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RESEARCH ARTICLE

Mechanism Formation Carbon Dioxide Around Muriah Trough And Bawean Arc, North East Java Basin, Indonesia

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Abstract

CO_2 content in natural gas in Muriah Trough and Bawean Arc, North East Java Basin. Understanding the origin and distribution of carbon dioxide is important for the research of natural gas exploration risk. This research uses gas geochemistry to identify the origin of carbon dioxide formation around the Muriah Trough and Bawean Arc. The chemical composition of CO_2 and $\delta^{13}C_{CO_2}$ was measured in 10 gas samples taken from 6 exploration wells around the Muriah Trough. The results of the analysis indicate the origin of the carbon dioxide and carbon dioxide mechanism around Muriah Trough and Baswean Arc derived from organic and inorganic processes. The process of forming the carbon dioxide mechanism around the Muriah Trough and Bawean Arc is dominated by inorganic processes, presumably derived from the mantle degassing process. The mantle Deggasing process was related to volcanism Muriah and Bawean the Late Miocene-Pliocene.

Keywords: Geochemistry, Carbon Dioxide, Muriah, Bawean

1. Introduction

Several mechanisms that produce inert gases, but it's still unclear where different inert gas compositions and quantities come from (Khan, et.al, 1992; Saqi, et.al; Ahsan, et.al., 2003; Nazeer, et.al., 2012). The three main non-hydrocarbon gases (CO_2, N_2, and H_2S, for example) that are frequently found in the natural gas mixture in a reservoir pool are assumed to be included in the phrase "inert gases". Understanding of nonhydrocarbon gas or inert gas (carbon dioxide) is economically important due to the significant increase in production costs of production facilities and pre-processing processes before sale (Katz, 2002). Due to the corrosive nature of CO_2 and the need for separators for its processing, this will increase the investment value in field development and reduce the volume of hydrocarbon gas (Copper, et.al., 1997). One of the main nonhydrocarbon components of natural gases is carbon dioxide and its concentration in these gases ranges widely, from trace levels to about 100 % (Wang, 2022). In addition, this gas content will decrease the value of BTU content. Natural gas reservoirs can produce CO_2 concurrentlywith hydrocarbon gases, mix it with hydrocarbon gas reservoirs during gas migration and buildup, or even produceit as a byproduct of gas reservoir rebuilding like TSR (Dai, et.al 2014). When choosing the gas processing methods, gas composition is a crucial issue (Speight, 2017).

The research location is located in the North East Java Basin. The focus areas of research are around the Muriah Trough andBawean Arc as depicted in Figure 1. exploration activities in the offshore area of North East Java, in the Karimun Jawa High, Bawean High, Muriah Basin, JS-1 Basin areas began in 1967 (Roniwibowo, 2014), then in the 1991-2000 era, three exploration wells were carried out by SHELL to prove the commercial aspects of the Kepodang Field, with obstacles and failures, namely dry holes and inert gas factors in the form of CO_2 and nitrogen**.** The research area has potential gas in the biogenic, thermogenic, and mixing between biogenic and thermogenic gas system (Prahantanto, et. al., 2001). With the aid of anaerobic microbes and a CH_4 level greater than 97%, organic material breaks down to produce biogenic gas at low temperatures. Biogenic gas accounts for roughly 20 percent of all gas discovered worldwide (Rice and Claypool, 1981). This makes biogenic gas an important target for exploration because its presence can be predicted geologically, and it is spread quite widely in large quantities at shallow depths.

The wells in research area are fairly high CO_2 content in natural gas in formation has biogenic gas. This study aims to determine the origin of its formation, its distribution and estimate when carbon dioxide is formed which is expected toreduce the risk in natural gas exploration.

2. Geologi Regional

The North East Java Basin, especially the Kepodang Field located around the Muriah Trench, has biogenic gas potential. The research location is in the North East Java Basin. The area that is the focus of the study is around the Muriah Trench and the Bawean Arc is 120 km or 80 miles north of Gresik City (Figure 1), where its history cannot be separated from history of the structure and tectonic of Java Island. Tectonic of Southeast Asia are controlled by the interaction of four majorplates: Indo-Australian Plate to the south, the Philippine Plateto the north Pacific Plate to the east and Eurasian Plate to thenorthwest. Daly et al. (1991)

stated that history of the East Java basin formation began at the beginning of the Cretaceous, when the Indo-Australian Plate moved north and the Pacific Plate moved westward. There has been a collision between the microplate at the southeastern tip of Sunda-land which produces accretion mélange during Cretaceous and East Java formed due to the roll-back during Paleocene- Eocenecollision.

