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15 - 17 August 2016

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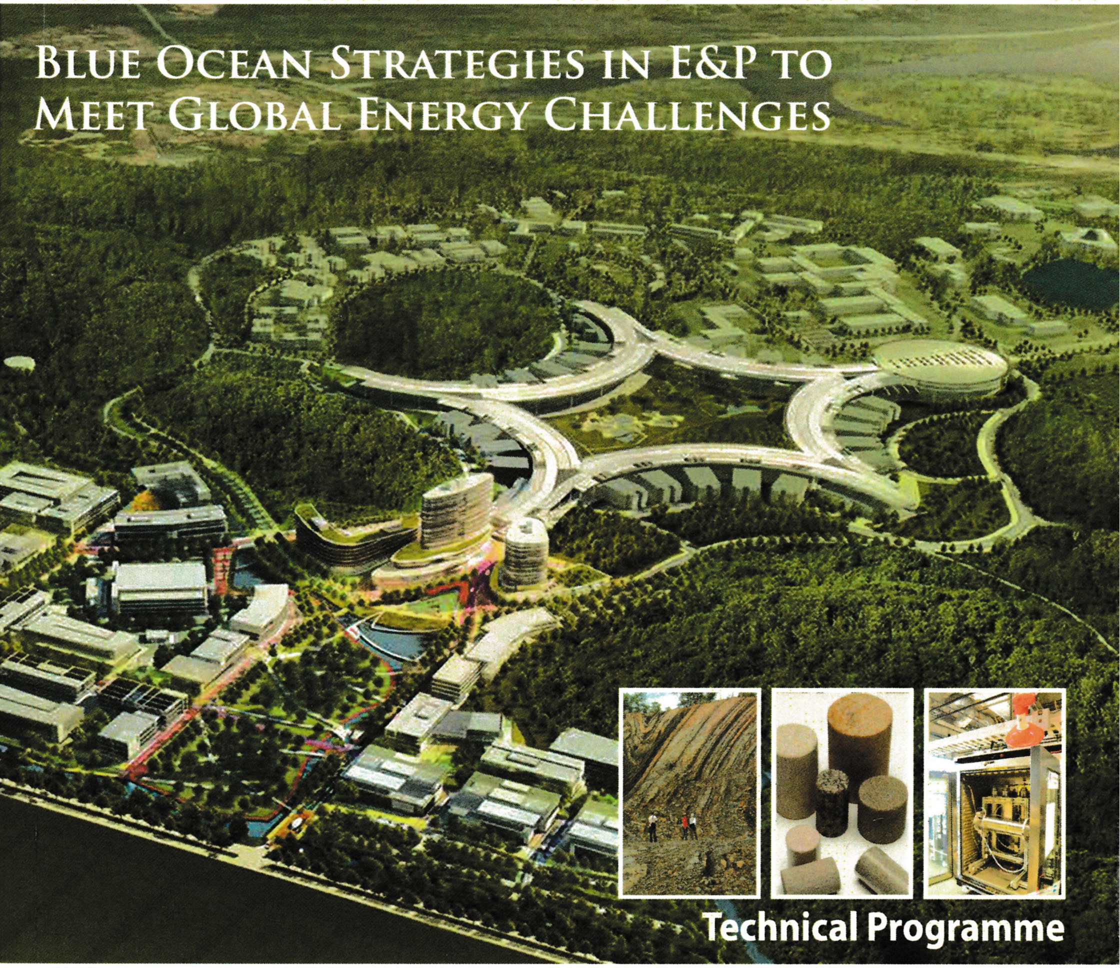

BLUE OCEAN STRATEGIES IN E&P TO MEET GLOBAL ENERGY CHALLENGES

Technical Programme

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WORLD ENGINEERING, SCIENCE & TECHNOLOGY CONGRESS
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A Conference of

World Engineering, Science & Technology Congress (ESTCON)

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TECHNICAL PROGRAMME

The 4th International Conference on Integrated Petroleum and Geosciences (ICIPEG 2016)

