 well.

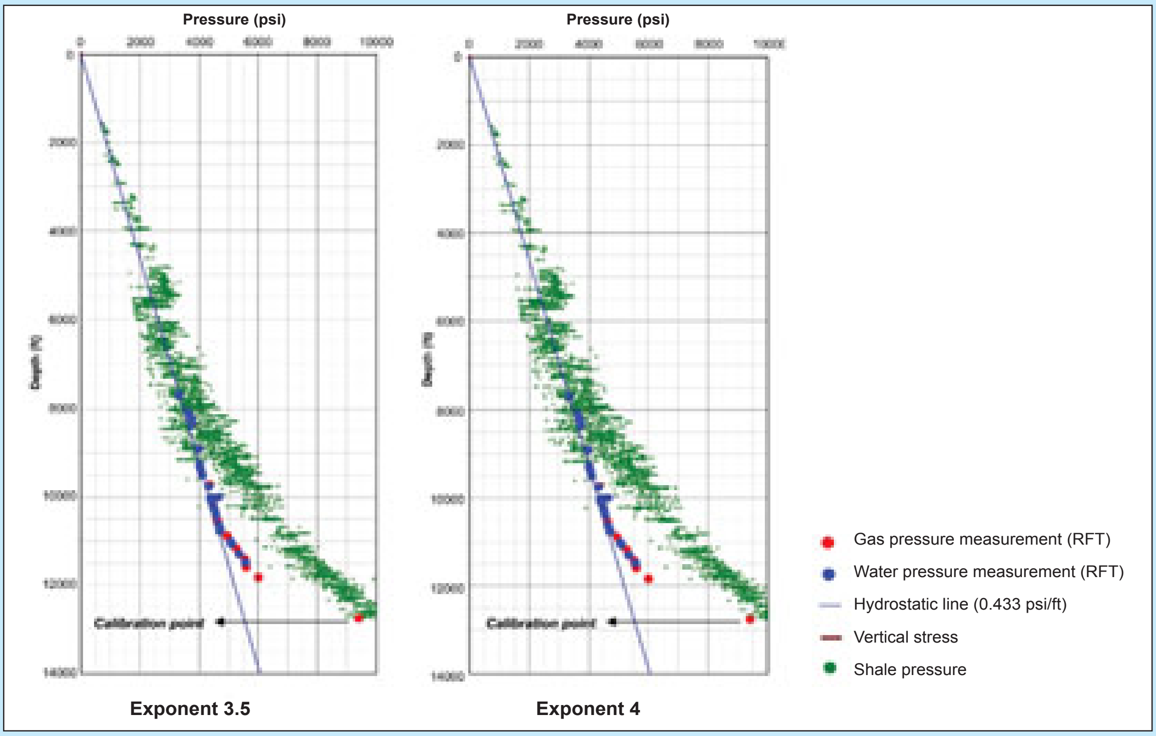

Figure 10
Sensitivity analysis of Eaton Method to the exponent with the exponent greater than 3 in NWP-9 well.