The North East Java Basin evolved in response to two structural episodes, according to Bransden and Mathews (1992). The first was extensional during the Paleogene period, which created dip faults and locally developed extensional electric fault geometry. The second was reactivation during the Neogene period, which caused Paleogene faults to experience inversion or move in the opposite direction, resulting in their uplift. According to plate interactions, the East Java Basin's tectonic evolution can be split into three major periods: the Middle Miocene-Late Miocene (20-5 Mya), the Oligocene-Early Miocene (35-20 Mya), and the Late Cretaceous-Eocene (70-35 Mya) (Sribudiyani et al., 2003).

The East Java Basin developed as a back arc basin and the emergence of a volcanic zone in the southern part of Java occurred in the Middle Eocene age, based on the geochemistry and geochronology of 35 selected magmatic rocks distributed throughout Java. Soeria-Atmadja et.al., 1994 concluded that Tertiary magmatism in Java occurred in two different periods, namely the Eocene-Early Miocene (40-18 Mya) and the Late Miocene-Pliocene (12-2 Mya).

1.2 Stratigraphy

Regional stratigraphy in the area of research is divided into Paleogene and Neogene sediments (Satyana, 2005). Paleogene sediment is related to syn-rift or tensional processes during Paleocene to Eocene time. The accommodation space was heavily influenced by the basin configuration, while Neogene sediment deposition is related with compressional processes that are influenced by tectonic activity of subduction zone to the south of Java Island.

The North East Java Basin is one of the back-arc basins that has been proven to produce hydrocarbons. The stratigraphy of the East Java Basin (Lunt, 2013) is generally composed of shallow marine clastic sedimentary deposits and carbonate deposits (Figure 2). The underlying bedrock is igneous and metamorphic rocks of Cretaceous age. These rocks can be diorite, slate, and phyllite. The Ngimbang Formation consists of the Ngimbang Clastic Member in the form of sandstone and conglomerate that gradually become sandstone, the Ngimbang Carbonate Member in the form of foraminifera so that limestone sedimentation is obtained with a wide area coverage.

The sedimentation of the Prupuh Formation is also still dominated by carbonate sedimentation, limestone, and the Ngimbang Shale Member in the form of calcareous shale. Based on the results of biostratigraphy studies, the Pre-Ngimbang Formation and the Ngimbang Formation have continuous ages. However, at the beginning of the deposition of the Ngimbang Formation there was always an undetermined zone which was a zone whose age could not be determined.

Based on the content of nanoplankton fossils, the Pre-Ngimbang Formation shows an age of the Paleocene-Early Eocene, while the Ngimbang Formation has an age of the Middle Eocene.

The lower Ngimbang Formation and also the Pre-Ngimbang Formation are syn-rift deposit types. The Kujung Formation consists of carbonate deposits that were deposited unconformably on top of the previous formation, namely the Ngimbang Formation. The existence of this unconformity is interpreted as the impact of the sea level drop that occurred (Smyth, 2005).

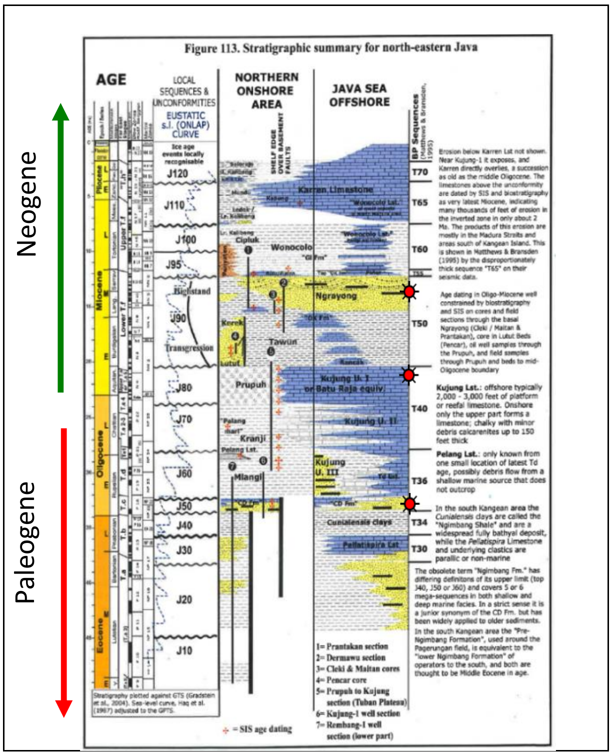

Fig 2. Stratigraphy summary for North Eastern Java with red point as hydrocarbon gas modified from (Lunt, 2013).

