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2D Basin Modelling as For Hydrocarbon Charging Model (Charge Access), Tangguh Field, Bintuni Basin, Papua

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Abstract. Bintuni Basin is a foreland basin located in the Bird's Head of Papua. There were three fields observed in this study, namely Alpha, Beta and Charlie. The subsurface data indicated a mismatch of the order of hydrocarbon maturity in the three fields. This study aimed to explain the causes of incompatibility of the order of field maturity with the concept of generation-migration. The methods which were used in this study were 2D field-scale basin modelling on two seismic lines for subsurface observation, then calibrated to several geochemistry evaluations. Based on the results of source rock analysis, Bintuni Basin has two source rocks, Aifam group and Kembelangan Bawah Group, both of them are gas prone. The accumulated hydrocarbons in the Alpha field leaks into shallower sedimentary layers and do not migrate laterally due to the low clay factor and the distant trap height. The existence of lateral migration is caused by a sloping trap height. From the result of the research, it can be concluded that each field are filled by different charge focus from different migration route. Therefore, there is no correlation between three fields, including the maturity of the hydrocarbon accumulated, other than generated from same source rocks.

INTRODUCTION

Oil and gas industry are still one of the industries that support the Indonesian economy. However, there is no denying that Indonesia's oil and gas reserves are declining. Coupled with the state of petroleum prices that declined drastically and political policies that limit the flexibility of oil prices. To solve this problem, oil and gas companies need innovation and periodic evaluation of the reserves and basins that are their working areas.

Basin modelling can be done using the integration of log, seismic and geochemical data which are essential data in basin modelling. The combination of those data can provide information on the geometric and horizontal subsurface conditions, the history of the maturity phase of the source rock and the processes that occur from generation, migration to hydrocarbon accumulation in the prospective reservoir layer. This evaluation needs to be done periodically to see the specifics of the changes as well as the need for the field to maintain production figures.

This study took place in a basin in The Bird's Head, Papua, which is the Bintuni Basin. Bintuni Basin which is the front basin of the main continental crust in eastern Indonesia. The Bintuni Basin is a basin that has high hydrocarbon potential and has been produced. Geological conditions in this area are very complex with thediscovery of various geological records in the form of geological structures and diverse rocks.

The Bird's Head area is in an area with a complex tectonic circuit, which is between three main plate crusts: the Indo-Australian Plate, the Eurasian Plate, and the Pacific Plate [7]. Initially, the area was part of the south-eastern tip of the Pangea Continent which was drifting towards the Tethys Sea and this part was again split due to extension rifting from the east and west. The southern part of the subcontinent becomes the Papua New Guinea Microcontinent/Australian Plate/Indian Plate. While the northern part continues to move northwards and is currently Indochina/Afghanistan [9].

The Bintuni Basin is a foreland basin located on the Head of a Papuan Bird. Its position around the collision of the

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Australian, Eurasian, and Pacific Plates caused the basin to experience a complex history of tectonics and precipitation. The Bintuni Basin is a basin with an area of ± 30,000 km^2. The basin developed rapidly during the process of lifting the Lengguru Fold Belt (LFB) to the east and the Kemum block from the north.

The Cenozoic period is an active tectonic period in the Bird's Head Area. This period contributed a lot to the geographical, structural geological and rock deposition conditions in the Bird's Head Area [3]. This area was formed by the movement of the Australian Plate towards the northwest and the Pacific Plate to the southeast [4]. Changes in the direction of tectonic movement occurred in the Pliocene-Pleistocene, when the Pacific Plate and the Australian Plate were collision east – west. This changed the tectonic regime from contractual to strike-slip [8].

