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Petrophysics Analysis for Reservoir Characterization of Upper Plover Formation in the Field "A", Bonaparte Basin, Offshore Timor, Maluku, Indonesia

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ABSTRACT. Hydrocarbon potential within Upper Plover Formation in the Field "A" has not been produced due to unclear in understanding of reservoir problem. This formation consists of heterogeneous reservoir rock with their own physical characteristics. Reservoir characterization has been done by applying rock typing (RT) method utilizing wireline logs data to obtain reservoir properties including clay volume, porosity, water saturation, and permeability. Rock types are classified on the basis of porosity and permeability distribution from routines core analysis (RCAL) data. Meanwhile, conventional core data is utilized to depositional environment interpretations. This study also applied neural network methods to rock types analyze for intervals reservoir without core data. The Upper Plover Formation in the study area indicates potential reservoir distributes into 7 parasequences. Their were deposited during transgressive systems in coastal environments (foreshore - offshore) with coarsening upward pattern during Middle to Late Jurassic. The porosity of reservoir ranges from 1–19 % and permeability varies from 0.01 mD to 1300 mD. Based on the facies association and its physical properties from rock typing analysis, the reservoir within Upper Plover Formation can be grouped into 4 reservoir class: Class A (Excellent), Class B (Good), Class C (Poor), and Class D (Very Poor). For further analysis, only class A-C are considered as potential reservoir, and the remain is neglected.

Keywords: Upper Plover Formation · Rock typing · Depositional environment · Bonaparte basin · Maluku · Indonesia.

1 INTRODUCTION

Plover Formation is the main target for hydrocarbon production in North West Offshore Australia as well as the Outer Banda arc of Indonesia (Barber *et al.*, 2003). However, in the Field "A" the upper part of this formation has not been produced and need to further study to reveal the characteristics and hydrocarbon potential within reservoir. Geographically, the study area took place in the offshore Maluku, about 70 km to the south of the Selaru Island, Maluku Provinces (Figure 1) and geologically belong to the Bonaparte Basin.

The Upper Plover Formation was deposited during transgression phase within transitional to shallow marine environments, which produce heterogeneous succession of sedimentary rocks. Understanding of depositional environment and petrophysics leads the grouping of rocks types, which then useful to support modeling process and calculation of hydrocarbon in place. The study was carried out to identify vertically facies succession of each sequence, to determine physical properties and fluid content of reservoir, and to classify rock types of reservoir within interest zone.

This study utilized three wells data within research area, namely A-1; A-2 and A-3, including las data, geological drilling final report, routine core analysis (RCAL) report, core description, FMI log analysis reports, biostratigraphy

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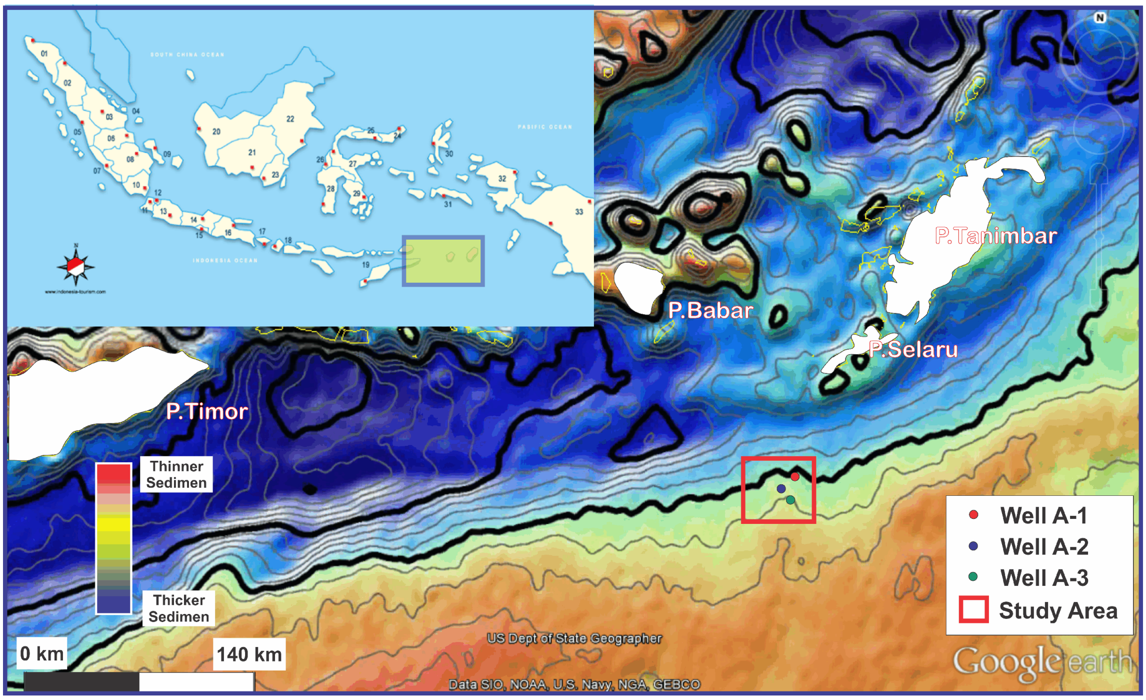


Figure 1: Research area located in the southern outer Banda Arc, of Offshore Maluku, where three exploratory wells are available as primary data in this study.

reports and sedimentary facies logs. All data are otillized to run reservoir characterization using IP (Interactive Petrophysics) software.