Regressive sedimentation of clastic sediments causes the dominance of carbonate sedimentation rich in According to Prasetyadi (2007),this can be caused by rising sea levels or reduced relief in the source area. These Oligocene-Miocene carbonate deposits partly contain layers of volcanic material as a result of sedimentation from the volcanic arc of the Southern Mountains (Smyth, 2005). Neogene inversion causes changes tectonic and the beginning of siliciclastic sedimentation begins with the Tuban Formation. The younger it is, the more dominant the siliciclastic sedimentation is followed by a regression process when there is coal in the upper part of the siliciclastic sediment. This change is indicated by the sedimentation of the Tawun Formation which is dominated by fine-grained rocks.

At the end of the Middle Miocene–Late Miocene, the Wonocolo Formation was deposited. In the Late Miocene, the sedimentation tended to be transgressive, characterized by the formation of carbonate deposits. In the Pliocene- Pleistocene, the Mundu, Selorejo, and Lidah Formations were deposited. The Mundu Formation is still a carbonate deposit type. Hydrocarbon gas found in:

- Ngimbang clastic located in the in the East Florence ridge or horst. Sandstone, coal, deposited in the Eosen-Oligocene.
- Prupuh/Kujung located in the ridge/horst in Bawean and East Florence. Limestone, Oligocene- Early Miocene
- Tuban/Tawun/Ngrayong Formation, located in the Muriah trough. Sandstone.

2. Data and Methodology

2.1 Methodology

Stable isotopes are essential data in hydrocarbon geochemistry, because they can show the characteristics of the nature, type and origin of gas (Humaida, 2005). The two main fields of petroleum geochemistry where carbon isotope values are most frequently used are (1) as markers of depositional settings and (2) as instruments in correlations between oil and oil source rock (Sofer, 1984).

The notation used is the δ notation and uses a standard, namely R. R is the isotope ratio of an element using a known standard isotope. Reference. The scale used is the Peedeee Belemite (PBD) which is commonly used (Dunn, et.al. 2024).

$$\delta = \frac{(R\ Sampel - R\ Standard)}{R\ Standard} - 1000\ (ppt) \qquad (1)$$

Gas sampling was done using a 1.5 L stainless steel gas cylinder with valves at each end. The mass spectrometer used was Optima-Micro mass combined with gas chromatography (GC) (Figure 3) using He carrier gas, Porapak-Q column, and FID detector, CO_2 and CH_4 gases were separated in gas chromatography. After that, the separated gas entered the quarry oxidation furnace at a temperature of 850°C. The gas produced from the oxidation of the sample was then stored in a liquid nitrogen cooling system at a temperature of -70°C. Furthermore, the CO_2 gas that had been separated from the water entered the mass spectrometer system.

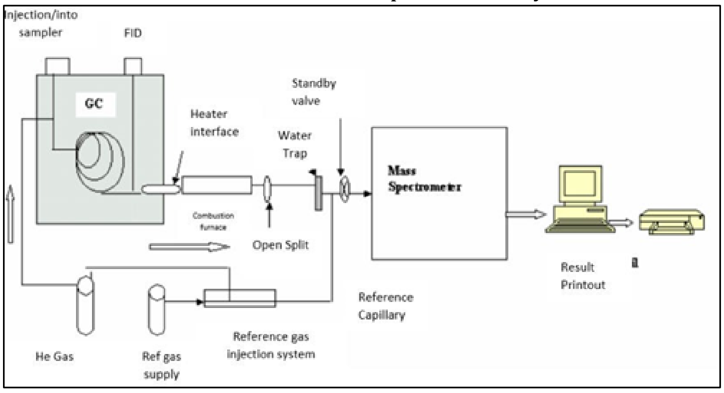

Fig 3. Isotope analysis scheme with gas chromatography-isotope ratio mass spectrometer (GC_IRMS) (Humaida, 2005).