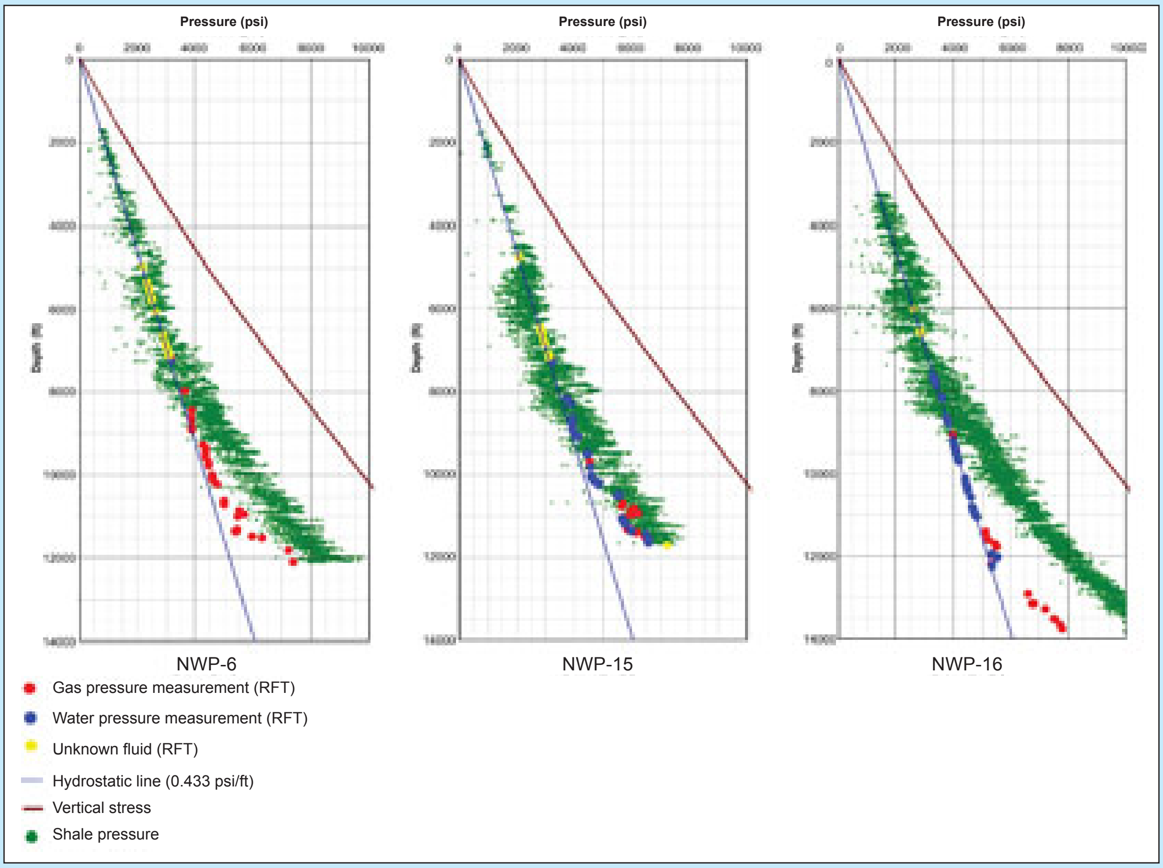

Figure 11
Typical results from eaton method.

We have applied the Soil Mechanic method for 16 wells in the study area. A typical result is shown in Figure 13. All of the results share a similarity, i.e. reservoir – shale pressure equilibrium at shallower interval which is hydrostatically pressured and under-predicted at depth. Moreover, the lithostat-parallel pressure profile is also absent in the result.

IV. DISCUSSION

From the above description, it seems that the results from the Eaton Method are more plausible for the following reasons:

1. pore pressure predicted in the shale is what it would be expected for rapid burial, mud dominated young deltaic sediment, i.e. sub-lithostatic parallel at depth
2. leak-off test (LOT) values in the Peciko Field as shown in Figure 13, show that the LOTs give high value (about 40% of Sv) for Sh at depth which implies that pore pressures are overpressured
3. reservoir – shale pressure discrepancy is also what it would be expected for an active hydrodynamic environment

If results from the Soil Mechanics Method are correct, then overpressure in the reservoir at deeper interval (as under-predicted by this method) must be due to other mechanisms besides disequilibrium compaction, such as lateral transfer and fluid expansion. If these overpressure in the reservoir is transferred into the shales, then one could argue that Point 2. above could also be explained by this process.

