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The Integration of Geochemical Characteristics and Stable Isotopes Analyses of δ^2H and δ^{18}O in the Paleogene Carbonate Rocks Unit of the M-Field, Ciputat Sub-Basin, North West Java Basin, Indonesia

Integrasi Karakter Geokimia dan Analisis Isotop Stabil d^{2}H dan d^{18}O dari Satuan Batuan Karbonat Paleogen di Lapangan M, Sub-Cekungan Ciputat, Cekungan Jawa Barat Utara, Indonesia

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Abstract - The Paleogene carbonate unit in the North West Java Basin has no cropped out and never been shown in the regional stratigraphy, whether as a formation or as a member of the existing formation. This paper provides new insight of the diagenetic process evidence by the stable isotope of ^{2}H and ^{18}O in formation fluids integrated with petrographic and geochemical data of rock and fluids samples analysis. The major minerals of this carbonate unit are: calcite, clay minerals, dolomite, quartz, plagioclase, and pyrite. From ICP-OES analyses result this carbonate rocks has the content of Fe, Mg and Al ranges 450-7800 ppm, 497-10892 ppm and 96-3900 ppm respectively, while Si and Sr are relatively low around 0.1 ppb to 0.7 ppm and 60 ppm to 570 ppm respectively. Formation water chemistry data shows the total charges for cation and anion were relatively balanced from 75.5 to 396.8 meq, the TDS from 4,904 mg/l to 22,351 mg/l, and SG from 1.005 to 1.016 and were dominated by elements of Na, Ca, Mg, Cl and HCO3. The d2H and δ18O from water samples are between -26.2 to -37.2 (‰) and between -3.63 to 2.50 (‰) respectively. With all the correlation of geochemical and isotope data of both rock and water indicate that the Paleogene Carbonate system in the M-Field has been through at least once uplifting and one sea water rise/drowning event, with meteoric water affected diagenetic process. These geological processes shown by the calcite cementation, the presence of pyrite and quartz, recrystallization of the carbonate grains and mylonitic dolomite, high content of Mg, Fe and Al, and also the abruptly change of the δ^{13}C and δ^{18}O values.

Keywords: Paleogene carbonate, geochemistry, water chemistry, stable isotope, diagenesis.

Abstrak *- Unit karbonat Paleogen di Cekungan Jawa Barat Utara tidak pernah tersingkap dan tidak pernah ditampilkan dalam stratigrafi regional baik sebagai formasi ataupun anggota formasi. Makalah ini menyajikan bahasan baru proses diagenesis yang dibuktikan oleh analisis isotop stabil ^{2}H dan ^{18}O dalam fluida formasi, diintegrasikan dengan analisis contoh geokimia batuan dan air. Mineral utama yang terkandung dalam unit karbonat tersebut adalah: kalsit, mineral lempung, dolomit, kuarsa, plagioklas dan pirit. Dari hasil analisis ICP-OES, batuan karbonat ini memiliki kandungan Fe, Mg dan Al yang masing-masing memiliki rentang antara 450-7800 ppm, 497-10892 ppm dan 96-3900 ppm, sementara Si dan Sr relatif rendah masing-masing berkisar antara 0.1 ppb - 0.7 ppm dan 60 ppm - 570 ppm. Data kimia air formasi menunjukkan total tegangan untuk kation-anion relatif seimbang dari 75,5-396,8 meq, TDS dari 4904 mg/l – 22351 mg/l, dan SG dari 1,005-1,016 dan didominasi oleh unsur Na, Ca, Mg, Cl dan HCO3. δ 2H dan δ18O dalam contoh air masing-masing antara 19.068 sampai -0.155 (‰) dan antara 3,63 sampai 2,50 (‰). Dengan korelasi data geokimia batuan dan isotop air mengindikasikan bahwa sistem Karbonat Paleogen di lapangan-M telah melewati setidaknya sekali pengangkatan dan satu penggenangan air laut/ penenggelaman, dengan dipengaruhi air meteorik dalam proses diagenesisnya. Proses geologi ini ditunjukkan oleh sementasi kalsit, kehadiran pirit dan kuarsa, rekristalisasi butiran karbonat dan milonitisasi dolomit, kandungan Mg, Fe dan Al yang tinggi, dan juga perubahan yang tiba-tiba nilai δ^2H dan δ^{18}O.*