2 Review of Plover Formation

Research area is considered as northern part of the passive Australian plate boundaries and lies on Calder Graben, Bonaparte Basin. Calder Graben has southeast rifting pattern that formed northeast - southwest trending structures. This Graben has thick succession of Jurrasic – Cretaceous sediments that according to Barber *et al.* (2003), the early Jurassic massive erosion truncate the Abadi High Pre-Cambrian to the Triassic interval. Continental to shelfal marine sedimentation continued throughout Early to Middle Jurassic, leading to deposition of the Malita Formation red beds and overlying Plover Formation fluvio-deltaic sediments up to 1500–2000 m thick, and terminated by rifting (break-up) on the Australian continental crust during the Oxfordian.

According to Helby *et al.* (1987), the characteristics of lithology in conjunction with biostratigraphic control indicate that sedimentation patterns during Plover Formation times were dominated by a series of widespread braided trunk river systems feeding a relatively narrow wave-dominated coastline and beyond a wide marine shelf. The river system has relatively northwest – southeast directions along a line of weakness provided by the axis of the Goulburn Graben. Study area is most probably situated in the shoreface area where rivermouths distributed sediments northward to the shelf (Figure 2).

Nagura *et al.* (2003) divided Plover Formation into four intervals (Figure 3). The following are description for each zone from the bottom to the top part. The Zone 4 is considered as Lower Plover Formation of deltaic sediments with limited reservoir potential. Succession delta is terminated by thin shale associated with verrucosa MFS flooding event. The Zone 3 overlying the Zone 4 marked by verucossa MFS. This zone begins from a lower interval of offshore shales with thin storm sands, into lower shoreface silts and fine sands and eventually into fine to medium grained, planar and cross-bedded, extensively bioturbated upper shoreface sands. The Zone 2 overlying above base *indotata MFS* were tested in the Abadi-1 and Abadi-3 wells as main reservoir. In lower part, this zone consist of shales, silt and sands of offshore to upper shoreface environments. To the upper part, this zone is capped by the massive, extensively bioturbated, predominantly medium grained sands. In the well logs,

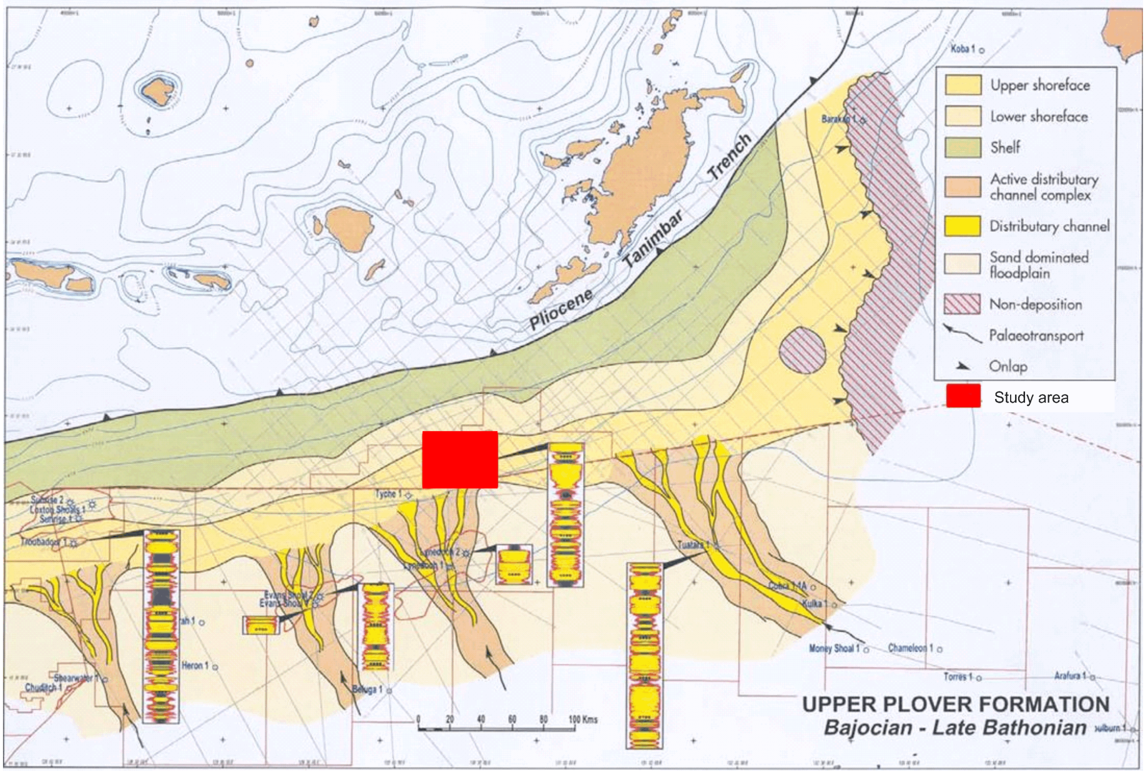


Figure 2: Paleogeography of Upper Plover Formation indicate fluvial to shelfal depositional environments during Middle Jurassic (Barber *et al.*, 2003).

