Available Online : https://proceeding.researchsynergypress.com/index.php/cset/index
RSF Conference Series: Engineering and Technology
ISSN 2809-6843 (Online) | 2809-6878 (Print)
Volume 1 Number 1 (2021): 78-94

Depositional Environment of Nampol Formation and Its Implications as Potential Source Rocks in the Sumbermanjing Area, South Malang

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Abstract

The decline in oil and gas production inevitably forces explorationists to be more creative in finding new potential reserves. Nampol Formation is expected to have the potential to become hydrocarbon source rocks due to their organic matter content. However, the depositional environment of Nampol Formation has not been thoroughly researched. The focus of this research is to reveal the depositional environment of Nampol Formation that may lead to a suitable condition for the deposition of potential source rocks layers. Detailed geological mapping in several selected traverses and micropaleontological analysis was carried out to determine lithological characteristics and depositional environment of Nampol Formation. The microfacies approach was also used to determine the carbonate facies zone of this unit. Source rock samples taken from outcrops on the surface then were analysed to evaluate organic matter content, type of kerogen thermal maturity, and its potential to produce hydrocarbons. The Nampol clastic limestone unit in the study area is composed of clastic limestone with intercalation of black shale, claystone, siltstone, sandstone and calcareous claystone. The microfacies approach shows that the wackestone and mudstone belong to the SMF 15-M (Ooid wackestone) and SMF 23 (Non-fossiliferous mudstone) which can be interpreted belong to Facies Zone (FZ) 8 in the Flügel carbonate facies model (2004). This zone is located in the Restricted interior platform or platform environment with closed water circulation which is situated behind the barrier reef (back reef). Based on the results of geochemical analysis, source rock samples from Nampol Formation can be considered as a gas prone source rock, with type III kerogen, total organic content ranging from 3.48 – 26.18 wt%, po-sess the potential to produce good to very good hydrocarbons and a hydrogen index ranging from 43 to 86 mg HC/g TOC.

Keywords: Depositional environment, microfacies, Nampol Formation, source rock

INTRODUCTION

The oil and gas industry just had a horrible turmoil. Based on SKK Migas statistics from 2016, the decline in oil and gas production from year to year shows that domestic gas demand has climbed by an average of 9% per year, but oil and gas lifting has remained stagnant. Moreover, Indonesia which is the third biggest gas exporter in the world is estimated to become a gas importer in 2019 (Dirjen Migas). Explorationists are facing a situation where they have to get two choices which are finding greater reserves or seeking new alternative resources.

Recent studies proposed that Nampol Formation is expected to have the potential to become hydrocarbon source rocks due to their organic matter content. Shale, siltstone, calcareous claystone and coal inserts (Samodra & Wiryosujono, 1989) in this formation are thought to contain organic matter that supports the presence of potential source rocks. On the other side, the depositional environment of Nampol Formation has not been thoroughly researched, especially in the Sumbermanjing District, Malang Province.

The research area is located in the eastern part of Southern Mountain, more precisely in Malang Regency, East Java Province. The focus of this research is to reveal the depositional environment of Nampol Formation that may lead to a suitable condition for the deposition of potential source rocks layers. The objectives of this research are: (1) to determine the depositional environment of Nampol Formation, and (2) to identify investigate the possibility of potential source rock in the research area.

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Figure 1. Research Area

LITERATURE REVIEW

Regional Stratigraphy

The Southern Mountains of East Java are generally composed of rocks with Neogene to Quaternary age. Volcanic rocks and limestone predominate in this area. Rock sequences are arranged based on detailed stratigraphy through selected paths and displayed in a stratigraphic column.

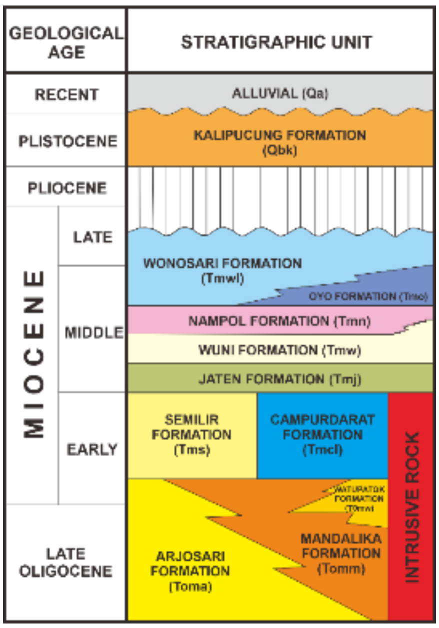

Figure 2. Southern Mountain East Java stratigraphic column (Samodra and Wiryosujono, 1989).

Regional Geological Stucture

According to Sribudiyani et al., (2003), the eastern part of Java is the intersection of two main structural patterns, the Meratus structure with a northeast-southwest trend and the Sakala structure with an east-west direction. The Meratus direction is more developed in the offshore area of the East Java Basin, whereas the Sakala direction is developing to the eastern part of the mainland of Java.

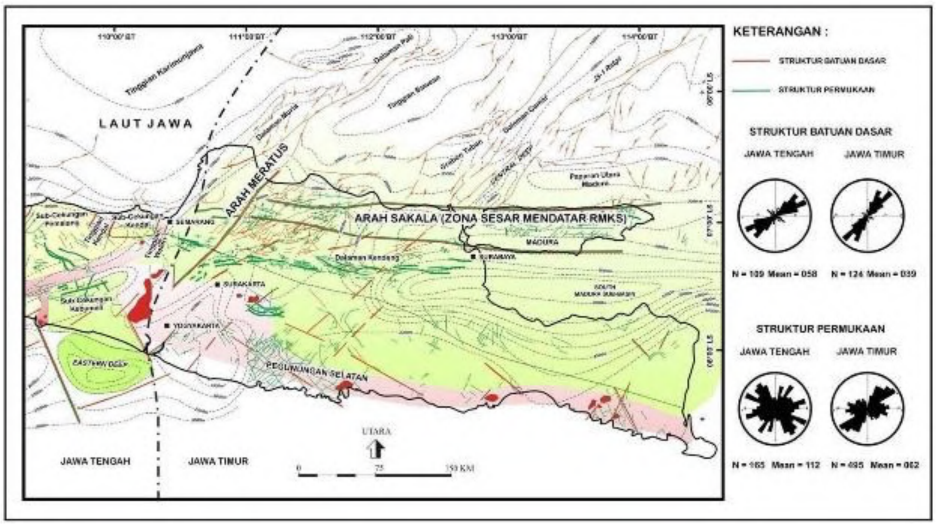

Figure 3. The structure of the Meratus direction is east-southwest and the Sakala structure is east-west (Sribudiyani *et al.*, 2003).