Kata kunci*: Karbonat Paleogen, geokimia, kimia air, isotop stabil, diagenesis.*

INTRODUCTION

The Miocene-Pleistocene Formation units in the West Java has been massively studied, while the the pre-Miocene carbonate rocks are poorly understood. This pre-Miocene carbonate sequence has never been found or exposed across the region of West Java. Wilson and Hall (2010) indicate that the tectonic subsidence of back arc areas in north of Java and Sumatra resulted in marine flooding, allowing carbonate development during the latest Oligocene to Early Miocene. This pre-Miocene carbonate might also be part of the Oligo-Miocene carbonate which is described by Satyana (2005) as distributed regional across Java, which mainly divided into two trends, northern trends (Cepu-Surabaya-Madura-Areas, North Central Java, and Ciputat-Jatibarang Areas), and southern trends (Gunung Kidul-Banyumas-Jampang, Bayah-Sukabumi-Padalarang Areas). The northern trend developed mainly in the subsurface of the back arc setting and was located far from the volcanic arc, while the southern trend developed in the intra-arc setting and shared the same location with or close to the volcanic arc (Satyana, 2005; Metcalfe, 2017). Due to lack of geochemical data for oil and gas exploration the Paleogene carbonate in the West Java Basin are not well defined. The variety, limited number and quality of the geochemical and stable isotopes of rock and fluids samples which could only be taken from several oil and gas wells that has penetrate and cored the carbonate rocks down to the depth of 2900-3000 mMD were few among many challenges in this area. Thus, it is important to gain geochemical and isotope analyses of the Paleogene carbonate in this study area, to get better understanding and give new insight in petroleum system development concept.

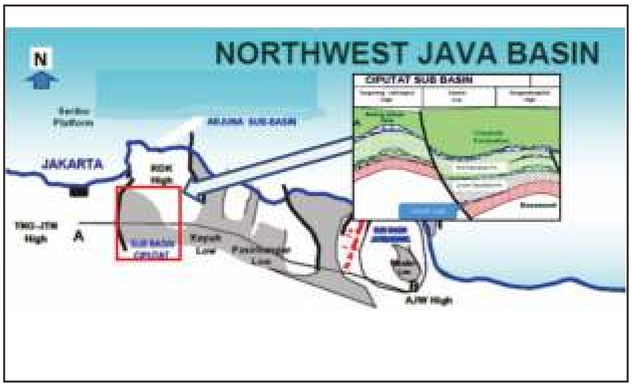
GEOLOGICAL SETTING

The position of Paleogene carbonate in Ciputat Sub Basin of the North West Java Basin were varies when correlated with other lithology of volcanic and metamorphic rocks, which in this sub basin were commonly identified as the basement. The position of Paleogene carbonate at some place was found higher than the basement, but in some location were lower. This might be due to the tectonic or diastrophic events in this sub-basin, nevertheless as the sub-basin is part of North West Java Basin (Figure 1). The Ciputat Sub-basin was also formed and affected by the North West Java regional tectonic as well as subduction system of Southern Java.

There were at least 4 stage of tectonics related to rifting process (Doust and Noble, 2017) which driven the geology and stratigraphy of the North West Java Basin, the early synrift, the late synrift, the early post rift and the late post rift. The Ciputat Sub-Basin presumed to start developed during the pre-rift tectonic event on the North West Java Basin upon the pre-Tertiary basement as described in the previous regional study shown in Figure 2. The rifting and subduction process at the Southern of Java and diastrophic events in the Northwest Java Basin were causing the faults and fractures to growth over Ciputat Sub-Basin. The major faults orientation is relatively in the direction of north-south and shown as a normal fault at the eastern part of Ciputat Sub-Basin.