it is characterized by a blocky log profile and excellent reservoir properties. The Zone 1 is the top of Plover Formation, which then overlain by Echuca Shoals and marked by regional unconformity. It comprises a thin succession of non-reservoir quality sands possibly representing deposits of an offshore. This interval only develop in Abadi-1 well and mostly are absent in other area due to erosion.

Based on the crossplot porosity versus permeability core plug data (Nagura *et al.*, 2003), Plover sandstone indicates three different lithofasies. Lithofacies 1 shows high porosity and permeability values, consist of medium to coarse-grained quartzarenite with excellent visible porosity resulted by tidal delta sedimentation. Lithofacies 2 is characterized by fine to medium grained, moderately to well sorted quartzarenite to subarkose/ sublitharenite. Although the magnitude of lithofacies 2 is lower than Facies 1, but it still retains good reservoir properties. Lithofacies 3 is predominantly medium-grained, moderately to well sorted, clean quartzarenite. It is below the gas water contact and characterized by diagenetic calcite cement dominant.

3 RESEARCH METHODS

To run the reservoir characterization using IP software, well data including wireline log and core are used as input data. Qualitative analysis to interpret lithofacies and depositional environment as well as quantitative analysis to petropysics calculation have been done in this study. Before all analyses were carried out, the first step is to do well quality control data. As horizons marker for interval are given in each well, stratigraphic correlations among wells are sequentially carried out to determine reservoir zone intervals and to ensure that they are appropriate for further analysis. The next step is determining the facies and depositional environment of each stratigraphic sequence in each well with lithology data (core) and wireline logs data using electrofacies method then followed by quantitative analysis.

The quantitative analysis is done by petrophysical analysis of well log data and validating by routine core analysis data (RCAL). Petrophysical analysis is conducted to obtain rock properties such as clay volume, porosity and water saturation (Tiab and Donaldson, 1996). Rock typing (RT) carried out to clas-

