Jurnal Geologi dan Sumberdaya Mineral Vol. 23 No. 3 Agustus 2022 hal. 163-176

Geo-Resource

Jurnal Geologi dan Sumberdaya Mineral
Journal of Geology and Mineral Resources
Center for Geological Survey, Geological Agency, Ministry of Energy and Mineral Resources
Journal homepage: http://jgsm.geologi.esdm.go.id
ISSN 0853 - 9634, e-ISSN 2549 - 4759

Source Rock Characterization of the Eocene-Miocene, Central Deep, North East Java Basin

Karakterisasi Batuan Induk Eosen-Miosen, Central Deep, Cekungan Jawa Timur Utara

Fauzan Iqbal Hidayat[1], Ade Yogi[2], Eriko Sabra[2], Taufik Ramli[3], Muhammad Firdaus[3], Hanif Mersil Saleh[2], Gadis Ghia Arviallyn[2], Andi Setyo Wibowo[2]

[1]Geology Engineering, Institute Science & Technology of AKPRIND Yogyakarta,
Kalisahak No. 28, Komplek BalapanTromol Pos, Yogyakarta, Indonesia, 55222.
[2]Centre for Geological Survey, Geological Agency, Ministry of Energy and Mineral Resources of Indonesia
Diponegoro No 57, Bandung, West Java, Indonesia, 40122.
[3]Research Centre of Geological Resources, National Research and Innovation Agency of Indonesia
Cisitu Sangkuriang, Bandung, West Java, Indonesia, 40135.
emai:: Fauzaniqbal93@gmail.com;ade.yogi@esdm.go.id

Naskah diterima: 02 Juli 2022, Revisi terakhir: 09 Agustus 2022, Disetujui: 23 Agustus 2022, Online: 24 Agustus 2022
DOI: http://dx.doi.org/10.33332/jgsm.geologi.v23.3.163-176

Abstract - This study was conducted to obtain the characteristics of the source rock through organic geochemical analysis in Central Deep, NE Java Basin, in the field off the north coast of Madura. Three samples of Cassiopeia-1, Pollen-1, and Alpha-1 wells were analyzed using organic geochemical methods including Total Organic Carbon analysis, Maturity using vitrinite reflectance, Tmax, and Production Index data, and then analysis of the kerogen type, isoprenoid, sterane, and carbon isotope. Based on those data, an analysis was carried out to determine the origin of the material and the depositional environment. The rock samples in the three wells showed characteristics in TOC, maturity, kerogen type and source of organic material have a similarity. The source rock characteristics have a medium to a good category as source rock and tend to generate gas and a little oil from kerogen types II and III. This source rock is included in the category of immature to mature, deposited in delta until terrestrial depositional environment and contains sources terrestrial and marine organic material.

Keywords: Madura, North East Java Basin, organic geochemical, source rock.

Abstrak *- Studi ini dilakukan untuk mengetahui karakteristik dari batuan induk dengan menggunakan analisa geokimia organik pada Central Deep, Cekungan Jawa TimurUtara, di lepas pantai utara Madura. Tiga sampel sumur Cassiopeia-1, Pollen-1, dan Alpha-1 dianalisis menggunakan metode geokimia organik meliputi Total Organic Carbon (TOC), kematangan menggunakan reflektansi vitrinit, Tmax, dan Production Index, kemudian analisis jenis kerogen, isoprenoid, sterane, dan isotop karbon. Berdasarkan data tersebut, dilakukan analisis untuk mengetahui asal material organik dan lingkungan pengendapannya. Sampel batuan pada ketiga sumur menunjukkan karakteristik TOC, kematangan, jenis kerogen, dan sumber bahan organik yang memiliki kesamaan. Karakteristik batuan induk memiliki kategori sedang sampai baik sebagai batuan induk dan memiliki kecenderungan menghasilkan gas dan sedikit minyak dari kerogen tipe II dan III. Batuan induk ini termasuk dalam kategori belum matang hingga matang, diendapkan pada lingkungan delta sampai terestrial dan mengandung bahan organik dari lingkungan darat dan laut.*

Katakunci*: Madura, Cekungan Jawa Timur laut, geokimia organik, batuan induk.*

INTRODUCTION

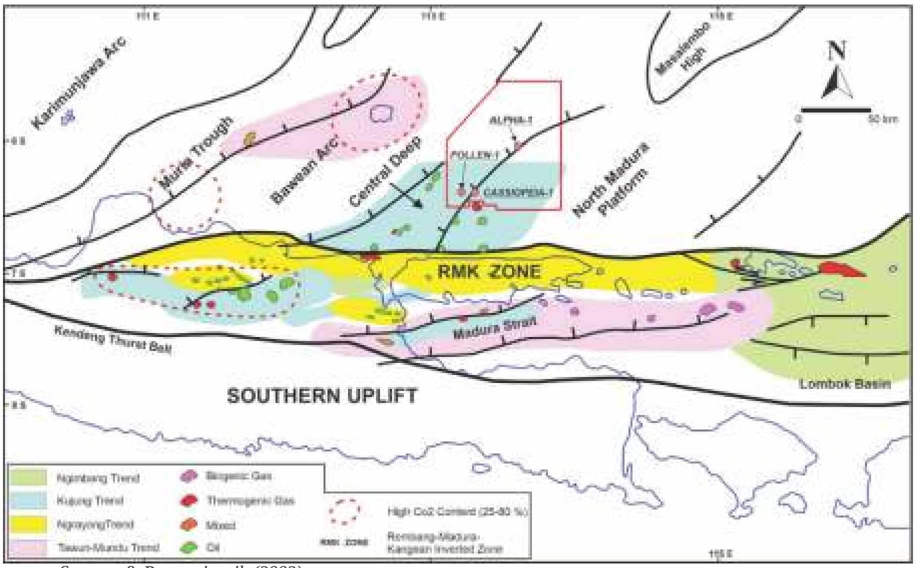
The East Java Basin is one of the largest hydrocarbon-producing basins in Indonesia. Oil and gas exploration has only been focused on the evaluation in reservoirs and traps, while the evaluation of hydrocarbon filling includes evaluation of source rock and its migration is often simplified or neglected, even though this evaluation can answer the time (when) and amount of oil formed in a hydrocarbon basin. In terms of habitat, according to Satyana & Purwaningsih (2003) and Satyana (2010), some of the studied areas are the prolific source rock which is dominated by the Kujung trend, Figure 1 it is shown by the blue area. Thus, the trend and characterization of the source rock in the study area need to be studied further because many drillings have been carried out and are generally "dry holes". Therefore, the study of the petroleum system needs to be re-examined, especially in this study the emphasis is on the source rock which needs to be re-characterized.

The Central Deep is located in the North East Java Basin. The focus area of this study is shown in Figure 1. The North East Java Basin is a dynamic area. This basin has an area of more than 200,000 km^2 and contains accumulated sediments with an average thickness of 1,500 m in the exposure section up to 9,000 m in the depression section and according to Lunt (2019), the study area consists of several sections of the basin (Muriah Through, JS-1 Through, East Florence Basin, and Central Deep) and highlands (Karimunjawa Arch, JS-1 Ridge, Bawean Arch, and North Madura to Eastern Platform) which are generally controlled by tectonic activity during the Late Cretaceous to Paleogene as shown in Figure 2.