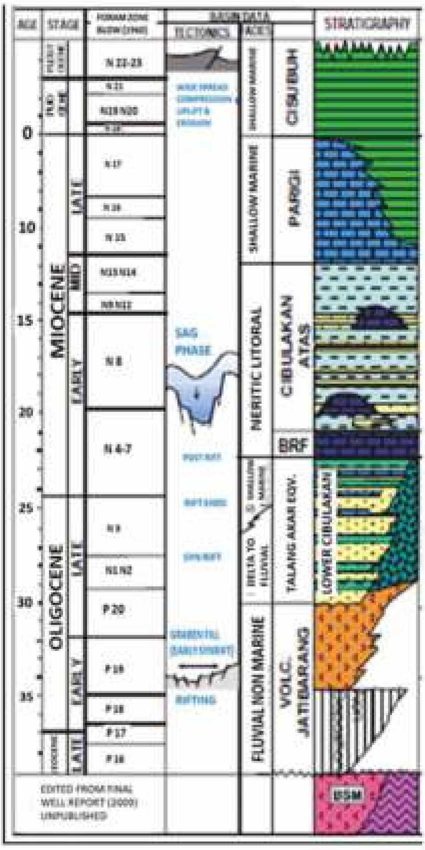
The regional stratigraphy of the North West Java Basin shows that the oldest sedimentary rock formation above the basement is Jatibarang Volcanic Formation, which were formed during early synrift in the Paleocene-Eocene series, while the Paleogene carbonate is not presence nor considered as a member among the Oligocene formation of Volcanic Jatibarang or basement but it has been considered as part of the Paleogene basement (Figure 2).

The Ciputat Sub-Basin is a back arc type of basin, which was filled and growth mostly by coarse clastic sediments during rifting processes at Paleocene-Eocene to Oligocene series and from Oligocene to Present the deep marine volcanoclastic were dominant with turbidite mechanism as a product of subduction process and at the same time it was also developed the limestone sediment at the shelf edge.



sumber: Modified from PEP, 2009

Figure.1 Location and profile of Ciputat Sub Basin as part of North West Java Basin



sumber: PEPPDM, Final Well Report, (2012)

Figure 2. Regional Stratigraphy of North West Java Basin

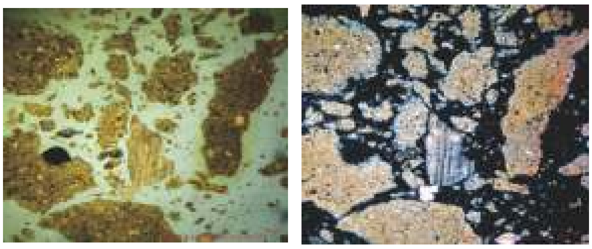


Figure 3. Depth 2744 mMD, Packestone, Grainstone and Wackestone with calcite, aragonite, quartz and feldspar as fragments. On the left is picture of parallel Nicol and right picture is cross Nicol.

METHODOLOGY

The method for this research is using the geochemical analysis by ICP-OES method from 5 core samples which taken from 2 wells and supported by stable isotope analysis of formation water from 6 samples with 3 samples each for 18O and 2H respectively which collected from 3 wells. The results will be used to characterize the chemistry compound of the formation water and also the geochemical characteristics found within the Paleogene carbonate in Ciputat Sub-Basin. From geochemistry analysis we prognoses the process of geological event in this sub-basin that would cause diagenetic in the Paleogene carbonate unit.

RESULTS

Petrography

The petrological and mineralogical analyses presented here were gained from the previous study and has been already describe (Anonym, 2008, LAPI ITB, 2014). The petrographic samples were collected from one well (M-11) at depth of 2744 mMD, 2757 mMD, 2760 mMD and 2771 mMD. These were used as complimentary evidence of diagenetic processes in form of matrix replacement and recrystallization of skeletal fragments (Figure 3). The specimens are also shown some proof that can be considered as evidence of materials/minerals enrichment to the original depositional environment (Flugel, 2004), which is shallow marine facies.

Neomorphosed mudstone shows as skeletal grains, mostly neomorphosed to calcite spar and the matrix replaced by micrite and indeterminate clays (Figure 4). The texture is difficult to recognize, diagenesis occur in form of calcite, micrite and indeterminate clays and pyrite, siderite and dolomite. Fractures is also develop but not intense and it has very poor visible porosity (1%).

The sample from 2760 mMD (Figure 5) and 2771 mMD (Figure 6), were also showing evidence of diagenetic process from mylonitic dolomite and mylonitic limestone presence which might be due to deep burial effect after deposition (Moore and Williams, 2013).

Stable Isotope

The Paleogene carbonate unit in the M-field were analyzed using stable isotope from formation water samples and interpretation of major elements geochemical data taken from 3 wells (M-11, M-19 and M-20). The vertical position of the target reservoir in these 3 (three) wells were flattened at the top of Paleogene carbonate and measured to the bottom of completion which is not yet reach the bottom of carbonate unit.

