Predicting the Hydrocarbon Limit on Peciko Unconventional Trap Giant Gas Field

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Abstract. Peciko is a mature giant multilayer gas field, located in the offshore area of Mahakam Delta, Indonesia. The field has been in production since 1999 with more than 150 development wells drilled. The first exploration well (Peciko-1) was drilled in 1983 in the crest of Peciko anticline. Although it found only insignificant gas bearing in a mostly poor quality reservoir and high pressure, this well proved that the hydrocarbon trapping system was worked. The 2nd well, Northwest Peciko-1 was drilled on 1991 in the flank of the structure and hit more than 200-meters gas net pay. Realizing the potential of an unconventional trap with potential gas column up to 240-meters, 19 more delineation wells were drilled and finally confirmed the presence of giant gas accumulation with hundreds of individual sand bodies distributed in about 1500-meters gross intervals. The thickest net pay accumulation was located in the flank of the structure, while the crest was mainly constituted by high pressure water bearing reservoirs. This was interpreted as a counter pressure mechanism due to an active lateral S-SE directed compaction water (from higher pressure zones) flow conveyed between flooding surfaces through the pay zones and down-dip across syncline towards the lower pressure zones, while the circulation of compaction water was diverted around the trap.

An observation on the stratigraphic cycles concludes that there is a correlation between regressive and transgressive sequence versus distribution of gas accumulation and gas in place volume. In the regressive-type reservoir, reservoirs are generally more widely connected, while in the transgressive-type reservoir, over the same stratigraphic interval may contain several hydrocarbon pools, it is very likely due to the reservoirs size are relatively small and rather detached. By carefully applying the tilted-contacts conceptual, where it defines a hydrocarbon pool limit as an equipotential pressure (water head) on a given equipotential map (U-map), therefore the hydrocarbon accumulation limit of this mature field could be predicted more reliable (when the hydrocarbon filling ratio equal to zero on a given equipotential map). Moreover, adopting the methodology where the tilted-contacts occurred, into multi-layer Peciko reservoirs depending on the degree of its certainty on contact and fluid interpretation, it is now possible to see the extension of the hydrocarbon accumulation limit towards the step-out perimeter of this mature field, and thus, opening a new possible area for future delineation targets in Peciko field.

Keyword: counter-pressure, filling ratio, hydrocarbon limit, net sand, modelling, U-map, water head

1 Introduction

Peciko field is a mature giant multilayer gas field, located in the offshore area of Mahakam Delta, southward of the supergiant Tunu gas field, in water depths of around 40 meters (Figure 1). The field produces gas from Upper Miocene deltaic reservoirs. The lithology comprises a repetition of superimposed deltaic cycles (average thickness in the range of 30 - 50m). The structure is dipping to North-West and no fault has been identified on 3D seismic. The Upper - Main gas accumulation is 20 km long and 10 km wide with multiple layering divided in 5 stratigraphic units (SU0 to SU5). Occurring between 2100 to 4000 meter TVDSS, Upper-Main Zone deposits are mainly dominated by mouth bar at delta front environment (Figure 1). This field started its first gas production in December 1999 and currently it becomes a mature field. During this stage, prospect evaluation (step-out well candidates) in the peripheral area of Peciko field is more interesting to be explored in order to maintain the production or to sustain the development of this mature field. The current condition (from 2017 onwards), production was supported mostly by well intervention activities focusing mainly on perforation portfolio and zone changes. After more than 20 years of production, the remaining portfolio of both existing un-perforated reservoirs and current future development well candidates mostly located in the "pseudo-crest" location with limited stakes. Bare that in mind, the necessity to find an un-mapped sweet spot area for additional step-out well candidates of future Peciko field development become a priority.

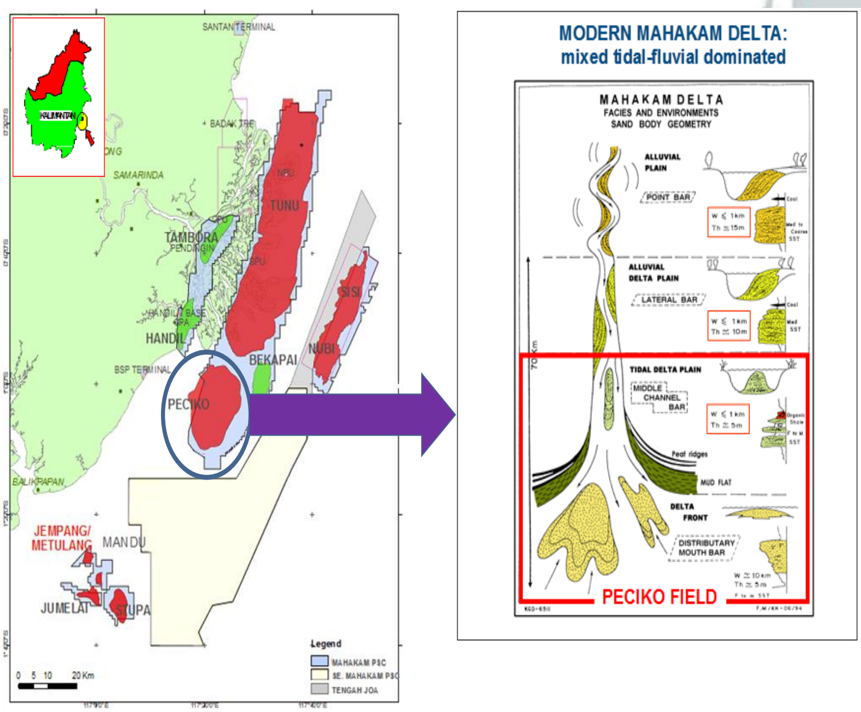


Figure 1. Peciko field location map, at Mahakam Delta, East Kalimantan, Indonesia.
The palaeo depositional environment is as described as deltaic, from fluvial to delta front environment

In addition, after becoming on-stream in 1999, drilling results in the Peciko area that close to the supposed limit of this mature field still give surprisingly positive results and leaving the main question remains; where is the actual hydrocarbon accumulation limit of the field? (Figure 2). With all those backgrounds, this study is performed to answer the question.