Microfacies

Microfacies, according to Flugel (2004), are all paleontological and sedimentological data that may be characterized and identified in thin sections, polished sections, or rock samples. Microfacies analysis begins in the field with rocks sample collection. Then proceed to the laboratory, where thin sections are prepared for determination of the relative abundance of the main constituents (granules, matrix, cement), grain shape, grain size, degree of separation, and other characteristics of carbonate grains, including the type of fossil organism, matrix properties, cement type, and fabrics. The ultimate goal of microfacies analysis is interpretation of ancient depositional environment. Microfacies evaluation in the context of facies interpretation requires classifying the observed microfacies data in various samples into Microfacies Type (MFT) (Table 1). MFT can be grouped into "belt" facies or zones, which are then used to build common deposition models for carbonate rocks (Figure 4).

Table 1. List of Standard Microfacies Type (Flügel, 2004)

No	Standart Microfacies (SMF) Name
SMF 1	Spiculitic wackestone or packstone, often with calcisiltite matrix.
SMF 2	Microbioclastic peloidal calcisiltite with fine grainstone and packstone fabrics.
SMF 3	Pelagic lime mudstone and wackestones with abundant pelagic microfossils.
SMF 4	Microbreccia, bio- and lithoclastic packstone or rudstone
SMF 5	Allochthonous bioclastic grainstone, rudstone, packstone, floatstone, breccia with reef-derived biota.
SMF 6	Densely packed reef rudstone.
SMF 7	Organic boundstone. Subtypes try to differentiate the kind of contribution by potential reefbuilders to the formation of reefs and other buildups.
SMF 8	Wackestones and floatstones with whole fossils and well-preserved endo- and epibiota.
SMF 9	Strongly burrowed bioclastic wackestone.
SMF 10	Bioclastic packstone and wackestone with abraded and worn skeletal grains.
SMF 11	Coated bioclastic grainstone.
SMF 12	Limestone with shell concentrations. Subtypes characterize shell-providing fossils.
SMF 13	Oncoid rudstone and grainstone.
SMF 14	Lag deposit.
SMF 15	Oolite, commonly grainstone but also wackestone. Subtypes highlight the structure of ooid.
SMF 16	Peloid grainstone and packstone. Subtypes differentiate non-laminated and laminated rocks.
SMF 17	Grainstone with aggregate grains (grapestones).
SMF 18	Bioclastic grainstone and packstone with abundant and rock-building benthic foraminifera or calcareous green algae.
SMF 19	Densely laminated bindstone.

SMF 20	Laminated stromatolitic bindstone/boundstone.
SMF 21	Fenestral packstone and bindstone. Subtypes characterize fenestral voids and the contribution of calcimicrobes.
SMF 22	Oncoid floatstone and wackestone.
SMF 23	Non-laminated homogenous micrite or microsparite without fossils.
SMF 24	Lithoclastic floatstone, rudstone or breccia.
SMF 25	Laminated evaporite-carbonate mudstone.
SMF 26	Pisoid cementstone, rudstone or packstone.

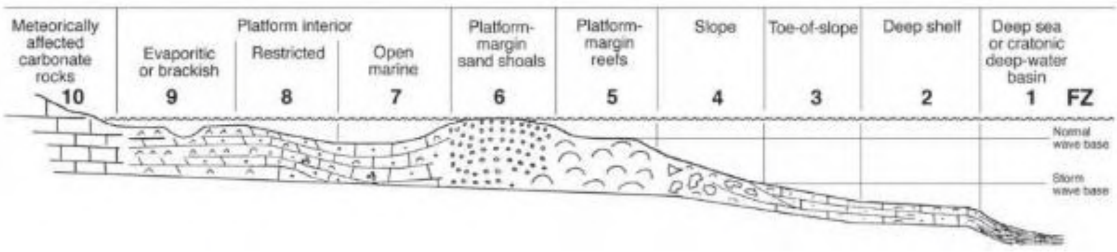

Figure 4. Rimmed carbonate platform: The Standard Facies Zone of modified Wilson model (Flügel, 2004).

RESEARCH METHODOLOGY

Detailed geological mapping was carried out in several selected traverses. Study of lithological composite profiles, which showed lithological characteristics of the Nampol clastic limestone unit's, and micropaleontological analysis of numerous rock samples are used to determine the depositional environment of Nampol Formation. The microfacies approach was also used to determine the carbonate facies zone of this unit. Source rock samples taken from outcrops on the surface then were analyzed to evaluate organic matter content, type of kerogen thermal maturity, and its potential to produce hydrocarbons through TOC analysis and Rock-Eval pyrolysis (Figure 5).

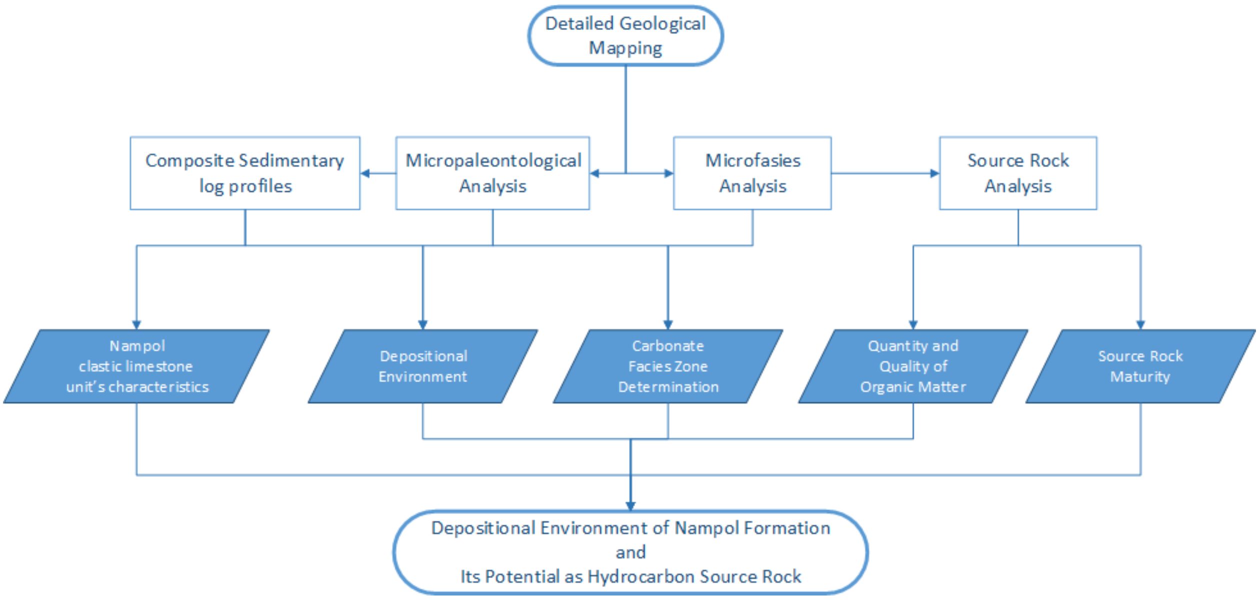

Figure 5. Research Flow Chart

FINDING AND DISCUSSION

Lithological Characteristics

The Nampol clastic limestone unit in the study area is composed of clastic limestone with intercalation of black shale, claystone, siltstone, sandstone and calcareous claystone.