This study was conducted to explain the difference in maturity level and focus of hydrocarbon accumulation in three large fields namely, Alpha, Beta and Charlie which are not in accordance with the concept of generation and migration in the fields observed in the Bintuni Basin, Bird's Head, Papua. The intended discrepancy is a random sequence of the maturity levels of the three pitches. Supposedly, the closer the field location with the kitchen, the level of hydrocarbon maturity that accumulates is higher than the hydrocarbons accumulated in the field farther fromthe kitchen location. However, the results of the geochemical evaluation of hydrocarbons accumulated in each field do not support this. The order of maturity should be Alpha, Beta then Charlie, while geochemical evaluation results indicate the order of Charlie-Beta-Alpha maturity.

The discussion of this study focuses on the explanation of the model of charging method (charge access) and the focus of hydrocarbon accumulation (charge focus) on each field. The modelling used is field-scale 2D modelling and does not use map-based 2D modelling. Closure filling and migration flows are also visualized in 2D cross section map that can show only one migration path (unlike 3D Map). In the process of data processing, the discussion focused on the evaluation of the results of analysis of the geochemical data of rocks and hydrocarbons which is the primary data. Some geological processes recorded in basin modelling are carefully calculated and adjusted to boundaries that limit the geometry and scope of modelling of the basin itself [6].

METHODOLOGY

The data used in this study include primary and secondary data. Geochemical data includes evaluation data of source rocks, such as screening and analysis data, like TOC, Rock-eval pyrolysis, Kerogen Typing, and vitrinite reflectance. This data is used in determining the quantity, quality, and maturity of source rocks and hydrocarbons based on Waples, 1985 classification [10]. All of this data is summarized in Rock Geochemistry Data. Correlation data ofsource rocks and oils samples are summarized in the GC analysis results, saturated and aromatic GCMS fraction, and carbon isotopes. These data are used in determining the origin of organic materials, deposition environments, and thermal maturity and are applied in correlations between source rock and oil sample. The entire data above is primary data.

Secondary data used in the form of books, articles, and scientific journals containing regional condition studies include tectonic settings and regional structures, stratigraphy and concepts of petroleum and seismic systems of the Bintuni Basin, as well as studies on hydrocarbon geochemistry and basin modelling.

The next analysis is an analysis of the results of modelling the two basin pathways conducted to determine the method of hydrocarbon filling in the Bintuni Basin. This method is an analysis method that is done using the help of Petro Mod software™. The analysis includes stratigraphic analysis of basin scale, paleo heat-flow, paleo water depth, sediment water interface temperature, burial history, maturation and generation of hydrocarbons as well as access to replenishment and accumulation of hydrocarbons using percolation invasion methods in Bintuni basin. Thebasin modelling performed is 2D type. The invasion of collation is an algorithm popularized by Wilkinson and Willemsen (1983) that can realistically describe fluid displacement and distribution.

Basin modelling can also predict the direction of migration and the location of hydrocarbon accumulation. Rock maturity and hydrocarbon generation can also be analyzed based on the evolution of thermal regimes in basins. This value relates to the depth of the controlling of the source rock in the hydrocarbon system in the basin and the thermal gradient of the basin [5].

In this study, 2D modelling was conducted on two lines (Figure 1). Line 1 is shown with a red line starting from the Alpha-10 well and continuing to Alpha-2, Alpha-6, Alpha-3, Alpha-7, Beta-1, Charlie-5, Charlie-2, Charlie-3 and ending at Fox-9. While Line 2 (green) starts from the southerner regions and continues to Beta-2, Beta-1, Charlie-5, Charlie-2, Charlie-3 and Fox-9.

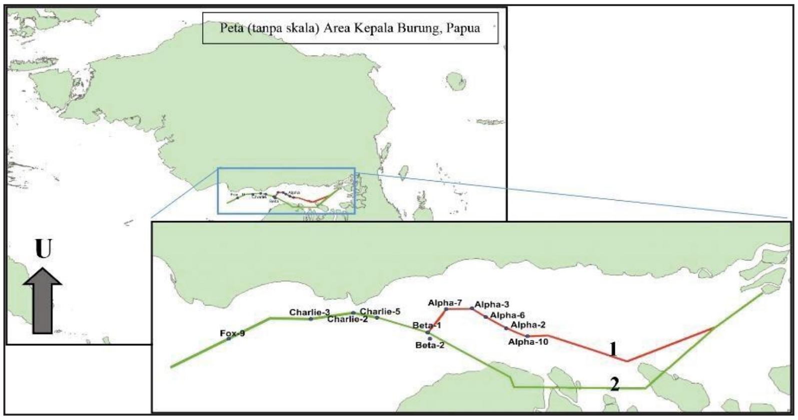


FIGURE 1. Seismic line map for basin modelling analysis shows 2 seismic line trajectories.