Regional Geology

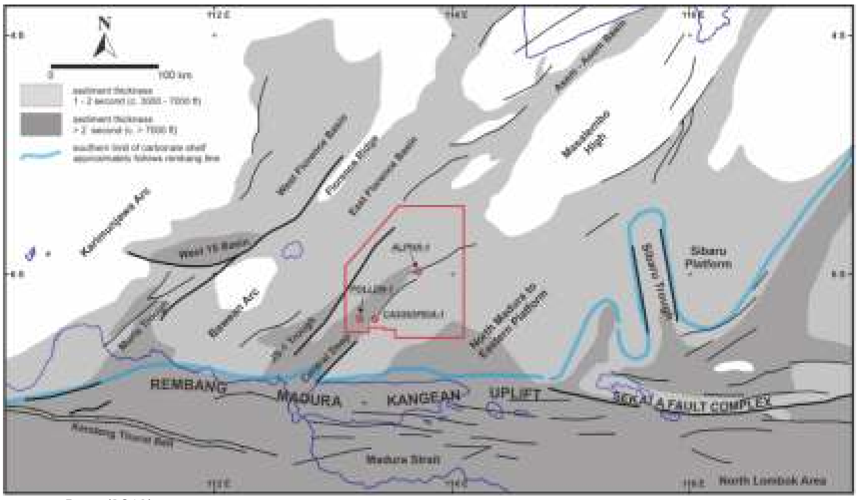
The North East Java Basin is a fragment of East Java-West Sulawesi (EJWS) that bloomed from Gondwanaland in the Jurassic period. The EJWS fragments moved northward and then collided with the South West Borneo (SWB) fragment in the Late Cretaceous (Smyth *et al.*, 2007; Hall, 2012). The collision between the EJWS and SWB fragments resulted in the Meratus suture in a southwest-northeast direction (Hall, 2012).

Physiographically, the East Java Basin can be divided into three main configurations (Figure 1), namely Northern Shelf, Rembang-Madura-Kangean Zone (RMK Zone), and Southern Uplift (Satyana, 2005). The northern shelf consists of sub-basins trending northeast-southwest as an implication of the basin being segmented into several horsts and grabens. The formation of rifting in a northeast-southwest direction is controlled by the trend of the Meratus Suture (Hall, 2012) and the constituent components of the microcontinent itself (Mudjiono & Pireno, 2001; Sribudiyani *et al.*, 2003). Meanwhile, according to Lunt (2019), the rifting trending southwest-northeast of the North East Java Basin is influenced by the expansion that occurred in the Makassar Strait. The RMK zone is designated by uplift in the Tuban Area and Madura Island as a result of the developing horizontal fault system. While the southern uplift is marked by its northernmost boundary by the Kendeng Fault Belt. Central Deep itself is part of the Northern Shelf, with having a trending structure of northeast-southwest.



source:Satyana & Purwaningsih (2003).

Figure 1. Oil and gas habitat in the East Java Basin. The habitat is related to the structural arrangement and the petroleum system.



source: Lunt (2019).

Figure 2. Tectonic elements in the East Java Basin.

Sediment filling in the North East Java Basin, especially the Central Deep is closely related to its tectonic development (Manur & Barraclough, 1994). The expansion occurred in the Eocene-Oligocene along with the deposition of alluvial clastics, clays, and lacustrine shales. This shale is rich in organic material and is the source rock for hydrocarbons in this area. This was followed by tectonic quiescence in the Early Miocene, which was marked by the development of carbonate rocks, and generally became reservoir rocks in the North East Java Basin. According to Doust & Sumner (2007) based on the tectonostratigraphy that developed in the investigated (studied) area, there are two proven petroleum systems, namely the late syn-rift transgressive deltaic petroleum system and early post-rift marine petroleum system.

Stratigraphy

Rocks at the study site are exposed in the areas of Tuban, Lamongan, and Madura (Figure 3). These rock outcrops have been mapped onto geological maps at a scale of 1:100,000 on the Tuban Sheet (Hartono & Suharsono, 1997), the Surabaya and Sapulu Sheets (Supandjono et al., 1992), the Tanjung Bumi and Pamekasan sheets (Azis *et al.*, 1992) and the Waru Sheets-Sumenep (Situmorang et al., 1992), which includes rock formations of the Oligocene-Quarter age, with the oldest known formation being the Kujung Formation. The older formations such as the Ngimbang Formation and the “CD Formation” (Pertamina BPPKA, 1996) are not found in the outcrop, only found in the well data. The following is a description of the formation on a geological map (Figure 3).

Prupuh Formation

This formation has Oligocene to Early Miocene in Age. It consists of alternating dirty white limestone with white light grey bioclastic limestone. The limestone is very fine-grained and very compact. Bioclastic limestone is in the form of plates with a thickness of 6-50 cm with medium-coarse grain, well separated, poor porosity, packed tightly, and rich in orbitoids and algae. This formation is overlain conformably by Kujung Formation.

Kujung Formation

Kujung Formation has a Late Oligocene to Early Miocene age. This formation overlies Prupuh Formation and overlaid conformable consists of Marl and marl clay, greenish-grey, yellow-brown with intercalations of bioclastic limestone, containing large foraminifera and algae. In the upper part, claystone and marl clay, greenish-grey in colour, predominate with intercalations of very hard bioclastic limestones. This formation is overlaid unconformably by Tuban Formation

Tuban Formation

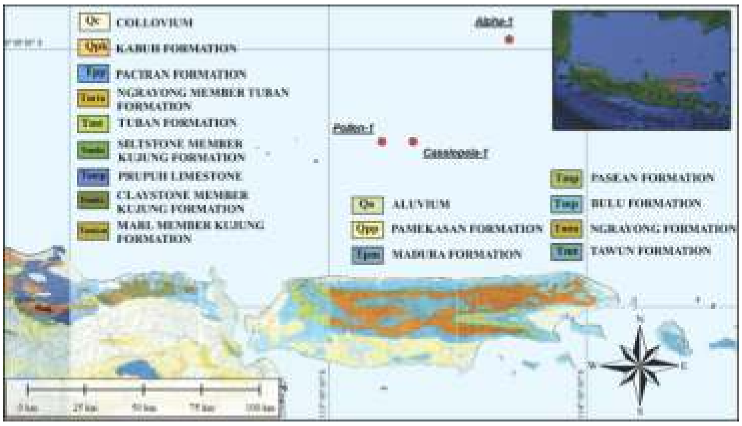
The siltstone is green-grey with local sandy limestone alternations and contains grey-brown iron claystone concretions.

Tawun Formation

Claystones, marl, and sandstones that are getting higher up there are dominant limestones that are rich in orbitoid content.

Ngrayong Formation

Alternating quartz sandstone with orbitoid Limestone with a dirty white to yellowish colour with medium grains. At the top, it contains glauconite, and also the insertion of claystone and lignite layers.



source: Hartono & Suharsono, 1997; Supandjono et al., 1992; Azis et al., 1992; Situmorang et al., 1992.

Figure 3. The studied location is off the northern coast of Madura, North East Java Basin .

Bulu Formation

Limestone to sandy limestone, yellowish-white to brownish in colour, hard, compact, thinly layered to massive, containing large foraminifera, coral, and algae.

In the study area, the deposition of limestone and shale together with the deposition of sandy sediments repeatedly (episodic) occurred throughout the Tertiary era. As a basin that has been explored for a long time, of course, the data regarding the geochemistry of the source rock will be very large and varied. The application of chemical principles to study the origin and maturity of hydrocarbons and their use in exploring hydrocarbons is the goal of studying petroleum geochemistry (Peter & Cassa, 1994). By analyzing the geochemical content of rock samples, the composition and various factors that control the formation, maturity process, biodegradation, and accumulation of generated petroleum can be determined (Hunt, 1996).