Calcarenite clastic limestone is fresh milky white color and weathered dark brown color, fine sand size (1/8-1/4 mm), intact grain, angular-shaped, and well-sorted, allochem composition consists of interclast, bioclast (mollusk shell) with mud micrite and carbonate cement, with parallel stratified structure.

Figure 6. Clastic limestone outcrops in research area. (A,B) FB-01 located in Bambang River, Argotirto. (C,D) MM-24 located in Sumbernanas River, Ringinsari. (E,F) MM-22 located in Sumbernanas River, Ringinsari

Black shale, clay grain size (<1/256 mm), contains organic matter and shell fragments.

Claystone, fresh gray color and weathered black color, clay grain size (<1/256 mm) with parallel laminate structure, contains organic matter and shell fragments.

Siltstone, fresh gray color and weathered reddish-brown color, silt grain size (1/64-1/256 mm), and massive structure, show signs of oxidation (redness).

Calcareous claystone, fresh grey color, and weathered brown color, clay grain size (<1/256 mm), parallel stratified structure, contains shell fragments and lignite inserts.

Figure 7. Black shale, calcareous claystone and siltstone with lignite inserts, shaly coal in research area. (A,B,C) FB-01 and FB-11 located in Bambang River, Argotirto. (D) DA-62 located in Sekarbanyu, Dampit (E,F) MM-22 and MM-24 located in Sumbernanas River, Ringinsari.

Thin-section analysis was carried out for rock samples at observation sites FB-01, FB-19, and FB-40. Wackestone clastic limestone was obtained with white to dark yellow color, with very fine sand (1/16-1/8mm) to fine (1/8-1/4mm) sand, well sorted, fabricated with micrite-supported, composed by allochem (20-30%) ie relatively intact skeletal foraminifera, and a few fragments of algal organisms, sparite content (25-50%), and micrite (50-20%). Parallel stratified and massive sedimentary structures. The grains do not show any alignment or a certain pattern (distributed randomly). Rocks deposited at energy index II. The porosity of interparticle, intraparticle, moldic, and vug rock types resulting from dissolution is 4-15% based on quantitative analysis of rock.

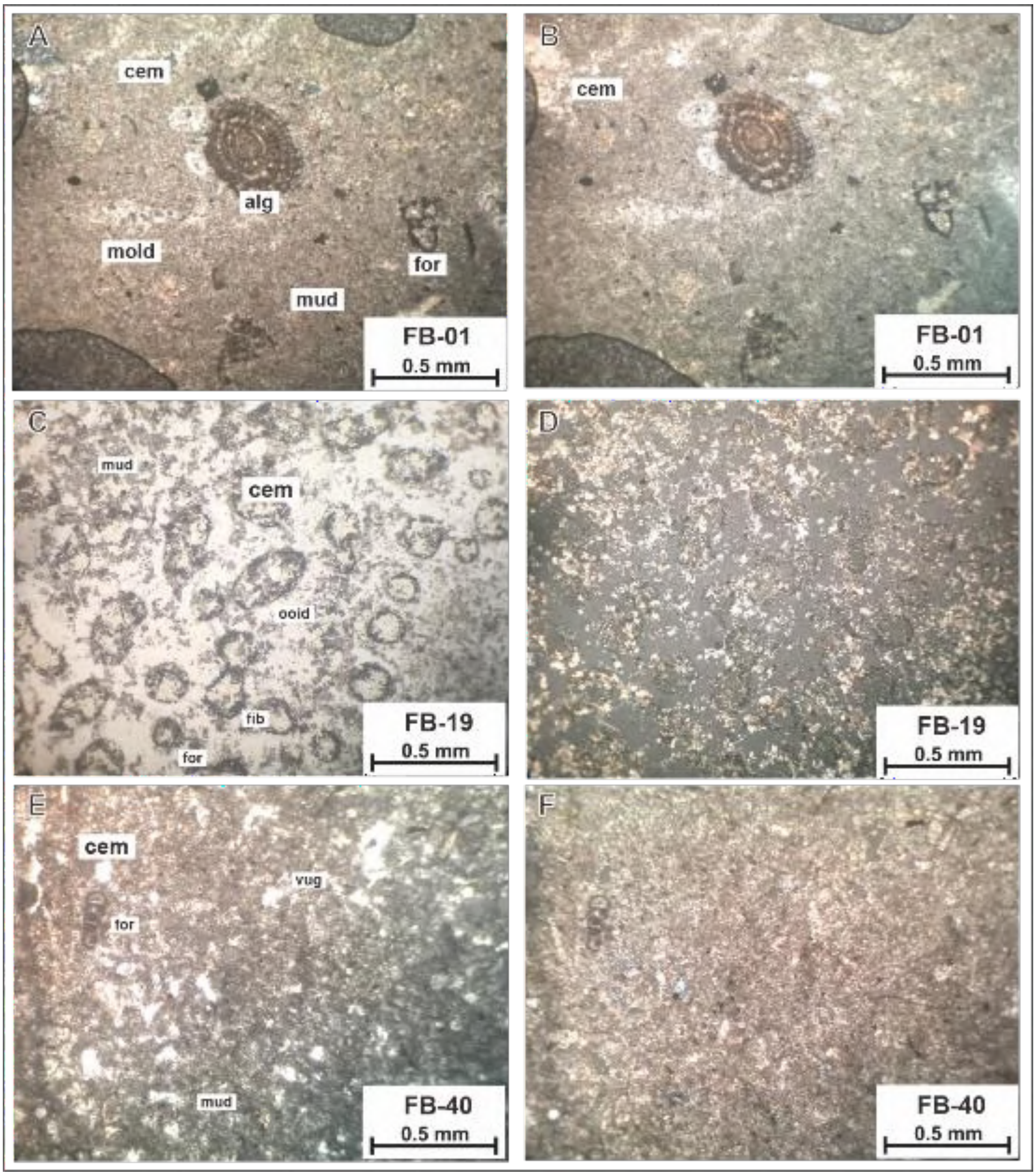

Figure 8. Thin section petrographic analysis for clastic limestone rocks. Similar appearance of PPL (left) and XPL (right) as a specific characteristic of a carbonate rocks thin section. These three samples described as Wackestone (Dunham, 1962).