1.1 Data

Data used in this research taken from six exploration well; Srijati 1 Well, Cempaka Well, Titan BP 1 Well, Calypso 1, Merak 1A Well, and Lengo 1 Well. The Drill Steam Test (DST), Rapid Formation Test (RFT), and Modular Dynamic Test (MDT) were conducted in these wells. Ten gas samples were collected and sent to laboratory to composition and stable isotope analyses. The result analysis showed in Table 1.

Table 1. Data composition of carbon dioxide and $\delta^{13}C_{CO_2}$ in Muriah Trough and Bawean Arc.

No	Well Name	Sample	Depth (m)	C1	C2+	$\delta^{13}C_{CH_4}$	$\delta^{13}C_{CH_2}$	CO2 (%)	Geothermal Gradient	Formation	Litology
1	Cempaka 1	RFT-LT	654	99,9	0,01	-66,95	-27,35	0,1	4°C/100 m	Tawun	Sandstone inserts claystone
		RFT-KJ	1158				-3,64	35	4°C/100 m	Kujung	Claystone inserts sandstone
2	Srijati 1	RFT-PR	1070	97,92	2,08	-58,82	-34,22	0,49	3,67°C/ 100 m	Prupuh	Limestone inserts claystone. Limestone, white, contains fossil fragments (wackestone-packstone). Claystone greenish gray, carbonaceous.
		RFT-TA1	1359	96,6	3,4	-52,55	-5,11	44,4	3,67°C/ 100 m	Ngimbang	Claystone inserts sandstone. Sandstone light grey-white, fine grain-fine, medium sorting. Claystone brown, carbonaceous.
		RFT-TA 2	1366	97,02	2,97	-52,1	-5,35	51,4	3,67°C/ 100 m	Ngimbang	
		RFT-TA 3	1379	97,01	2,99	-51,96	-5,72	51,6	3,67°C/ 100 m	Ngimbang	
3	Calypso 1	MDT	743	100		-61,63	4,17	98,86	4,2°C/100 m	Prupuh	Limestone (85%), shale (5%), and contaminant (drilling fluid) (10%)
4	Titan BP 1	MDT	743	96,69			4,27	98,43	4,2°C/100 m	Tuban	Sandstone (97%), limestone (2%) and shale (1%)
5	Merak 1A	MDT	701	94,5		-45,3	-3,4	96,39		Tuban	Sandstone inserts claystone. Sandstone has coarse grain, medium sorting, subangular, quartz, nodule glauconite. Claystone, brown, noncarbonaceous, lignite, fragments of shells and pyrite.
6	Lengo 1	DST	959	97,4		-61,1	-5,4	12,79		Kujung	

2. Analysis and Discussion

Major sources for natural gas accumulation in sedimentary basins (Zhang, et al., 2008) show in Table 2.

1. Organic decomposition of materials at low temperatures(initial catagenesis),
2. Oxidation of hydrocarbons by thermochemical or microbial sulfate reduction,
3. Decomposition of carbonates and
   Calcination is a well-known industrial process that involves the thermal breakdown of calcium carbonate. This procedure is used to extract CO_2 from carbonate rocks, and it is followed by the straightforward chemical breakdown of $CaCO_3$ when heat is present (Nazer, et.al. 2018).
   $CaCO_3 \longrightarrow CaO + CO_2$

Table 2. Distinction of carbon dioxide sources (Zhang et al., 2008).

No	Carbon	CO_2 (%)	$\delta 13CCO_2$	$^3He/^4He$
1	Organgenic	<3%	-10 Until -20	<0,5
2	Decarbonization Of Carbonate Sedimentary Rocks	<10%	+2 Until-2	0,5<1
3	Mantle Degassing	>15%	-5 until -3	>1

4. Derived from the mantle (mantle degassing)
   CO_2 is directly degassed from mantle along super lithosphere fractures; the distribution of gas source fault system and the mantle volcanic activity degassing are the two main controlling factors dominating the accumulation and migration of inorganic CO_2 reservoirs (Guang, et.al, 2011).

CO_2 compositions and $\delta^{13}CCO_2$ are used to distinguish the origin of carbon dioxide. Organogenic carbon dioxide is derived from the thermal decomposition of the organic material having and the value of $\delta^{13}CCO_2$ is lower than -10‰, whereas carbon dioxide derived from inorganic sources such as decarbonization or mantle degassing has heavier isotopes.