RESULTS

There are two source rock groups found in the area that is, Jurassic and Permian source rocks. Correlation of hydrocarbons and rocks, is done by screening at the similarity of organic material, depositional environment, depositional conditions and maturity level. Data obtained from the laboratory were tested on predetermined curves. This method is also called the oil to source correlation method.

The evaluation of maturity levels (Figure 2) in all three fields as observed is as follows: Charlie-1 has a slightly higher maturity (Ro~2.5) than Beta-1 (Ro~2.46) and alpha field (Alpha-2 and Alpha-3) is in the lower Ro range of 1.83. If observed at different wells, Charlie-2 and Beta-2 have maturity data from isotopes that tend to be the same.

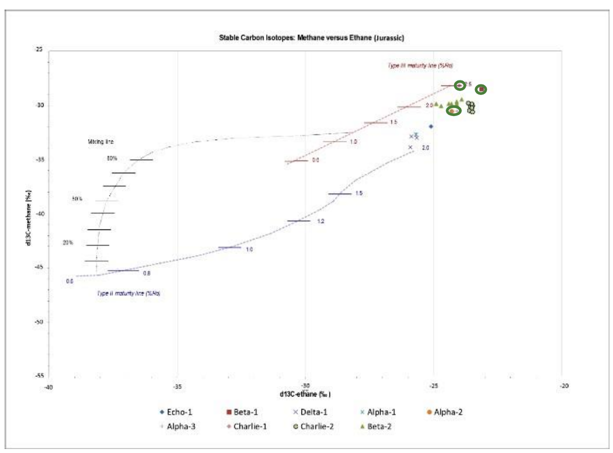


FIGURE 2. d13C- methane vs. d13C-ethane diagram for maturity level evaluation.

DISCUSSION

Source Rock Groups

In this study, two source rocks were identified with different geochemical specifications and characteristics. The first group is Jurassic's source rock which consists of samples from Charlie-1 and Charlie-4 well. The group's depositional environment includes deltaic to open marine environments with the main supply of organic material being non-marine algae. The second source rock group is Permian with samples from Beta-1, Charlie-2 And Charlie-3 well. The results through isotope curve show that the depositional environment of this source rock is shallow/coastal sea. Hydrocarbons are produced from mature shales deposited in the sea (marine), with small input from terrestrial organic material.

Hydrocarbon Groups

The Permian hydrocarbon group consists of the P-1 sample group. The P-1 group consists of samples taken from Beta-1 well samples at depths of 11667 and 11728 feet. The interpretation of deposition environment of isotope data is shallow or coastal seas. The organic material that makes up the source rock of this hydrocarbon group is dominated by algae. Hydrocarbons are produced from mature shales deposited in the sea (marine).

The Jurassic group deposition environment interpreted from the isotope data is Open Marine. The characteristics of the macerals that composes the source rock are dominated by non-marine algae as organic material, while hydrocarbons are produced from mature shales deposited in the sea. The second hydrocarbon group is. The interpretation of its depositional environment of isotope data is transitional environment between terrestrial and shallow marine. The organic material that composes this group is dominated by plankton and algae. Hydrocarbons are produced from mature shale, are also deposited in the sea (marine).

The Palaeocene hydrocarbon groups are Pa-1 and Pa-2. The depositional environment based on isotope data is Open Marine. The characteristics of the organic material are dominated by non-marine algae, while hydrocarbons are produced from mature shales deposited in the sea. The second hydrocarbon group is Pa-2. The depositional environment of the isotope data is Open Marine. The organic material that composes the source rocks of is a mixture of land and sea organic materials. Hydrocarbons are produced from mature shale deposited in the sea (marine), with small input from land organic material.

