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International Conference on Intergrated Petroleum Engineering & Geosciences

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ICIPEG 2016

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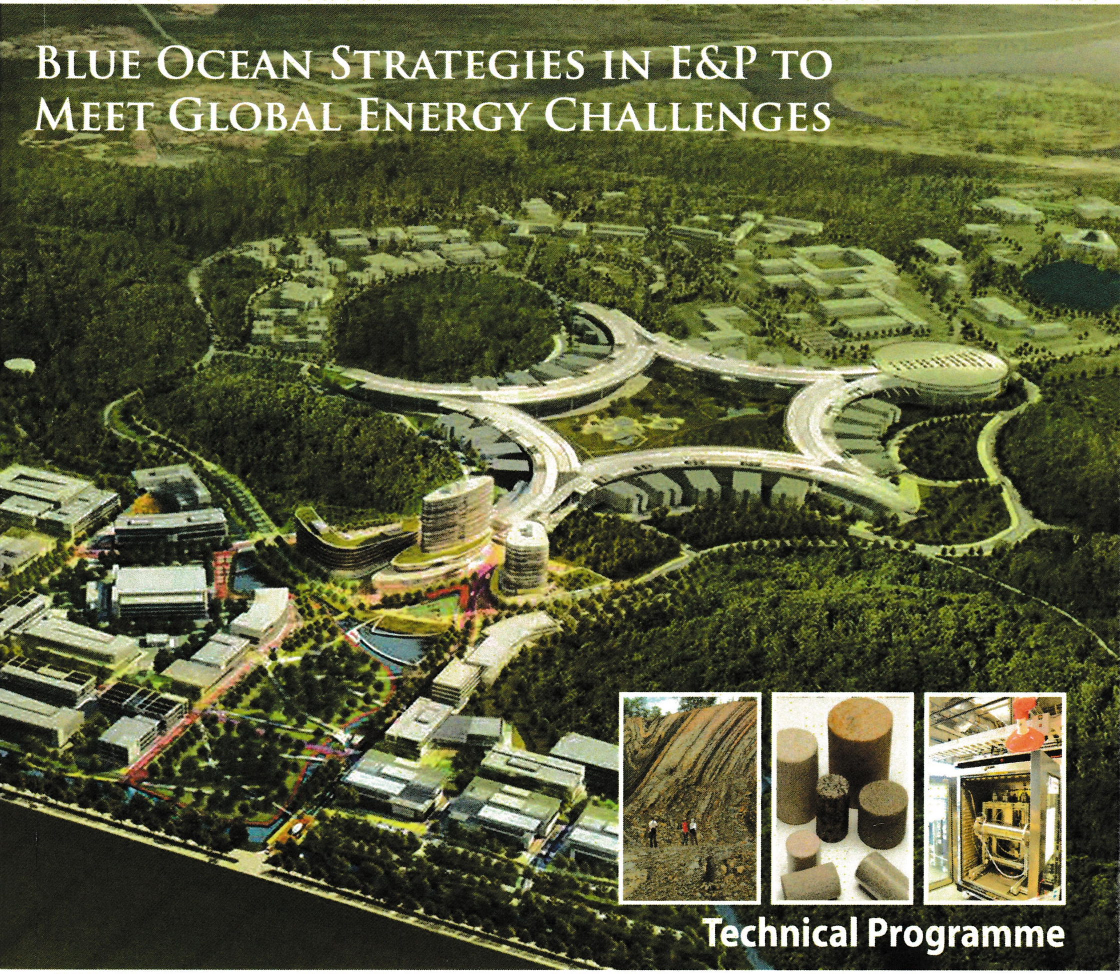

Technical Programme

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TECHNICAL PROGRAMME

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

Day 2 • Tuesday (16th August 2016)

Venue: RM 302
Track: ADVANCES IN GEOLOGICAL CONCEPTS IN SILICICLASTICS
Time : 1055 - 1325
Chairpersons: A GHANI MD RAFEK, AWALLUDIN HARUN