A schematic of the lateral transfer is shown in Figure 14. In the figure, it can be seen that the direction of the pressure transference is from a structurally higher region to a lower region. Structurally, the Peciko Field is lower than the northern area. Therefore, if there is a lateral pressure transfer, it should be directed from the northern area

Table 2
Compaction parameters for each GR API class

No	Lithologic class (GR API)	e_{100}	Cc
1	70 ≤ GR API < 80	1.36	0.5
2	80 ≤ GR API < 90	1.46	0.52
3	90 ≤ GR API < 100	1.4	0.5

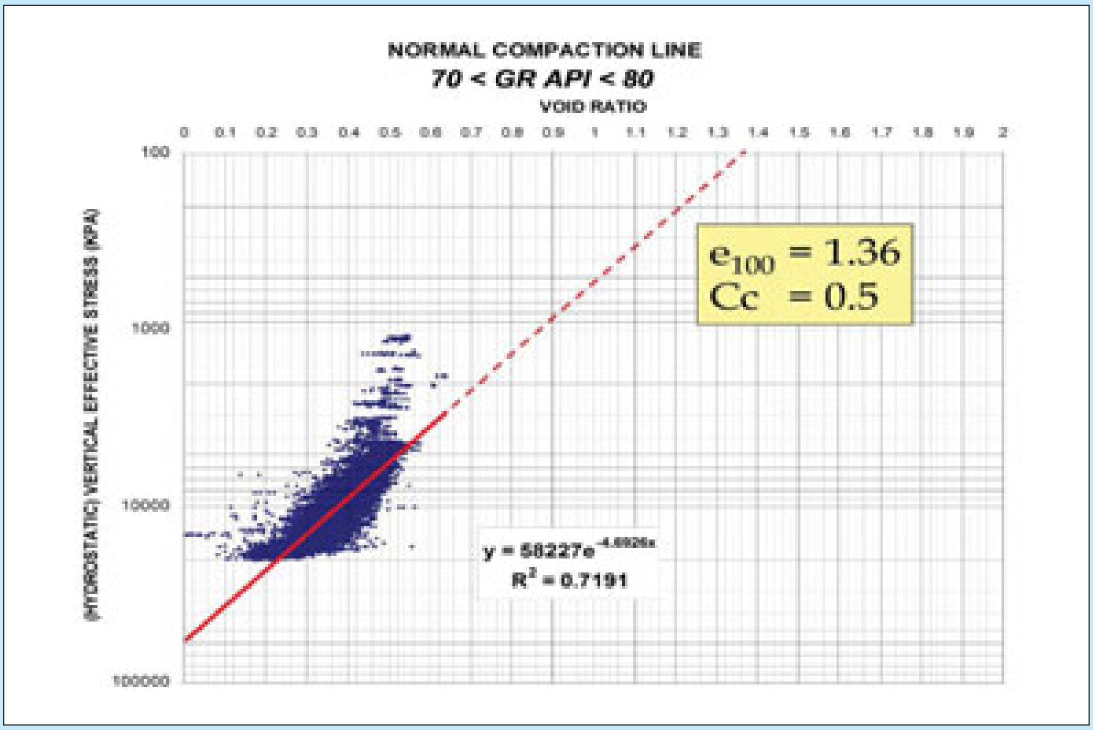

Figure 12
Example of compaction parameters determination.