Correlation of Source Rocks and Hydrocarbons

The next evaluation is the matching process between the geochemical characteristics of fluid samples extracted from rock samples and hydrocarbon groups of each age (Palaeocene, Jurassic, and Permian). This is done to find for the source rocks of each hydrocarbon group, based on the geochemical characteristics. This correlation needs to be done to determine the source rock to be inputted in the basin modelling by exploring the origin of the hydrocarbon samples obtained

Based on correlation results, Palaeocene-aged hydrocarbons (Pa-1, Pa-2) and Jurassic age (J1, J2) as well as the Permian-aged hydrocarbon group has Jurassic-aged Source rocks. While the hydrocarbon group Permian P1, derived from the Permian source rock.

Maturity Level Sequence

The maturity level of hydrocarbons is controlled strongly by pressure due to the loading of overburden rocks above the source rock. This loading causes an increase in temperature that accelerates the process of maturing the source rock, so that the transforms into hydrocarbons. At that time, the source rock reaches the phase of thermal maturity or the point when the hydrocarbon is produced (hydrocarbon generation).

The condition of thermal maturity of the source rock does not only occur once and then the source rock is 'dead' or depleted. Depleted source rock is a condition when the kerogen that has reached the limit so that no hydrocarbons can be produced from the source rock. Thermal maturity can occur several times, at different temperatures and higher than the previous temperature, until finally the source rock no longer produces hydrocarbons. In other words, hydrocarbon generation can occur several times until finally the source rock 'dies'.

The higher the thermal maturity of the source rock, the hydrocarbons is more mature than the hydrocarbons produced from the previous generation. This is due to the variation in composition and preservation time of organic materials which are the macerals of kerogens as well as the increase in temperature itself. Some organic materials will be accelerated into kerogen at a certain temperature, while at the same temperature other organic materials that have turned into kerogens have changed phases into fluids or hydrocarbons. Each organic material has a different point of maturity. It means, we never know 100% in detail the composition of organic material that composes the source rock so that the difference in the maturity level of organic material or kerogen that causes several times the hydrocarbon generation must exist in each source rock. A longer preservation process also contributes to the kerogen maturation process. Based on the explanation above, the next produced hydrocarbon must be more mature than the previous generation hydrocarbons.

In reality, from the evaluation of maturity level through isotope data it is obtained that the order of maturity level is not like what we have discussed before. Analysis of maturity levels using ethane d13C vs d13C methane data showed different sequences of maturity levels. The data for evaluation was taken from wells in all three related fields and in the Jurassic and Palaeocene bed.

Based on that interpretation, the hydrocarbons accumulated in Charlie's field are slightly more mature compared to the Beta field and the maturity of the Alpha field is lower than beta and Charlie. This is in contrast to the theory of ideal conditions that have been described earlier. Therefore, based on the subsurface data that has been collected, hydrocarbon basin modelling covers the three fields observed to answer the discrepancy in the order of maturity level.

Basin Modelling

The coverage area modelled in this study was taken based on the results of 2D seismic mapping in the Bintuni Basin. Specifically, the seismic line modelled is the one that passes through the three main fields of Alpha, Beta and Charlie. The selection of seismic lines for modelling is focused on high area which is the dominant type of hydrocarbons trap in the Bintuni Basin.

There are two seismic pathways used as modelling references. The first trajectory passes through the north high trajectory through the Alpha field. In comparison, the second seismic lines pass over a higher area in south than the first line. This line is stretched in such a way as to have a deviation of direction towards the kitchen area of the hydrocarbon system, thus allowing for a different migration path from line 1. The field and wells passed by line 2 are the same as line 1.