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Paper ID	Title	First author email	Authors
1570234680	*Full Waveform Inversion: A Multiscale Approach to Tackle Gas Cloud Problem*	geoscience.srichand@gmail.com	Srichand Prajapati
1570234985	*Carbonate Pore Type Quantification and Analysis GUI on Central Luconia Lab Measurement Data*	muhammadnurarif.zanuri@gmail.com	Muhammad Nur Arif Zanuri; Luluan Almanna Lubis; Sara Bashah
1570235015	*A Case Study of Carbon Dioxide Sequestration in a Coal-bed Methane Site in Iran*	ehsan.ghanaatpisheh@gmail.com	Ehsan Ghanaatpisheh; Hamid Behmanesh; Hosein Vahdani;Mohammadhassan Barzegar; Mostafa Mohkam
1570235016	*CO2 Sequestration Beneath the Caspian Sea, Potential and Assessment*	ehsan.ghanaatpisheh@gmail.com	Ehsan Ghanaatpisheh; Hamid Behmanesh; Hosein Vahdani;Mohammadhassan Barzegar; Mostafa Mohkam
1570235041	*General Geology of Jerantut - Jengka Transect with Emphasis on Depositional Environment*	ezanizzah@gmail.com	José A. Gámez Vintaned
1570235086	*Effects of Particle Size Distribution of Drilling Mud's Bridging Agent on Formation Damage*	edwin6200@gmail.com	Edwin Lawrence; Noor Ilyana Ismail; Muhammad Yasin Naz
1570235182	*Characteristics of Pore Pressure Changes Due to Hydrocarbon Production by Velocity Analysis Approach*	kurniawanadhaa@gmail.com	Kurniawan Adha; Wan Ismail Wan Yusoff; Luluan Almanna Lubis;Nurhajeerah Mhd hanapiah
1570235196	*Compatibility of Blended Jatropha Biodiesel as Oil-Based Drilling Fluid*	yutami.kania@gmail.com	Utami Yerikania; Kurniawan Adha; Syahrir Ridha; Azmi Kamis
1570235264	*Geochemical Study of Jatibarang Fm. Source Rock and Oil in Cipunegara Area, Northwest Java Basin*	anggita.oktafiana@gmail.com	Anggita Dewi; Basuki Rahmad; Sapto Daryono; Andi Mardianza
1570235300	*The Applied Rock Typing Study: The Link Between Lithofacies Attribute and Pore Geometry-Structure*	rini_diah@upnyk.ac.id	Dyah Rini R, Bambang Bintarto, Herianto, Zaki Muttaqin
1570235330	*Shortcut of Permeability Prediction: Rock Typing the Facies Association in Fluvial-Delta Environment*	herianto.topan@upnyk.ac.id	Herianto, Bambang Bintarto, Dyah Rini R, Zaki Muttaqin
1570235361	*Comparison of Multi Attributes Analysis for Fractures: A Case Study in Malay Basin*	kee.shook_g03063@utp.edu.my	Shook Peng Kee; Prof. Dr. Ghosh; Askury Abd Kadir
1570235515	*Taking Seismic Acquisition Artifacts Beyond Mitigation*	mmahgoub@adnoc.ae	Mohamed Mahgoub; Abdul Halim Abdul Latiff; Prof. Dr. Ghosh;Fernando Neves
1570235664	*An Overview of Dissolution and Fractured Porosity of the Kujung Formation North East Java Basin*	putricjturnip@gmail.com	Putri Turnip; Muhamad Irfan; Muhammad Nashir
1570236035	*The Isoelectric Point of Some Selected Black Shales From the Setap Formation Sarawak Basin*	love.duah@gmail.com	EvelynLove Fosu-Duah; Eswaran Padmanabhan; Jose Gamez Vintaned

Poster Sessions

Venue :
Track : Poster Session
Time :

Session Code Paper ID	Paper Title Authors
1570235300	**The Applied Rock Typing Study: The Link Between Lithofacies Attribute and Pore Geometry-Structure** Dyah Rini R, Bambang Bintarto, Herianto, Zaki Muttaqin
1570240517	**Diagenetic History of Carbonate Formations in East Sabah** Rozen Raymond; Nor Syazwani Zainal Abidin; Sara Bashah
1570243867	**Nanoparticles Surface Modification for Defining Oil and Water Interface** Mohd Zulkifli Mohamad Noor; Mariyamni Awang; Umar Islam Muhammad Dimyati
1570245262	**The General Geology & Petrography Study of Gua Sai Limestone, Kuala Lipis, Pahang** Ee Von Chang; M Suhaili Ismail
1570246724	**Experimental Study on Poisson's Ratio Change During WAG Injection** Mahmood Bathaee; Sonny Irawan; Syahrir Ridha
1570247444	**A Strategy for Handling Excessive Water Problems in Well MYR-01 Field Y** Mutia Yusri Ristanti
1570247994	**Development of New Formulation Geopolymer Cement for Oil Cementing System** Raja Rajeswary Suppiah
1570249014	**Effects of Well Inclination Angles to Torque Intensities** Clifern Ong Ket Ferng; Sonny Irawan; Totok Biyanto; Ilen Kardani
1570249764	**Enhancement of Filtrate Loss Control Using Nano-WBM to Minimize Tight Spots in Wellbore** Asif Zamir; Ahmed Khattab
1570250316	**Investigation on Cationic Polymeric Inhibitors for Mitigating Silicate Scales During ASP Flooding** Ismail Mohd Saaid; Siti Qurratu' Aini Mahat

The Applied Rock Typing Study: The Link Between Lithofacies Attribute And Pore Geometry-Structure

Dyah Rini Ratnaningsih, Bambang Bintarto, Herianto, Zaki Muttaqin
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Abstract

Well 'A' was done conventional coring (6787-6963 MD) at sandstone reservoir 'X'. Core analysis results 126 core samples for RCAL and core description, 6 core samples for SCAL, petrography (XRD and photomicrographs).

As see this core availability, the reservoir 'X' needs to have reliable and quick reservoir characterization, we have appeared idea to conduct rock type using Pore Geometry-Structure (PGS). Because of most cases, petrophysical data has been used traditionally for purpose of predicting permeability based on permeability-porosity semilog plot without understanding its spread. Permeability is one of the most important parameter, it should have been predicted if the selection of rock typing itself is correct. This study are to characterize rock type of reservoir, to predict permeability and to get initial production test close to actual test.

Classifying rock type is initiated by considering the lithofacies attribute (lithology, color, rock texture and mineralogy composition). They are then plotted into PGS plot, X-axis is (k/ø^3) as pore structure, Y-axis is (√(k/ø)) as pore geometry. Each rock type will have distinct line whose slopes no more than 0.5. Once established, rock type equation is merged with initial-saturation = f(permeability) equation, then porosity-saturation-permeability correlations are formed to result equation predicting permeability that is valid to core data. Continued by applying rock region into single well radial model based on *k*-Core and *k*-PGS, respectively. The results are PGS plot has shown 9 rock types based on lithofacies attribute; permeability prediction equation has been valid through core data (R^2 = 0.9951). Hence, it could be used for predicting permeability on the wells that do not have core data at reservoir. The initial production test simulation shows PGS-model has approached actual initial production test. This could be an alternative reservoir characterization using reliable core data which leads to a well-built reservoir model.