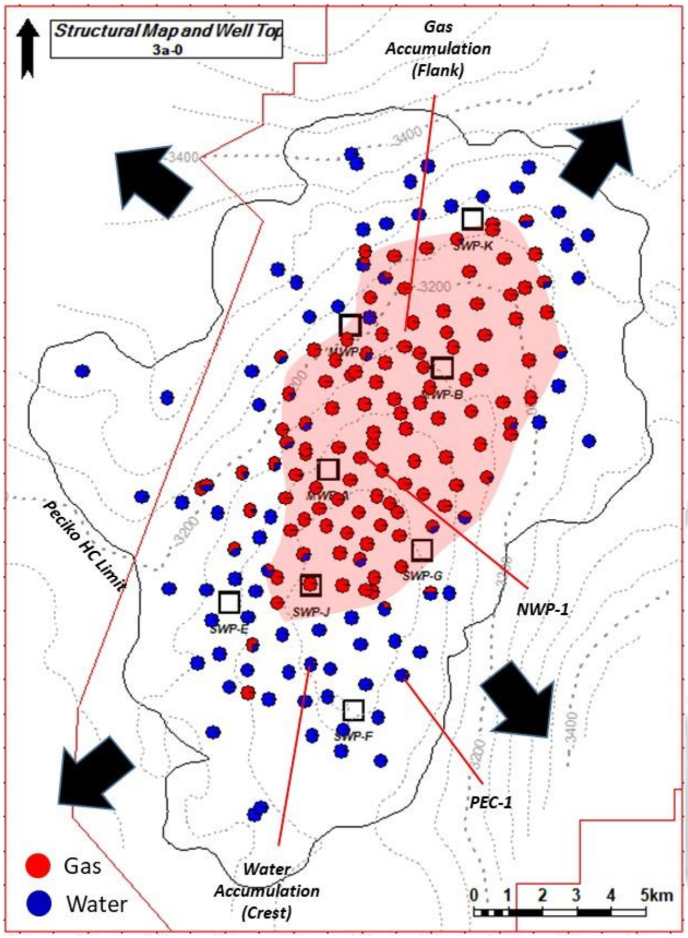


Figure 2. Gas accumulation in the flank of the Peciko structures

2 Methodology

There are several reasons for hydrocarbon water contacts to be at different levels in the same reservoir such as lithological barriers, sealing faults, perched water or production effects; hydrodynamic tilting is another mechanism. When dealing with tilt defined by pressure data, the data refer to the Free Water Level (FWL). According to Hubbert (1967), under hydrodynamic conditions a buoyancy force and moving water exert major control over distribution of water, oil, and gas in a reservoir, causing the oil/water and gas/water contact to be tilted. The discovery of Peciko field in the Mahakam Delta Province, East Kalimantan, Indonesia, has shown the example of this type of trap (Figure 3).