Session Code Paper ID	Paper Title Authors
1570235041	**General Geology of Jerantut - Jengka Transect with Emphasis on Depositional Environment** José A. Gámez Vintaned
1570235330	**Shortcut of Permeability Prediction: Rock Typing the Facies Association in Fluvial-Delta Environment** Herianto, Bambang Bintarto, Dyah Rini R, Zaki Muttaqin
1570240375	**Organic Geochemistry and Petrology of Tertiary Source Rock in Mukah-Balingian, Sarawak** Nor Syazwani Zainal Abidin
1570241919	**Sedimentology of the Lambir Formation in Northern Sarawak, Malaysia** Mazshurraiezal Nasir; Abdul Hadi Abd Rahman; Zainey Konjing; M Suhaili Ismail
1570244065	**Facies Analysis of the Kubang Pasu Formation, Pokok Sena, Central Kedah** Cassy Kee
1570247972	**Provenance Study on the Sandstone of Kubang Pasu Formation, Kedah** M Suhaili Ismail
1570248842	**Sandstone Facies Reservoir Properties and 2D-Connectivity of Siliciclastic Miri Formation, Borneo** Numair A. Siddiqui; Abdul Hadi Abd Rahman; Weng Sum Chow; Muhammad Murtaza
1570249269	**Morphological and Spectroscopic Characterization of Goethite-humate Complex Chelated on Quartz** Abdullah Ali; Eswaran Padmanabhan
1570249585	**Sedimentology and Stratigraphy of Clastic Sediments in Sungai Lembing Area, Pahang, Malaysia** Kar Ying Ong; Weng Sum Chow

Shortcut of Permeability Prediction: Rock Typing The Facies Association in Fluvial-Delta Environment

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

Transitional sedimentary environment experienced two energy-phase (shore and marine) resulting insertion of sand-shale content, will have unusual petrophysic relationship and vertical pattern from well log attribute. Meanwhile the petrophysic (permeability) distribution has to be predicted accurately, well log attribute cannot do, even a simple conventional porosity-permeability semilog plot is firmly used, the fallacy comes. Here we present a methodology of rock typing by integrating geological aspect from 112 detailed core description and well log gamma ray attribute as shortcut to predict permeability that closes to real one.

Reservoir rock typing is a process by which geological facies or lithofacies characterized by their dynamic behaviour. Facies and the role of sedimentology could be the base to conduct rock types. Hereby lithofacies is defined by the sedimentary texture. Meanwhile, core description should be done in a great detail, therefore it is recommended to lump or bin lithofacies types into facies association. Gamma ray log that shows vertical stacking pattern of lithofacies (fining-upward, coarsening-upward) explain the system tracts. In this paper we propose integration of the core description and the facies association to be used to produce representative rock types into PGS method. Once established, porosity-saturation-permeability correlations are formed to result permeability equation. Moreover, stratigraphic modified lorenz plot (SMLP) is used to define flow unit in stratigraphic order.

The study results 2 rock types based on facies association in PGS method; permeability prediction equation has been valid through routine core data (R^2=0.9576), hence, it could be used for predicting permeability on the uncored-wells by sequence stratigraphy-correlation for reservoir 'X'. The SMLP has confirmed 4 flow units which the best flow zone is in coarsening upward pattern. This could be an alternative reservoir characterization using reliable core data which leads to a well-built reservoir model and to know the best layer to be produced.

Keywords: lihtofacies, facies association, rock typing, pore geometry-structure, permeability prediction

Introduction

Unless from core data, permeability is an uncertain petrophysical parameter to measure whereas it determines the capacity of reservoir fluid flowing through connected pore space or pore throat. Well log attributes have difficulty in predicting permeability accurately, as well as such a simple conventional porosity-permeability semilog plot is firmly used, the fallacy comes. Moreover if it does in transitional sedimentary environment where the sand-shale content and deposit over and over again causing unusual petrophysically relationship, exactly it will have difficulties to characterize rock type for further study of geological modelling. Definitely is, well log attribute responses still show a robust pattern to assist in rock typing. Here, the concept of sequence stratigraphy will be reviewing the rock types applied into pore geometry-structure method as it could also result a permeability prediction equation.

There are some definitions of rock typing based on common technical terminologies found in the literature. Geologists consider rock types as depositional facies or lithofacies which emphasize the genesis of rock formations to enable 3D stratigraphic reservoir modeling (Fisher, 1982; Kerans and Tinker, 1999; Slatt, 2007). Petrophysicists define rock types based on pore geometry that relates all static and dynamic petrophysical properties (Archie, 1950). Reservoir and production engineers group rock types as flow units that are stratigraphically continuous intervals of similar geologic and petrophysical features to upscale reservoir grids for efficient fluid-flow simulation (Gunter et al., 1997b). Noteworthy is that reservoir characterization teams are working toward a common objective: to construct a verifiable reservoir model populated with accurate petrophysical properties for reserves estimation and production forecasting (Lucia, 1999). Therefore, developing new rock classification schemes and workflows that serve multiple characterization purposes from different disciplines remains a challenging but important task. It is important that an integral endeavor to classify rock types are so identified geologically and petrophysically unique.