Keywords: reservoir characterization, rock typing, pore geometry-structure, permeability prediction, reservoir simulation

Introduction

Reservoir characterization is a type of engineering to create geometry and characteristic of nature to get economical benefit from oil or gas field (Wibowo, 2013). Every kind of reservoir has their own specific petrophysical properties collected from several field and laboratory measurements as well as through by analytic data processing in order to support creating real reservoir model. Besides of porosity and fluid saturation, one of the important rock properties is permeability which is strongly controlled by architecture of pores system. Permeability as a result of geological processes will cause the permeability-porosity-saturation relationship that is unique. Complexity of the architecture leads investigation to proposing different ideas and approaches for predicting the permeability. The big fallacy is, permeability is traditionally predicted based on regression analysis of semilog plot of permeability and porosity data obtained from routine core analysis without detailed geological justification. Such a simple prediction could result in errors as high as tens folds.

Permeability can only be determined by direct measurement of the rock samples in the laboratory. Although coring gives a satisfactory result, but there are some weaknesses that take a lot of time and huge costs that cannot be done on all the wells. The trick is to do well logs to predict the permeability indirectly. The result shows the relationship between the permeability of the core and log responses. Furthermore, the permeability of which has been obtained will be propagated throughout the reservoir using geostatistic methods. The quality of the results of this approach is influenced by many factors. The most important thing is the chosen method for the determination of the rock type itself. If the selection of the rock typing is done with the right method, it is found that the permeability prediction approaching the original properties of rocks and has a stronger scientific basis

Literally, the method developed on the basis of capillary tube model that is firstly employed by Kozeny and then modified by Carman can represent porous medium enabled correlating permeability with other rock properties such as porosity, tortuosity, specific surface area, and shape factor (Scheidegger, 1960). The well known Kozeny-Carman equation is then employed to develop concept of hydraulic unit in relation with permeability prediction (Amaefule et al., 1993, and Abbaszadeh et al., 1996). This concept says that a hydraulic unit is a representative volume of reservoir having similar pore geometry or pore throat characteristics. Recently, based on a set of mercury injection capillary pressure data it is found that the Leverett's mean hydraulic diameter $(k/ø)^{0.5}$ correlates very well with volumetric average of mode values of pore aperture size distribution then called as effective hydraulic diameter of the pores (Permadi et al., 2004). Such a capillary model may be used as an approach to characterize not just pore geometry but also the pore, if it does, the model may also be employed to identify rock types (Permadi et al., 2009).

Thus, this paper will discuss three components of study which are selection of rock type based on lithofacies attribute into pore geometry-structure plot, predicting reservoir permeability compared to other methods, then applying the results of reservoir rock type into single well radial model to shows that the initial production test whether gets closer to initial production tes or not.

Background Theory

Pore Geometry-Structure (PGS). One of the acceptable approaches to represent a porous medium in relation with permeability of the medium is the use of capillary tube model. The medium consisting of straight cylindrical capillary tubes with an average inside diameter đ has the following equation for permeability (Scheidegger, 1960):

$$k = \frac{\text{ø}\,\text{đ}^2}{32} \quad \text{.......} \quad (1)$$

For tortuos capillary tubes with tortuosity *T*, Eq. (1) may be written as :

$$k = 31.6875\ \text{ø}\,\text{đ}^2 / T \quad \text{.......} \quad (2)$$

where $T = La/L$ is the average distance for fluid particles to travel through the tubes from the inlet to the outlet, and *L* is the straight length of the medium.

Referring to Eq.(2) for the ideal, cylindrical capillary tube system đ can be replaced with specific surface area $S = 4$ ø/đ so that Eq.(2) now takes the following form :

$$k = \text{constant}\ \text{ø}^3 / (TS^2) \quad \text{.......} \quad (3)$$

where the term (TS^2) is the internal characteristic of tubes, representing the variation of tube size and the structure of the tubes, and determines how ease a fluid can pass through the tubes. The smaller the term (TS^2), the easier the fluid passes through the tubes. For porous rocks, parameters *T* and *S* are difficult to measure but Eq.(3) can be adopted and written in the following form:

$$k = C\ \text{ø}^3 \quad \text{.......} \quad (4)$$

the J-Function, rock typing requires identification of both pore geometry and structure similarities for a given samples set. This can be approached by applying th capillary tube model to a natural pore system for which Eq.(4) can be rearranged to separate pore geometric term from the pore structural term,

$$\sqrt{\frac{k}{\text{ø}}} = \text{ø}\sqrt{C} \quad \text{.......} \quad (5)$$

this equation says that plotting $(k/ø)^{0.5}$ versus C on log-log scale should yield a straight line. Theoretically for a perfectly smooth, cylindrical capillary tube system, the slope of the straight line should be 0.5. The position of the straight line in the graph depends on both the degree of tortuosity if the capillary system and the specific internal surface area of the capillary tubes affecting the effective hydraulic quality. When the values of $(k/ø)^{0.5}$ are plotted against the corresponding values of C on log-log scale, data points that tend to form a straight line with positive slope reflects the existence of similarity in the pore architecture among the samples. Oppositely, two rock samples having the same value of C but different $(k/ø)^{0.5}$should indicate that these samples come from different rock types (Permadi et al., 2009).

Leverett's J-Function. Rock type is rock or parts of rock that has been deposited in the same environment and has undergone similar diagenetic process (Archie G.E., 1950). Parts of rock which the same rock type tend to have a certain correlation between the physical properties. Pore size distribution of rocks control the porosity and permeability and saturation correlates with water. Rock type tends to have a certain pore size distribution and shape of the curve will have the unique capillary pressure.

Leverett (1941) did an approach by identifying dimensionless function from water saturation then called as J-Function: $J(Sw) = 0.21645\ \frac{Pc}{\sigma}\sqrt{\frac{k}{\text{ø}}}$ .... (6)

Ratio between *k* and ø could be meant as pore diameter. Lately, advantage from J-Function from others in explaining flow unit in reservoir simulation study. Guo et al. (2005) stated that Leverett interpreted ratio between *k* and ø as a proportional mean pore radius, this has shown that both of pore size and pore structure have important role in define rock unit or flow unit.