Geochemical Analysis

The following is a geochemical analysis of three wells, namely Cassiopeia-1, Pollen-1, and Alpha-1 which includes Total Organic Carbon, maturity level using reflectance data of vitrinite, Tmax, and PI, then kerogen type, isoprenoid, sterane, and carbon isotopes used for knowing the character of the source rock and to determine the type of sediment.

Total Organic Carbon (TOC)

Total Organic Carbon (TOC) is the quantity of organic carbon material deposited in the rock. The higher the TOC value, the better the source rock and the higher the possibility of hydrocarbon formation (Waples, 1985). According to (Waples, 1985) source rock samples with a TOC content of < 0.5% do not have sufficient potential to produce petroleum. Therefore, it is defined as not the source rock. Samples with TOC content between 0.5% - 1.0% have sufficient or moderate values as source rock, while for TOC between 1.0% - 2.0% have a good average value and if TOC> 2% is above average (rich) as source rock.

Maturity Level

Parameters commonly used to monitor the level of maturity is the temperature (Tmax) > 435°C. On the other hand, the maturity of organic matter can also be expressed by the Production Index (PI). Changes in kerogen to bitumen during the formation of hydrocarbons, wherewith increasing maturity the peak S2 decreases and S1 increases. The S1 value represents the hydrocarbons that have been present in the rock since deposition plus those generated below the surface. The value of S2 represents the remaining generative capacity of the hydrocarbons. The ratio between Sl/(S1 + S2) is called the Production Index (PI). A PI value of less than 0.1 indicates unformed organic matter or which produces little or no petroleum. A PI from 0.1 to 0.4 is in the oil window, while a PI above 0.5 indicates that the rock has undergone advanced maturity (Waples, 1985).

Kerogen

Kerogen is a part of organic material in sedimentary rocks that cannot be dissolved in ordinary organic solvents (Waples, 1985). Kerogen in certain sedimentary rocks consists of many particles that often come from various sources, so only a very small amount of kerogen

Table 1. Maceral, kerogen type, and original organic material (Waples, 1985)

Maceral	Kerogen Type	Original Organic Material
Alginite	I	Fresh-water algae
Exinite	II	Pollen, Spores
Cutinite	II	Land-plant cuticle
Sesinite	II	Land-plant resins
Liptinite	II	All land-plant lipids; marine algae
Vitrinite	III	Woody and cellulosic material from land plants
Intertinite	IV	Charcoal; highly oxidized or reworked material of any origin

consiating of only one type of maceral. Waples (1985) divided kerogen into four types based on the type of maceral which can be seen in Table 1.

Pyrolysis

Pyrolysis is a method of heating a sample without oxygen to produce a thermal decomposition reaction. Pyrolysis is used to measure the generative capacity of hydrocarbons remaining from sedimentary rocks. Pyrolysis is used to measure the quantity, quality, and thermal maturity of organic materials in rock samples (Peters & Cassa, 1994) which is then combined with the measurement of total organic carbon (TOC).

Vitrinite reflectance (Ro)

Vitrinite reflectance is a method of determining the maturity of organic matter by measuring the ability of small vitrinite particles in kerogen or coal to reflect incident light. According to Waples (1985), kerogen will generally start to produce oil when the Ro value is around 0.6%. The peak yield will be obtained when the Ro value is around 0.9%, while the end of the process of producing oil is estimated when the Ro value is around 1.35%. Tissot & Welte (1984) estimated the maturity limit based on the type of kerogen and huminite vitrinite reflectance, which can be seen in Table 2.

Isoprenoid

According to Illich (1983) and also Jamaluddin et al. (2019) that the ratio of pristane to phytane can be used as an indicator of the amount of oxygen during the diagenesis process. A high ratio of these ratios is considered to be associated with sediments that are influenced by the terrestrial environment, and vice versa.

Table 2. Maturity limits for kerogen types I, II, and III (Tissot & Welte, 1984)

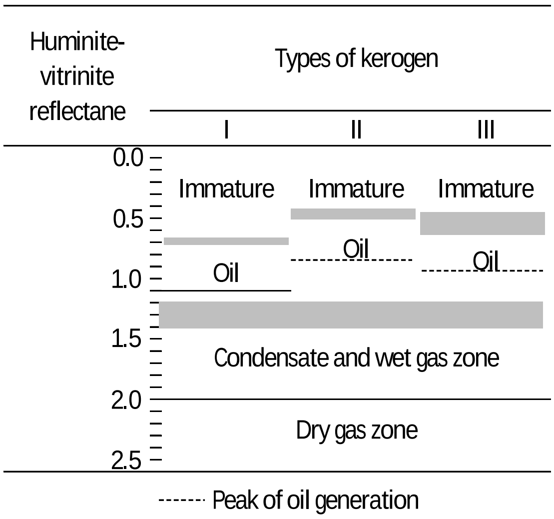


Table 3. Generalizations about pristine/phytane ratios as indicators of the depositional environment (Waples, 1985)

Sediment Type	Pristane/Phytane
Anoxic marine sediments	<1
Oxic marine sediments	1-3
Coals	>3

Sterana

Steranas are derived from sterols found in most higher plants and algae and rarely or not found in prokaryotic organisms. According to Huang & Meinschein (1979) that the relative proportion of C27-C29 in sterols usually comes from living organisms associated with a particular environment. A sterane is a cycloalkane that usually contains three 6-carbon rings and one 5-carbon ring.

Carbon Isotopes

Variations in isotopic abundance are measured by isotope ratio mass spectrometry and can reveal information about the age and origin of rocks, fluids, or fluid-rock mixing processes (Dai *et al.*, 2005; Adedosu *et al.*, 2012).

Carbon isotope values are applied as indicators of the depositional environment in this discussion. This value is obtained from the rock extract or the C15+ saturation and aromatic fraction of the oil. A positive correlation is found if the same fractions of different oils are only separated by values less than 1‰. The isotopic composition of the oil may change due to ripening and possible migration effects and due to minor organic inconsistencies in the source material.

According to Sofer (1984) that carbon isotopes can be used to distinguish between oil from marine depositional environments and oil from terrestrial depositional environments. This value is referred to the as canonical variable (CV) with the following calculation formula:

CV = 2.53 13 Csat + 2.22 13 Caro – 11.65

Where 13 Csat is the ratio of saturated carbon isotopes and 13 Caro is the ratio of aromatic carbon isotopes.

If the Cv value is greater than 0.47, it indicates that the oil is dominated by sources derived from terrestrial organic materials, while the Cv value is less than 0.47, which indicates that the oil is dominated by sources derived from marine organic materials.

From the organic geochemical aspect data above, it is used to determine the characteristics of the source rock in the area around the Central Deep, North Northeast Java Basin.

METHODS AND DATA

The method was carried out based on data from geochemical analysis of sidewall core (SWC) rock samples in 3 wells (Cassiopeia-1, Pollen-1 and Alpha-1) that had been previously carried out in the laboratory. Data on Total Organic Carbon (TOC), pyrolysis, Vitrinite Reflectance (Ro), and carbon isotopes were then analyzed as the basis for characterization of the source rock which was then integrated to produce an interpretation of the depositional environment in the Central Deep, North East Java Basin.