This configuration as shown in Figure 7 showing the position of formation water samples taken in each wells that penetrated the Paleogene carbonate. While the well M-11 has the longest completion interval (310 m), the data from imaging logs has shown fractures with good connectivity are only occurred within the 50 m of the well's top interval completion (Figure 8). All the samples were collected from the well head of each well to assure there was no mixing with other well samples.

Later (in the Figure 9) we can see the cross plot of stable isotope values (^{2}H and ^{13}C) in each well were able to show the evolution of geology event during the depositional and the forming of Paleogene carbonate rocks in Ciputat Sub-Basin

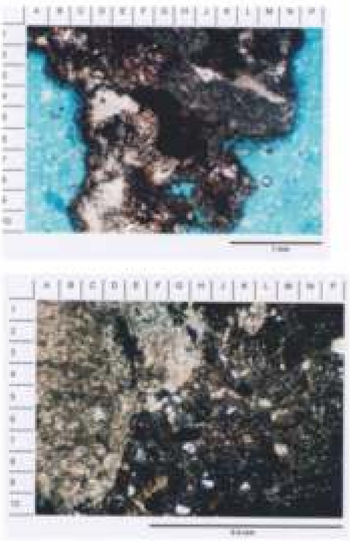


Figure 4. Depth 2757 mMD, Neomorphosed Mudstone: A (left): relict of skeletal grain and carbonaceous materials as accessory minerals, B (right): Monocrystalline Quartz and Plagioclase in minor amount, most grains and matrix were replaced by calcite, siderite and dolomite.

Figure 5. Depth 2760 mMD, Mylonitic dolomite comprise of lime mud and fragment skeletal have undergone recrystallized become calcite and dolomite, Aggregate dolomite is 70%. Rock porosity of channel and vug is about 3%. (Left picture is parallel Nicol and right picture is cross Nicol.)

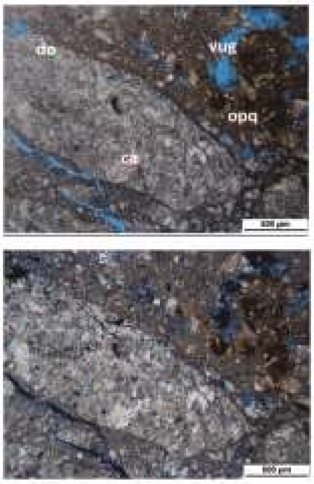


Figure 6. Depth 2771 mMD. The mylonitic limestone, with porosity consists of vuggy (vug) (left picture) and channel porosity (channel, right picture). Grains of carbonate rocks (left and right pictures), opaque minerals (opq, left and right pictures), and picture on the left shows dolomite (do) and calcite (ca) possibly had replace the original grain and matrix.

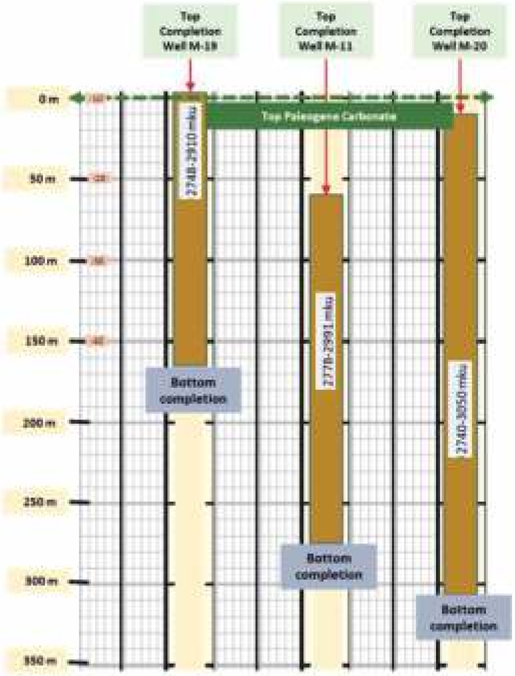


Figure 7. Formation water samples were taken from completion interval length as shown above along with depth position (mMD/mku) and interval length between Top Paleogene/Old Carbonate and Top of Open Hole Completion.

Figure 8. Imaging logs of Well M-11 show the first 50 m interval of the Top Paleogene/Old Carbonate has good connected fractures as proof of formation water major contributor comes from the interval of 2740-2775 mMD in the Open Hole completion.