Data point in the J-Function plot if it tends to form a single curve indicating that data points are a flow unit or a rock type that has similarity both of pore geometry $\sqrt{(k/\text{ø})}$ and pore structure ($C = \frac{k}{\text{ø}^3}$) (Permadi et al., 2009, and Wicaksono, 2011). Nevertheless, the pore size distribution does not necessarily define or characterize rock type, some rock types that have the pore size distribution is generally the same. Integration aspects of geology and engineering are necessary to define or characterize the rock type.

Model of Permeability Prediction

Conventional Permeability Transform. In predicting permeability of a reservoir, traditionally engineers employ semilog plot of porosity-permeability. Wicaksono (2011) has confirmed the fallacy of prediction, such this simple way may cause the over or underestimate of the value, even as high as tens folds.

PGS. Rock type equation from PGS plot (Wibowo, 2013) : $y = a\,x^b$

$$\left(\frac{k}{\text{ø}}\right)^{0.5} = a\left(\frac{k}{\text{ø}^3}\right)^b$$

$$k = \text{ø}^3\left(\frac{\left(\frac{k}{\text{ø}}\right)^{0.5}}{a}\right)^{\frac{1}{b}} \quad \text{.......} \quad (7)$$

equation of *k-Swi* relation :

$$Swi = m\,k^{-n}$$

$$k = \left(\frac{m}{Swi}\right)^{\frac{1}{n}} \quad \text{.......} \quad (8)$$

match action into 'elimination' equation (7) and (8) :

$$\frac{\left(\frac{k}{\text{ø}}\right)^{0.5}}{a} = \left(\frac{\left(\frac{m}{Swi}\right)^{\frac{1}{n}}}{\text{ø}^3}\right)^{b}$$

$$k = \left(a^2\, x\, m^{\frac{2b}{n}}\right) x \left(\frac{1}{\o^{(6b-1)}\, x\, Swi^{\frac{2b}{n}}}\right) \quad (9)$$

If k is permeability (mD), ø is porosity (fraction), *Swi* is irreducible water saturation (fraction) @Pc = 150 psi, "a" is rock type equation constant, "b" is rock type slope, "m" is constant of *k-Swi*, "n" is slope of *k-Swi*, thus the correlation between permeability, porosity and water saturation is :

$$k = C\ x\ \frac{1}{\o^{A}\ x\ Swi^{B}} \quad (10)$$

Plot between k against $\left(\frac{1}{\o^{A}\ x\ Swi^{B}}\right)$ into log-log plot, each rock type will have their own straight line with constant (C) and the certain slope, then it is the equation of permeability prediction.

Wyllie-Rose. Permeability Equation proposed by Wyllie-Rose could be written as :

$$k = 62500\ \frac{\o^{5.58}}{S_{wi}{}^{2}} \quad (11)$$

Timur. Permeability Equation proposed by Timur could be written as :

$$k = \left(\frac{100\ \o^{2.25}}{S_{wi}}\right)^2 \quad (12)$$

Tixier. Permeability Equation proposed by Tixier could be written as :

$$k = \left(\frac{250\ \o^{3}}{S_{wi}}\right)^2 \quad (13)$$

Methodology

First study is by grouping data having the same attribute from core description. This detailed microscopic observation (lithofacies) describes all the geological events that occurred during the forming of rocks. Kind of grouping is including lithology name, rock texture (grain size, sorting, color, packing) and mineral composition (slight or abundant in relative to pore space).

Ater selecting the lithofacies from RCAL data, then calculate the pore geometry and pore structure value, then plotting into plot PGS for each group of lithofacies. Each rock types will have straight line whose slopes less than 0.5. Continues to validation with J-Function which also shows rock types from their different curves. Meanwhile, we do petrophysical calibration to Well 'A' log curve with SCAL *Swi* data. After that, plotting k = f(Swi) where k is RCAL horizontal permeability to obtain relation among them. Then substituting the equation obtained with the resulted rock types to form equation of permeability prediction as function of porosity and *Swi*. Then comparison to estimated-permeability with several common methods like Tixier, Timur, Wyllie-Rose. After that, it will be validated with the real core permeability.

The second study is applying (two models) the core permeability and k-PGS, respectively, into single well radial model by employing rock region (permeability data distribution method). The permeability data distribution method is conducted by plotting number sample vs permeability in increasing order. Then, simulation steps are also included to built the same condition of grid geometry and other properties in radial well model. The differences among them are only characteristic of each resulted rock region, the capillary pressure curve is same for the same region number for the two models. After that, Well 'A' for each model are tested to know the intial production test and compares it with the real one. **Fig.1** shows flowchart of methodolgy.