Another thin-section analysis at observation locations FB-11 and FB-29 obtained clastic mudstones with white to dark yellow color, with very fine sand grain size (1/16-1/8mm), well-sorted, fabricated with grains supported by micrite, composed by allochem (15-20%) i.e. bioclastic skeletal, and a few relatively intact foraminifera, sparite content (30-35%), and micrite (35-45%). Parallel stratified and massive sedimentary structures. The grains do not show any alignment or a certain pattern (distributed randomly). Rocks were deposited at energy index I. The porosity of rock types is vug, interparticle, and fenestral.

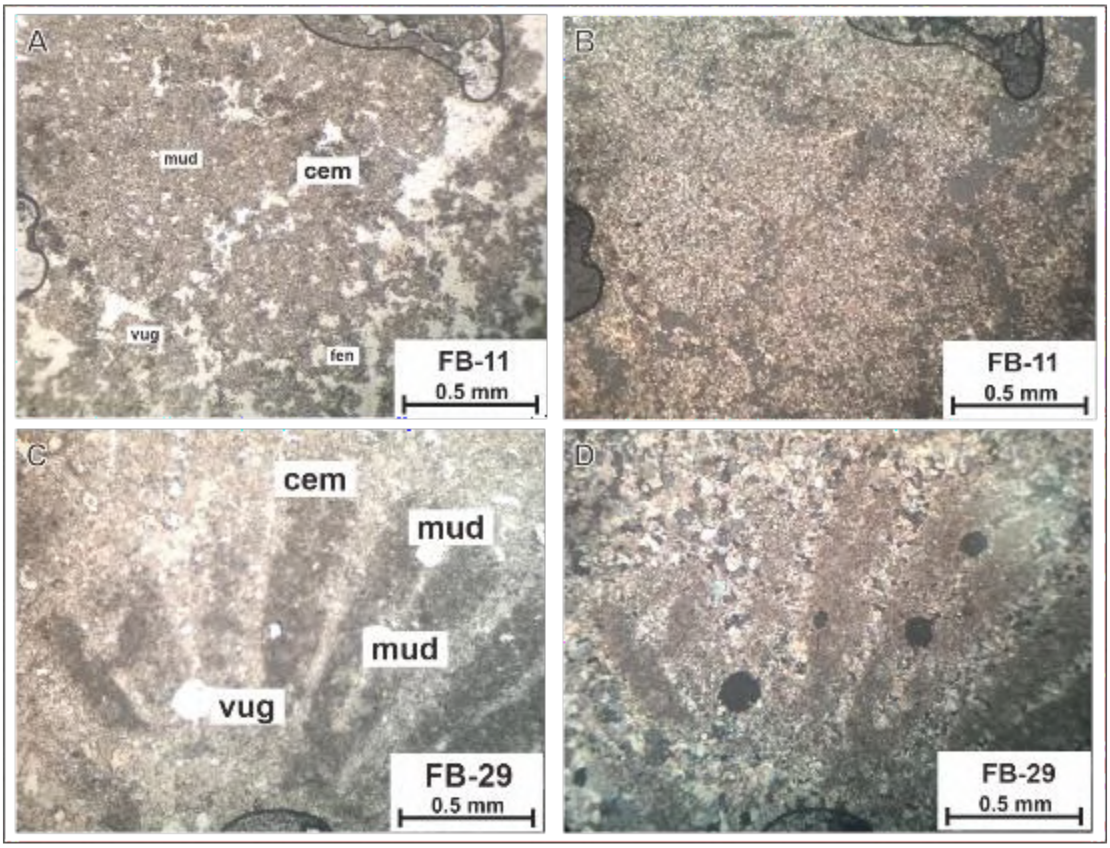

Figure 9. Another micrograph photo of a clastic limestone rocks thin section. PPL (left) and XPL (right). These two samples described as Mudstone (Dunham, 1962).

Age Determination

Age determination for Nampol clastic limestone unit was carried out by micropaleontological analysis of several rock samples. Rock samples were taken in the measured stratigraphic section with sample codes FB-01, FB-11, FB-19, and in another widely-spread observation location such as MM-05 and DA-108. The recognizable microfossil (planktonic & benthonic foraminifera) from these samples were *Orbulina universa*, *Globorotalia bermudezi*, *Praeorbulina curva*, *Globoquadrina altispira*, *Globigerinoides subquadratus*, *Globigerinoides immaturus, Sphaeroidinellopsis disjuncta, Globigerinatella insueta, Globigerinoides ruber, Globoquadrina dehiscens, and Tubinella funalis, Elphidium crispum,* and *Noniella turgida*. The relative age of the Nampol clastic limestone unit referring to the Blow (1969) Zonation was in the Early Miocene - Middle Miocene (N8-N12) age.

Figure 10. Planktonic foraminifera fossil appearance on rock samples in research area.

Figure 11. Another planktonic foraminifera fossil appearance and bentonic foraminifera fossil appereance (the bottom three photos) on rock samples in research area.

Depositional Environment Interpretation

The depositional environment of this rock unit was determined based on lithological characteristics of the Nampol clastic limestone unit compiled in composite profile analysis and micropaleontological analysis of several rock samples. Flügel (2004) microfacies approach was also used to determine the carbonate facies zone of this rocks unit.

Based on the analysis of the composite profile in several observation locations, the main constituent rocks of this unit are clastic limestones with shale inserts as well as siltstones and calcareous siltstones, so it can be concluded that this unit was deposited in a shallow marine environment or neritic, due to deposition of carbonates require evaporation of supersaturation from seawater, which is only found in shallow marine environments.

The microfacies approach shows that the wackestone and mudstone lithology in rock samples FB-01, FB-19, FB-40, & FB-11 and FB-29 respectively belong to the SMF 15-M (*Ooid wackestone*) and SMF 23 (*Non-fossiliferous mudstone*) microfacies which can be interpreted belong to Facies Zone (FZ) 8 in the Flügel carbonate facies model (2004). This zone is located in the Restricted interior platform or platform environment with closed water circulation which is situated behind the barrier reef (back reef).

