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SPATIAL AND TEMPORAL DISTRIBUTION OF PORE THROATS IN RESERVOIR SANDSTONE: IMPLICATION TO PERMEABILITY VARIATION IN WEST BARAM DELTA, MALAYSIA

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ABSTRACT

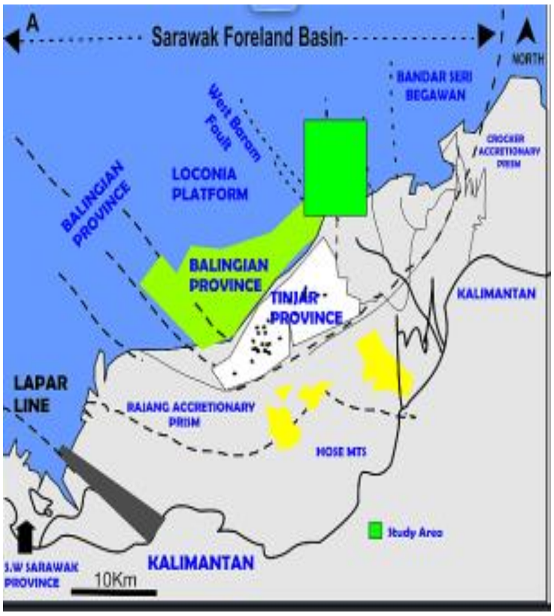
This paper attempts to quantify pore throats distribution towards more effective approach to permeability prediction. The mercury inoculation capillary pressure (MICP) is used to calculate pore throat diameters, and porosity-permeability system (POROPERM) validates effect of pore throats diameters on permeability variations from core plugs. Results reveal three major classes of pore throats diameters (micropore, mesopore and macropore) from five identified pore throat types. It indicates also that the abundance of mesopore and macropore throats above 30% in upper section (1475 *m* – 1480 *m*) of Siwa well increases permeability above 990 *mD*, an increase in micropore throats in middle unit (2106 *m* – 2114 *m)* of BK-102 well vary permeability from 495 *mD* to 600 *mD*. Whereas, in the TK well, permeability is moderate lower between 230 mD to 670 *mD* due to abundance of macropore throats in groundmass of the fine to very fine-grained sandstones. In WL well, at depth from 1720 *m* to 1850 *m,* permeability is moderate higher varying between 120 *mD* to 945 *mD* attributed to abundance mesopore and macropore throats presence in coarse friable and medium grained sandstones within stratigraphic succession. The results also indicates that increase in percentage composition of mesopore and macropore throats above 20% holds potential increase in permeability, and conversely increase in micropore throats type 1-3 disrupts or lowers permeability. The understanding of spatial and temporal distribution of pore throats in wells, could improve accurate prediction permeability and hydraulic flow units in reservoirs.

Keywords: pore throats, mercury capillary pressure, permeability, Baram Delta

INTRODUCTION

Pore throats size in siliciclastic rocks develops a continuum from the sub millimeter to the nanometer range, Nelson (2010). It also determines fluids transmissivity within reservoir rock and thus outsized interconnected pore throats interprets to high permeability, Sneider and Bolger (2008). However, pore throats have critical control on fluid flow, Lala-Sayed & El-Sayed (2014). Petroleum geologists are familiar to evaluating reservoir rocks in considering porosity and permeability with less concern on the pore throats size. Reservoir rock parameters such as throats size, throats sorting, pore configuration and shapes constantly contribute to fluid flow, Wardlaw and Cassan (1978). However, till date estimation and prediction of permeability in reservoir is still a challenge, Gao and Qinhong (2013); Ben-Awuah and Padmanabhan (2017). This paper attempts to characterize and quantify pore throats distribution towards developing a more effective approach to prediction of permeability. This work asses, for the first time, pore throat sizes distribution in one hundred and thirty two (132) specimens in five exploratory wells from five (5) selected reservoir sandstones from study area. The objectives will be: 1) to quantify and classify pore throats and evaluate their potential implication on permeability variations. The study area is situated at the offshore (Figure 1) Sarawak, with hydrocarbon exploration history of above thirty-four years (34), Surdiman et al.,(2011), perhaps with a present recovery rate of 30%, Bakar et al., (2011); Ben – Awuah et al., (2016) from approximately more than one hundred and fifty (150) exploratory wells within the Delta.