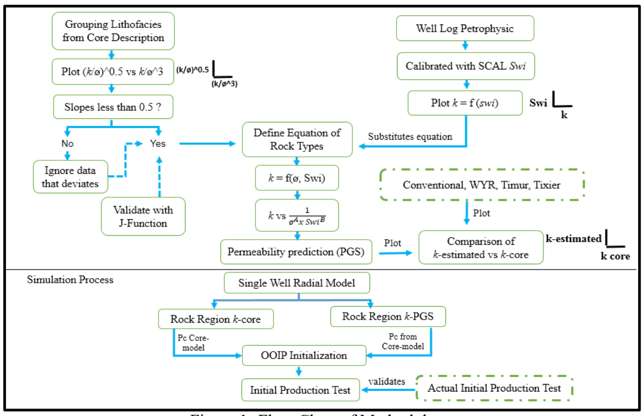


Figure 1- Flow Chart of Methodology

Data Used

Three data sets of RCAL are available to evaluate the methods developed. Geology reports consist of detail core description, XRD, petrography and photomicrographs, also Well 'A' log curves, RCAL and SCAL report in addition like shown in **Table 1**. From report of 126 RCAL samples and 6 SCAL samples that are correct-recognized contains detail geological description, for example "*Sst gy vf modsrt hd abd silt pyr cly lam*" and "*Cgl ylgy m-vcrs poorsrt coal abd qtz frag*" which means the core samples are devided into 2 distinct lithology namely sandstone and conglomerate, but for further rock typing study the rock texture and composition will be used. The sandstone samples have porosity ranging from 3 % to 23 % and permeability ranging from 0.01 md to 4120 md. The conglomerate have porosity and permeability resepectively ranging from 8 % to 17 % and from 0.68 md to 2153 md. The capillary pressure data available are obtained from six core plugs with porosity and permeability ranging from 10.7 % to 20.5 % and 9.54 md to 787 md, respectively. The **Fig.2** is well log interpretation after corrected with irreducible water saturation (*Swi*) from special core analysis. After rock typing is finished, the data used are petrophysical parameter from each rock type, PVT data, drill stem test and other conditions of first time Well 'A' drilled.

Table 1- Data Used

Analysis	Number of Sample	Unit
Sedimentology		
Petrographic (thin section)	6	Samples
SEM and XRD	4	Samples
Core Log Description	175	ft
Routine Core (RCAL)		
Permeability	126	Samples
Porosity	126	Samples
Core Plug Description	126	Samples
SCAL		
Capillary Pressure	6	Samples

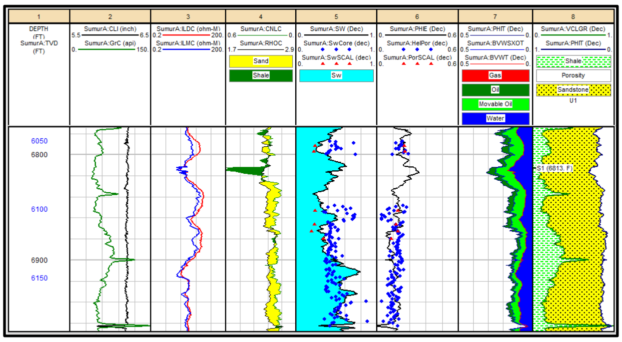


Figure 2- Corrected SCAL- Well-A Log Interpretation

Results and Discussion

Conventional Transform Permeability. **Fig.3** shows that determination coefficient R^2 = 0.6146 is not accurate enough for predicting permeability if only porosity data used. In reservoir static model, the availability of water saturation as results from modelling study will be more usefull to be included in permeability equation in order could spread the permeability into grid cell.

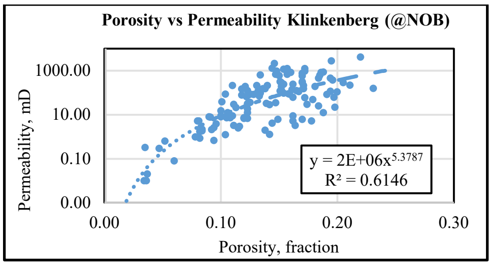


Figure 3- Conventional Transform Permeability

PGS. Fig.4. shows that rock tpe classification based on lithofacies could be visually differed. Rock Type then we called as RT. RT's sandstone contain of RT 1, RT 2, RT 5, RT 7 and RT 9; RT's conglomerate that are RT 3, RT 4, RT 6 and RT 8. All the RT's have slopes with gradien no more than 0.5, except for RT 9 that is 0.5269 which deviate from cylindrical capillary tube system. It maybe caused a bit of data point in analysis.

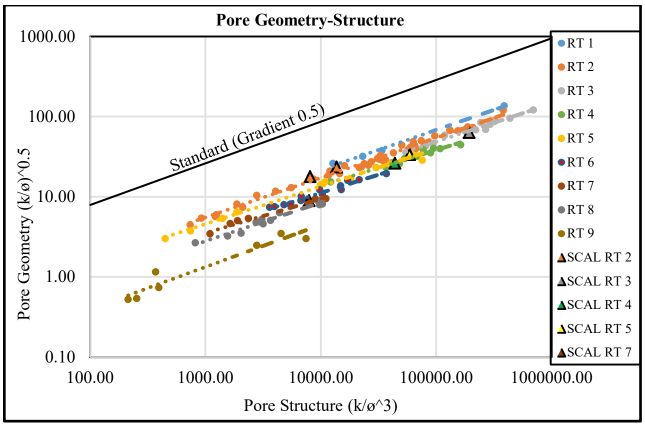


Figure 4- Result of PGS Rock Types

RT1 has the biggest value of porosity and permeability ranging from 17 % to 23 % and 111 md to 4120 md respectively. Each rock types has their own lithofacies that are different from others, clearly see **Table 2**.