Based on the ratio of $\delta^{13}CCO_2$ with the abundance of CO_2, (Zhang, et al., 2008) divide the carbon dioxide source into four groups show in Figure 4:

- Group A: containing less than 2% CO_2 and $\delta^{13}CCO_2$ lower than -10‰ until -20‰ is carbon dioxide produced from thermal alteration oforganic material.
- Group B: contains less than 10% CO_2 and $\delta^{13}CCO_2$ lower than-2‰ and +2‰ are carbon dioxide produced from decarbonization of carbonate sediment.
- Group C: has intermediate values between groups A and B, so it is a mixture of organogenic carbon dioxide and carbonate.
- Group D: has a high carbon dioxide composition (>15%), indicating not including CO_2 produced mixture between group A and group B and to ensure the carbon dioxide origin is required analysis of $^3He/^4He$ and $^{40}Ar/^{36}Ar$ isotope ratio.

Helium and argon in natural gas come from radiogenic decay or mantle degassing. Helium in the mantle is the basic component of the mantle and the $^3He/^4He$ ratio increases with increasing ratio of40Ar / 36Ar explaining the carbon dioxide gas comes from mantle degassing. Zhang, et al. (2008) divide the ratio of $^3He/^4He$ (ratio R)in natural gas into three groups; ratio R <0,5Ra, R ratio 0.5-1Ra, and R ratio> 1Ra. Comparison of $^3He/^4He$ (R/Ra) with $\delta^{13}CCO2$ and carbon dioxide content to determine carbon dioxide source (Figure 5a).

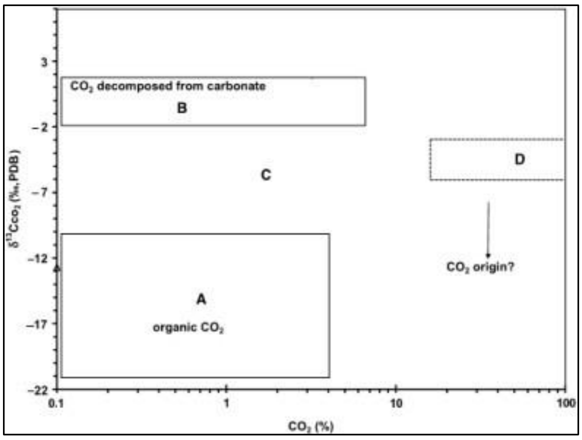

Fig 4. Diagram of CO_2 content versus $\delta^{13}CCO_2$ (Zhang, et al., 2008).

Carbon dioxide derived from the decomposition of organic matter and carbonate minerals associated with a ratio of $^3He/^4He$ less than 1 Ra indicating the dominant helium crust is derived from radiogenic (Group A, Group B, and Group C). Group D gas, carbon dioxide has a value of $\delta^{13}CCO_2$ ranging from -3 to -7 ‰ with a value ratio of $^3He/^4He$ higher than 1 Ra indicating helium is the enrichment product of the mantle (^3He has a significant ccontribution). CO_2 content greater than 10% associated with high $^3He/^4He$ ratio> 1 Ra. The $^3He/^4He$ ratio value increases with increasing CO2 (Figure 5).

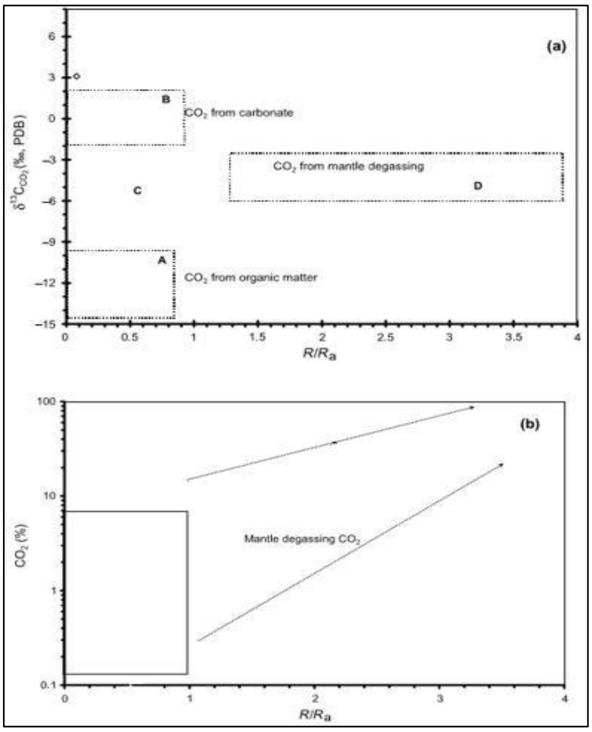

Fig 5. Diagram $\delta^{13}CCO2$ versus R/Ra (Zhang, et al., 2008).