However, productive reservoir units are made up of an approximately 21420.06 m thick piled sequence of shallow marine sands (Figure 2), [Tan et al., (1999) dispersed in excess of more than 195 zones, and broadly faulted. The offshore formation sequence of the Baram Delta include coastal to coastal-fluviomarine sands deposited in a northwestward since the Middle Miocene (from Cycle IV onwards), in which the Cycle V (Middle - Upper Miocene) to Cycle VII (Upper Pliocene) are the most developed [Tan *et al.*, (1999); Ben-Awuah and Padmanabhan, (2015)



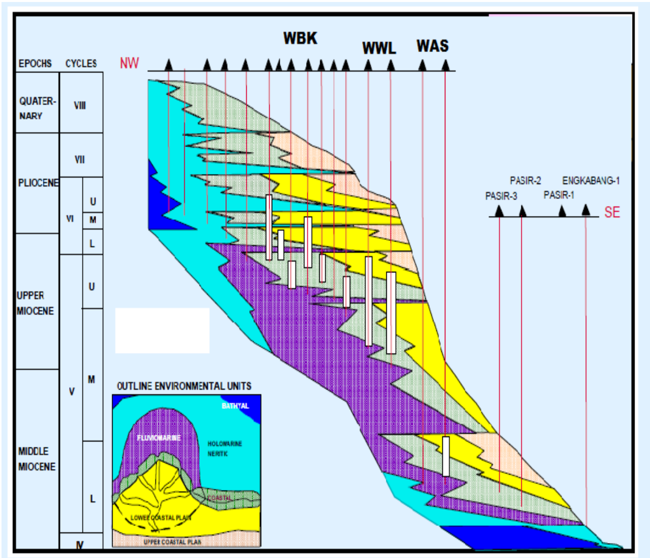


Figure 2 showing stratigraphic framework of study wells in Baram Delta province, Sarawak (modified after Pauzi et al., 1999)

Figure 1: Location of the Sarawak basin and the study area (Modified after [5])

MATERIALS AND METHOD

From five (5) reservoir sandstone lithofacies, twenty – five (25) 1.5" core plugs and one hundred – thirty two (132) sandstone specimens within Cycle IV/V of Middle- Upper Miocene age at variable depths were used for this study. Mercury porosimetery equipment (MICP) Thermo Scientific PASCAL 240 Series was used for measurements and analysis of pore throats diameters by injection of mercury into the samples at high pressure.

The highest test pressure of 200MPa, at a temperature up to 25^{o}C with mercury density of 13.534g/cm^3 was applied. The machine is programmed to automatically correct for variations in compressibility of samples.

The twenty – five 1.5" representative core plugs were examine for permeability variations using an unsteady state gas permeameter and porosimeter (Coreval 30). The equipment is powered within 110 -220 VAC, 60 *Hz*, and helium gas was injected into the core plugs at confining pressure up to 400psi and pore pressure of 250psi.The equipment measures permeability between 0.001 *md* to 10 Darcie's and porosity up to 60%.

RESULTS AND DISCUSSION

Effects of pore throats distribution on Permeability variations

From mercury Injection capillary pressure (MICP) dataset, pore throat diameter is statistically classified and quantified into five major categories; the Type 1 vary between 0.001 – 0.01μm, while Type 2 is between 0.101 – 0.1 μm, and the Type 3 vary between 0.1001 – 1 μm. The Type 4 pore throats also vary between 0.001 to 10μm and lastly the Type 5 is between 10, 0001 – 100 μm respectively. The vertical profile (figure 3) reveals effect of pore throat type permeability variation in Siwa 5 well, with higher permeability values varying from 540 *mD* to 1320 *mD* at the Upper section (1475 *m* – 1480 m) attributed to the large quantity of the meso pore and macro pore throats over 30% in overall composition in coarse and massive medium the coarse-grained sandstone. But decreases between 180 *mD* and 990 *mD* in massive friable fine and fine grained sandstones having abundance of micropore throat above 30% around 1485 m. At lower section within 1495 *m* – 1510 *m*), decrease in permeability is due to high percentage of micropore throat in fine grained and high fine sand and silts fractions clogging pores in the massive medium grained sandstone.