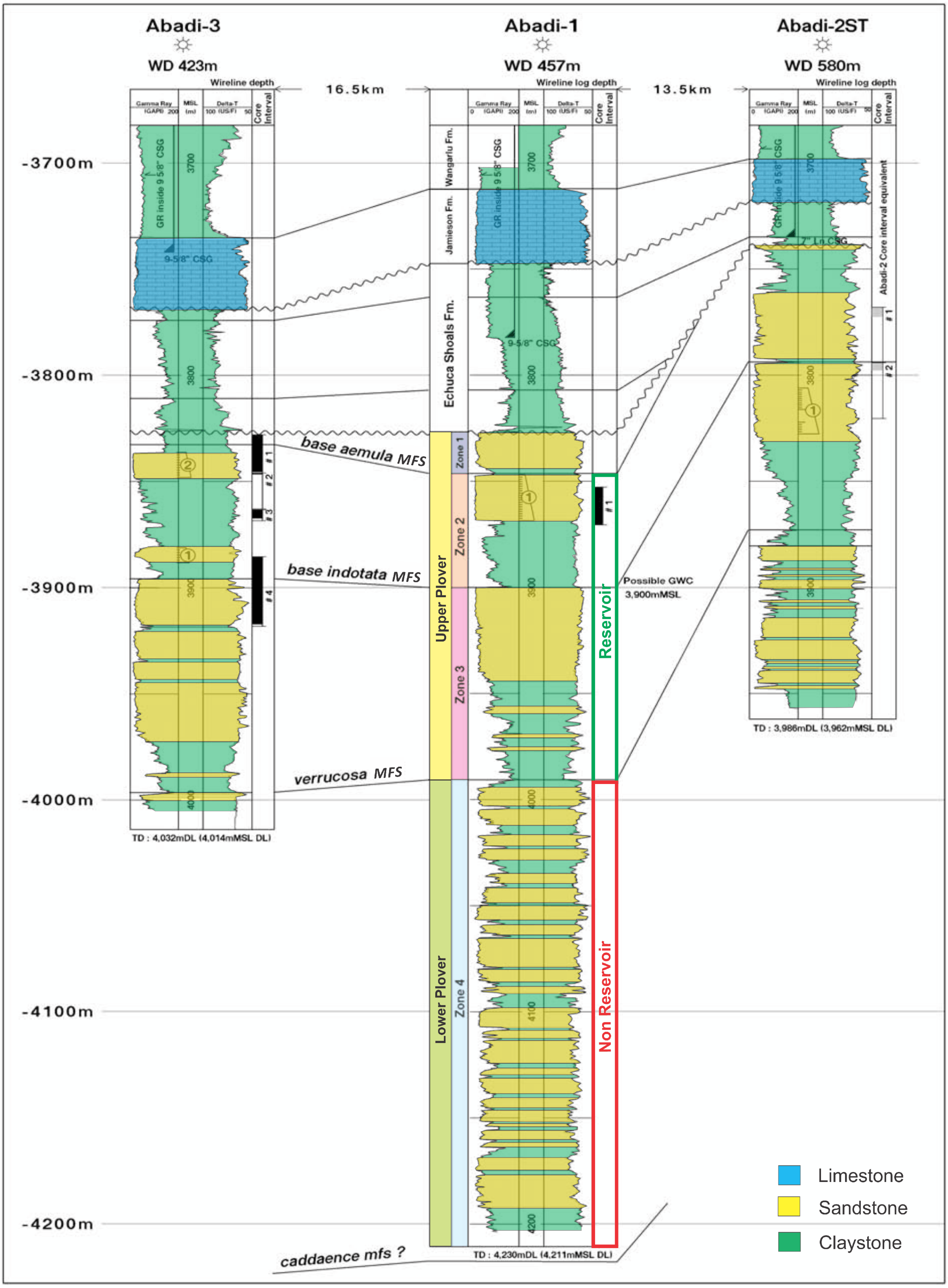


Figure 3: Reservoir correlation between Abadi-1, 2ST and 3. (Modified after Nagura *et al.*, 2003).

sify the rock type of routine core analysis data (RCAL), followed by distributing rock type using neural network for rock intervals that do not supported by core data. Result of those analyzes will be used to identify the character of the reservoir. Rock type form whole well log is predicted by neural network method. This method has been proven to successfully applied as a predictive tool lithofasies by Bohling and Dubois (2003).

In this study, reservoir rock typing in the "A" Field is carried out by "Windland R35" methods by Windland (1972) Equation 1 and using Hydraulic Flow Unit (HFU) by Amaefule *et al.* (1993) Equations 2-4. The concept of these two methods is to identify and characterize rock types based on geological conditions and physical parameters of the pore size (Radiansyah, 2014).

$$\log R35 = 0.732 + 0.588 \log k - 0.864 \log \phi \quad (1)$$

$$RQI = 0.0314 \times \sqrt{\frac{k}{\phi_e}} \quad (2)$$

$$\phi_z = \left(\frac{\phi_e}{1 - \phi_e} \right) \quad (3)$$

$$FZI = \frac{RQI}{\phi_z} \quad (4)$$

4 RESULTS AND DISCUSSION

Facies and depositional environment

Core description (Figure 4) provides typical sedimentary succession of Upper Plover Formation for Zone-2. It consists of sandstone and claystone lithofacies with coarsening upward succession. In the lower part, bioturbated sandstone-claystone (SC-b), laminated sandstone-claystone (SC-l) and laminated claystone (C-l) vertically develop with total thickness around 4.5 m. to the upper part, lithofacies changes to sandstone dominant including bioturbated sandstone (Sb), and interbedding of laminated sandstone (S-l1) and massive sandstone (S-m) to form thickly bedded succession up to around 10 m. In the Well A-2 lithofacies S-l1 and S-b identified in more cemented become lithofaceis cemented laminated sandstone (Sl-c) and cemented bioturbated sandstone (Sb-c).

Table 1: Facies association of progradation shoreline depositional environment

	Facies									
Facies Association	S-m	S-l1	S-l2	S-b	Sl-c	Sb-c	SC-l	SC-b	C-l	C-b
Foreshore (FS)	Common	Common								
Upper Shoreface (USF)	Less	Common		Common	Less					
Lower Shoreface (LSF)			Common	Common	Less	Less				
Offshore Transition (OT)			Less				Less	Common	Common	Common
Marine Embayment (ME)							Common	Common	Less	

Red: Common; Yellow: Less

Lithofacies assemblage with associated in sedimentary attributes lead to depositional environment interpretation (Miall, 1990) is termed as facies association. In the study area, six facies association interpreted based on the core description and interpretation, which then correlate to well logs analysis. Facies association represents depositional environment and composing lithofacies served in Tabel 1, which are: (1) foreshore (FS), (2) upper shoreface (USF), (3) lower shoreface (LSF), (4) offshore transition (OT), (5) marine embayment (ME) and (6) offshore (OS). General succession for Upper Plover is coarsening upward, where depositional environment relatively change from marine to transitional zone of shoreface or even estuarine (Figure 2–4.

Stratigraphy

Stratigraphic correlation in this study is based on the concept of sequence stratigraphy. Some markers were obtained from biostratigraphic analysis in the well report, where 5 markers are defined from fossil analysis of core and sidewall cores. The name of the marker is taken from the dinoflagellates fossil (Helby and Partridge, 2001). Marker interpretation for stratigraphic correlation for Plover Formation in the study area and their age are described as follow: (1) Dissiliodinium caddaense marker as flooding surface 1 (fs-1) at Middle Jurassic; (2) Wanaea verrucosa marker as flooding surfaces (fs-3 and fs-4) at Middle Jurassic; (3) Wanaea Indotata marker as flooding surface 5 (fs-5) at Late Jurassic; (4) Rigaudella Aemula marker as flooding surfaces (fs-6 and fs-7) at Late Jurassic and (5) E. Torynum marker at the end of Upper Plover as unconformity boundary at Late Jurassic age (Figure 5).