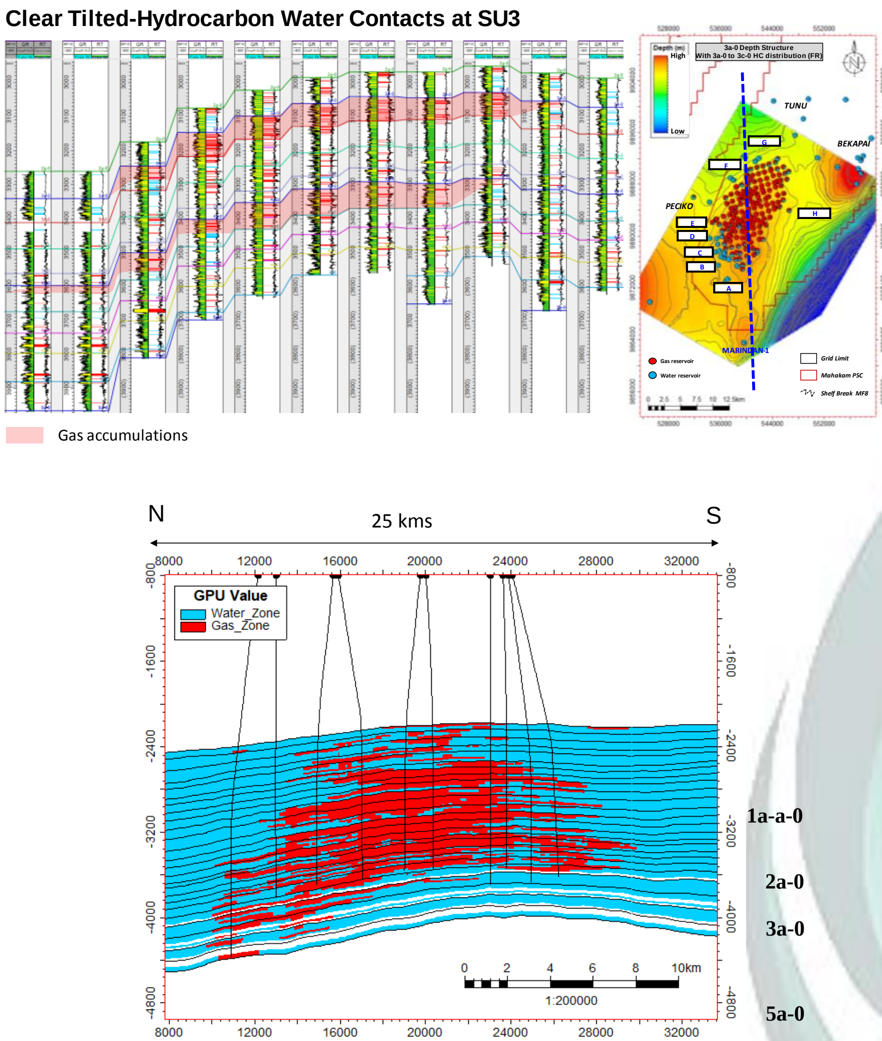


Figure 3. A schematic tilted-gas water contacts at Peciko Field, (a) well correlation along the N-S section (b) gas accumulation (red colour) in each of stratigraphic units (SU)

The methodology used in this study consists of static model parameters, i.e., net sand and hydrocarbon filling ratio to determine the hydrocarbon distribution, elaborated with the equipotential surface pressure and equipotential map (U-map) adopted from Hubbert (1953 and 1967) to predict the hydrocarbon accumulation limit of this mature field.

2.1 Net Sand Model

The main difficulty in evaluating a shale-dominated deltaic environment is how to predict and properly map the sand distribution and its consequences on fluid distribution and reservoir dynamic behavior. Peciko reservoirs are classified into three (3) sand qualities from clean sand to degraded sand; A, B and C.

The C sand type is considered as connected reservoir if the sandy layer is attached to A or B sand or if the vertical distance is less than 2 feet at well scale. Constant cut off are applied on Porosity Effective (Phie) and Wet Clay Volume (Vsh) in order to distinguish the three (3) sand qualities; A, B and C (Figure 4). The modeling approach is different from previous Peciko geo-model where it consists up to 90 layers with average thickness 25-meters. In this study, net sand model has been created by using net sand mapping which honors the sedimentological concepts within 4th order stratigraphic cycles (R-T cycles). It consists of 13 regressive and 11 transgressive layers with average thickness 85-meters. The layering is also calibrated by the 3D seismic data (Figure 5). Net sand model corresponds to the total sand deposits A+B+C connected and disconnected C sand derived from log interpretation on each well. The logs based on the criteria before are then scaled-up in the 3D property model and used as the main input to map the net sand distribution.

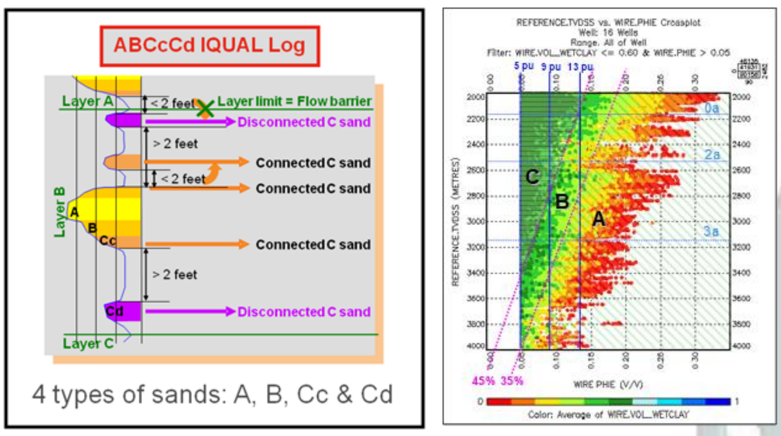


Figure 4. Types of sand (left) and Phie & Wetclay cut off versus depth (right)