The data used in this study include lithological data obtained from the cutting/SWC description, age from biostratigraphic analysis, and geochemical data such as Total Organic Carbon/TOC, Vitrinite Reflectance, temperature, kerogen, pyrolysis, sterane, isoprenoids, and carbon isotopes in the well. Its use was carried out with data from the Cassiopeia-1, Pollen-1, and Alpha-1 wells.

All kerogen maturity indicators do not directly measure the formation of hydrocarbons or changes in the bitumen fraction. It is belived that changes in the kerogen indicate the formation of hydrocarbons. Thus, the application of GC/MS (Gas Chromatography-Mass Spectrometry) to measure the maturity of bitumen and oil directly from the distribution of sterane and triterpene is expected to replace most of the indicators of kerogen maturity. This method was also carried out by Zajuli & Suyono (2011) and Scheeder et al. (2020).

Cassiopea-1

Cassiopea-1 well is located at 006 21' 28.050"S and113 19' 41.190"E, as seen in Figure 2 is located in the Central Deep, North East Java Basin. With a total of 17 samples, the lithology description was obtained from cutting and SWC data in the Final Report of Sedimentology and Petrography of Conventional Cores and Sidewall Cores Well: Cassiopeia #1 (Western Atlas International, 1992a). Meanwhile, the age and formation were obtained from the report of Cassiopeia-1 And 1-Sidetrack NE Java Sea Block VI, Inpex Offshore Madura Ltd. Biostratigraphy and Depositional Environments (Robertson Utama Indonesia, 1992) and geochemical data obtained from the report Geochemical and Detailed Source Rock Characterization of Selected Samples from The Cassiopeia-1 Well (Western Atlas International, 1992b). All data are then tabulated in Table 4.

Pollen-1

The Pollen-1 well is located at 006°21'33.01"S and 113°12' 27.72"E, as seen in Figure 2 is located in the Central Deep, North East Java Basin. With a total of 22 samples, the lithology description, as well as age and formation, were obtained from cutting and SWC data in the Geological Operation Completion Report Pollen-1 Karapan Ltd. (Pckl) North Madura Offshore, East Java Sea (Petronas Carigali, 2007). Meanwhile, geochemical data were obtained from the Pollen-1 Well report, Karapan Psc, Petroleum Geochemistry Study of Unwashed Cuttings Samples (Corelab, 2012). All data are then tabulated in Table 5.

Alpha-1

Alpha-1 well is located at coordinates Latitude 005 58' 04.92" S Longitude 113 42' 04.59" E, as seen in Figure 2 is located in the Central Deep, North East Java Basin. With a total of 17 samples, the lithology description, as well as age and formation, were obtained from cutting and SWC data in The Biostratigraphy of The Houston Oil and Minerals Inc. report. Alpha No.1 Well Drilled in The Java Sea (Lemigas Biostratigraphic Service Unit, 1981). Meanwhile, geochemical data were obtained from the report A Petroleum Geochemical Evaluation of The Alpha-1 Well, Drilled in The E. Java Sea Indonesia (Robertson Research (Singapore) Private Limited, 1981). All data are then tabulated in Table 6.

Table 4. Geochemical data of Cassiopea-1 Well

Depth	Formation	Lithology	Total Organic Carbon	Reflectance Vitrinite	Maximum Tempetarure	Production Index	Hydrogen Index	Sterane			Pristane	Phytane	Isotopes of Carbon	
(feet)			TOC	%Ro	Tmax (F)	PI	HI	C27	C28	C29	pr/nC17	ph/n18	13Caro	13Csat
6035.20		Sh	1.62		435.00	0.08	289.00	45.16	16.53	38.31	2.57	0.44	-28.06	-27.92
6428.80		Sh	1.08		437.00	0.08	337.00	40.45	18.12	41.42	1.56	0.30	-27.73	-27.66
6789.60		Coal	64.14	0.51	428.00	0.04	416.00	40.53	16.74	42.73	19.23	0.93	-28.34	-29.92
6888.00		Sh	1.58		439.00	0.05	334.00	42.79	20.09	37.12	3.29	0.37	-28.68	-28.18
7304.00		Coal	66.50	0.49	419.00	0.05	359.00	47.81	13.16	39.04	8.60	0.71	-27.78	-28.98
7390.85		SST									2.34	0.36		
7406.24		Sh	2.02	0.53	435.00	0.07	227.00							
7411.62		SST									1.51	0.26		
7424.77	Kujung	Carb. Sh	4.03		434.00	0.11	270.00	49.77	12.56	37.67	10.32	0.85	-27.75	-29.66
7429.20		Coal	61.32		424.00	0.09	325.00	43.75	16.32	39.93	12.70	0.76	-27.97	-29.80
7436.00		LST									1.98	0.42		
7438.00		LST									2.19	0.39		
7451.18		Sh	1.24		440.00	0.12	104.00							
7464.30		Sh	1.33		439.00	0.08	223.00							
7642.40		Sh	1.33		446.00	0.10	110.00							
7872.00		Carb. Sh	3.51	0.57	436.00	0.10	224.00	51.46	18.71	29.82	4.73	0.62	-27.70	-28.99
7872.00		Coal	68.63	0.57	423.00	0.05	358.00	48.03	14.57	37.40	7.94	0.72	-28.31	29.76

S1 = Free Hydrocarbon
S2 = Pyrolysable Hydrocarbons
S3 = Organic CO2
Tmax = Temperature of Maximum S2
Oxygen Index = (S3/TOC) x 100
Hydrogen Index = (S2/TOC) x 100
Oil Production Index = Transformation Ratio = S1/(S1+S2)
*Pyrolysis by Rock Eval 6: TOC content by Leco Analyzer

Table 5. Pollen-1 Well geochemical data

Depth	Formation	Lithology	Total Organic Carbon	Reflectance Vitrinite	Maximum Tempetarure	Production Index	Hydrogen Index	Sterane			Pristane	Phytane	Isotopes of Carbon	
(feet)			TOC	%Ro	Tmax (F)	PI	HI	C27	C28	C29	pr/nC17	ph/n18	13Caro	13Csat
5970		brnsh gy Sh	2.13		347.00	1.13	217.00							
6360		brnsh gy Sh	3.01		433.00	0.05	293.00	14.50	21.68	63.79	6.97	1.08		
6480		brnsh gy Sh	2.06	0.53	437.00	0.07	153.00							
6570		brnsh gy Sh	1.15		439.00	0.09	101.00							
6660		blk Coal	47.73		420.00	0.80	280.00							
6690		brnsh gy Sh	1.43		439.00	0.09	111.00							
6750	Kujung	med dk gy Sh	1.35		437.00	0.08	107.00							
6855		med dk gy Sh	1.04		438.00	0.10	124.00							
6990		med gy Sltst	1.04		439.00	0.14	142.00							
7170		med gy Sh	1.25		435.00	0.10	133.00							
7260		blk Coal	71.57	0.51	437.00	0.60	275.00	14.30	18.84	66.82	5.46	0.89	-28.29	
7680		blk Coal	73.00		427.00	0.07	296.00							
7675		blk Coal	71.03	0.53	419.00	0.07	350.00	22.10	17.25	60.66	10.01	1.35	-28.53	-29.69
7890		brnsh gy Sh	2.07		440.00	0.11	150.00							
8985	CD	brnsh gy Sh	1.12		347.00	0.18	439.00	40.10	8.89	51.30	2.75	0.92	-27.20	
10800		blk Coal	51.37		469.00	0.20	171.00							
10815		blk Coal	63.19		469.00	0.15	172.00	30.00	4.75	65.21	7.84	0.56	-25.77	
10830		blk Coal	53.36		465.00	0.16	164.00							
10860	Ngimbang	blk Coal	61.56	0.91	465.00	0.09	198.00							
10965		med dk gy Sh	1.03		343.00	0.17	454.00	35.10	12.16	52.78	2.35	3.38	-27.14	-25.53
11175		blk Coal	69.20	1.06	474.00	0.18	166.00							
11190		blk Coal	53.90		469.00	0.16	137.00							