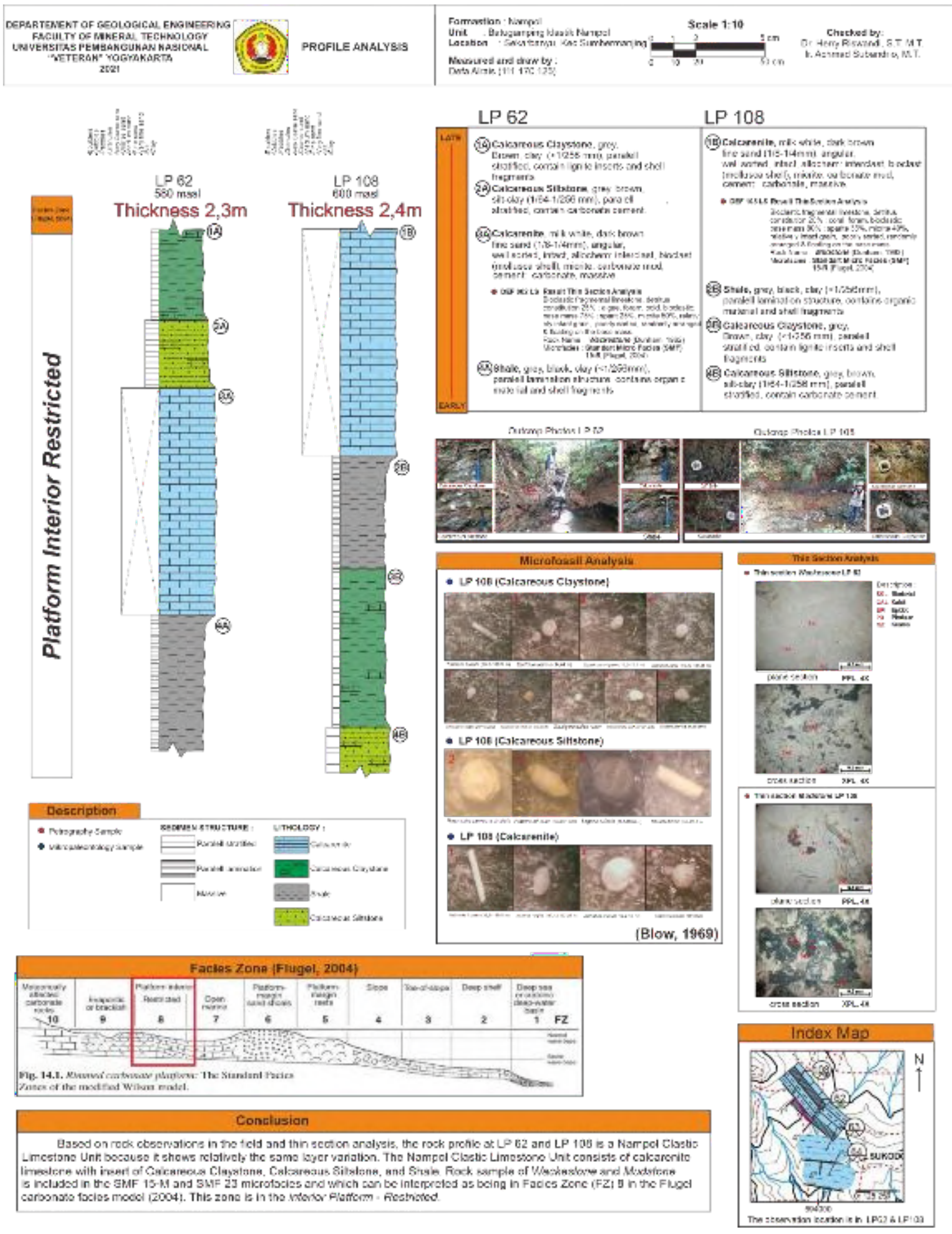

Figure 12. Composite of lithological outcrop profile in Sekarbanyu, Dampit.

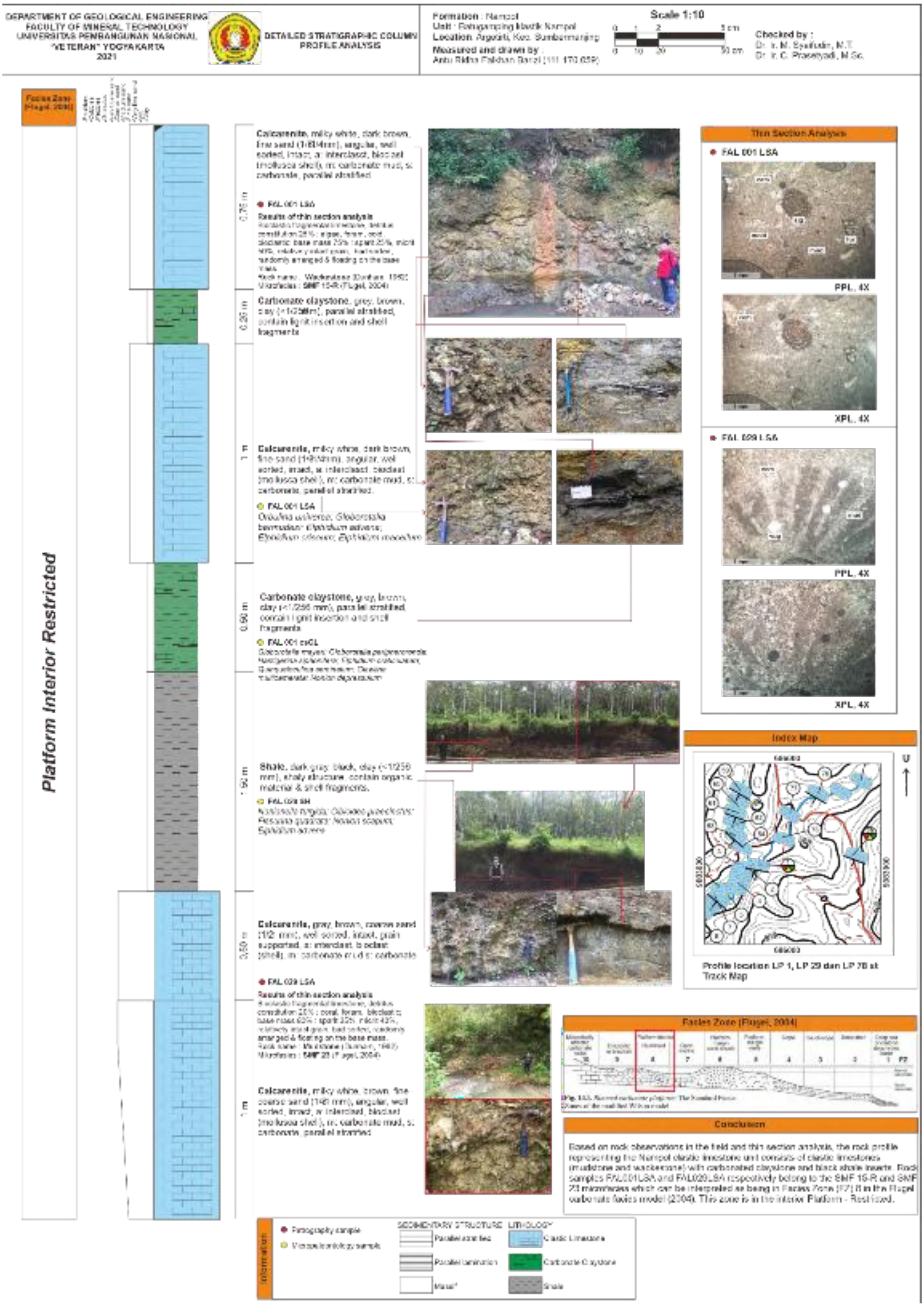

Figure 13. Composite of lithological outcrop profile in Argotirto, Sumbermanjing Area.