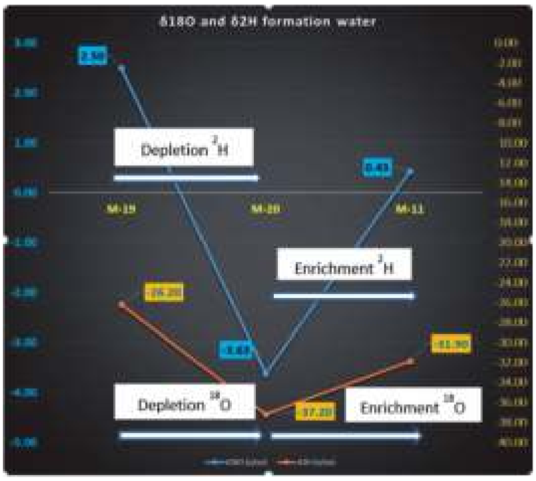


Figure 9. Stable isotope values of ^{18}O and ^{2}H in 3 wells of M-19, M-11 and M-20 in Paleogene/Old Carbonate environment system.

DISCUSSION

This study provides the integration of geochemical and isotope data from rocks and formation water in order to explain the geology and diastrophic event which could be seen through some evidence of diagenetic processes and changes of depositional setting in the Paleogene carbonate unit and its formation water of the M-Field, at Ciputat Sub-Basin.

From the petrography analysis reveal some evidences of diagenetic processes and depositional setting where diagenetic process could formed. Some evidences are in forms of matrix replacement (Figure 6) and recrystallization of skeletal fragments (Figure 5). This clearly shows the diagenetic process in forms of minerals dissolution and precipitation which occurred when carbonate rocks were exposed to meteoric water interaction, so the less stable minerals of aragonite and high-Mg will dissolute and more stable minerals such as Low-Mg Calcite are often re-precipitate.

Other proof of diagenetic process in this Paleogene Carbonate that it was also related with high pressure which shown from occurrences of fractures development in the carbonate rocks that forms fracture porosity and mylonitic limestone/dolostone which is quite obvious in the thin section (Figure 5), these diagenetic evidence were related with deep burial depositional setting.

The occurrences one of minerals quartz are also can be considered as evidences of enrichment in the origin of depositional environment of marine facies with some sediment sources of detrital influx (Figure 4) where transition depositional setting took place. These could possibly be the impact of volcanic activity, faulting or uplifting events within or nearby the area that would cause mixed processes between the carbonate system and volcanic, magmatic or detrital source of deposits. Hence, from petrographic analysis we could predict that diagenetic setting were occurred which is supported in variety and changes of depositional setting of this Paleogene Carbonate.

Thus, the Depositional setting of this Paleogene Carbonate were varies from shallow marine setting that interact with meteoric water which has diagenetic process shown in mineral replacement, dissolution and precipitation, to deep marine depositional setting which has diagenetic process shown in fracture growth as secondary porosity and occurrence of mylonitic dolomite, and also transitional setting of shallow marine-terrestrial depositional environment which has evidence of diagenetic in presence of quartz, siderite and pyrite minerals in carbonate rock.

Water Chemistry analysis in carbonate rocks can also be considered as rock sources tracing tool, knowing the association and dissociation reaction of elements contain in the water for example the presence of Ca, Mg, Na and abundance of HCO_3 means the reaction would favor between Ca and HCO_3 then followed by Mg, Na, K for the excess of HCO_3 until it exhausted, and when the Ca is in abundance, then it will favor to form reaction with the HCO_3, followed by sulfate, chloride and nitrite until it exhausted (Collins, 1975).

The results of Water chemistry analysis shows that the samples in the well M-20 has the most abundance of Ca with 5230.44 mg/l and 1573.14, followed by the Ca content in the well M-15 with 3547.08 mg/l and 2232.46 mg/l, and the third well is M-11 showing 1202.40 and 1152.30 mg/l (as shown in Table 1). The HCO_3 on the other hand also showing the opposite values which is the least concentration of HCO_3 is also in the well M-20, M-15 and M-11. Hence, we could presume the most favorable solvent that react with the rocks is HCO_3 followed by sulfate and chloride, while the most reacted elements are Ca, followed by Mg and Na. All of these elements could lead us to conformed that source of this formation water is sea water from paleo environment.