Petrophysically, reservoir characterization involves identifiying rock type with similar flow and storage characteristics. Rock types as unit of rocks deposited under similar geological condition, undergone similar diagenetic processes resulting in unique porosity-permeability, capillary pressure and water saturation above free water (Gunter et al., 1997). Recently, based on a set of mercury injection capillary pressure data it was 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 structure, if it does, the model may also be employed to identify rock types (Permadi et al., 2009). Later, it was indicated in the work of Guo et al. (2005) that good history matches were quickly achieved where the defined flow units or rock types were in accordance with the capillary pressure data in terms of J-funtion. These all indicate that both pore geometry and its structure play an important role in defining a rock type or a flow unit.

Geologically, sequence stratigraphy has been usefull to identify a similar time-set of sedimentary facies. Sequence stratigraphy study acquaints parasequence set that accomodates the sedimentary facies commonly showing a certain stacking pattern, i.e. coarsening upward, fining upward, etc, from well logs gamma ray attribute response that is in accordance also with grain size (core description). In fact, bed thickness and rock type (grain size) could be integrated and agree with interpreted depositional context from core description and well logs (Xu, 2013). Facies, itself, could be group into facies association with prerequisite happened within a same environment and has permeability-porosity relationship. Gomes et al. (2008) defined facies associations are groups or bins of lithofacies from the same depositional environment/facies tracks with common ø-k relationships/trends.

Based on the definitions stated, one perspective of facies and the role of sedimentology could be the base to conduct rock types. This paper shows that the rock typing in transitional zone could be conducted by integrating facies association derived from gamma ray response (coarsening upward and fining upward) in fluvial-delta environment, and pore geometry-structure method, hence it is a good simplification of rock typing in fluvial-delta environment. Thus, for further wells correlation in the same layer in this reservoir 'X', the resulted permeability prediction equation could be used steadily.

Literature Review and Basic Theory

Facies and the role of sedimentology

Lithofacies types are described from preferrably, slabbed cores using a hand lens and with the help of petrographic thin section analysis. Lithofaies types are defined by the sedimentary texture (Dunham, 1962; Embry and Klovan, 1971), the grain types, and optionally by the sedimentary structures. Lithofacies types are the basic building blocks for all subsequent analysis. Conventional porosity-permeability data derived from core plugs should be tied to the lithofacies types. Core description (lithofacies description) should be done in a great detail, because it is always easy to lump lithofacies types together at a later stage. Therefore it is reommended to lump or bin lithofacies types into facies association (FA, facies bins). The lumping should be done using common lihtofacies tracts (facies of similar depositional environment) and one should be very careful of grouping them based on porosity versus permeability cross-plots without prior knowledge of the diagenetic overprint. Binned lithofacies types with similar diagenetic overprint should follow the same porosity-permeability trends. In addition, the lithofacies types binned in the facies association should have approximately the same range of porosity-permeability (Gomes et. al., 2008).

Lithofacies types should be described within a sequence stratigraphic framework, because the vertical stacking of lithofacies (shallowing upward, deeping upward, thinning upward, thickening upward, or fining upward as well as coarsening upward) depends on the system tracts (TST: retrograding system, HST: prograding system). Time-lines (chronostratigraphic boundaries: sequence boundaries, maximum flooding surfaces, and flooding surfaces) identified on core and subsequently tied to well-logs (distinctive well-log character) should be used to subdivide the reservoir at a third-(depositional sequences) fourth-(parasequence sets) and if needed, fifth-order (parasequences) scale. Lithofacies or facies association maps (GDE: gross depositional environment or EOD: environment of deposition maps) should be built at fourth- or fifth-order scale. These GDE/EOD maps also serve as a quality check for the correct lithofacies interpretation), (Gomes et. al., 2008).

Grain-Size Analysis from Gamma Ray Log Attribute

Grain size is directly associated with depositional energy (Xu, 2013). Large grains are deposited under highly energetic flow conditions, whereas small grains are deposited under low flow energy (Reading, 1996). Grain size information provides key data for geologist in their facies interpretation work (Glaister et.al., 1974). In addition, grain size distribution determines the pore-size distribution of most clastic rocks when diagenesis effects are not significant. Consequently, grain size information becomes a good indicator of reservoir quality in terms of hydraulic capacity.