Ro data obtained also records temperature changes during the deposition process, or in other words, the temperature that ripen the kerogen. Through calibrated Ro data, paleo heat-flow approach can be done. The flow of past materials is also influenced by tectonic movements that are closely related to basal heat-flow. The flow of plate material is closely related to the radioactive elements of the plates that become heat catalysts. Thus, temperature changes in a basin are affected by loading due to the deposition and supply of sediment and convection heat flow from the underlying plate of the basin.

The first step that needs to be done in evaluating erosion and flow of past materials is to determine present temperature. The determination of current temperature or 0 million years ago serves as the first calibration against fluctuations in temperature changes against rock age. Calibration of today's temperature is to adjust the measured temperature curve (based on the model algorithm) with the trend formed from gradients formed from the points of the temperature data set on all wells. There are three types of data being used, namely, measurement temperature values from sonic log, BHT calibration (borehole temperature) against Plot Horner, and DST (Drill-stem test) result temperature. The temperature before the current temperature is made stable or the past temperature to the present is the same, because it is determining the control variable. While Ro data samples are taken from core rocks, cuttings and shales on the column of rocks (ditch cuttings).

Determining the present-day temperature, was done by calibration using well temperature data by direct measurement. For erosion evaluation, the data used is Ro data. This was because present days are not recorded in vitrinite reflectance, which is closely related to sedimentation. Then the current temperature is recorded from the layer of recent rock or top layer.

Figure 3 shows a fairly representative temperature figure and the closest to the subsurface temperature data set is the 3rd experiment with a temperature of 47º C. Then the chosen current temperature is 47º because it is the closest value to the trend of measured data. After determining the current temperature, to determine the flow of past materials, the value of past temperature changes need to be entered immediately. The figures included are based on the amount of temperature value in accordance with tectonic events that have a major impact on the formation of the Bintuni Basin. The reference temperature figures are included in the program using the classification of Allen and Allen (1990). The temperature used uses a range system, starting from the minimum, middle and maximum values.

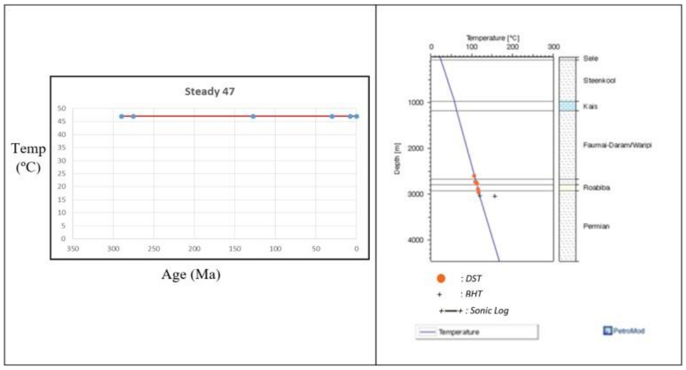
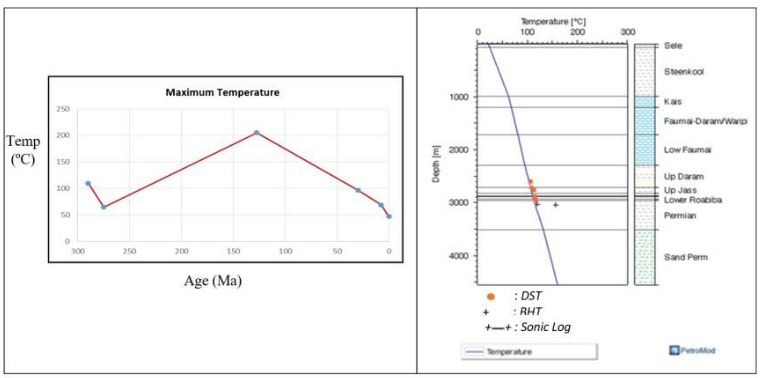


FIGURE 3. Test result 3 with a temperature of 47ºC; (a) Graph of age gradient (Ma) vs. temperature (ºC), and (b) Temperature graph (ºC) vs depth (m) on Petro Mod software™.