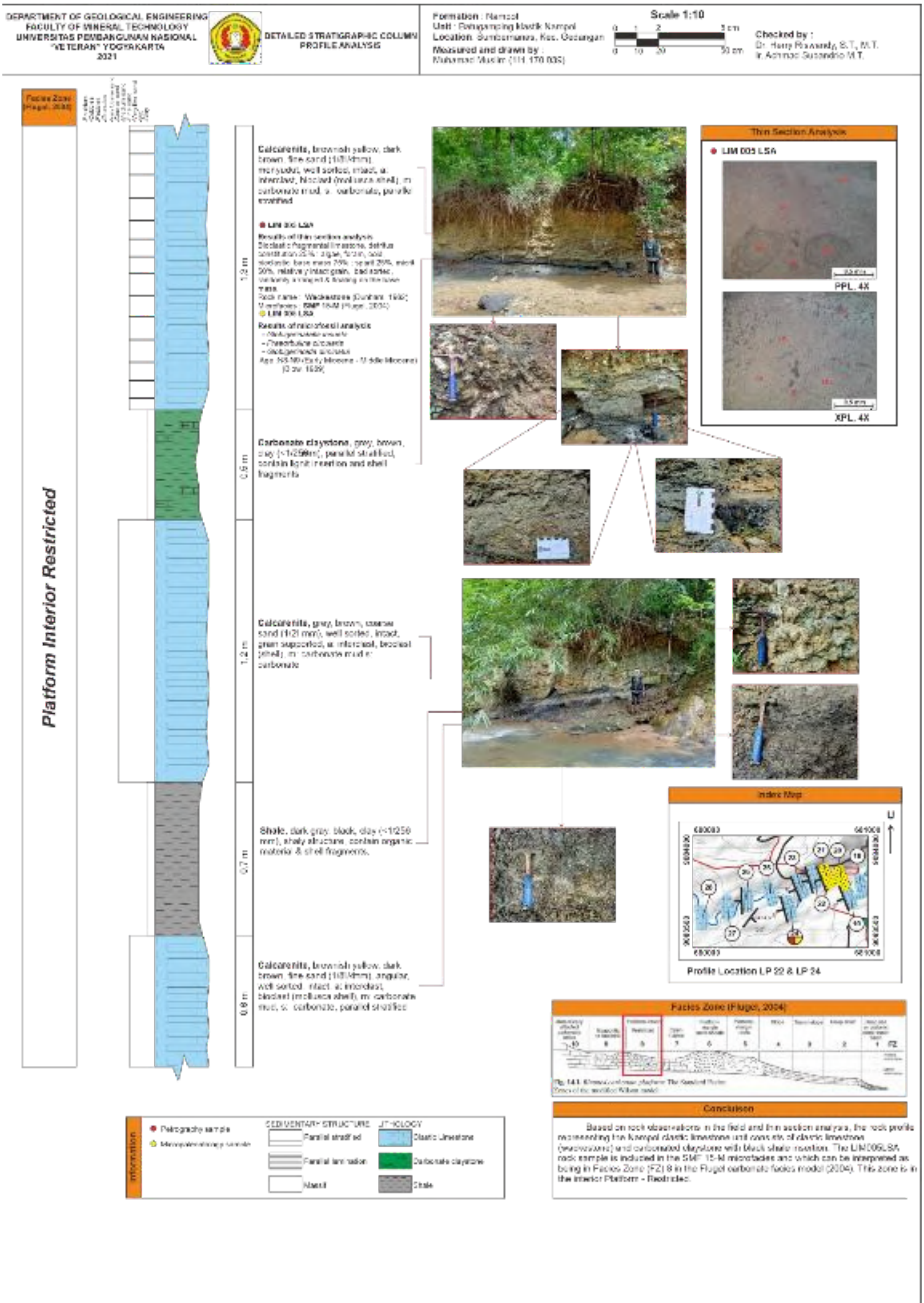

Figure 14. Composite of lithological outcrop profile in Ringinsari Area.

According to Flügel (2004), restricted interior platform is a flat platform within euphotic zone. When the platform margin is protected by sand shoals, islands, or reefs, it is called a lagoon. The open ocean is less well connected, resulting in considerable differences in salinity and temperature. Typically, strongly differentiated tidal zones with freshwater, salt water and hypersaline conditions as well as subaerially exposed areas. Shallow, cut-off ponds and lagoons with restricted circulation and hypersaline water. Lagoons behind barrier reefs, within atolls or behind coastal splits. Water depths below one meter and a few meters to a few tens of meters. This facies zone considered as a wide facies belts.

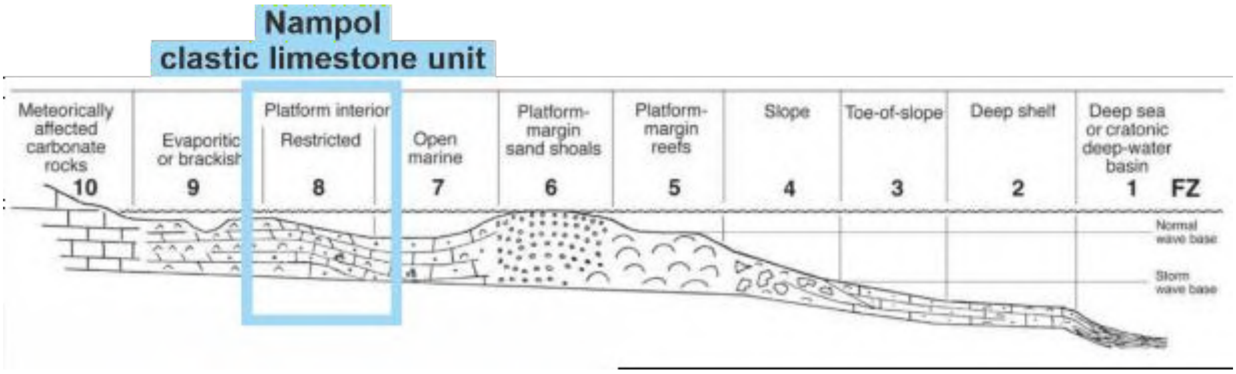

Figure 15. Nampol clastic limestone unit carbonate facies zone (Flügel, 2004).