Grain size is typically measured from core samples. To date, there exists no effective physical measurement capable of measuring grain size directly at downhole conditions. However, there are causative and correlational effects between grain size and physical logs. Gamma ray logs are sensitive to the natural radioactivity of rock formations. Th radioactive elements (U, K, Th) are predominantly associated with small grains such as silt or clay (Serra, 2003). Consequently, often there is a correlation between gamma ray log and grain size distribution (Xu, 2013), see **Fig.1**. In fact, the gamma ray log as been long used as a single indicator of grain size in many geological field studies because it is more readily available than others (Pirson, 1983; Rider, 1990).

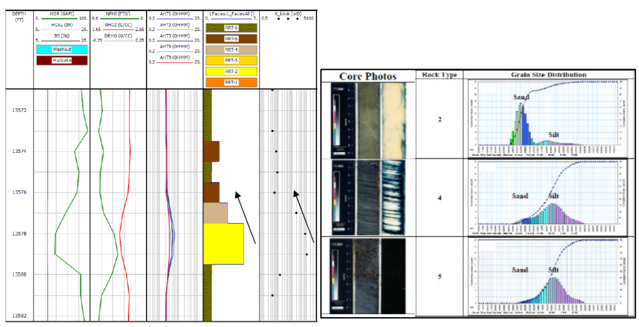

Figure 1- Gamma ray log respondly consistent to rock type (grain size), (Xu, 2013)

Parasequence, Parasequence Set and Stacking Pattern Formed

Parasequence consists of several layer and stack of layer of rocks that are relatively conformable, formed by sedimentary proccess and restricted by flooding-sea level or equal level. There are two mechanisms forming parasequence namely the increase of sea depth relatively fast, and increase of sea level fast. **Fig. 2** shows 3 parasequence sets relating to the gamma ray log response of each.

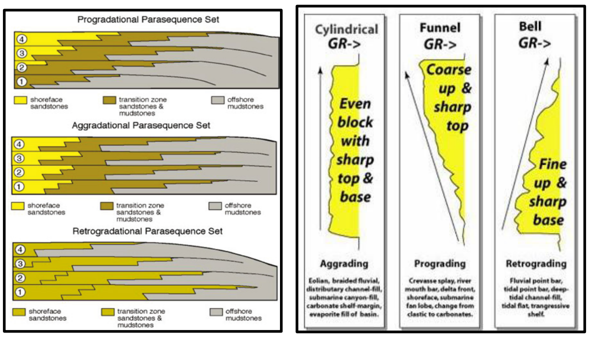

Figure 2- Parasequence set of formation and gamma ray log response

The parasequence is restricted above and beneath by the surface of marine flooding which is as boundary separating young layer and older one resulted by an increase of sea level depth suddenly and the spreading towards laterally. Parasequence set is a combination of parasequences that are related genetically to forming distinct stacking pattern. **Fig.2** shows that progradational parasequence set is typically formed when the sediment supply is higher than accommodation, and the stacking pattern formed is coarsening upward from gamma ray log response. Aggradational parasequence set has equal sediment supply and accomodation which forms stacking pattern of cylindrical from gamma ray log response, while the retrogradational parasequence set has opponent process from progradational, hence it has stacking pattern of fining upward.

Pore Geometry-Structure

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. Permadi et al. (2009) proposed a rock typing method which is pore geometry-structure, simply as :

$$k = C\, ø^3 \quad \text{.......} \quad (1)$$

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.(1) can be rearranged to separate pore geometric term from the pore structural term,

$$\sqrt{\frac{k}{ø}} = ø\sqrt{C} \quad \text{.......} \quad (2)$$

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 (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, 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:

$$J(Sw) = 0.21645\ \frac{Pc}{\sigma}\sqrt{\frac{k}{ø}} \quad \text{.......} \quad (3)$$

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 $\sqrt{(k/ø)}$ and pore structure $(C = \frac{k}{ø^3})$, (Permadi et. al., 2009; Muttaqin, 2015). 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 petroleum engineering are necessary to define or characterize the rock type.

Flow Unit from SMLP

The best way to assess the minimum number of flow units in a reservoir is to make use of the Stratigraphic Modified Lorenz Plot (SMLP) technique (Gunter et al., 1997). To compute the SMLP, countinous (foot-by-foot) core porosity and permeability and the respective k/phi ratio are arranged in stratigraphi order. Subsequently, the products of k*h and ø*h were calculated, the partial sums were computed and, subsequently, a normalization to 100% was carried out (Gomes et al., 2008).