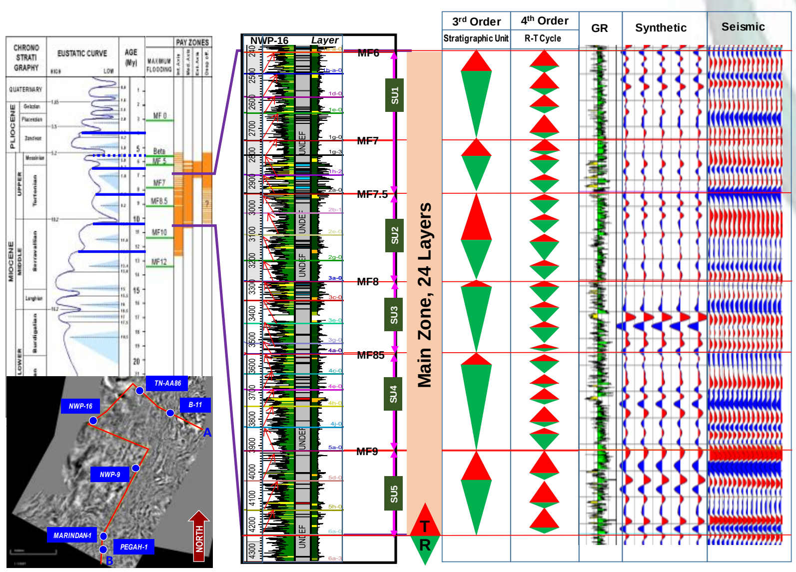


Figure 5. Peciko Stratigraphic Frameworks and Seismic Layering

As the result of well and seismic data observation, two distinctive trend has been identified; regressive and transgressive respectively. By constructing imaginary timeline and development-line representing the main axis of mouth bar development during a certain time, it could be observed that on the regressive trend, mouth bar development is thickening towards the southeast (SE) into the distal area and thinning towards the southwest (SW) as it further away from the sediment sources. While on the transgressive trend, general mouth bar pattern is more detached and separated with an overall southeast thinning trend towards the distal area. Based on that observation, guided by those timeline and development-line, the thickness and width of potential mouth bar bodies could be predicted in area where the well data is not available, as a continuation of the observed trend following the sedimentological trend based on the well data (see the illustration on Figure 6 for the regressive and transgressive layers).

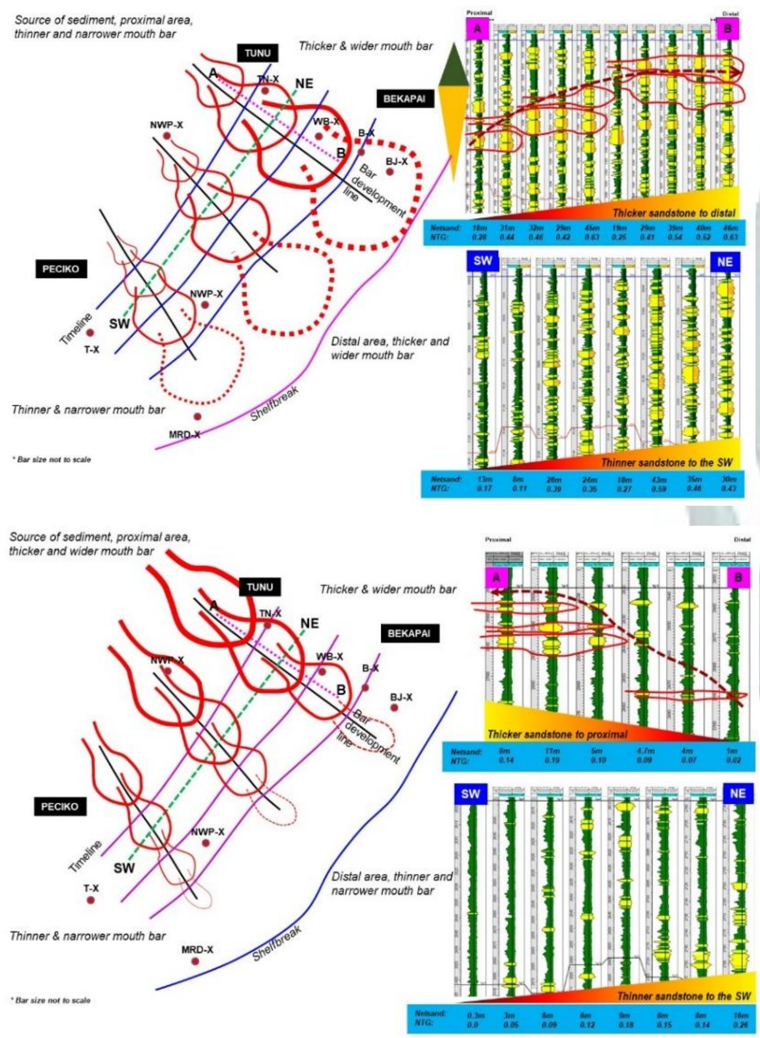
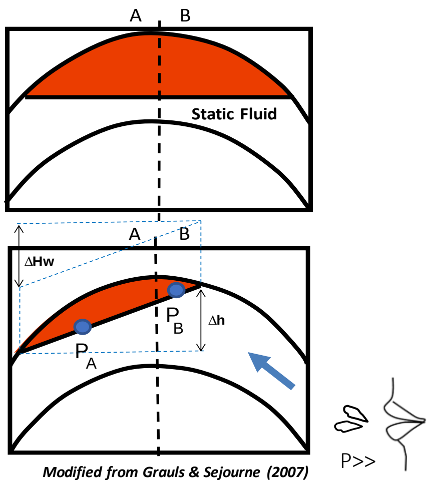


Figure 6. Net sand mapping methodology, (a) an example from regressive layer 3a-0 to 3c-0, (b) an example from transgressive layer 1g-0 to 1g-3

2.2 Equipotential Surface Pressure (Water Head) and Equipotential Map (U-map) Model

One of the building blocks of this study is a detailed investigation of every well involved in terms of pressure plots. These plots reveal relationships between hydrocarbon and water gradients. The most obvious manifestation of hydrodynamic effects on hydrocarbon accumulations is that of hydrodynamically induced tilts of the oil or gas-water interfaces. In the Peciko field cases, the tilted Free Water Level (FWL) has been observed at several layers and indicated the occurrence of this mechanism. Hydrodynamic influence in this field will be depending on the fluid pressure and buoyant forces. The fundamental calculation for the hydrodynamic condition could be seen from the Figure 7.