The stable isotopes values reveal that the formation water in the carbonate rocks has been through some significant changes in geological events (Table 2). Based on the information in the Figure 8 & 9 and Table 2, we could see the length of completion intervals such as in Well M-11 is not always in a porous zone, but may also flow through some fractures as we can see from the FMI analysis (Figure 8). Thus, we could conclude that the deeper portion of the carbonate rock already through some continuous pressure and compaction process. Those presumption could only be thoroughly understand only after we analyze the isotope value combine with the geochemical/ICP OES interpretation.

Table.1 Water Chemistry from 5 wells (M-11, M-15, M-18, M-19 and M-20)

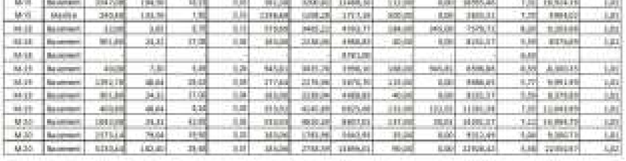


Table.2 Well numbers, completion intervals, isotope values and interpretation

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M-20	2728-2991 mku	83,5	[illegible]	depleted	
M-11	2740-3050 mku	14,5	0,43	enriched	depletion
M-19	2748-2910 mku	-6	2,50	enriched	depletion
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M-20	2728-2991 mku	83,5	[illegible]	depleted	
M-11	2740-3050 mku	14,5	[illegible]	depleted	depletion
M-19	2748-2910 mku	-6	-26,2	depleted	depletion

The porosity in the upper section of carbonate rocks from M-11 well has a good porosity of matrix and fractures while after depth of 2775 mMD the carbonate rocks has a different property with vuggy porosity in the isolated position, the matrix could not provide flowing media for the fluids with only less than 1% of porosity while the fractures porosity in carbonate will dominate the flow of formation water.

The stable isotopes values from formation water used in this study were based on the change of values in ^{18}O isotope due to reaction with influx of meteoric/fresh water that mixed with depositional environment of sea water (Bowen, 1994). As in Figure 9 above, there are two phase of events which is an isotope depletion as both isotope values significantly dropped (2.5 to -3.63 ‰ and -26.20 to 37.20 ‰ for ^{2}H and ^{18}O respectively), and followed by isotope enrichment process which is seen as a significant increase of both isotope values (-3.63 to 0.43 ‰ and 37.20 to -31.90 ‰ for 2H and 18O respectively) in the Paleogene carbonate rocks environment system. Depletion and enrichment process for ^{18}O and ^{2}H were due to the redox condition of the paleo marine environment that could possibly be triggered by the local diastrophic events or some process in facies changing of the Paleogene carbonate rocks. Based on the ^{18}O and ^{2}H cross plot shows that the depositional environment and major influence to the carbonate rocks are divided into 3 (three) zone of geological processes (Figure 10), as described:

1. The isotopes value from the samples collected far below the local meteoric water line has shown that the interval zone is not contaminated with meteoric water or surface water,
2. The formation water in this Paleogene carbonate rocks reservoir is not an isolated zone,
3. There are at least two or three condition zones for the carbonate rocks: deep reservoir environment or magmatic/alteration impact, and the third possibilities is there are zone that has both condition which is deep environment and close to magmatic/alteration.

Further analyses of these isotope values has enable us to correlate the diagenetic of the formation water with the Paleogene carbonate diagenetic process and it depositional setting. It is presumed that formation water in these 3 wells in the M-field were contained originally as deep carbonate rock reservoir due to burial process and later was heavily affected by magmatic alteration through intrusion or faulting as part of diastrophic event.

Evaluation of stable isotope data from formation water as we could see such in Figure 11, there are two series of events in the development of this carbonate zone, first is depletion of ^{2}H and ^{18}O events then followed by enrichment events of ^{2}H and ^{18}O. The isotope values of ^{18}O for paleo marine (shallow) environment is between 0 - 4 ‰, so when isotope values within interval of depth 3050 - 2990 mMD is significantly depleted to -3.6 ‰ that means the formation water environment settings has change from marine-terrestrial transition environment (due to near zero isotope of ^{18}O) to a more reduce environment such as deep buried or near the magmatic/alteration this is presumably due to continuously and massive supply of sediment along with sea water rise/drowning event. The next process is from depth of 2990-2910 mMD where there were evidence of enrichment of ^{18}O to 2.5 ‰ that would mean the formation water environment had experience abundance influx of sea water where the formation water facies had change back to the shallow paleo marine environment by an uplifting event.