S1 = Free Hydrocarbon
S2 = Pyrolysable Hydrocarbons
S3 = Organic CO2
Tmax = Temperature of Maximum S2
Oxygen Index = (S3/TOC) x 100
Hydrogen Index = (S2/TOC) x 100
Oil Production Index = Transformation Ratio = S1/(S1+S2)
*Pyrolysis by Rock Eval 6: TOC content by Leco Analyzer

Table 6. Geochemical data for Alpha-1 Well

Depth (feet)	Formation	Lithology	Total Organic Carbon TOC	Reflectance Vitrinite %Ro	Maximum Tempetarure Tmax (F)	Production Index PI	Hydrogen Index HI	Pristane pr/nC17	Phytane ph/n18
2500	Ngrayong	a/a	0.69	0.29	432	0.07	42		
3500		Brn-gy sh	1.42	0.3	440	0.03	54		
4200	Kujung	Gn-gy calc sndy sh + brn-gy sh	1.05	0.4	440	0.07	25		
4500		Brn-gy sh	0.9		439	0.02	112	3.52	1.16
4700		a/a	1.07		444	0.04	70		
5700		Dk brn-gy calc sh	2.84		447	0.04	135		
5700		Med dk gy calc sh	0.57		437.5	0.07	50		
5800		Med gy calc sh	0.72	0.37	443	0.08	41		
5800		Brn blk sh	2.13	0.37	445	0.04	98		
5900		Med gy calc sh + med dk gy calc sh	1.08		503.5	0.06	51		
6000		Med dk gy calc sh	1.42		440	0.06	90	10.7	1.05
6100		Dk brn-gy sh	1.25		449	0.06	64		
6200		a/a	2.06	0.41	446	0.05	123	8.17	1.15
6300	CD	a/a	1.18		452	0.06	55		
6400		a/a	1.72		451	0.04	99	9.78	1.04
6500		Dk brn-gy sh	1.67		451	0.05	79	8.11	0.81
6600		a/a	1.32		443	0.06	83		

S1 = Free Hydrocarbon
S2 = Pyrolysable Hydrocarbons
S3 = Organic CO2
Tmax = Temperature of Maximum S2
Oxygen Index = (S3/TOC) x 100
Hydrogen Index = (S2/TOC) x 100
Oil Production Index = Transformation Ratio = S1/(S1+S2)
*Pyrolysis by Rock Eval 6: TOC content by Leco Analyzer

RESULTS AND DISCUSSION

Type and Quality of Organic Material

TOC data is used to determine the interval of rock samples that have the potential to become source rock. A plot between depth and TOC values is shown in Figure 4. The source rock in the Cassiopeia-1 Well at a depth of 6000-7800 ft, is composed of shale and coal with TOC values ranging from 0.60-4.03% for shale and 61.32-68.63% for coal. This value has the potential to be a source rock of moderate to very good quality to form hydrocarbons (Waples, 1985). HI values in this well ranged from 104-416 mgHC/g with an average of 275 mgHC/g.

The source rock in the Pollen-1 Well shows that 3 formations have potential as source rock, namely the Kujung Formation at a depth of 5,970-7,890 ft, the CD Formation at a depth of 8,985 ft, and the Ngimbang Formation at a depth of 10,800-11,190 ft which is composed of shale and coal. The TOC content in the Kujung Formation ranges from 1.04 -3.01% for shale and 47.73 -71.57% for coal, the CD Formation has a TOC content ranging from 1.12 -2.07% for shale and 71.03- 73.00% for coal, and the Ngimbang Formation has a TOC content ranging from 1.03 -1.82% for shale and 51.37-69.20% for coal and has the potential to be a source rock of good to very good quality to form hydrocarbons (Waples, 1985). HI values in these wells ranged from 101- 454 mgHC/g with an average of 217 mgHC/g.

The source rock in the Alpha-1 Well at a depth of 2,500-6,600 ft, is composed of shale which has a TOC value of 0.57-2.84% and has the potential to become a source rock of moderate to very good quality to form hydrocarbons (Waples, 1985). HI values in this well ranged from 25-135mgHC/g with an average of 74.8 mgHC/g.

The results of the sample plots in the study area on the HI vs Tmax of the Van Krevelen diagram (Mukhopadhyay et al., 1995; El Nady *et al*., 2015; Peters *et al.,* 2016; Al-Areeq et al., 2018; Zajuli & Wahyudiono, 2018; Zajuli et al., 2020) showed that the sample of these organic materials include kerogen types II-III, which can be seen in Figure 5. Of the 9 samples analyzed, only 3 samples indicated maturity and had entered the oil window, namely the Kujung Formation shale at Cassiopea-1 Well, Ngimbang Formation coal at Pollen-1 Well. , and the CD Formation shale at the Alpha-1 Well.

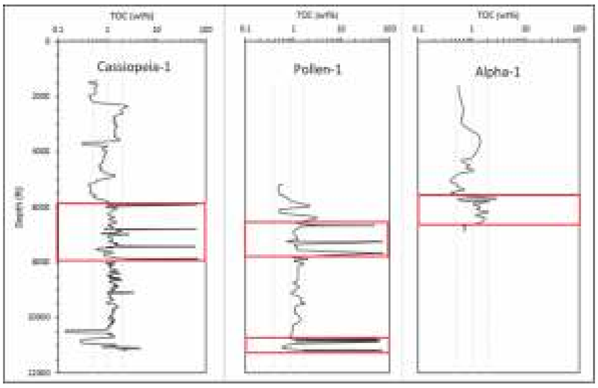


Figure 4. Depth with Total Organic Carbon (TOC) to determine the interval that has the potential to become source rock.

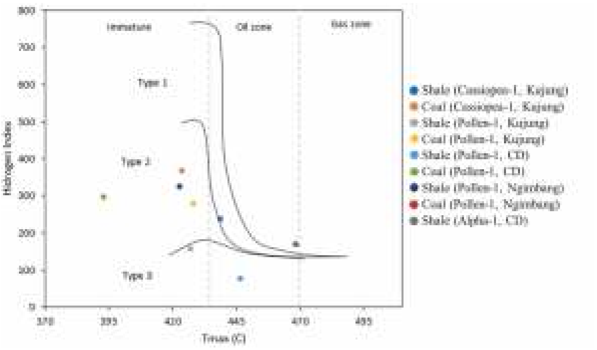


Figure 5. Modified van Krevelen diagram of the three wells on the Tmax diagram against the hydrogen index showing the kerogen type and maturity level (modified from Peters et al., 2016).

Maturity Level

The comparison between PI values to Tmax (Tissot & Welte, 1984; Al Areeq et al., 2018). shown in Figure 6 can be used to indicate the ripening and nature of the hydrocarbon product (i.e. native or migratory). The source rock in the Cassiopeia-1 Well has a PI value in the range of 0.04–0.12 (Table 4) which indicates that most of the host rock in this well is thermally immature and is outside the oil window. The source rock in the Pollen-1 Well has a PI value in the range of 0.05–1.13 (Table 5), with the Kujung Formation which has a PI value of >0.2 and the CD Formation and the Ngimbang Formation it has a PI value of <0.2. Most of the host rock in the Pollen-1 Well has not yet matured thermally and is still outside the oil window except for the Kujung Formation which has migrated. The source rock in the Alpha-1 Well has a PI value in the range of 0.02–0.08 (Table 6), which indicates that most of the source rock in this well is thermally immature and is outside the oil window.