At top structure pressures are equilibrated

Hydrodynamics :
$P_B = P_A + \rho_w . g . \Delta Hw$

Bouyancy :
$P_B = P_A + (\rho_w - \rho_g) g . \Delta h$

➔ $(\rho_w - \rho_g) g . \Delta h = \rho_w . g . \Delta Hw$

➔ **$\Delta h = \Delta Hw . TAF$**

$TAF = \rho_w / (\rho_w - \rho_g)$

Remarks

Δh	: contact position difference
ρ_w	: water density
ρ_g	: gas density
P_A	: pressure at point A
P_B	: pressure at point B
ΔHw	: potential difference
TAF	: Tilt Amplification Factor

Figure 7. Peciko tilted-hydrocarbon water contacts calculation for U-map modeling input

Formation fluid pressure data are necessary for mapping prospective counter-pressure trap. Combining formation fluid pressure with other data, such as different phase of fluid density (ρ) and subsea elevation (Z), produces equipotential surface maps that help outline area where the hydrocarbon accumulation limit of the Peciko field are (Figure 8).

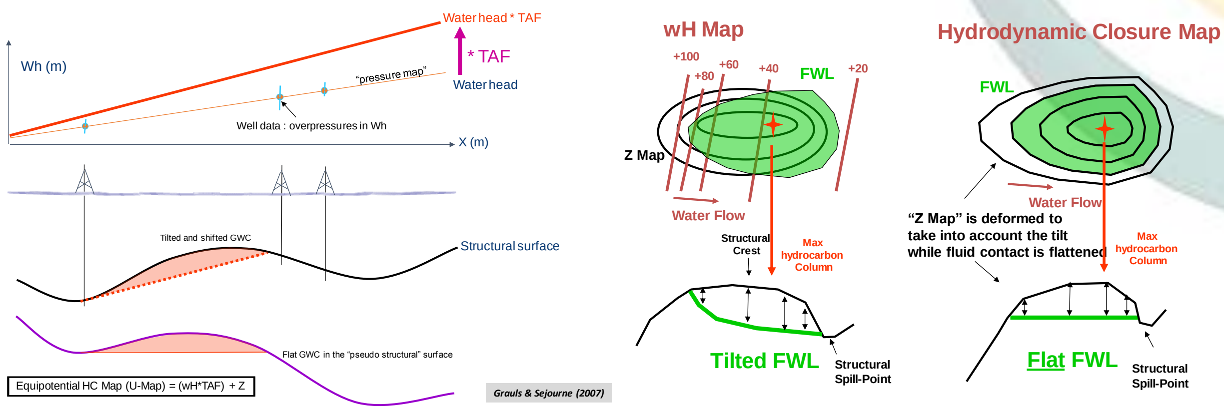


Figure 8. Creation of equipotential hydrocarbon map/U-map (Grauls and Sejourne, 2007)

2.3 Hydrocarbon Filling Ratio Model

In many fields in the Lower Kutai Basin, the net pay thickness above the gas-water contact (or free-water level to be more precise) is not necessarily equal to the net sand thickness. For a given hydrocarbon accumulation pool, it is very common to have the isolated water bodies above a well-defined gas-water contact, these phenomena known as perched water which could be explained as the result of by passed sandstone bodies during gas migration. This may result in a complex vertical fluid distribution within a layer as shown in Figure 9-a. Since it is not realistic to interpret and model a gas water contact at layer scale, an alternative fluid modeling technique known as Hydrocarbon Filling Ratio mapping has been used for this study.

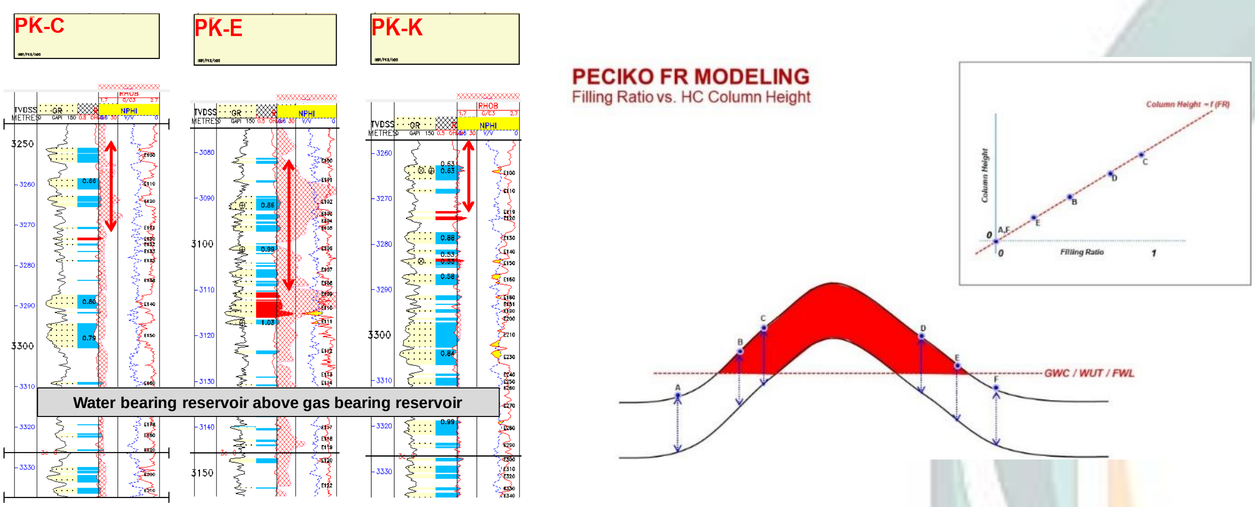


Figure 9. Complex vertical fluid distribution, (a) water bearing reservoir above gas bearing reservoir at well data, (b) Peciko filling ratio methodology, the plot filling ratio (FR) vs hydrocarbon column