Six parasequence is defined from flooding

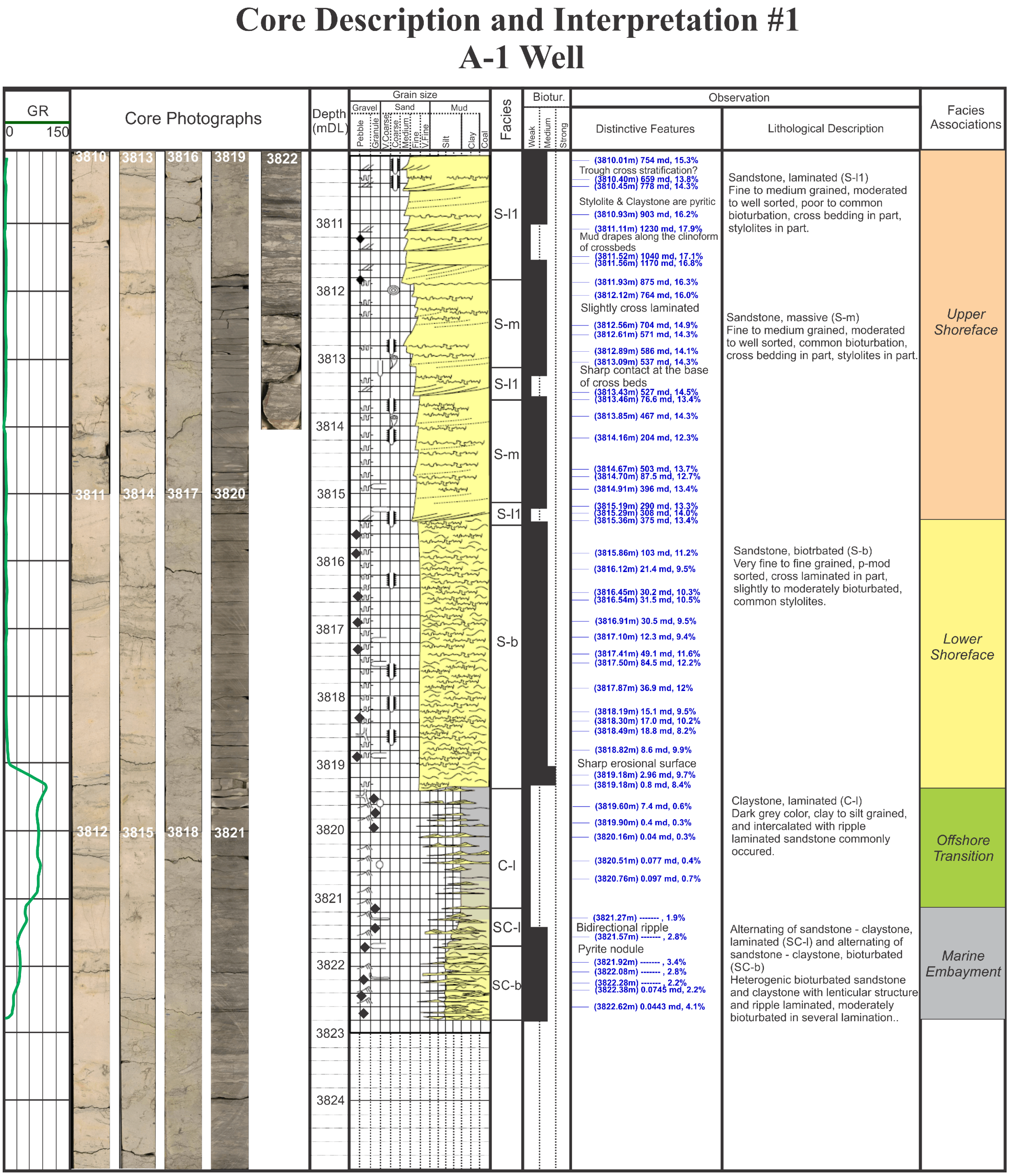


Figure 4: Core #1 description and interpretation of A-1 well.