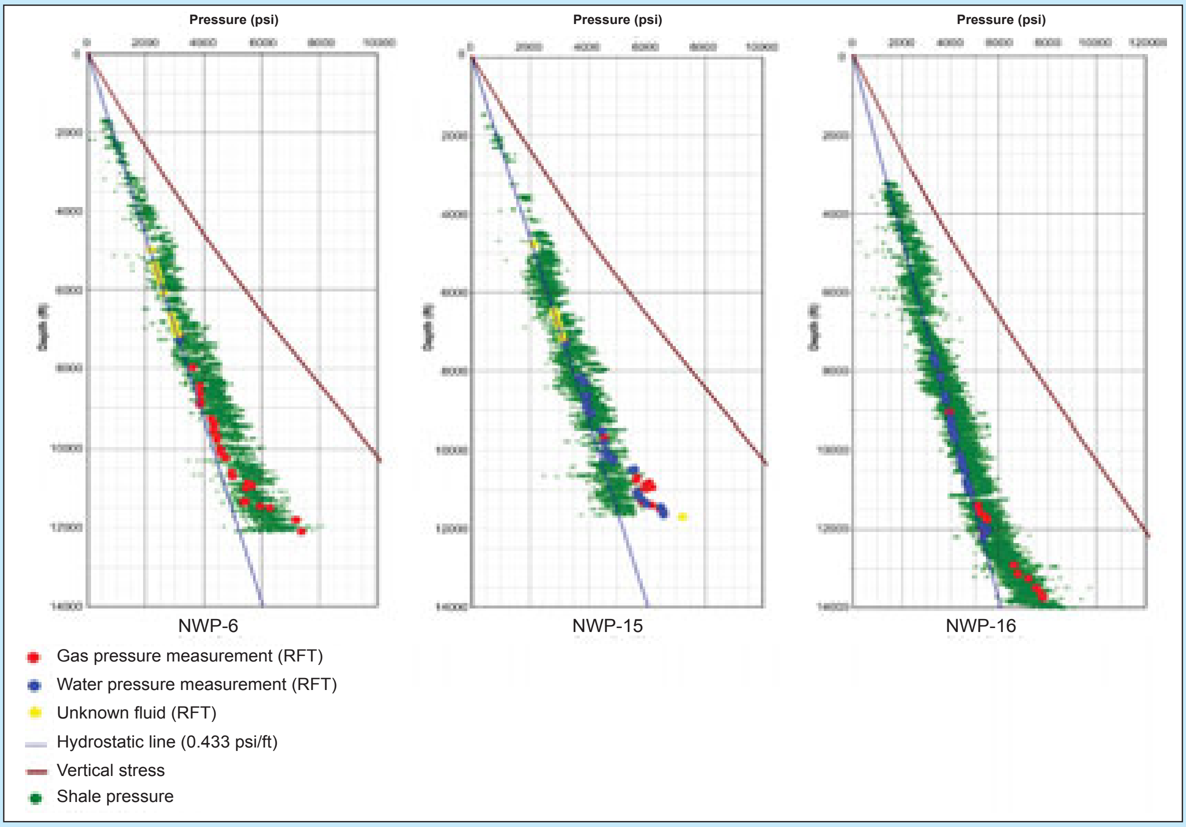

Figure 12
Typical results from soil mechanics method.

to the southern area of the field. This is inconsistent with the hydrodynamic flow direction as shown in Figure 3, which is from the southern area to the northern area. Considering this fact, the possibility of the lateral transfer as the overpressuring mechanism could be ignored.

As pointed out by Bowers (1995), a fluid expansion process could be observed in the velocity log in the form of velocity reversal. From the16 wells used in this research, the presence of the velocity reversal cannot be observed. A typical sonic log is shown in Figure 6 above. Therefore, the fluid expansion as the overpressuring mechanism could also be ignored.

One remaining question about the result of the Eaton Method is the presence of the shoulder effect on a sonic log as the evidence of the presence of lateral reservoir drainage. For 4000 psi pressure discrepancy, calculation by using Eq. 1 in the Peciko Field shows that the expected shoulder effect in the sonic log is about 20 ms/ft. An example of the observation of the shoulder effect is shown in Figure 15. In the figure, it can be seen that it is hard to see a clear evidence for the 20 μs/ft shoulder. Moreover,

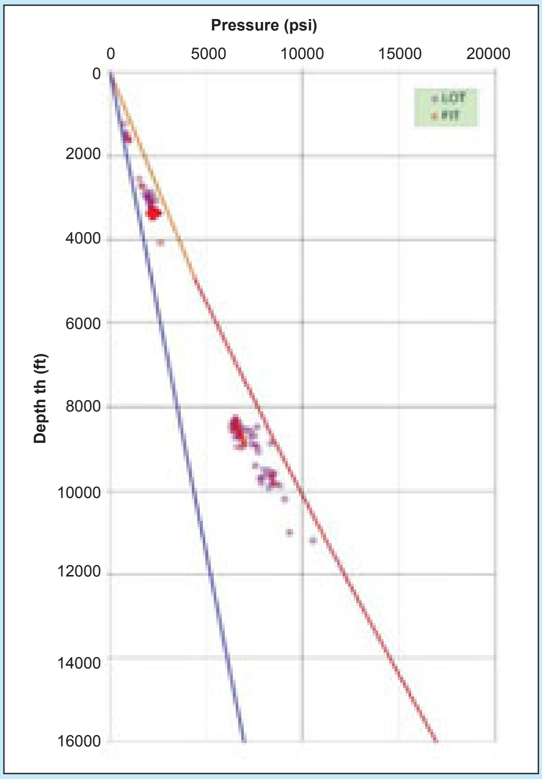

Figure 13
LOTs value in the Peciko Field.