The filling ratio (FR) is defined as the percentage of reservoir that is filled with hydrocarbon above the gas-water contact (Formula 2). That is why in Peciko field, the hydrocarbon column itself is a function of the filling ratio (FR).

$$Filling\ Ratio = \frac{Net\ pay\ thickness}{Net\ sand\ thickness} \qquad (2)$$

It could be seen from the schematic Figure 9-b, the greater the FR number, resulting the large hydrocarbon column, and vice versa. Since there is a linear relationship between the hydrocarbon filling ratio and hydrocarbon column, then the amount of pressure along the area, where the tilted-hydrocarbon water contacts occurred, could be modeled as well.

3 Results and Discussion

Based on the net sand model construction, we could observe that there is a correlation between regressive and transgressive sequence versus distribution of gas accumulation and gas in place volume. In the regressive-type reservoir, reservoirs are generally more widely connected, while in the transgressive-type reservoir, over the same stratigraphic interval may contain several hydrocarbon pools, it is very likely due to the reservoirs size are relatively small and rather detached (Figure 10).

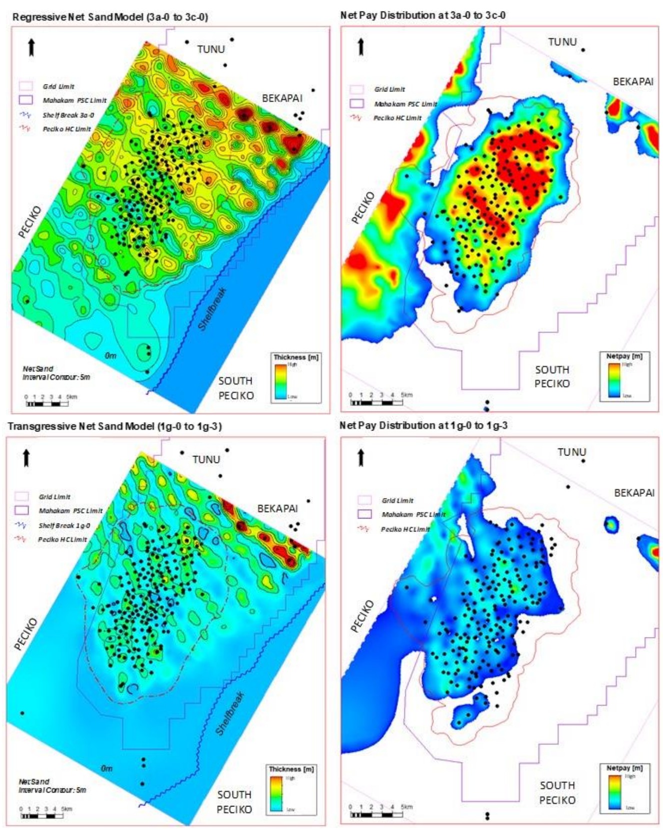


Figure 10. Net sand model and net pay distribution at regressive layer (3a-0 to 3c-0) and transgressive layer (1g-0 to 1g-3)

According to the equipotential pressure plot, it could be seen that the FWL's position is varying depending on the well location. From north-south (N-S) section, the FWL's position is tend to shallower towards the south where the water bearing reservoirs found at structural high (the crest of Peciko anticlinal structure) (Figure 11). In this study, the FWL's variation is simplified into one single contact surface to calculate the equipotential pressure along the area where the tilted-contacts occurred. The equipotential pressure data along the incline contacts then populated by functional algorithm honoring the pressure trend close to the shelf break, multiplied by the Tilt Amplification Factor (TAF), to generate the equipotential map / pseudo-structural map (U-map) as a hydrodynamic closure where the hydrocarbon is accumulated (Figure 12).