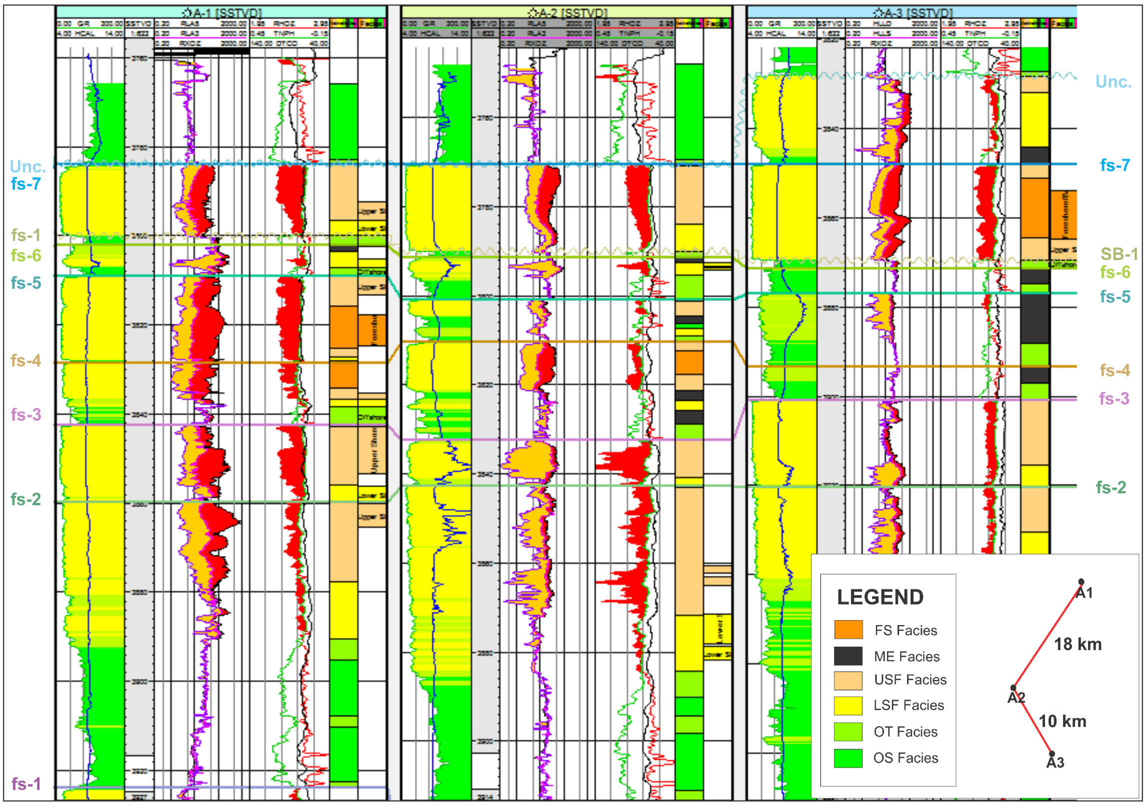


Figure 5: Sequence stratigraphy correlation from well logs in study area.

surface boundary (Van Wagoner *et al.*, 1988) indicates vertically regressive with thinner parasequence. Laterally, to the northward, depositional environment tends to deeper due to increasing sand-shale ratio (Figure 2).

Rock type identification

Two methods have been applied to identify rock types (RT) that are Windland R-35 (Windland, 1972) and Hydraulic Flow Unit (Amaefule *et al.*, 2003), in order to get the best result. RT identification by Windland R-35 is carried out by plotting all value of porosity versus permeability from RCAL to define iso pore throat curve. In this study, four different iso pore throat curve was identified, which are 0.1 micron, 2 micron, 15 micron and 40 micron (Figure 6a left side). Iso pore throat curve represent one rock type (RT) that consist of certain facies association, therefore four RT are also defined from this methods.

Hydraulic Flow Unit (HFU) methods for grouping characters rock types has a similar way to the "Windland R-35" methods. RT by HFU method is identified by value of Flow Zone Indicator (FZI) or cross plot Reservoir Quality Index value (RQI) versus Matrix Pore Ratio (PMR) or ϕz (Figure 6b). From FZI calculation and crossplot log RQI versus ϕz, the Upper Plover Formation is can be divided into four HFU.