Table 2- Rock Type Equation, Permeability and Porosity

Rock Type	Rock Type Equation	Permeability (mD)	Porosity (fraction)	Permeability avg (mD)	Porosity avg (fraction)	Lithofacies
RT 1	$y = 0.2216x^{0.4978}$	111 - 4120	0.17 - 0.23	832.91	0.20	Sandstone, yellowish gray, fine-medium grained, moderately sorted, hard, slightly quartz fragment, containing carbon
RT 2	$y = 0.18x^{0.496}$	5.17 - 2826.48	0.15 - 0.2	358.30	0.17	Sandstone, yellowish gray, fine-very coarse grained, poorly-moderately sorted, hard, slighlty-abundant quartz fragment, containing slightly carbon
RT 5	$y = 0.1776x^{0.47}$	1.28 - 154.49	0.1 - 0.15	55.02	0.14	Sandstone, yellowish gray, fine-coarse grained, poorly-moderately sorted, hard, silty argillic, quartz fragment, containing slightly pyrite
RT 7	$y = 0.1827x^{0.4283}$	1.23 - 122.82	0.08 - 0.19	14.62	0.13	Sandstone, yellowish gray, very fine-fine grained, moderately sorted, hard, silty argillic, slighlty cemented, containing carbon, pyrite
RT 9	$y = 0.035x^{0.5269}$	0.01 - 0.64	0.03 - 0.06	0.19	0.04	Sandstone, gray, very fine grained, moderately sorted, hard, abundant silt, slightly clay laminated, containing pyrite
RT 3	$y = 0.2131x^{0.4719}$	192.09 - 2153	0.13 - 0.17	830.05	0.15	Conglomerate, yellowish-mottled gray, fine-very coarse grained, poorly sorted, hard, quartz fragment
RT 4	$y = 0.2347x^{0.4427}$	32.62 - 215.83	0.11 - 0.14	127.52	0.13	Conglomerate, yellowish-mottled gray, fine-very coarse grained, hard, poorly sorted, abundant quartz fragment, containing slightly carbon
RT 6	$y = 0.173x^{0.4528}$	6.7 - 38.06	0.1 - 0.12	15.46	0.11	Conglomerate, mottled gray, medium-very coarse grained, hard, poorly sorted, cemented, abundant quartz fragment
RT 8	$y = 0.1001x^{0.4821}$	0.68 - 7.64	0.08 - 0.1	3.00	0.09	Conglomerate, mottled gray, medium-very coarse grained, hard, poorly sorted, cemented, quartz fragment, containg slightly carbon

It's quite interesting to observe, if we compare apple to apple of RT's sandstone, we see :

- RT 1 vs RT 2, where RT 1 has grain size moderately sorted and only has a few quartz fragments, causing higher porosity and permeability rather than RT 2
- RT 1 vs RT 5, where the existence of silty argillic and fine - coarse grained cause porosity and permeability of RT 5 significantly low. Also, the difference between the two is RT 1 contains carbon while RT 5 contains pyrite
- RT 1 vs RT 7, where RT 7 has very fine – fine grained, the existence of silty argillic, pyrite and carbon mineral as well as cemented cause reduction of porosity and permeability highly significant for RT 7
- RT 5 vs RT 2, where RT 5 has various grain size (very fine - coarse grained) while grain size for RT 2 from fine – very coarse grained, these mean grain size for both of them barely similar and poorly-moderately sorted. However, the existence of silty argillic causes porosity and permeability lower for RT 5. The difference between the two is RT 5 contains pyrite while RT 2 contains carbon
- RT 5 vs RT 7, based on grain size, RT 7 has finer grain (very fine – fine grained), moderately sorted, contains carbon and pyrite, and several cores are cemented thus causing porosity and permeability lower than RT 5
- RT 7 vs RT 9, where only RT 9 has grain size very fine grained, abundant silt and laminated clay in several data causing porosity dan permeability extremely low than RT 7. The difference between them is RT 9 is colored gray and absence of carbon mineral, while RT 7 is colored yellowish gray and has carbon mineral

For RT's conglomerate we could discuss about :

- RT 3 vs RT 4, both of them have similar grain size (fine – very coarse grained), poorly sorted and yellowish-mottled gray. However, the abundance of quartz fragments and the existence of carbon mineral reduces porosity and permeability for RT 4
- RT 3 vs RT 6, where RT 6 has bigger grain size (medium – very coarse grained), more abundant quartz fragments, and also cemented lead to reduction of its porosity, and lower permeability significantly than RT 3
- RT 4 vs RT 6, where RT 6 has bigger grain size (medium – very coarse grained) and also cemented lead to reduction of its porosity, and permeability lower than RT 4
- RT 4 vs RT 8, where RT 8 has bigger grain size (medium – very coarse grained), and the existence of cemented attribute lead to reduction of its porosity. This cementation also has caused permeability extremely low for RT 8
- RT 6 vs RT 8, both of them have similar grain size (medium-very coarse grained), mottled gray colored, an adequate abundance of quartz fragments, and cemented. However, the existence of carbon mineral a bit affects reducing porosity and permeability for RT 8

From PGS method we could see that the higher of C and geometry value, the better the rock type and the more simple the pore structure inside, oppositely prevails. The closer to slopes of 0.5, the more ideal the rock pore geometry that refers to cylindrical capillary tube system.

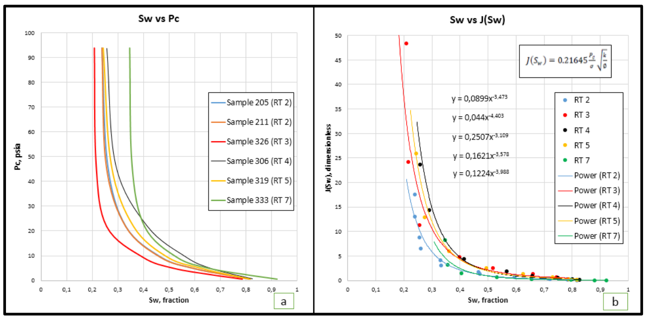


Figure 5- J-Function Curves Validate PGS Rock Types

Subsequently, the **Fig.5.** J-Function has formed 5 curves that are distinctively different. Where sample ID 205 and sample ID 211 tend to form one shape, then it should be categorized as a rock type. And the other sides, clearly seen on previous **Fig.4** that sample ID 205 and sample ID 211 are in RT 2's track which means this RT 2 is accurately validated with J-Function curve, also for RT 3 validated by sample ID 326, RT 4 validated by sample ID 306, RT 5 validated by sample ID 319, RT 7 validated by sample ID 333. The 4 RTs left are not validated with SCAL it might be limitedness of SCAL data. Microscopic observation for sample ID 205 and ID 211 are attached at **Fig.6**. This figure gives justification for the pore architecture of the RT 2 that is same.