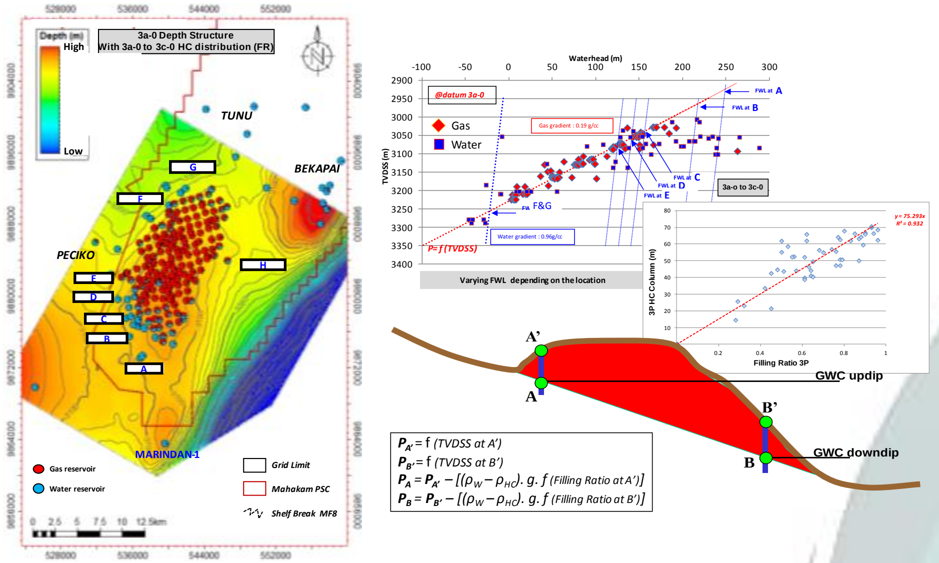


Figure 11. Equipotential pressure calculation along the contact reference depth

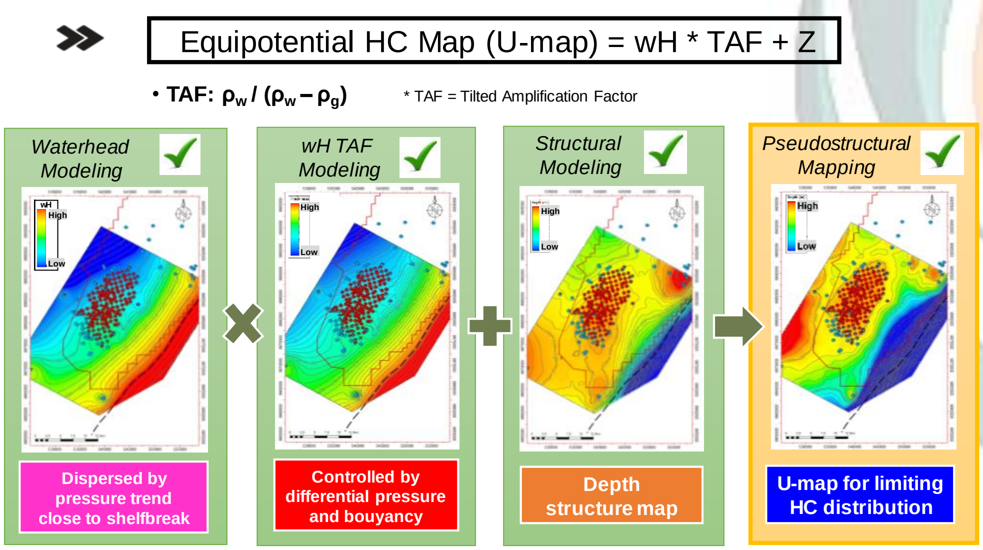


Figure 12. Peciko equipotential hydrocarbon (U-map) modeling workflow

After that, we combine all the parameters in U-map with the hydrocarbon filling ratio. Hydrocarbon filling ratio is important to estimate the hydrocarbon column also to help us determining the position of contact reference depth. Below is the plot between filling ratio and hydrocarbon column at layer 3a-0 to 3c-0 as an example (Figure 13). After knowing the position of hydrocarbon contacts (tilted contacts in this case) and also the equipotential map (U-map) of each well then we could predict the hydrocarbon accumulation limit on a layer basis.