Similar plot also happened to ^{2}H where there is a depletion from depth 3050 - 3015 mMD which ^{2}H has fall to -37.2 ‰ that presumably due to continuously drowning event which buried the sediment deeply and later from depth 3015-2910 mMD the ^{2}H has been enriched significantly to 26.2 ‰, which means the old carbonate rocks is getting the impact from diastrophism process. One of diastrophism process that could take place in that condition is uplifting. The analysis from stable isotope of ^{2}H and ^{18}O characteristic could provide us with environmental depositional presumption during development of The Paleogene Carbonate in M Field, they were: Marine-terrestrial transition environment, buried/deep marine environment and shallow marine environment with magmatic influence affecting the isotope characteristic

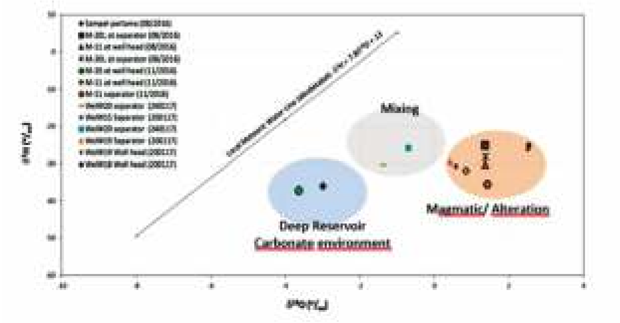


Figure 10. The ^{18}O and ^{2}H cross plot with local meteoric line equation above all the cross plot isotope values.

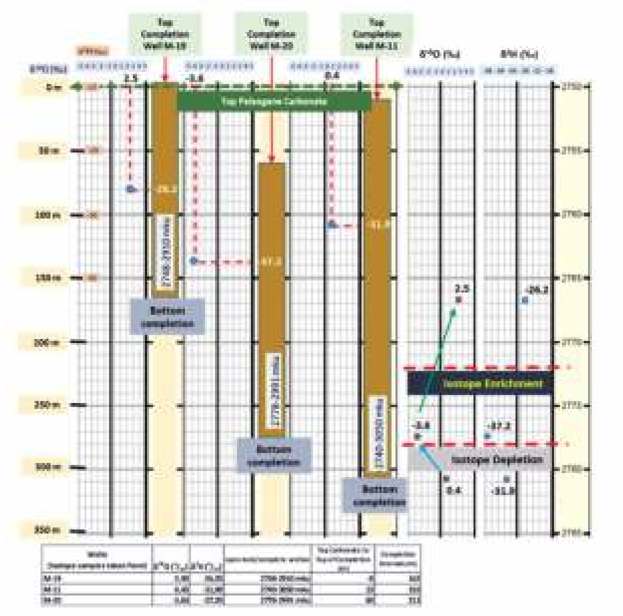


Figure 11. Cross plot from 3 wells (M-19, M-11 and M-20) of ^{18}O and ^{2}H Isotope values from formation water as shown in the Table with completion interval length, depth position (mku/mMD) and distance between Top Paleogene/Old Carbonate and Top of Open Hole Completion. The isotopes plot on the right showing changing phase of depletion and enrichment related to geological event of diastrophism that would impact on diagenesis of the formation water and carbonate rocks

CONCLUSIONS

The carbonate Rocks of the M-Field in the Ciputat Sub-Basin, North West Java Basin has several distinct properties and characteristic that could explain depositional setting related to diagenetic process of the formation water and carbonate has been through. Distinct properties of some element such as Ca, Mg, Na and Cl, HCO_3 contained in the formation water of Paleogene carbonate found to be the most dominant elements in the rock-water interaction processes, which typified the water type of the formation water in the M-Field. The depositional condition from the petrography description are of shallow marine with diagenetic events that forming neomorphosed limestone which identified from the appearance of quartz, pyrite and siderite. The diagenetic setting from petrographic is aligned with the result of stable isotope cross plot of ^{2}H and ^{18}O which shows there are three carbonate rocks setting in this Paleogene Carbonate of M-Field in Ciputat Sub Basin: 1. transition of marine-terrestrial depositional environment with diagenetic evidence in the occurrence of quartz, pyrite and siderite, 2. marine depositional setting with buried/deep diagenetic environment setting, shown by the presence of fractures porosity and mylonitic dolomite and 3. shallow marine depositional setting with diagenetic setting environment influenced by meteoric water and magmatic activity which shown by mineral dissolution and precipitation and also affecting the isotope characteristic.

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