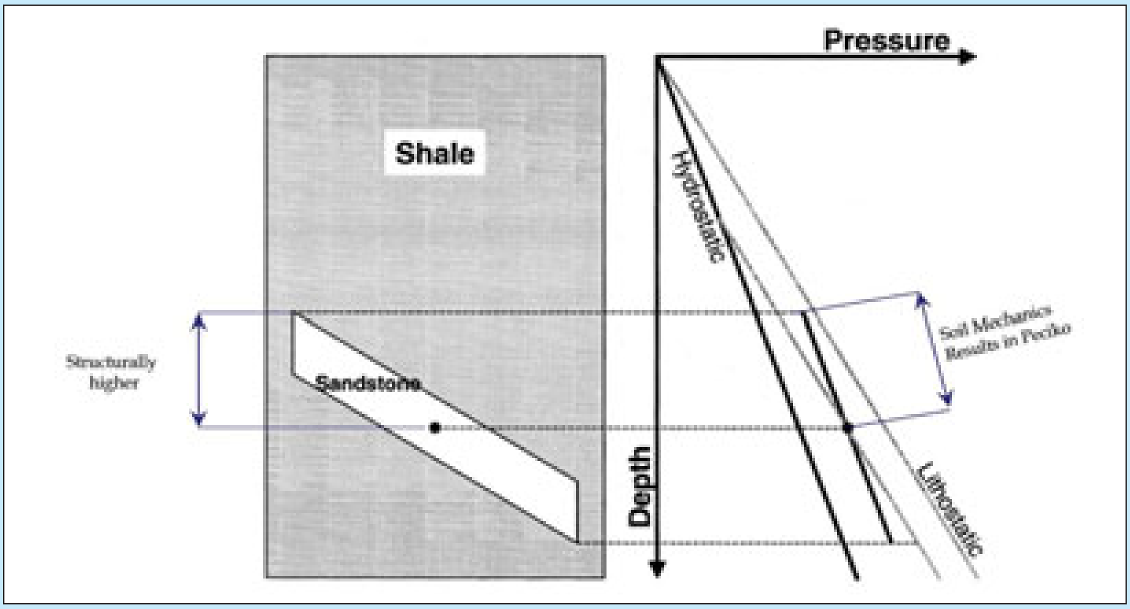

Figure 14
Schematics of lateral transfer (modified from Yardley & Swarbrick 2000).