Stratigraphic Relationship

Nampol clastic limestone unit overlain unconformably Mandalika tuff and breccia unit. This is indicated by the difference in geological time between this unit and previously formed rock units. This unit has a fingering relationship with the Wonosari reef limestone unit which can be seen from the gradual change from south to north of clastic limestones into reef limestones.

Implications to Potential Source Rock

Deposited in restricted platform interior, Nampol clastic limestone unit has suitable conditions for the deposition of limestone with intercalation of shale, claystone, or siltstone. This intercalation of shale and claystone is expected to have the possibility to became a potential source rock due to their organic matter richness. The presence of black shale and claystone in the Nampol clastic limestone unit need an additional investigation in order to determine the total organic matter quantity, type of kerogen, and thermal maturity level of organic matter so its potential to become source rocks can be determined properly.

Table 2. Results of TOC and Rock-Eval Pyrolysis analysis on rock samples in the Nampol Fm.

	Sample ID	Lithology	TOC (wt.%)	mg/gm rock			Tmax (°C)	Oil Production Index (OPI)	Potential Yield (S_1+S_2)	Hydrogen Index	Oxygen Index	%Ro
				S	S	S						
1	LP 1	Calc. claystone	3,48	0,04	1,48	0,38	430	0,03	1,52	43	11	0,44
2	LP 62	Shale	4,01	0,22	3,44	2,19	417	0,06	3,66	86	55	0,46
3	LP 05	Shaly Coal	26,18	0,27	19,28	11,82	408	0,01	19,55	74	45	0,45

S_1 = Free Hydrocarbons
S_2 = Pyrolysable Hydrocarbons
S_3 = Organic CO_2
Oil Production Index = Transformation Ratio = S_1/(S_1+S_2)
Tmax = Temperature of Maximum S_2
Oxygen Index = (S_3/TOC) x 100
* Pyrolysis by Rock Eval II; TOC content by Leco Analyzer
Hydrogen Index = (S_2/TOC) x 100
*** = Not Detected

The organic matter composition, kerogen type, thermal maturity, and hydrocarbon producing capability of three samples located in research area were all evaluated with geochemical analysis. Based on the results of geochemical analysis, the three samples from the Nampol Formation have a TOC content of 3.48 – 26.18 wt% and possess good to excellent hydrocarbon generating potential according to Peters (1986) and Waples (1985). To assess the overall hydrocarbon-generating capacity of each sample might produce, a cross-plot of TOC values was performed on the values of S1+S2. The plotting findings reveal that the total hydrocarbon potential for the sample 'LP01' is poor; 'LP62' is fair; and 'LP05' is good.

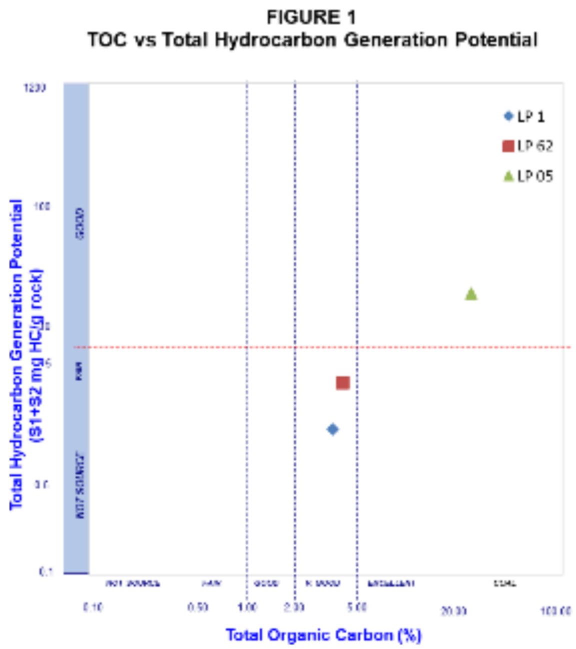

Figure 16. Cross-plot between Total Organic Carbon (TOC) and Potential Yield (PY) content. The results show that the total hydrocarbon potential that can be produced for the code sample 'LP01' is not good; 'LP62' is fair; and 'LP05' is good.

The diagram of the content of Total Organic Carbon (TOC) versus Potential Yield (PY) depicts the potential for hydrocarbons in the study area which is indicated by the level of richness of organic material content. This diagram shows that two samples from the Nampol Formation demonstrated good organic material quality with TOC values of 3.48 wt% and 4.01 wt% and PY of 1.52 and 3.66 mgHC/g, respectively. Another sample had a TOC of 26.18 percent and a PY of 19.55 mgHC/g, indicating very good organic material quality. All of the three samples tend to form gas (gas prone) with one of the samples, code LP 05, possess the possibility to become a potential or effective source rock.

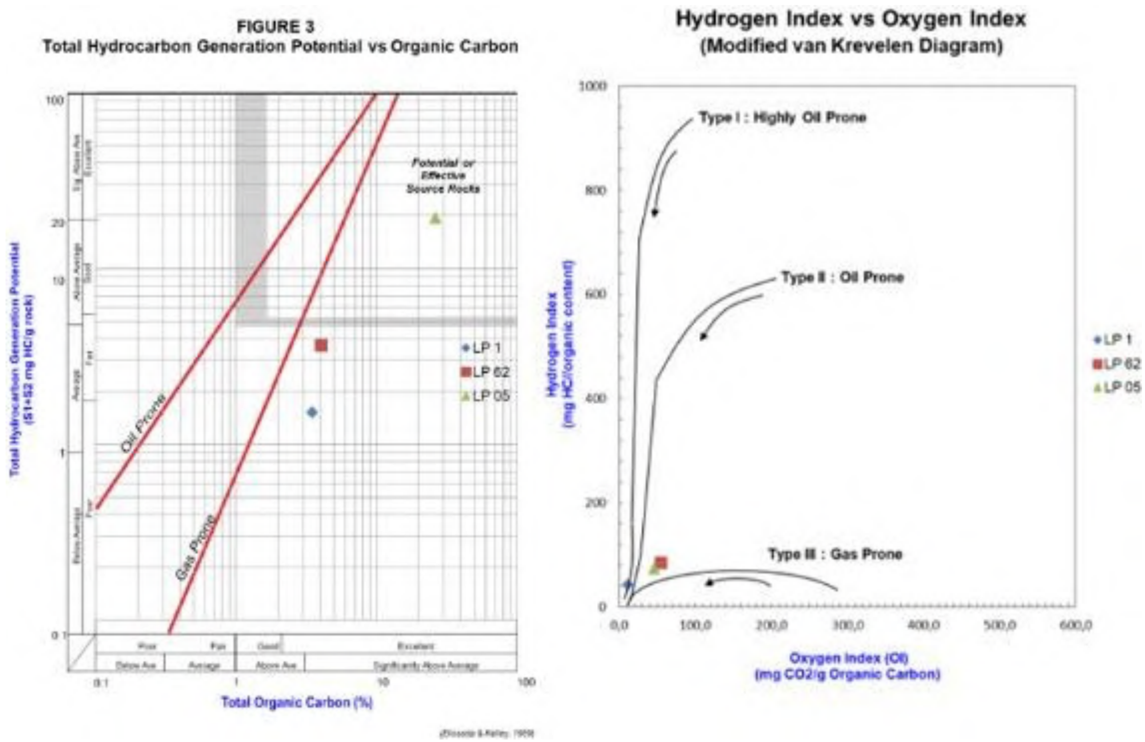

Figure 17. Diagram of Total Organic Carbon (TOC) versus Potential Yield (PY) content (left). Cross plot between Oxygen Index (OI) and Hydrogen Index (HI) values (right). All three samples is gas prone.