One of the obstacles in production around the Muriah Trough and Bawean Arc is the high carbon dioxide content of more than 90% (Roniwibowo, 2014). Katz (2001) stated that general interpretation scheme of CO_2 origin can be separated by the stable carbon isotope. Isotopically light CO2 ($\delta^{13}CCO_2$ <-10‰) is derived by organic origin, while heavier isotope composition ($\delta^{13}CCO_2$ >-4‰) sourced from inorganic origin shown in Figure 6. Mixing between inorganic origin and organic (composition ($\delta^{13}CCO_2$ -10‰ to -4‰).

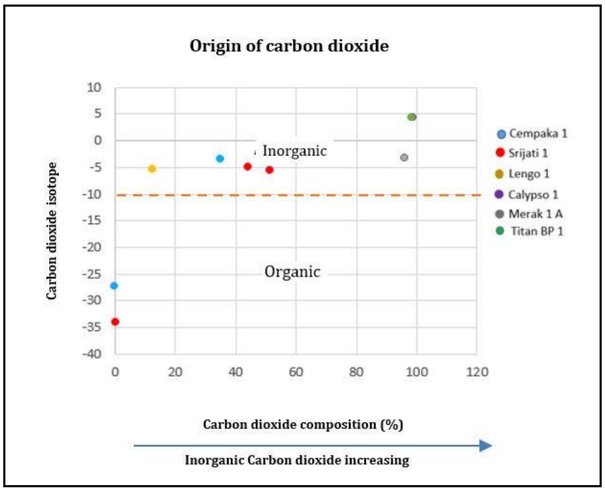

Fig 6. The relationship of $\delta^{13}CCO_2$ and CO_2 composition around the Muriah Trough (modified from Katz, 2001).

The origin of carbon dioxide is viewed in detail using diagrams $\delta^{13}CCO_2$ and CO_2 composition plotted logarithmically in Figure 7. The results are grouped into three groups:

- Group A, derived from organic material that is Cempaka 1 Well (Tawun Formation) and Srijati 1 Well (Prupuh Formation). The Cempaka 1 Well sample (Tawun Formation) has a light $\delta^{13}CCO_2$ value of -27‰ and a low carbon dioxide composition of 0.1%. The sample of Srijati 1, well (Prupuh Formation) has a light $\delta^{13}CCO_2$ value of -34.22‰ and low carbon dioxide composition of 0.49%.
- Group C, this group has isotope value $\delta^{13}CCO_2$ between group A, organic, (<-10‰) and group B, thermal decomposition carbonate, (-2‰ to +2‰). Carbon dioxide Lengo 1 Well comes from organic mixture and thermal decomposition carbonate but high enough gas composition (12,79%), interpreted carbon dioxide formed by influence of group D formation (mantle degassing (?)).
- Group D is a group of carbon dioxide derived from inorganic. This group has a high carbon dioxide composition (> 15%) and a heavier $\delta^{13}CCO_2$ (>-10‰) indicates excluding carbon dioxide which is between the mixtures of groups A and group B. Samples derived from wells in Muriah, Cempaka 1 Well (Tawun Formation), Srijati 1 Well (Prupuh Formation) and Lengo 1 Well, are all included in this group. To ensure the origin of carbon dioxide is required the analysis of $^3He/^4He$ and $^{40}Ar/^{36}Ar$ isotope ratios.

Qian (1991) describes the origin of carbon dioxide gas (Figure 8). In the study area, the origin of the inorganic carbon dioxide gas is derived from the organic process and influenced by CO_2 derived from the mantle. The carbon dioxide formed in Muriah is thought to originate from the influence of Muriah and Bawean volcanism (Late Miocene-Pliocene) and the structure with the southwest-northeast direction becomes conduit for the migration of carbon dioxide.