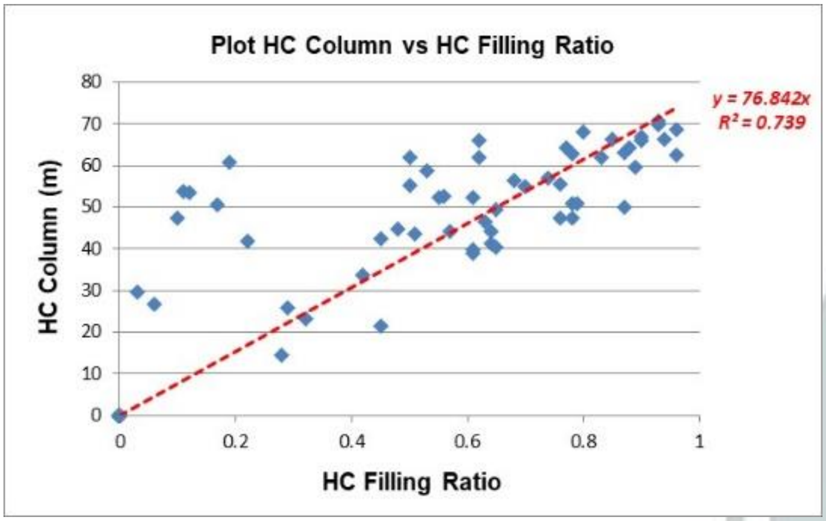


Figure 13. Plot between filling ratio versus hydrocarbon column at 3a-0 to 3c-0

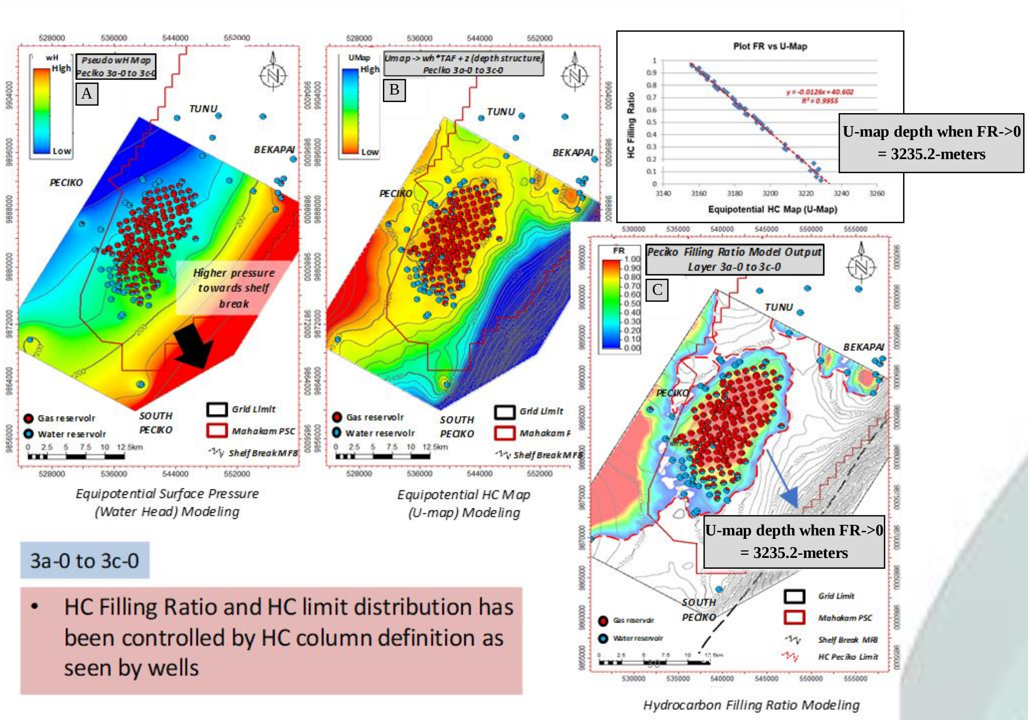


Figure 14. Complete workflow and static model parameters output (a) pressure/water head model, (b) equipotential map (U-map) model, and (c) hydrocarbon filling ratio model at layer 3a-0 to 3c-0 (an example from regressive layer)

Figure 14 is a complete workflow and static model parameters output, start from equipotential surface pressure (water head) model, equipotential map (U-map) model, and hydrocarbon filling ratio model at regressive layer 3a-0 to 3c-0. From the equipotential pressure model (Figure 14-a), we could observe there is a tendency of pressure getting higher towards the South Peciko with trend NW-SE close to the shelf break. Figure 14-b is showing the prospective equipotential map (U-map) which is created from the equipotential pressure multiplies with a tilt amplification factor (TAF) and combined with depth structure maps. Figure 14-c is the output from the hydrocarbon filling ratio model. This model has been constructed by respecting the well data and using the prospect equipotential map (U-map) as a trend. To predict the hydrocarbon accumulation limit on a layer basis, it is represented by the equipotential map (U-map) where the hydrocarbon filling ratio (FR) is zero. In this case (layer 3a-0 to 3c-0), the accumulation limit will be located in 3235.2 meters at U-map depth contour (see the red dot lines in the map).

Moreover, by adopting the above techniques into multi-layer Peciko reservoirs depending on the degree of its certainty on contact and fluid interpretation, it is now possible to determine the hydrocarbon accumulation limit in the field level until find the possibility of sweet spot area in the peripheral or step-out (North East - South East - South West - North West) area of Peciko field (Figure 15 – red dot lines).

Since the well data is very limited in the step-out perimeter, to reduce the bias result from this modeling approach, we need additional data such as seismic or production data in order to better predict the hydrocarbon accumulation limit of this mature field. Unfortunately, both the seismic and production data has not been incorporated yet in this study due to their limitations.

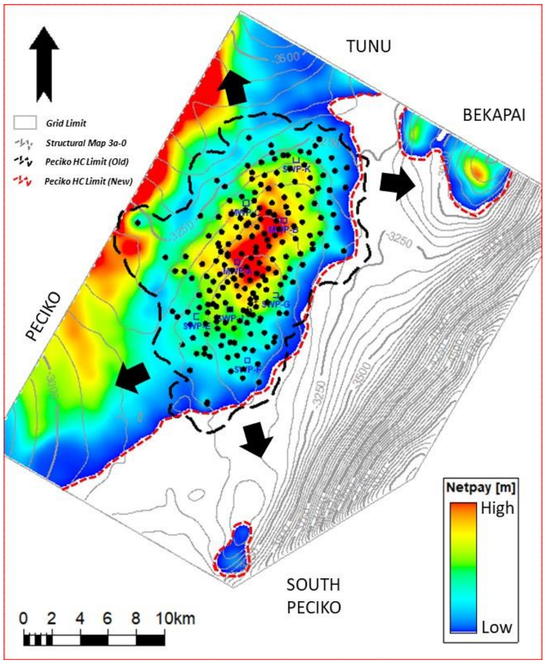


Figure 15. Peciko net pay map: the comparison between old and new hydrocarbon accumulation limit

4 Conclusion

Tilted hydrocarbon water contacts phenomena in Peciko field related to the counter-pressure trapping mechanism. The presence of this unconventional trap has been leading the new idea for the future field development strategy. Integrated static model (i.e., net sand, water head, U-map, and filling ratio) proved to be an effective way in order to predict the hydrocarbon accumulation limit in this mature field more reliable. This model also enables us to see the extension of the hydrocarbon accumulation limit towards the peripheral or step-out perimeter of Peciko field, and thus, opening a new sweet spot area for future delineation targets in this mature field. Furthermore, the additional data such as seismic and production data has not been incorporated yet in this study due to their limitations.

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