The maturity of organic material in Cassiopeia-1 Well, based on Tmax values ranging from 419-446°C, can be seen in Table 4. Of the 17 samples analyzed, as many as 5 samples were in immature condition, 4 samples had no Tmax detected and The other 8 samples were mature. Maturity of organic material in Pollen-1 Well, based on Tmax values ranging from 343-474°C, the data is presented in Table 5. Of the 22 samples analyzed, 8 samples were immature and 14 samples were mature. The maturity of organic material in the Alpha-1 Well, based on Tmax values ranging from 432-503.5°C, can be seen in Table 6. Of the 17 samples, 2 samples were immature and 15 samples were mature.

Based on the relationship between production index and temperature (Figure 6), most of the rock samples analyzed were not thermally mature but the hydrocarbon products were original. This also shows that the source rock in the three wells has immature organic material and has not yet entered the oil window.

Analysis of the Origin of Organic Materials

Isoprenoid

Based on the results of isoprenoid analysis carried out on several rock samples taken from the Cassiopeia-1, Pollen-1, and Alpha-1 wells, several rock groups were obtained indicating the origin of the organic material. A Diagram of phytane/C18 against pristine/C17 (Powell & McKirdy, 1973; Peters et al., 2005; Slameto et al., 2010; Jamaluddin et al., 2019) is used to provide an overview of the depositional environment of the origin of the organic material (Figure 7).

Sterana

Based on the results of the sterane analysis carried out on several rock extract samples taken from the Cassiopeia-1 and Pollen-1 wells, several groups of rock extracts were obtained indicating the origin of the organic material. Comparison diagrams between C27, C28, and C29 sterane (Huang & Meinschein, 1979 in Zajuli & Suyono, 2011) are used to provide an overview of the depositional environment of the origin of the organic material (Figure 8).

Examples of rock extracts in the Cassiopeia-1 well with shale and coal lithology, then in the Pollen-1 well with shale lithology of the CD Formation and shale for the Ngimbang Formation indicate an indication of contributions from the sea and land so that the depositional environment of the host rock characterizes a more shallow depositional environment. sea direction to the edge of the sea (Figure 8).

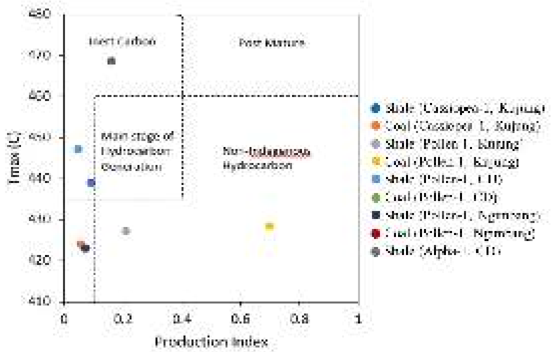


Figure 6. Cross plot between Tmax and Production Index showing the maturity and formation of hydrocarbons (modified from Al Areeq et al., 2018).

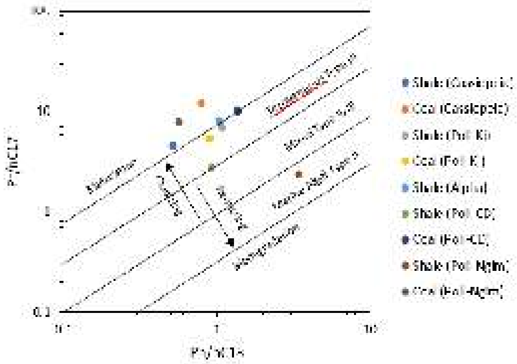


Figure 7. Plot between pristane and phytane with normal alkanes showing kerogen sources, rock facies, and oxidation and reduction conditions (modified from Jamaluddin et al., 2019).

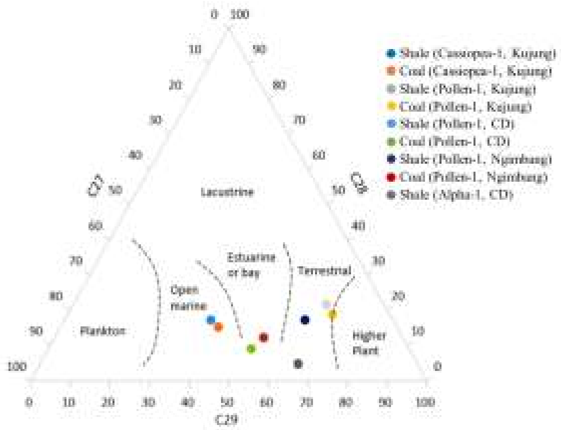


Figure 8. Ternary diagram of m/z 217 sterane C27-C28-C29 showing the depositional environment of the host rock (modified from Huang & Meinschein, 1979 in Zajuli & Suyono, 2011).

Rock extract samples from the Pollen-1 well of the Kujung Formation with shale and coal lithology, then the CD Formation coal and Ngimbang Formation coal show a larger amount of C29 sterane and indicate a strong contribution from a land so that the sample characterizes a more terrestrial depositional environment.

Carbon Isotopes

Based on the results of carbon isotope analysis carried out on rock extract samples taken from the Cassiopeia-1 and Pollen-1 wells, it was found that the oil group indicated the origin of the organic material, for carbon isotope data from Alpha-1 was not available. the carbon isotope diagram 13 Csat against 13 Caro (Sofer, 1984) is used to give an idea of the depositional environment of the organic material from which it originates (Figure 9).

Samples of rock extract in Cassiopeia-1 Well show Cv values are +0.13 for coal and -7.31 for shale which is an indication of the contribution of marine organic material so that the depositional environment of the host rock in Cassiopeia-1 Well is characterized by a depositional environment that is more towards the sea. The Pollen-1 well shows a Cv value of +1.11 for coal which is an indication of the contribution of terrestrial organic material and -3.51 for shale which is an indication of the contribution of marine organic material so that the depositional environment of the host rock in the Pollen-1 well is characterized by a depositional environment. influenced by marine and terrestrial.

Based on the results of isoprenoid, sterane and carbon isotope analysis, it can be seen that the environmental characteristics of the deposited source rock in the study area are divided into two groups (see Table 7).

The first rock group is a rock sample whose organic material comes from a mixture of terrestrial and marine, so the depositional environment of the parent rock for this rock group characterizes a depositional environment that is more toward a shallow sea. This rock group is characterized by higher phytane in pristane, greater amounts of C27 in sterane, and carbon isotope Cv values that are smaller than +0.13. Rock samples included in this group come from the Cassiopeia-1 Well for the Kujung Formation, Pollen-1 for shale from the Ngimbang Formation and Pollen-1 for the CD Formation.

The second rock group is an example of rock where a lot of organic material comes from land so the depositional environment of the parent rock for this rock group characterizes a depositional environment that is more terrestrial. This rock group is characterized by lower phytane/pristanes, greater amounts of C29 in sterane, and Cv values of carbon isotopes greater than +1.11. Rock samples included in this group come from the Pollen-1 Well of the Kujung Formation, Pollen-1 for coal from the Ngimbang and Alpha-1 Formation.