In this study, three experiments were conducted just like determining the present temperature until number that matches the gradient of the temperature data was concluded. The first calibration of paleo heat-flow also went through a testing process using temperature range values in accordance with tectonic activity. The diagrams in each image show depth – calculated temperatures relationships based on thermal model algorithms and immersion history based on stratigraphic arrangement data resulting from drill whole penetration [2]. Changes in temperature figures will cause deflection in the calculation results of the algorithm. Figure 4 shows that experiments using maximum temperatures are considered the most compliant because they are formed closest to a measured set of temperature data.



(a) **(b)**

FIGURE 4. Results of experiment 3 with maximum temperature; (a) Graph of age gradient (Ma) vs. temperature (ºC), and (b) Temperature graph (ºC) vs depth (m) on Petro Mod software™.

The accumulation of hydrocarbons is the result of hydrocarbon migration pathways analysis based on the algorithm of percolation invasion or fluid transfer to lower pressure due to the impulse of other fluids. These results show each field filled with hydrocarbons produced by the source rock. The focus of the research is the Late Jurassic aged reservoir filled with hydrocarbons produced by the source rock of Early Jurassic.

Figure 5 is the accumulation of hydrocarbons in Line 1. It can be observed that the field filled with hydrocarbon is Alpha field only. Hydrocarbons accumulated in the Alpha field also leak into the shallower sedimentary layer. This is supported by the presence of gas show on well-logging results. This leak is caused by gas-water contact and trap peaks that closer by distance and not ramping. In Figure 7, can be seen that the depth of gas - water contact (GWC) is at 3933 m of depth, while the anticline peak that becomes a reservoir is at 3530 m of depth. From both numbers can be calculated that the distance of both gas-water contact is only about 400 m. This number is a fairly small number for the distance between the two. The indifference of the position also led to the absence of lateral migration to the Beta and Charlie fields.

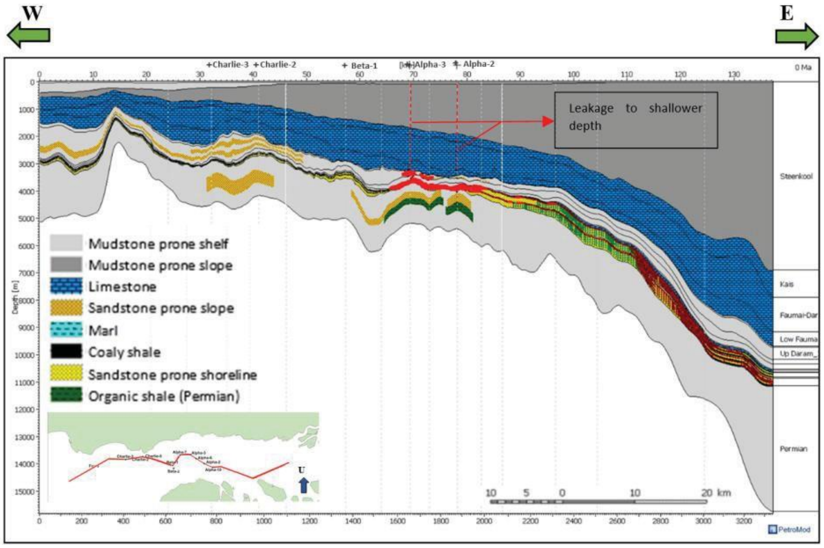


FIGURE 5. Modelling results of hydrocarbon accumulation Line 1 Bintuni Basin (CF 30%) petro mod software™.

In addition, the inability of seal rocks to hold fluid from the underlying sedimentary layer is also a factor in fluid leakage to shallower sedimentary layers. As explained earlier, the ability of seal rocks to build columns is closely related to the Clay Factor (CF). CF is strongly influenced by the quality of seal rocks, including from grain size, moisture content and so on. One of the CF supporting data is XRD. However, the company does not have an internal report for shale XRD data of the Daram Formation. So, the determination of CF can only depend on previous research (internal report (company). The CF value is 30%, the highest value that is still in the range of values of the previous study results (25-32%).