Model of Permeability Prediction

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

$$\left(\frac{k}{ø}\right)^{0.5} = a\left(\frac{k}{ø^3}\right)^b \text{ becomes } k = ø^3\left(\frac{\left(\frac{k}{ø}\right)^{0.5}}{a}\right)^{\frac{1}{b}} \quad \text{.......} \quad (4)$$

equation of *k-Swi* relation :

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

$$k = \left(\frac{m}{Swi}\right)^{\frac{1}{n}} \quad \text{.......} \quad (5)$$

match action into 'elimination' equation (4) and (5) :

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

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

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 :

$$k = C\ x\ \frac{1}{ø^A\ x\ Swi^B} \quad \text{.......} \quad (7)$$

Plot between *k* against $\left(\frac{1}{ø^A\ x\ Swi^B}\right)$ 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.

Methodology

Methodology used consists of determination of lithofacies types and depositional environment interpretation, Gamma ray log-based stacking pattern and facies association, Petrophysical grouping, Pore geometry-structure (PGS), Rock type using J-function as validation, and the result are permeability prediction as well as flow unit based on SMLP. **Fig.3** clearly shows the step-by-step of methodology proposed.

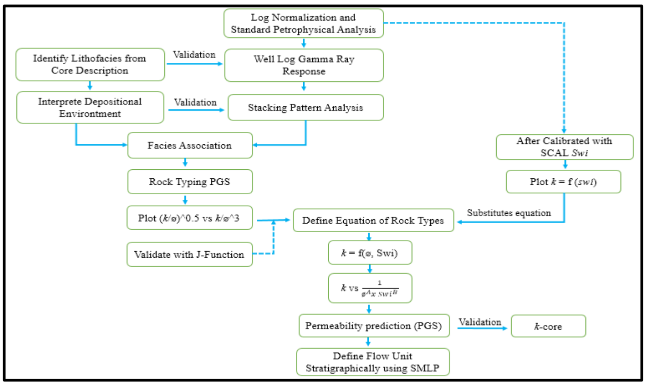

Figure 3- Workflow used based on core data and well log

Rock types defined by facies association from core description with certain stacking pattern from well log gamma ray response should be integrated into pore geometry-structure (PGS) method whether they are already in accordance together or not. The PGS method says that the slopes ideally is 0.5, but here the assumptions is made by the slope is no more than zero 0.7, this is because in the transitional zone the effect of shore-off shore energy has resulted unusual facies/lithofacies types stratigraphycally whereby the insertion content of shale happened over and over again. After rock types validated by J-function, the permeability equation could be gained by integrating the calibrated *Swi*-well log with rock type's equation, this step will result permeability prediction equation as function of ø and Swi. Subsequently, to know vertically in depth of the single well that has good layer performance, stratigraphic modified lorenz plot is employed to emphasize it.

Result and Discussion

Core-Based Lithofacies Types and Depositional Environment Interpretation

Core description can assist the lithofacies types formed and the depositional environment interpretation. Here 112 core samples are analyzed to guiding the well log gamma ray response later, tabulated in **Table 1**.

Table 1- Depositional Environment Interpretation based on Core description

Core-Body Photo (some parts of samples)	Description (lithofacies type)	Depositional Environment Interpretation

	(6848 ft – 6856 ft): Sandstone and small pebble conglomerate, pale to moderate yellowish brown and yellowish gray, lithic, coarser and finer interbedded, cross-bed sets typically 1 foot thick (6856 ft – 6863 ft) : Mudstone (6863 ft – 6874 ft) : Small pebble conglomerate, pebbly sandstone, pale yellowish brown, lithic, alternately coarser and finer beds, cross-bedded	• Lower Part of Channel Deposits (6848 ft – 6856 ft) • Channel sandstone and overbank mudstone (6856 ft – 6872 ft) • This two intervals occured in fluvial-delta environment
	(6873 ft – 6900 ft): Sandstone and small pebble conglomerate, pale to moderate yellowish brown and yellowish gray, lithic, coarser and finer interbedded, cross-bed sets typically 1 foot thick	• Fluvial cyle
	(6900 ft – 6912 ft): Sandstone and small pebble conglomerate, pale to yellowish gray, lithic, alternately coarser and finer grained, cross-bedded. Glossy black parting at base of unit. (6912 ft – 6915 ft): Sandstone, yellowish gray, coarse, poorly to moderately sorted, lithi, 1-foot cross-bed sets, glossy black partings (6915 ft – 6938 ft): Sandstone and small pebble conglomerate, yellowish gray, lithic, coal fragments, alternately coarser and finer grained and intergradational, some cross-bedding, large glossy-black leaves. Erosional base	• Stacked Channel Deposits (Still fluvial cycle)
	(6938 ft – 6939 ft): Sandstone, yellowish gray, coarse, poorly to moderately sorted, lithi, 1-foot cross-bed sets, glossy black partings. (6939 ft – 6940 ft): Sandy mudstone and mudstone pebble conglomerate. (6940 ft – 6951 ft): Small pebble conglomerate, yellowish gray, lithic, moderate sorted, inclined laminae (6951 ft – 6957 ft): Sandstone and Small pebble conglomerate, yellowish gray, lithic, coal fragments (6957 ft – 6958 ft): Mudstone or Mudstone pebble conglomerate, yellowish gray (6958 ft – 6963 ft): Small pebble conglomerate, yellowish gray, lithic, coarse poorly sorted.	• All sets in Fluvial-Delta Cycle