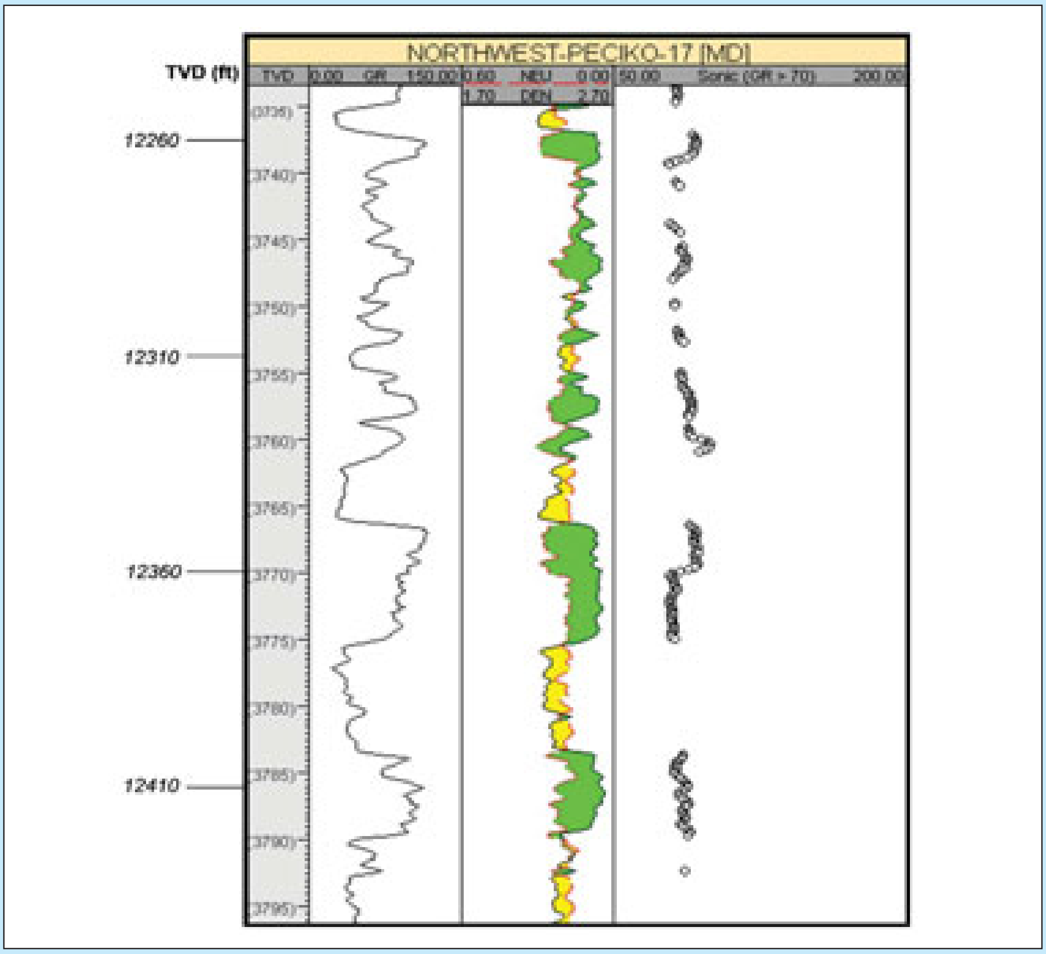

Figure 15
Example of observation of shoulder effect on sonic log.

the very intensive sand – shale intercalated may also contribute to the sonic reading so that the clear shoulder effect is not able to be observed.

An interesting point regarding the result from the Eaton Method is a relatively deep depth of fluid retention depth, i.e. 6500 – 7500 ft or almost 2 km in average, with respect to young mud-dominated deltaic sequence. Swarbrick et al. (2002) reported that the deepest fluid retention depth is about 1.5 km, in the Gulf of Mexico shallow silty interval. As the disequilibrium compaction is resulted from a combination of sedimentation rate and permeability of the rock, detailed investigation and analysis of both parameters, which are not covered by this research, will provide an insight understanding of the fluid retention depth in this field.

In other Indonesia's Tertiary sedimentary basins, the process of lateral reservoir drainage is quite common since a lot of their reservoirs crop out to the surface, and therefore, providing active fluid flow. This paper has demonstrated that in such circumstance, the standard pore pressure estimation method such as Eaton's method could result in unreliable overpressure estimation. I suggest that prior to applying any overpressure method, a geological and hydrogeological analysis is a compulsory work.

IV. CONCLUSION

From this research, it can be concluded that in the Peciko Field, Kutai Basin, Indonesia, the Eaton Method gives more plausible results compared to the Soil Mechanics Method in pore pressure prediction. The result of the Eaton Method can capture geological and hydrogeological processes operating in the Basin, i.e. rapid young deltaic sedimentation and hydrodynamic flow.

The rapid young deltaic sedimentation is reflected by sub-parallel pore pressure profile to lithostatic stress. The fluid retention depth in this field is about 2 km on average, which is considered deep compared to other reported fluid retention depths.

Hydrodynamic flow is captured by aquifer–shale pressure discrepancy which is ubiquitous in this field. As an addition, this conclusion can be used inversely: if the aquifer – shale pressure is present, then it is likely that hydrodynamic flow is present.

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