Figure 4 shows vertical profile of effect pore throat type on permeability variation in BK-102, permeability value are moderately lower ranging from 10 *mD* to 424 *mD* at 2095 *m* – 2099 *m*. The fluctuation in permeability values is attributed to above 20% great quantity of mesopore throat within the massive friable and the very fine grained sandstone in the lithofacies succession. In middle, permeability increases from 495 *mD* to 600 *mD* at depth 2106 m to 2114 m corresponding to 40% abundance of macropore throat within rock grandmas in the massive fine-grained and massive friable-fine grained sandstone facies. At the bottom, permeability continue to increases from 423 *mD* to 1189 *mD* within at the depth between 2121 *m* to 2129 *m*, due to occurrence of the macro pore throats that varies between 33% and 41% in massive medium coarse lithofacie, fine lithofacie and massive friable fine-grained sandstone lithofacie within the stratigraphic sequence units.

The figure 5 shows perpendicular profile of effect pore throat type on permeability variation in Tk-X well, at the Upper portion around 850 *m* to 860 *m*, permeability values vary from 143 *mD* to 840 *mD*. The slight decrease in permeability variations was due to abundance of micro pore and macro pore throats at 23% composition in fine grained sandstone facies. However, toward the bottom section at depth 880 *m* to 894 *m*, the micro pore and meso pore throats occurrences above 21% in abundance responsible for inconsistence in permeability values between 111 *mD* to 421 *mD* at maximum distribution in fine grained sandstone lithofacies.

The figure 3 shows perpendicular profile of effect pore throat type on permeability variation in TK X2 well, at the Upper portion, between 1380 *m* and 1386 *m*, permeability values is moderately higher and varying from 401 *mD* to 541 *mD*. The variances in values are due to composition of macro pore throat at 33% present in fine grained sandstone and approx of 29% meso pore throats in massive medium coarse sandstone lithofacie in the stratigraphic unit.

However, from middle at 1391 m towards bottom at 1407 m, permeability slightly increases varying between 230 m D to 670 m D at maximum distribution in fine grained sandstone due abundance of macropore throats.

The vertical profile of WL-X, at depth between 1721 *m* and 1746 *m* in Upper section of well, permeability variation in , composes of moderate good permeability varying between 120 *mD* and 330 *mD*, and could be attributed to abundance of above 20% mesopore and macropore throats in fine grained sandstone facies. In the middle section towards the bottom (1800 *m* – 1850 *m*), permeability values is very good between 130 *mD* to 945 *mD* in the region. The slight increase in permeability values is attributed to the above 25% mesopore and macro pore throats in massive medium coarse and very fine sandstone lithofacies.