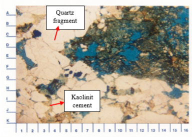
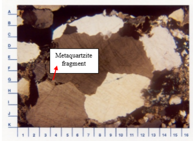
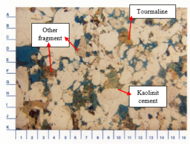
Petrography	XRD	*Photomicrographs (Plate a)*	*Photomicrographs (Plate b)*
Sample ID 205 : *Subarkose arenite with lithics, Grain : Quartz, (Pebbly sand, largest grains 6 mm); no matrix, Cement : quartz, kaolinit, siderit, Porosity : primary and secondary, poorly sorted, subangular, Structure : close pack.*	Quartz 77 K-feldspar tr Kaolinit 20 Illite 3		
Sample ID (211) : *Sublithic arenite, Grain : Quartz (Pebbly sand, largest grains 6 mm), no matrix, Cement : quartz, kaolinit, siderit, Porosity : primary and secondary, poorly sorted. subangular, Structure : close pack.*	(no analysis)		(no analysis)

Figure 6- Petrography, XRD, and Photomicrographs as Justification for RT 2

Based on the discussion above, it could be inferred that there is a correlation and interrelatedness between geological attribut (lithology, rock texture and composition) and petrophysical parameters (porosity, permeability). From J-Function curve and integration to PGS plot also have validated that this two method affirm the teory basis both of pore geometry and its structure. Thus, classifying works of rock without concerning about the interrelatedness will not have stronger scientific basis. From this sub-discussion, a conclusion could be obtained that relation of pore geometry and pore structure may give better perspective of knowledge in observing the link between geological aspect (lihtofacies attribute from core description) and its rock petrophysic

Permeability Prediction. Calibrating well log interpretation is a must when there are avalible core data, if it does not, the result will no interpret reliable vertically-data of the well. Porosity and saturation from core callibrate well log attribute. After that, corrected-water saturation are plotted with core permeability, each rock type will have their own equation of *Swi = f(k)*. These corrected-water saturation equations are then merged with rock type equation like Eq.(9) and then calculate like the Eq.(10). Finally, the plot of each rock type from Eq.(10) results permeability prediction equation. Now, all corrected-water saturation and porosity data are variables used in equation. **Fig.7** shows *k*-estimated based on several methods, and have been validated to core permeability.

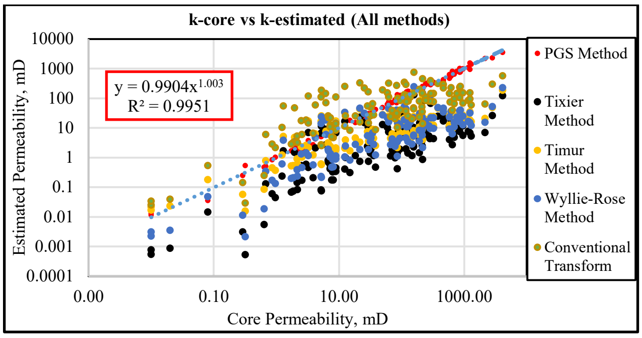


Figure 7- Validation and Comparison of All Permeability Prediction Methods

Fig.7 shows that PGS method gives high accuracy of determination coefficient of predicting permeability. R^2 = 0.9951, and this method has been supported with detail geological aspect where lithofacies as the main focus that exactly it is proper to facies condition. **Fig.7** also shows that common permeability prediction methods for sandstone case such as Tixier, Timur or Wyllie-Rose should have been more reviewed, because the constants they have are probably not suitable or proper to general sandstone reservoir.

Reservoir Simulation. To know how the resulted *k*-estimated (*k*-PGS) gives simulation of intial production test close to actual one, the researchers employed rock region based on that permeability vs sample number, the results see **Fig.8**. Then, next steps is calculating characteristic (SCAL end point data) of each region, the results see **Fig.9.**

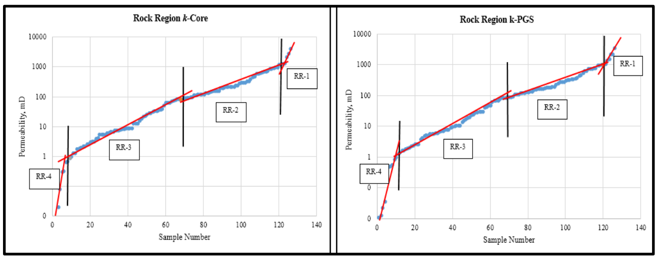


Figure 8- Rock Region for each Model

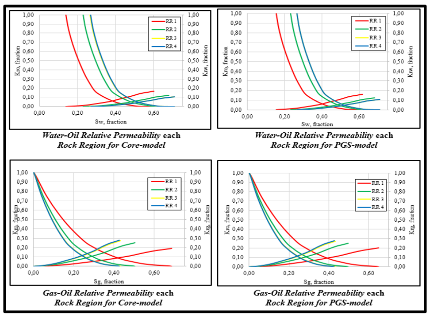


Figure 9- SCAL End Point Data for each Model

Characterization of reservoir ‘X’ is as the following condition:

Initial Condition of Well ‘A’ are :

- Core Sample Data : 6787–6963 ft MD
- Drilled and cored on November 18th 2000
- WOC : 6098 ft TVDSS
- Pi 2587.7 psia, Pb 2412 psia, Temp 270ºF
- Boi = 1.393 rb/stb
- Datum = 6092 ft TVDSS
- Rs (surface)= 650 scf/stb
- Production Casing 7 in (0.583 ft)
- SATNUM is convenient with each rock region model

Assumptions are:

- Radial Well Model
- Ri = 0.2916 ft , Re = 820 ft (250 m)
- Same perforation location (2 – 15; 17 – 25; and 31 – 61 grid number
- Ø, Kv, grid top face, height of grid are same
- Liquid Rate 1601 bbl/day (same as actual data)
- Ø, $k_{vertical}$, Capillary Pressure are same as Well ‘A’ Core-model

Initialization of OOIP uses Core-model’s capillary pressure data (Pc), see **Fig.10**, results 815 STB or 0.06 % of difference from volumetric-calculated OOIP. Core-model’s Pc is then applied to other PGS-model. The difference of OOIP among the models are too close, see **Table 3**. The researchers obtain the reservoir ‘X’ characterization in single well radial model, see **Fig.11**, and the graph of initial production test is in **Fig.12**.