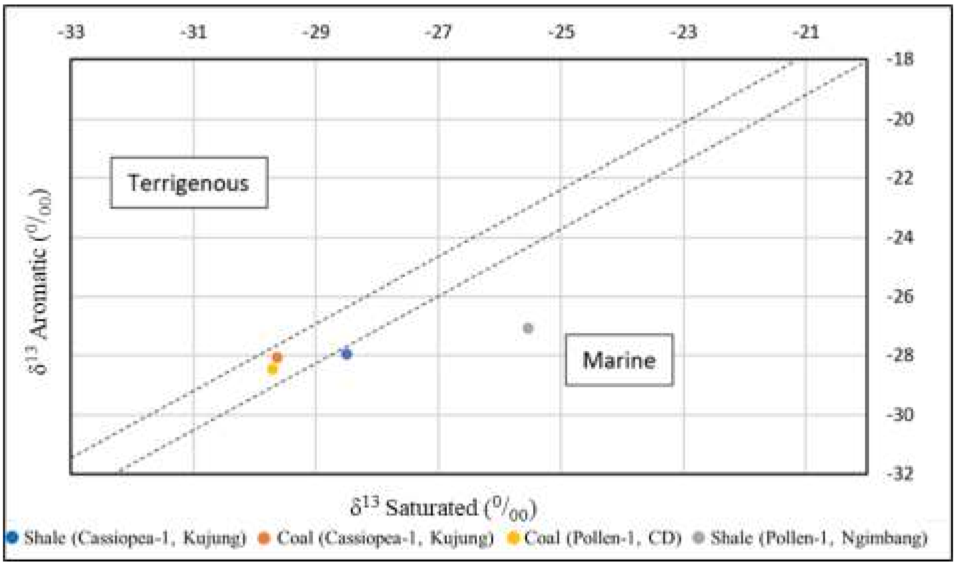


Figure 9. Crossplot of the Aromatic and Saturated carbon-13 isotope showing the facies of the host rock (modified from Sofer, 1984).

Table 7. Summary of Isopernoid, Sterana and Carbon Isotope Analysis in Cassiopeia-1, Pollen-1 and Alpha-1 Wells

Well	Formation	Lithology	Source of Organik Material			Depositional Environment
			Isoprenoid	Sterane	Carbon Isotopes	
Cassiopeia-1	Kujung	Shale	Terrestrial	Marine	Marine	Shallow Marine
		Coal	Terrestrial	Marine	Terrestrial	Shallow Marine
Pollen-1	Kujung	Shale	Terrestrial	Terrestrial		Terrestrial
		Coal	Terrestrial	Terrestrial		Terrestrial
	CD	Shale	Terrestrial	Marine and Terrestrial		Shallow Marine
		Coal	Terrestrial	Terrestrial	Marine	Shallow Marine
	Ngimbang	Shale	Marine Algae	Marine and Terrestrial	Marine	Shallow Marine
		Coal	Terrestrial	Terrestrial		Terrestrial
Alpha-1		Shale	Terrestrial			Terrestrial

CONCLUSION

Based on the total organic carbon, production index and maximum temperature from Cassiopeia-1, Pollen-1 and Alpha-1 wells, some rock samples have not yet reached thermal maturity. It is also shown that the source rock has immature organic material and has notyet entered the oil window. Also, it tends to produce gas and oil derived from type II and type III kerogens.

Based on the analysis of isoprenoid, sterane and carbon isotopes, there are two groups of rocks in the study area. The first rock group is a rock whose organic material comes from a mixture of terrestrial and marine, so the depositional environment of the parent rock for this oil group characterizes a depositional environment that is more toward the shallow sea. This rock group is characterized by a high phytane to pristane ratio, a greater amount of C27 in sterane, and a carbon isotope Cv value less than +0.13. Rock samples included in this group come from the Cassiopeia-1 Well for the Kujung Formation, Pollen-1 for shale from the Ngimbang Formation and Pollen-1 for the CD Formation.

The second rock group is a rock with more organic material originating from a land so the depositional environment of the source rock for this oil group characterizes a depositional environment more terrestrial. This rock group is characterized by a lower phytane to pristane ratio, a greater amount of C29 in sterane, and a carbon isotope Cv value greater than +1.11. Rock samples included in this group come from the Pollen-1 Well of the Kujung Formation, Pollen-1 for coal from the Ngimbang and Alpha-1 Formation.

ACKNOWLEDGEMENT

The author would first like to thank the Head of the Center for Geological Survey (CGS) for permission to publish this paper. The author would also like to thank the Oil and Gas Division of the Center for Geological Survey (CGS) for a comfortable environment for conducting study development.

REFERENCES

Adedosu, T.A., Sonibare, O.O., Tuo, J., and Ekundayo, O., 2012. Biomarkers, Carbon Isotopic Composition and Source Rock Potentials of Awgu Coals, Middle Benue Trough, Nigeria. *Journal of African Earth Sciences*, 66-67: 13-21.

Al-Areeq, N.M., Al-Badani, M.A., Salman, A.H., and Albaroot, M.A., 2018. Petroleum Source Rocks Characterization and Hydrocarbon Generation of the Upper Jurassic Succession in Jabal Ayban Field, Sabatayn Basin, Yemen, Egypt. *J. Petrol. Egyptian Journal of Petroleum*, 27(4): 835-851.

Azis, S., Sutrisno., Noya, Y., and Brata, K., 1992. *Geological Map of The Tanjungbumi and Pamekasan Quadrangle, Java, 1:100,000*. Geological Research and Development Centre, Bandung.

Corelab Indonesia, 2012. Pollen-1 Well, Karapan Psc, Petroleum Geochemistry Study of Unwashed Cuttings Samples. AWE (North Madura) NZ Limited.

Dai, J., Li, J., Luo, X., Zhang, W., Hu, G., Ma, C., Guo, J., and Ge, S., 2005. Stable Carbon Isotope Compositions and Source Rock Geochemistry of the Giant Gas Accumulations in the Ordos Basin, China. *Organic Geochemistry*, 36: 1617-1635.

Doust, H. and Sumner, H.S., 2007. Petroleum Systems in Rift Basins – a Collective Approach in Southeast Asian Basins. *Petroleum Geoscience*, 13: 127-144.

El Nady, M.M., Ramadan, F.S., Hammad, M.M., and Lotfy, N.M., 2015. Evaluation of Organic Matters, Hydrocarbon Potential and Thermal Maturity of Source Rocks Based on Geochemical and Statistical Methods: Case Study of Source Rocks in Ras Gharib Oilfield, Central Gulf of Suez, Egypt. *Egyptian Journal of Petroleum*, 24(2): 203-211.

Hall, R., 2012. Late Cretaceous – Recent Reconstructions of the Indonesian Region. *Tectonophysics*, 570–571: 1-41.

Hartono and Suharsono, 1997. *Geological Map of the Tuban Quadrangle, Java, 1:100,000*. Geological Research and Development Centre, Bandung.

Huang, W.Y., and Meinschein, W.G., 1979. Sterols as Ecological Indicators, *Geochimia Cosmochimia Acta*, 43: 739-745.

Hunt, J.M., 1996. *Petroleum Geochemistry and Geology, Second edition*. WH Freeman and Company, New York.

Illich, R.A., 1983. Pristane, Phytane, and Lower Molecular Weight Isoprenoid Distributions in Oil. *Bulletin of the American Association of Petroleum Geologists*, 67: 385-393.