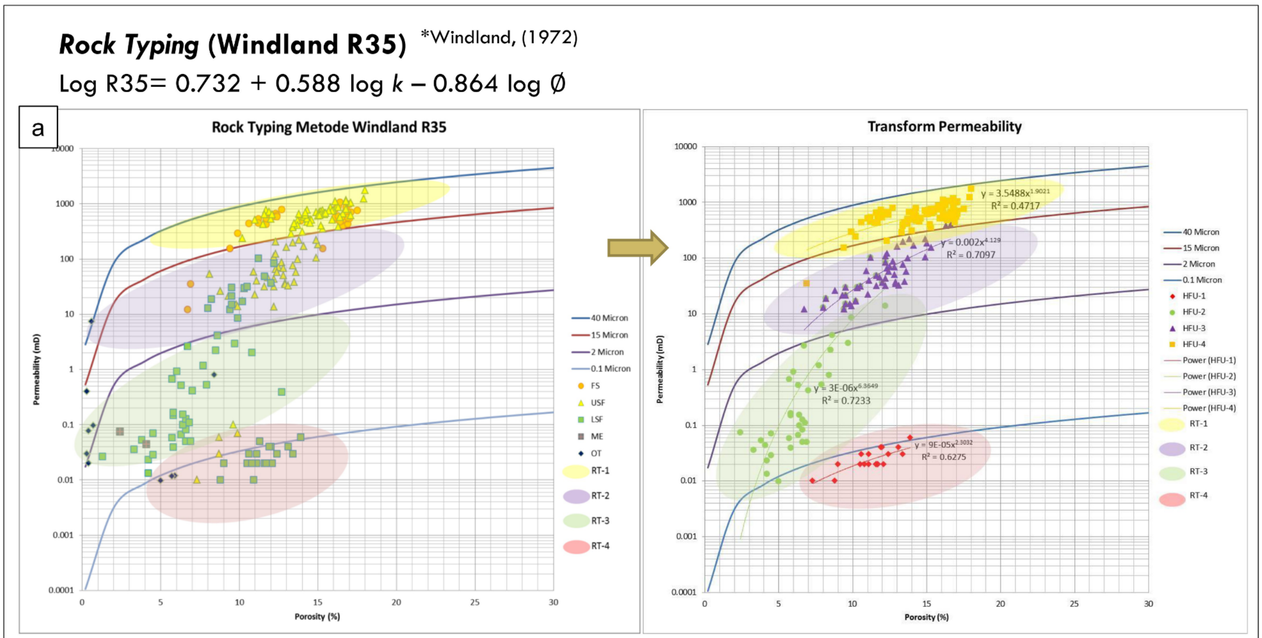
Final RT identification is taken from the highest number of coefficient correlation (R) of transform permeability. Four RT is identified from this final result (Figure 6a, right side).

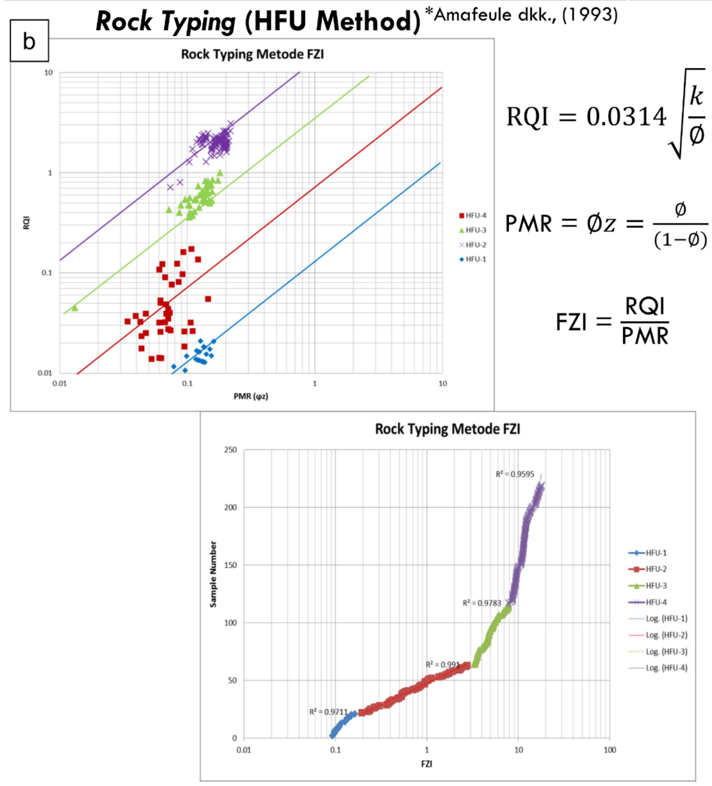
Reservoir characterization

The reservoir quality classification refers to the classification of reservoir established by Slatt and Hopkins, 1991 (in Slatt, 2006). Parameter used to distinguish reservoir classification is permeability, porosity, matrix grain size, pore throat, minimum water saturation and lithofasies (Table 2. Based on those parameter, Upper Plover Formation can be divided into four classes of reservoir, that are:

A Class dominantly consists of the FS and USF facies association, has the most excellent quality reservoir porosity that is 6.5–19 % with permeability ranging from 100–1300 mD.

B Class dominantly consists of USF, FS and LSF facies association, have good quality