Gamma Ray Log-Based Stacking Pattern and Facies Association

Study above can facilitate the same lithofacies into a same environment, here is fluvial-delta (fluvial is dominant). We validate it into gamma ray response that shows two stacking patterns (coarsening upward (CU) and fining upward (FU)). **Fig.4** shows that gamma ray response could be corresponded into lithofacies types. Facies association for the two is generally same (fluvial-delta), hence in manner of stratigraph, this way will easly to correlate other wells and facilitate a petrophysical paramater (permeability distribution).

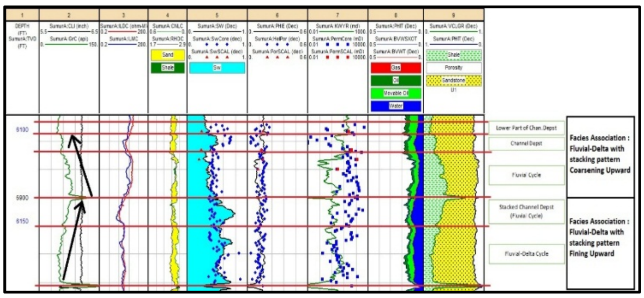

Figure 4- Stacking pattern of gamma ray response associated with lithofacies type to be facies association

Petrophysical Grouping

In order to etablish the petrophysical groups within a stacking pattern group, a concept of pore throat is used. Pittman plot employes equation differentiating quantitative petrophysical range in order to know their group. In **Fig.5** shows there are 4 average isopore throat lines called R35. These each lines will correspond to how many proper flow units will be in the stratigraphic order using SMLP method. The same relation in the **Fig.5** may apply for different stacking pattern group within the same facies association.

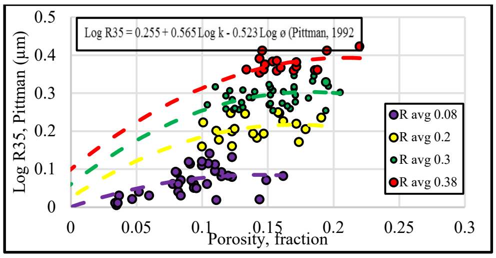

Figure 5- Pittman plot establishing the relationship between porosity-permeability for different stacking pattern group

Pore Geometry-Structure (PGS)

Pore geometry-structure will establish wheter the resulted two stacking pattern have a distinct architecture of pores well or not. Ideally for cylindrical capillary tube sistem the slope will be 0.5, but here we assumse that the limit of a good slope/ gradient is no more than 0.7. **Fig 6** confirmes each plots shows in excellent agreement with slopes are 0.67 for coarsening upward (CU) and 0.578 for fining upward (FU) petrophysical data. Subsequently, the CU and FU will be named as rock type 1 and rock type 2, respectively.

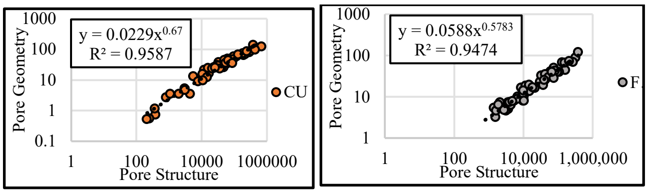

Figure 6- PGS plot based on the CU and FU petrophysical data, called RT 1 (CU) and RT 2

Rock Type using J-function as Validation to PGS

Special core analysis (SCAL) data as many as 4 core plugs will validate the resulted PGS-rock types. SCAL samples consist of 4 namely ID 306, ID 319, ID 326, and ID 333. All the samples are derived from coarsening upward section or RT 1. Subsequently, each ID has their own irreducible water saturation – capillary pressure data, all data were normalized by j-function method, see **Fig.7**. The result shows all data-spread are close each others and they tend to form a single curve like **Fig.7 (b)**. With determination coefficient R^2 = 0.9143. This figure has validate that coarsening upward section or RT 1 has been in accordance with j-function-rock type. Meanwhile, in the fining upward or RT 2 section has no SCAL samples to observe, so it has not been validated. Hence, for further recommendation is in that depth section should be taken any core samples to know the dynamic behaviour and to guide the rock type resulted before.