Jamaluddin., Fuqi, C., Maria., Syamsuddin, E., and Umar, E.P., 2019. Interpretation of Paleodepositional Environment using Biomarkers and Carbon Isotope (d13C) in Talang Akar Formation, South Sumatra Basin, Indonesia. *IOP Conf. Series: Earth and Environmental Science* 279 (2019) 012024.

Peters, K.E., Xia, x., Pomerantz, A.E. and Mullins, O.C., 2016. *Chapter 3 - Geochemistry Applied to Evaluation of Unconventional Resources, Unconventional Oil and Gas Resources Handbook*. Gulf Professional Publishing, p. 71-126. ISBN 9780128022382,

Lemigas Biostratigraphic Services Unit., 1981. The Biostratigraphy of The Houston Oil and Minerals Inc. Alpha No.1 Well Drilled in The Java Sea. Houston Oil and Minerals of Indonesia Inc.

Lunt, P., 2019. The Origin of the East Java Sea Basins Deduced from Sequence Stratigraphy. *Marine and Petroleum Geology*, 105: 17-31.

Manur, H. and Barraclough, R., 1994. Structural Control on Hydrocarbon Habitat in the Bawean Area, East Java Sea. *Proceedings Indonesian Petroleum Association, 23rd annu. conv.*, p. 129-144.

Mudjiono, R. and Pireno, G.E., 2001. Exploration of the North Madura Platform, offshore East Java, Indonesia, *Proceedings Indonesian Petroleum Association, 28th Annual Convention & Exhibition*.

Mukhopadhyay, P.K., Wade, J.A., and Gruge, M.A., 1995. Organic Facies and Maturation of Jurassic/Cretaceous Rock, and Possible Oil-sourcerock Correlation Based on Pyrolysis of Asphaltenes, Scotian Basin Canada. *Org. Geochem.*, 22(5): 43–55.

Pertamina BPPKA, 1996. *Petroleum Geology of Indonesia Basins: Prinsiples, Methods, and Application*. Pertamina BPKKA, Jakarta, Indonesia.

Peters, K.E. and Cassa, M.R., 1994. *Applied Source Rock Geochemistry*. The Petroleum System from Source to Trap, AAPG Memoir no. 60.

Peters, K.E., Walters, C.C., and Moldowan, J.M., 2005. *The Biomarker Guide*. Cambridge University Press, 1155p.

Powell, T.G. and McKirdy, D.M., 1973. Relationship between Ratio of Pristane to Phytane, Crude Oil Composition and Geological Environment in Australia. *Nature Physical Science*, 243:-.

Robertson Research (Singapore) Private Limited, 1981. A Petroleum Geochemical Evaluation of The Alpha-1 Well, Drilled in The E. Java Sea Indonesia. Houston Oil and Minerals of Indonesia Inc.

Robertson Utama Indonesia, 1992. Cassiopeia-1 and 1-Sidetrack NE Java Sea Block VI Inpex Offshore Madura Ltd. Biostratigraphy and Depositional Environments, NE Java Sea Block VI Indonesia, Inpex Offshore Madura Ltd.

Satyana, A.H., 2010. *Petroleum Geochemistry: Essential Concepts and Methods for Hydrocarbon Exploration and Production*. HAGI course, Bali.

Satyana, A.H. and Purwaningsih, M.E.M., 2003. Geochemistry of the East Java Basin: New Observation on Oil Grouping, Genetic Gas Types and Trends of Hydrocarbon Habitats. *Proceedings Indonesian Petroleum Association (IPA), 29th Annual Convention.*

Satyana, A.H., 2005. Petroleum Geology of Indonesia: Current Concepts. *Pre-Convention Course, Indonesian Association of Geologists 34st, Annual Convention*, Surabaya 28-30 November 2005.

Scheeder, G., Weniger, P., and Blumenberg, M., 2020. Geochemical Implications from Direct Rock-Eval Pyrolysis of Petroleum. *Organic Geochemistry*, 146 (2020) 104051.

Sitmorang. R.L., Agustianto, D.A., and Suparman, M., 1992. *Geological Map of the Waru – Sumenep Quadrangle, Java,1:100,000*. Geological Research and Development Centre, Bandung.

Slameto, E., Panggabean, H., and Bachri, S., 2010. Organic Material Content and Geochemical Properties of Paleogene and Neogene Claystones in the Serayu Basin: An Analysis of the Potential of Hydrokaron Source Rocks. *Jurnal Sumber Daya Geologi*, 20(4): 189-197.

Smyth, H. R., Hamilton, P. J., Hall, R. and Kinny, P. D., 2007. The Deep Crust Beneath Island Arcs: Inherited Zircons Reveal a Gondwana Continental Fragment Beneath East Java, Indonesia. *Earth and Planetary Science Letters,* 258: 269-282.

Sofer, Z., 1984. Stable Carbon Isotope Compositions of Crude Oils: Application to Source Depositional Environments and Petroleum Alteration. *AAPG Bulletin,* 68(1): 31-49.

Sribudiyani, Muchsin, N., Ryacudu, R., Kunto, T., Astono, P., Prasetya, I., Sapiie, B., Asikin, S., Harsolumakso, A.H., and Yulianto, I., 2003. The Collision of the East Java Microplate and Its Implications for Hydrocarbon Occurences in the East Java Basin. *Proceedings Indonesia Petroleum Association 30th Annual Convention & Exhibition*. Soft File: IPA03-G-085.

Supandjono, J.B., Hasan, K., Panggabean, H., Satria, D., and Sukardi, 1992. *Geological Map of The Surabaya and Sapulu Quadrangle, Java,1:100,000*. Geological Research and Development Centre, Bandung.

Tissot, B.P. and Welte, D.H., 1984. *Petroleum Formation and Occurrence. 2nd ed*. Springer, New York.

Waples, D.W., 1985. *Geochemistry in Petroleum Exploration*. International Human Resources Development Corporation, Boston.

Waples, D.W. and Machihara, T., 1991. *Biomarkers for Geologists: A Practical Guide to the Application of Steranes and Triterpanes in Petroleum Geology*. American Association of Petroleum Geologists Methods in Exploration Series 9, Tulsa, Oklahoma, USA.

Western Atlas International., 1992a. Final Report of Sedimentology and Petrography of Conventional Cores and Sidewall Cores Well: Cassiopeia #1, NE Java Sea Block VI Indonesia, Inpex Offshore Madura Ltd.

Western Atlas International, 1992b. Geochemical and Detailed Source Rock Characterization of Selected Samples From The Cassiopeia-1 Well, North East Java Sea Block VI, NE Java Sea Block VI Indonesia, Inpex Offshore Madura Ltd.

Zajuli, M.H.H., Oktavitania, R., and Rizkika, O., 2020. Organic Geochemistry of Eocene-Aged Hydrocarbon Shale in Central Sumatra Region. *Journal of Geology and Mineral Resources,* 21(1): 45-60.

Zajuli, M.H.H. and Suyono., 2011. Organic Geochemistry and Rock-Eval Pyrolysis of Eocene fine Sediments, East Ketungau Basin, West Kalimantan. *Indonesian Journal of Geology*, 6(2): 95-104.

Zajuli, M.H.H. and Wahyudiono, J., 2018. Rock-Eval Pyrolysis of the Oligocene Fine-grained Sedimentary Rocks from the Pamaluan Formation, Gunung Bayan Area, West Kutai Basin, East Kalimantan: Implication for Hydrocarbon Source Rock Potential. *Journal of Geology and Mineral Resources*, 19(2): 73 - 82.