The integration of isotope and geological data result in study area interpreted that main source of CO_2 is magmatic activities, but the absence of $^3He/^4He$ and $^{40}Ar/^{36}Ar$ isotope data becomes an obstacle to ensuring the mechanism of carbon dioxide formation around Muriah Trough and Bawean Arc The integration of isotope and geological data result in study area interpreted that main source of CO_2 is magmatic activities, but the absence of $^3He/^4He$ and $^{40}Ar/^{36}Ar$ isotope data becomes an obstacle to ensuring the mechanism of carbon dioxide formation around Muriah Trough and Bawean.

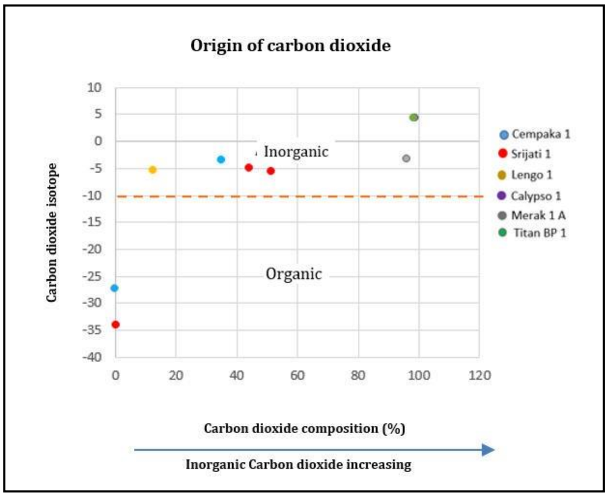

Fig 7. Grouping of carbon dioxide based on isotope carbon CO_2 and CO_2 composition around Muriah (modified from Zhang, et al., 2008).

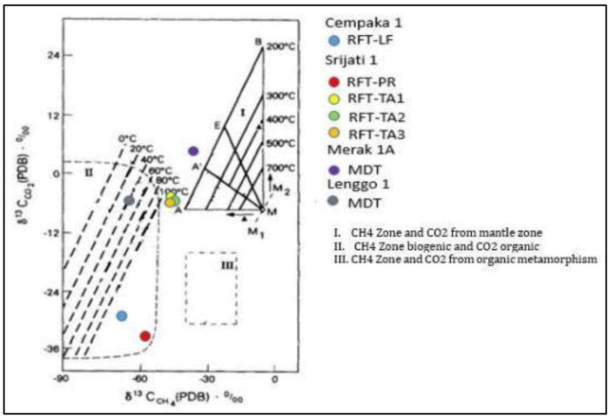

Fig 8. The origin of carbon dioxide is based on the relationship of δ13CCO2 and δ13CCH4 in the study area by adopting The Qian diagram, ,1991.

According to tectonic reconstruction (Husein and Nurkman, 2015), The Kendeng Basin was formed above the imprisoned oceanic crust during the Early Miocene-Middle Miocene when the East Java microcontinent started to clockwise rotate and seal its subduction tracks against Sundaland. Prior to the Progo-Muria Fault, the East Java microcontinent shifted to the west on the transform fault. The SW-NE trending fault, which may offer a migration route for volatiles coming from the mantle, is where natural gas with high carbon dioxide concentrations is found. According to Lunt (2013), the primary source of carbon dioxide is thought to be magmatic activity, which is somewhat connected to the Bawean, Lasem, and Muriah volcanic mountains. Since the late Miocene, volcanic activity has been occurring. Bawean has an extrusive rock of between 0.26 and 0.84±0.04 Ma (Bellon et.al, 1989; Lunt, 2013).

In oil exploration, subsurface geothermal gradients are important (Khan and Raza, 1986). Geothermal gradient (Figure 9 and Table 1) from the wells can be used to determine the risk carbon dioxide. The results of local magmatic activities and basement configuration are used as a guide to determine the geothermal gradient. These findings might be interpreted as a higher geothermal gradient, which higher the carbon dioxide.

4. Conclusion

The carbon dioxide formed in the area around the Muriah and Bawean Arc is formed from the thermal alteration of organic material, organic thermal alteration mixture and carbonate thermal decomposition, and inorganic, possibly derived from mantle degassing influence by Muriah and Bawean Volcanism (Late Miocene-Pliocene).

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