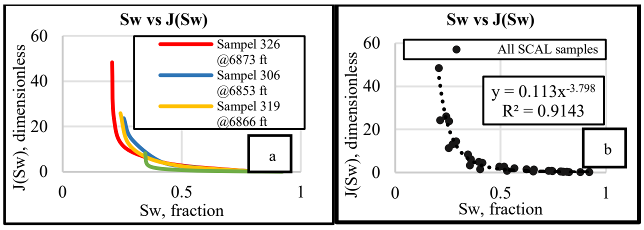

Figure 7- J-function just validates RT 1 (CU)by its single curve formed (b)

Permeability Prediction

Fig 8. is as consideration why conventional method does not necessarily correct to predict permeability distribution. Conventional porosity-permeability plot for each section has determination coefficient R^2 = 0,8367 (CU) and R^2 = 0,6078 (FU). These result is lower accurate for permeability prediction purpose. PGS could accomodate irreducible water saturation and porosity to corelate permeabiilty better. The steps are calculated using equation (4) until equation (8). The calibrated-Swi for each RT's are in **Fig.9**, and equations were merged with rock type equation to gain correlation of porosity-permeability-water saturation. The result of $\log(k) = \log(C) + \log\frac{1}{ø^A \text{ x } Swi^B}$ see **Fig.10**. Subsequently, calculate permeability estimation using each rock type's equation resulted from **Fig.10.** Finally, the estimated permeability for both conventional method and PGS approach are shown in **Fig.11**. We see, the k-PGS gives more accurate permeability that closes to core permeability.

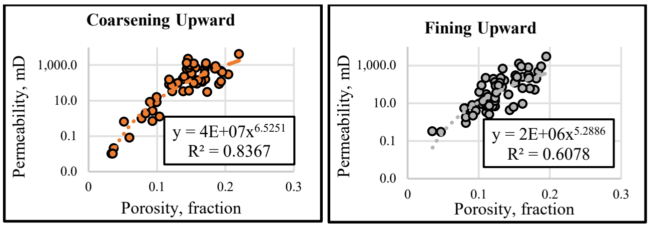

Figure 8- Conventional porosity-permeability plot

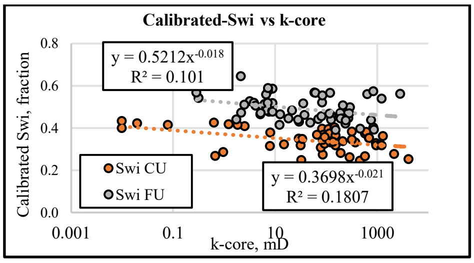

Figure 9- Calibrated-Swi for each rock type

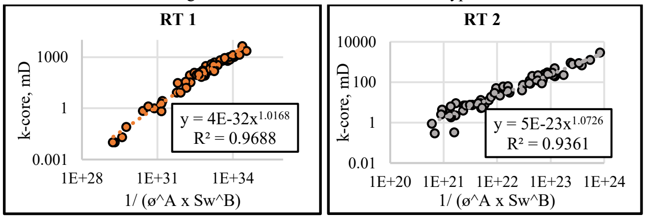

Figure 10- Permeability prediction equation as function of ø and Swi for each RT.