$$\mathrm{RQI} = 0.0314\sqrt{\frac{k}{\emptyset}}$$

$$\mathrm{PMR} = \emptyset z = \frac{\emptyset}{(1-\emptyset)}$$

$$\mathrm{FZI} = \frac{\mathrm{RQI}}{\mathrm{PMR}}$$

No	Perm (mD)	Por (%)	Litofasies	Dep Fasie	RQI	PMR	FZI	HFU
1	0.01	10.9	Sb	LSF	0.009511	0.122334	0.077744	1
2	0.02	12.1	Sb	LSF	0.012766	0.137656	0.092738	1
3	0.03	13.4	Sb	LSF	0.014857	0.154734	0.096018	1
4	0.02	11.7	Sb	LSF	0.012982	0.132503	0.097978	1
5	0.02	11.7	Sb	LSF	0.012982	0.132503	0.097978	1
6	0.02	11.6	Sb	LSF	0.013038	0.131222	0.09936	1
7	0.02	11.6	Sb	LSF	0.013038	0.131222	0.09936	1
8	0.02	11.1	Sb	LSF	0.013329	0.124859	0.106749	1
9	0.03	12.4	Sb	LSF	0.015445	0.141553	0.109109	1
10	0.01	8.8	Sb	LSF	0.010585	0.096491	0.109698	1
11	0.02	10.8	Sb	LSF	0.013512	0.121076	0.111602	1
12	0.04	13.1	Sb	LSF	0.017351	0.150748	0.115099	1
13	0.02	10.5	Sb	LSF	0.013704	0.117318	0.116811	1
14	0.06	13.9	Sb	LSF	0.02063	0.16144	0.127787	1
15	0.03	11.1	Sb	LSF	0.016324	0.124859	0.13074	1
16	0.04	12	Sb	LSF	0.018129	0.136364	0.132945	1
17	0.04	11.9	Sb	LSF	0.018205	0.135074	0.134777	1
18	0.03	10.6	Sb	LSF	0.016705	0.118568	0.140886	1
19	0.01	7.3	Sc	USF	0.011622	0.078749	0.147579	1
20	0.02	9	Sb	LSF	0.014802	0.098901	0.149666	1
21	0.05	11.3	Sb	LSF	0.020887	0.127396	0.163953	1
22	0.03	8.7	Sl	USF	0.018439	0.09529	0.193501	2
23	0.012	5.9	Sb	OT	0.014161	0.062699	0.225856	2
24	0.0117	5.7	Cb	OT	0.014226	0.060445	0.235354	2
25	0.07	9.9	Sc	USF	0.026403	0.109878	0.240298	2
26	0.00977	5	Cb	OT	0.01388	0.052632	0.263721	2
27	0.06	8.7	Sc	USF	0.026076	0.09529	0.273651	2
28	0.1	9.6	Sc	USF	0.032047	0.106195	0.301781	2
29	0.05	6.9	Sc	LSF	0.026729	0.074114	0.360654	2
30	0.39	12.7	Sb	LSF	0.055025	0.145475	0.378243	2
31	0.0505	6.6	Sb	LSF	0.027467	0.070664	0.388693	2
32	0.0133	4.2	Sb	LSF	0.01767	0.043841	0.403039	2
33	0.0394	5.8	Sb	LSF	0.02588	0.061571	0.420326	2
34	0.066	6.3	Sb	LSF	0.032139	0.067236	0.478003	2
35	0.0823	6.6	Sb	LSF	0.035064	0.070664	0.496204	2
36	0.0586	5.7	Sb	LSF	0.031838	0.060445	0.526718	2
37	0.0287	4.5	Sb	LSF	0.025076	0.04712	0.532176	2
38	0.0233	4.2	Sm	LSF	0.023387	0.043841	0.533457	2
39	0.11	6.8	Sc	LSF	0.039937	0.072961	0.547367	2
40	0.0999	6.4	Sb	LSF	0.03923	0.068376	0.573744	2

Figure 6: Rock Typing by Windland R-35 methods (b) Rock Typing by Hydrolic Flow Unit (HFU) methods. To get the best result, transform permeability has been utilized.

Table 2: Upper Plover Formation reservoir classification.

No	Class	Lithofacies	Fasies Association	Clay Volume	Por. (Φe)	Water Saturation (Sw)	Perm. (k)	Pore Throat (mm)	Rock Type	Flow Unit
1	A	Sm > Sl > Sb	FS, USF	0 - 12%	6.5 - 19%	0.1 – 0.75	1300 –100 mD	0.040- 0.015	RT-1	Excellent
2	B	Sl > Sb > Sm	USF, FS, LSF	0 - 12%	7 – 17%	0.1 – 0.8	500 – 10 mD	0.015- 0.002	RT-2	Good
3	C	Sb> SCb> Sl > Sbc	LSF, ME, OT	0 - 30%	1 – 13%	0.25 - 1	20 – 0.01 mD	0.002- 0.0001	RT-3	Poor (Pi)
4	D	Slc>Sbc> Sb	LSF, OT USF	5–100%	1 – 14%	0.35 - 1	0.08 – 0.001 mD	< 0.0001	RT-4	Very Poor (Pc & Pm)

reservoir with porosity of 7–17 % and permeability of 10 to 200 mD.

C Class dominantly consists of LSF dominant facies association, ME and OT facies association, have poor reservoir quality with a porosity of 1-13 % and permeability of about 0.1–2 mD.

D Class consists of LSF, USF and OT facies association, with experiencing diagenetic cementation, porosity 1–14 % with permeability 0.001–0.08 mD. This class is considered not a reservoir type due to unable to flow the reservoir fluid.

5 CONCLUSIONS

The Upper Plover Formation in the study area consist of alternating sandstones and shales to form coarsening upward sedimentary succession deposited mainly within marine to coastal environment of foreshore – offshore. The succession can be divided into 7 parasequences, ranges from Middle to Late Jurassic age.

The reservoir of Upper Plover Formation can divided into four classes: A class has excellent quality, B class with good quality, C class with poor quality and D class with very poor quality.

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