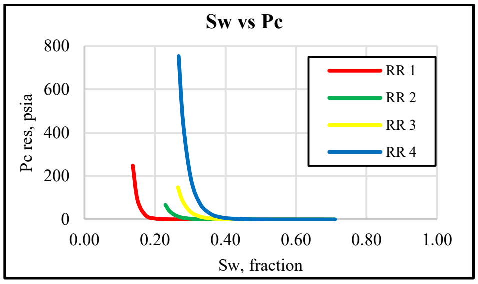


Figure 10- Capillary Pressure Data of Core-model to be used also for PGS-Model

Table 3- Result of OOIP Initialization towards to Volumetric OOIP

Region	Volumetric Calculation	Simulation of Core-Model	Simulation of PGS-Model	Oil Difference (%)	
				Core Model	PGS Model
	Oil (stb)	Oil (stb)	Oil (stb)		
Total	1448422.09	1449237.10	1442903.5	0.06	0.38
Reg 1	74945.24	85249.82	107707.81	12.09	10.18
Reg 2	807252.24	841573.82	765997.04	4.08	4.21
Reg 3	525567.56	483606.82	530391.98	8.68	8.85
Reg 4	40657.05	38806.69	38806.69	4.77	4.77

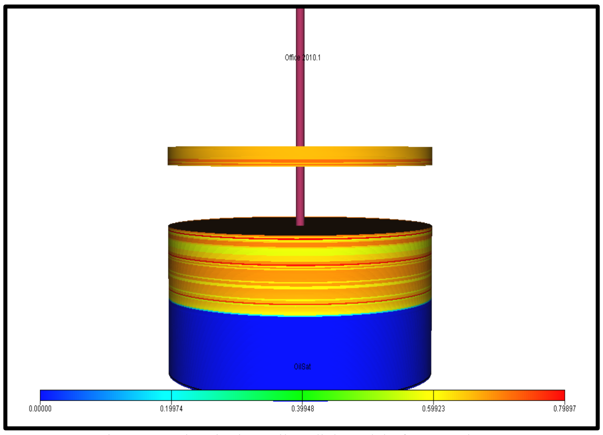


Figure 11- The Single Well Radial Model of Reservoir ‘X’

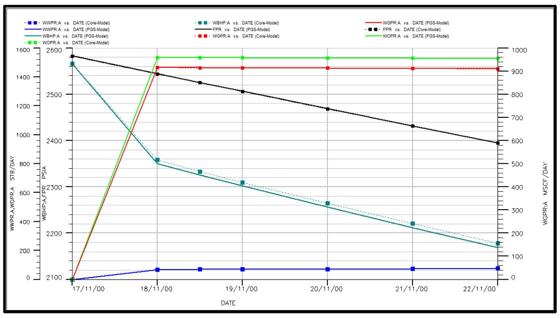


Figure 12- Result of Initial Production Test for Well ‘A’ Profile

The **Fig.12** shows that intial production test for Core-model has 1533.41 BOPD, 67.59 BWPD, 4.22% WC, for PGS-model has 1533.43 BOPD, 67.57 BWPD, 4.22 % WC, meanwhile the initial gas production is not considered because we did not calculate initial gas in place (IGIP) and only liquid rate as target that will be achieved, summarized result see **Table 5**.

Table 4- Result of Initial Production Test per November 18th 2000

	BOPD	BWPD	MCFD	%WC	GOR
Actual Test Data	1540.00	61.00	1320.00	3.80	857.00
Core-Model	1533.41	67.59	914.82	4.22	596.59
PGS-Model	1533.43	67.57	915.20	4.22	596.83

Conclusions

1. Rock typing study with Pore Geometry-Structure method to characterize reservoir ‘X’ from core data is successfully done through lithofacies attribute classification. Through this method, geological aspect could be integrated with engineering aspect in determining rock type that has stronger theoretical basis.
2. Pore Geometry-Structure method produces 9 rock type, while the integration of lithofacies rock type in PGS plot and J-Function have validated 5 rock type that are same namely RT 2, RT 3, RT 4, RT 5 and RT 7, thus the two method affirmed the concept theory of rock type.
3. In *k*-estimated vs *k*-core plot, *k*-PGS has given determination coefficient $R^2 = 0.9951$, thus each rock type’s permeability equation could be used to predict permeability in the wells that do not have core sample data from reservoir ‘X’ at ‘Y’ field.
4. PGS-model has produced intial production test that is closer to actual initial production data and Core-model’s simulation production test.
5. As recommendation, rock type resulted from PGS plot could be used for proposing the selection of core sample that is to be conducted SCAL further.

Nomenclature

- b = hydraulic diameter exponent, dimensionless
- C = hydraulic conductivity of pores, μm^2
- đ = average diameter of capillary tube, µm
- $d_{H\,max}$ = maximum effective hydraulic diameter, µm
- La = distance of fluid particles traveling through the porous medium, length
- Rs = gas solubility in oil
- RQI = $0.0314\,(k/ø)^{0.5}$
- $ø\,z = ø\,(1- ø\,)$
- τ = tortuosity, dimensionless
- S = specific surface area, 1/ µm

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