In fact, fluid migration on Line 1 can fill all three fields it passes, namely Beta and Charlie. However, due to vertical leakage, hydrocarbons do not migrate laterally to fill other fields. This makes the charging focus of Line is 1Alpha Field, or in other words, the migration pathway on track 1 boils down to Alpha Field.

One of the things that can negate vertical leakage is the increased of CF value. The author had experimented by changing the CF value in the Daram Formation to 35% (Figure 6). Figure 6 indicates the possibility of hydrocarbon accumulation in the Beta and Charlie fields. This reinforces the hypothesis that with higher CF values, seal rocks can eliminate vertical leakage and hydrocarbon fluids can migrate laterally. However, the CF value of 35% is beyond the range of CF values from the previous study. Indirectly, this reinforces the hypothesis that beta and Charlie Fields have different migration pathway than Alpha fields.

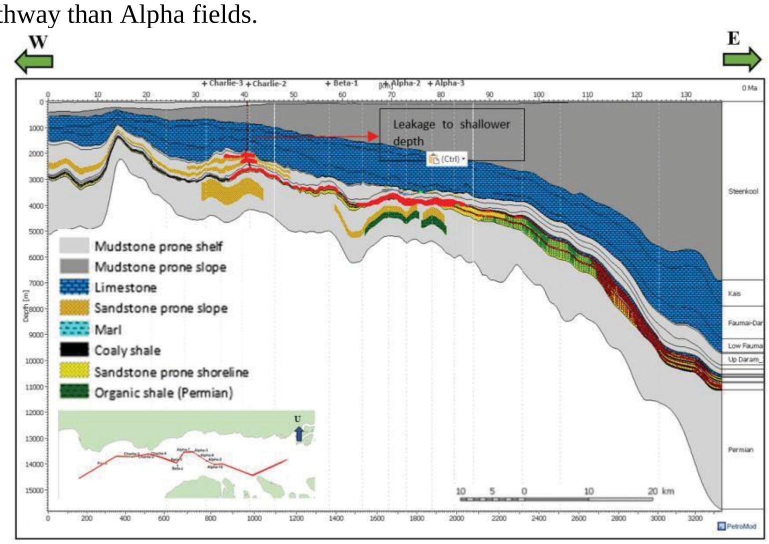


FIGURE 6. Modelling results of hydrocarbon accumulation Line 1 (CF 35%) Bintuni Basin uses Petro Mod software™.

The result of hydrocarbon accumulation on Line 2 indicates the accumulation of hydrocarbons in the Beta and Charlie fields. In Figure 7, it is shown that a leak into a shallower layer of sediment occurred in Charlie's field. The distance between the peak and GWC is close and fairly ramped allowing lateral migration from the Beta Field to Charlie's Field. In lateral migration at Line 2, hydrocarbons are easier to fill Beta Fields because the trap height value of the Beta field is even smaller.