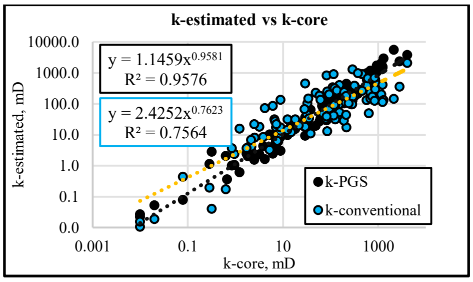

Figure 11- Estimated-permeability towards core permeability as validation

Flow Unit Based on SMLP

Flow unit is a reservoir layer that has certain characteristic of fluid flow. Flow unit always relates to the effective permeability/ pore throat space. In this case, from 112 core samples stratigraphically-analyzed has resulted 4 flow unit (characterized by data spread-shape). The advantage of SMLP, when applied to a single well, is that it resembles the gradients of a production loging tools (PLT) profile versus depth, whereby the shape of the SMLP curve is indicative of the flow performance of the reservoir. Segments with steep slopes have a greater percentage of reservoir flow capacity relative to storage capacity, and by definition have a high reservoir process speed. See **Fig.12**, A0 is a flow zone with depth from 6848 ft to 6867 ft, A1 is a flow zone with depth from 6878 ft to 6888 ft, A1 is a flow zone with depth from 6888 ft to 6908 ft. Segment of A0 has storage capacity around 16% but little flow capacity (5%). Segment of A1 has storage capacity 20% but high enough for the flow capacity (14%). Segment of A2 has storage capacity around 20% and the highest flow capacity (34%). Segment of A3 has highest storage capacity 40% with the flow capacity around 19%. Mathematically, A2 and A3 are the best flow unit, but we should correspond it to water saturation profile (**Fig.13**). Gomes et. al., 2008. said that the best flow unit is which has the steepest gradient. But if the highest flow zone has water-bearing layer, it will just like to produce water. Based on the observation from **Fig.12** and **Fig.13**, we may conclude that the best flow zone is A2 that has the steepest gradient, (flow capacity 34%), this zone dominantly consists of lower part of RT 1 (coarsening upward). The high-average permeability and lower water saturation are also located in the coarsening upward section. Thus, A2, A1 and A0 in a row are the best-row to produce oil.

Previosly, petrophysical group based on Pittman plot there are 4 groups, and these correspond also the flow unit resulted from SMLP, 4 groups of flow unit. This plot is very useful for optimization of the number of petrophysical groups and to asses their distinct dynamic behaviour.

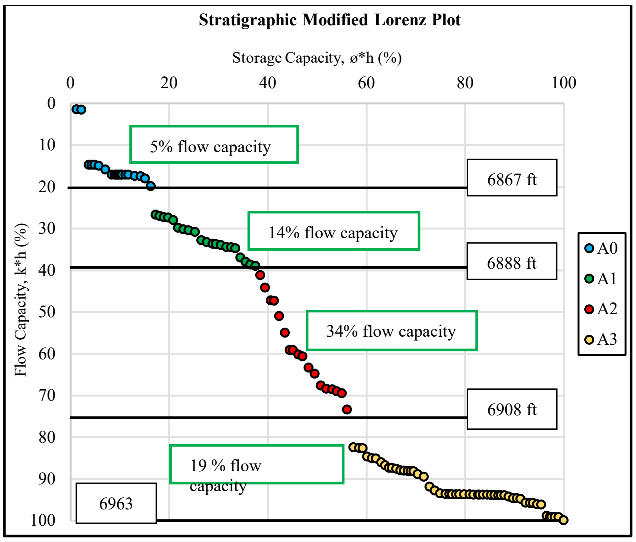

Figure 12- Flow zones based on stratigraphic modified lorenz plot

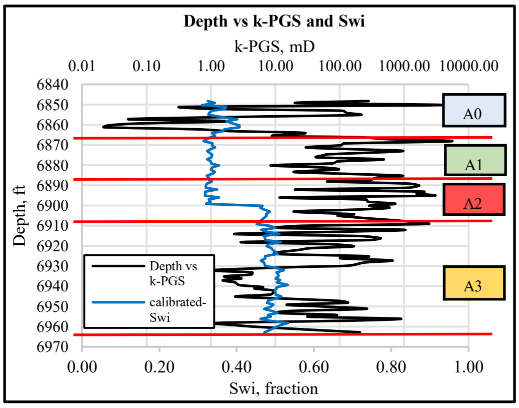

Figure 13- Swi and k-estimated (k-PGS) profile straigraphycally

Conclusion

1. The facies/lithofacies types found in a fluviatile environment may be grouped together to define a fluvial facies association for purpose of rock typing, even in fluvial-delta environment.
2. This study results 2 rock types based on facies association in PGS method namely RT 1 (coarsening upward), RT 2 (fining upward). This could be an alternative reservoir characterization using reliable core data which leads to a well-built reservoir model.
3. Permeability prediction equation has been valid through routine core data (R^2=0.9576), hence, it could be used for predicting permeability on the uncored-wells by sequence stratigraphy-correlation for reservoir 'X'.
4. The SMLP has confirmed 4 flow units which the best flow zone is in coarsening upward pattern, hence it assists knowing the best layer to be produced
5. As recommendation, PGS plot could be used for guiding which samples to measure SCAL further.

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