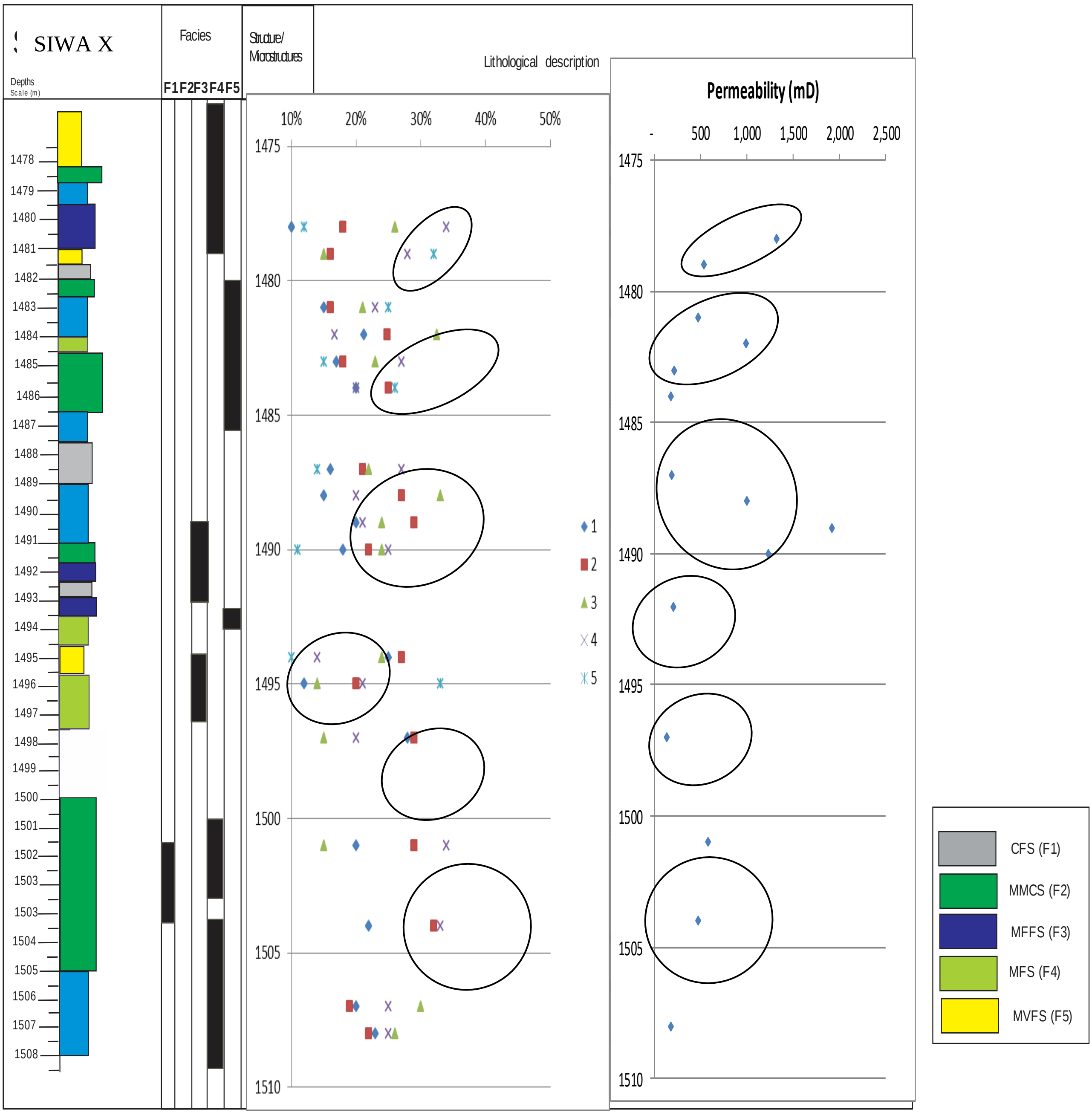


Figure 3: Showing vertical profile of effect pore throat type on permeability variation in Siwa X well

CONCLUSION

From this study, for the first time, pore throat diameters are quantified and characterized into the micro pore, meso pore and macro pore pore throats to evaluate their potential implication on permeability variations using mercury porosimetery and porosity-permeability system (Poropem). In Siwa X well, abundance of meso pore and macro pore throats at depth 1474*m* – 1480 *m* enhances raise in permeability to vary between 540 *mD* and 1320 *mD* in Upper section of the well, while abundance of micropore throats above 30% at depth 1488 m slightly lowers permeability values varying between 180 mD to 990 *mD*. However, in BK X well at upper section, permeability varies from 10 *mD* to 424 m D at depth between 2095 *m* – 2099*m* comprising of mesopores above 20% composition. Furthermore, in middle down bottom (2106 *m* – 2129 *m*) section, the abundance of macropore throat increasing permeability values from 495 *m D* to 1189 *m D*. In TK-X at depth 850 *m* – 860 m, micropore and macropore throats contributes to varying permeability from 143 m D to 840 *mD*, and in TK-X2 well, at 1380 *m* – 1386 *m* permeability varies from 400 *mD* to 540 *mD* due to macropore and mesopore throats. At middle to bottom (1391 *m* – 1407 *m)*, permeability slightly increases from 230 *mD* to 670 *mD* due to abundance of macropore throats. In WL-X well at upper to middle (1720*m* - 1850*m*), the abundance of mesopore and macropore throats increases permeability from 120 *mD* to 945 *mD* in the well section. Results reveal that increase in percentage composition of meso pore and macro pore throats above 20% increases permeability, and conversely increase in micropore throats type 1-3 disrupts, and lowers permeability variations. The understanding of spatial and temporal distribution of pore throats, can lead to betters permeability prediction in reservoirs.

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