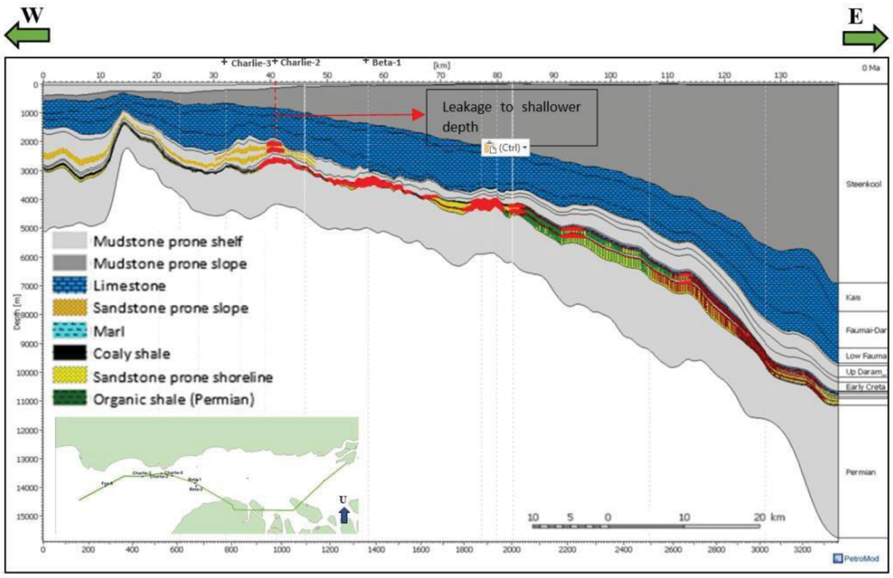


FIGURE 7. Modelling results of accumulated hydrocarbon line 2 (CF 30%) Bintuni Basin uses Petro Mod software™.

Based on Figure 7, the accumulation of hydrocarbons in model Line 2 focuses on the Beta and Charlie fields. Although accumulation is also present in Charlie field, the Charlie-3 well is not filled with hydrocarbons. However, the issue was not the main focus of the study.

The results of this model, answers the hypothesis that the three fields are filled by two different pathways. The Alpha field is the focus of the migration path 1, while the Beta and Charlie fields are filled by the migration path line 2. Differences in migration pathway and focus on hydrocarbon replenishment in each field affect the quality and maturity of accumulated hydrocarbons.

CONCLUSION

Based on the results of processing data and discussion obtained the following conclusions:

1. The Bintuni Basin has two source rocks, the source rocks Permian and Jurassic. The source rock of the Permian is found in the Aifam Group, especially the Ainim and Aifat Formations. This formation is deposited in a non-marine fluvial deposition environment with the dominance of black shales and coal. Jurassic's source rock, the Lower Kembelangan Group (lower Roabiba Formation) is composed of carbonate shale with claystone and fine grain glauconic sandstone and a small shale. These formations are deposited in a transitional environment. Permian and Jurassic's source rocks both have organic material compositions derived from terrestrial or land. Based on the results of the analysis, both source rocks are potential source rocks. Kerogen is the constituent of Permian and Jurassic source rocks have a tendency to regenerate hydrocarbons in the form of gas (gas prone kerogen).
2. Based on the collected data, the hydrocarbon samples that can be analysed consist of samples of Palaeocene hydrocarbon fluid, Jurassic and Permian condensate. Results from oil to source correlation show that Palaeocene hydrocarbon fluid samples (Pa-1 and Pa-2) were produced by Jurassic's source rock. Samples of Jurassic hydrocarbon fluid (J-1 and J-2) are produced by Jurassic's source rock. Permian condensate samples (P-1) are produced by Permian source rocks.
3. Based on the evaluation of the isotope composition of each field hydrocarbon sample, the order of field maturity is not in accordance with the theory, namely Charlie, Beta and Alpha. Bintuni Basin modelling is a field-scale

2D modelling conducted on two seismic pathways mapping. Seismic mapping results in the form of depth structure into the basic frame of modelling. Each seismic line is assumed to be a hydrocarbon migration path. Basin modelling for seismic line 1 shows that the focus of filling this path is the Alpha field. On this path there was no accumulation on the Beta field nor Charlie. The cause of the absence of hydrocarbon accumulation in the Beta and Charlie fields through seismic line 1 is low-capacity seal rock and trap height or a long and steep distance between the peak of the trap and the point of contact of water with gas (gas water contact). This leads to hydrocarbon leakage into the shallower sedimentary layer, so there is no lateral migration to the Beta and Charlie fields. Basin modelling for seismic line 2 shows that the focus of filling this path is the Beta Field and Charlie field. Hydrocarbons in this path are easier to migrate laterally due to the more sloping trap height position.

4. Different migration paths and differences in filling focus are the reasons for the irregularity of the hydrocarbon maturity sequence in all three fields. Both of these explain that there is no link between the hydrocarbons accumulated in each field other than coming from the same source rock.

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