The hydrogen index (HI) and S2/S3 values were used to assess the kerogen type of the samples, revealing that the organic substance in all three samples is Type III kerogen. This kerogen is mainly composed of humic organic matter from woody plants containing cellulose from terrestrial plants (equivalent to vitrinite in coal) (Waples and Curiale, 1999).

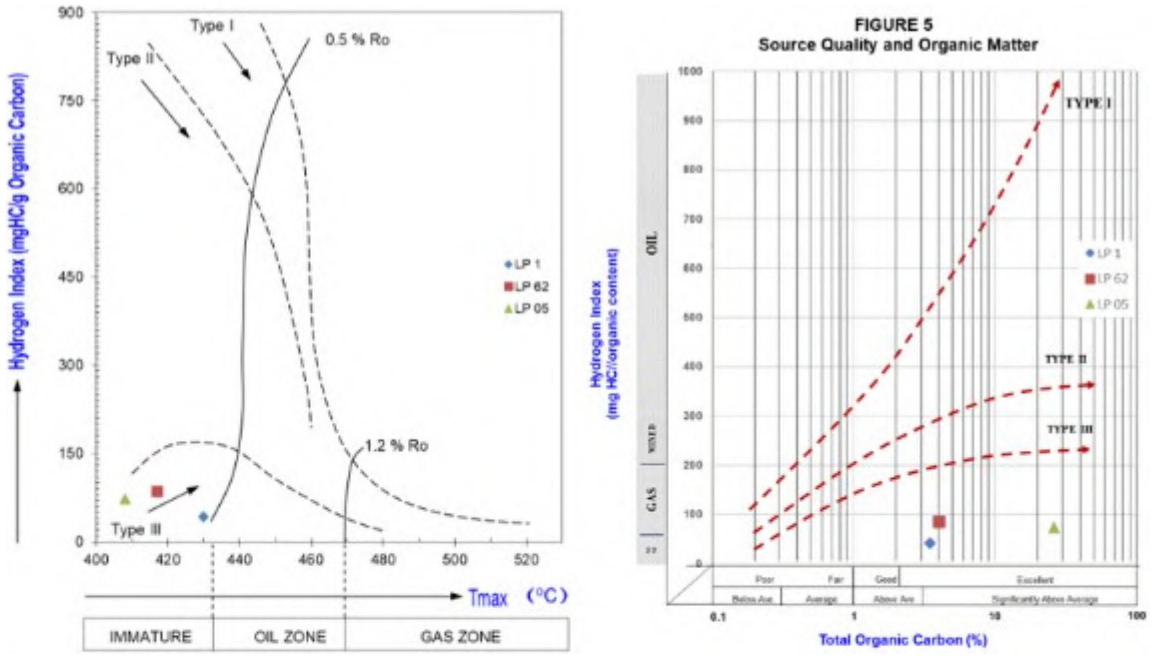

Figure 18. Cross plot between Tmax and Hydrogen Index (HI) values (left). Cross plot between TOC and Hydrogen Index (HI) values (right). The organic material from three samples were all classified as type III kerogen.

The thermal maturity of rock samples was determined using vitrinite reflectance (VR) and Rock-Eval Pyrolysis analyses. From the results of the analysis of vitrinite reflectance in rock samples, values of

<0.5%Ro are obtained. The rock samples are thermally immature to become hydrocarbon source rocks, according to Peters and Cassa (1994) classification of source rock maturity based on vitrinite reflectance value. Meanwhile, Rock-Eval pyrolysis data revealed that the maximum kerogen-breaking temperature for the three samples' was ranged from 408 to 430°C. The rock samples are classified as Immature source rock according to Tissot & Welte (1978)'s Tmax classification and its relationship with the source rock's thermal maturity.

Table 3. Guidlines for quantity, quality and maturity of source rock determination for immature source rocks.

Quantity		TOC	S1 mgHC/g rock	S2 mgHC/g rock
Poor		<0,5	<0,5	<2,5
Fair		0,5 – 1	0,5 – 1	2,5 – 5,0
Good		1 – 2	1 – 2	5 – 10
Very Good		2 – 4	2 – 4	10 – 20
Excellent		>4	>4	>20
Quality		**HI mgHC/g TOC**	**S2/S3 mgHC/g rock**	**Kerogen Type**
-		<50	<1	IV
Gas		20 – 200	1 – 5	III
Oil and Gas		200 – 300	5 – 10	II/III
Oil		300 – 600	10 – 15	II
Oil		>600	>15	I
Thermal Maturity		**VR (%)**	**Tmax (°C)**	**TAI**
Immature		0,2 – 0,6	<435	1,5 – 2,6
Mature	Early	0,6 – 0,65	435 – 445	2,6 – 2,7
	Peak	0,65 – 0,9	445 – 450	2,7 – 2,9
	Late	0,9 – 1,35	450 – 470	2,9 – 3,3
Over mature		>1,35	>470	>3,3

CONCLUSION AND FURTHER RESEARCH

The Nampol clastic limestone unit in the study area is composed of clastic limestone with intercalation of black shale, claystone, siltstone, sandstone and calcareous claystone. Age determination with micropaleontological analysis for this unit concludes that this unit is late Early Miocene to Middle Miocene aged (N8-N12). This unit was deposited in a shallow marine environment or restricted interior platform (lagoonal) carbonate facies zone (Flügel, 2004). This environment has suitable conditions for the deposition of limestone with intercalation of shale, claystone, or siltstone. This intercalation of shale and claystone is expected to have the possibility to became a potential source rock due to their organic matter richness. From the geochemical analysis, it can be concluded that black shale and coal in the Nampol Formation are immature source rocks but have the potential to produce hydrocarbons where at the peak of their maturity, can be predicted its tendency to produce gas. However, it is envisaged that future research would uncover the presence of oil seeps in the Southern Mountains, allowing for the correlation between oil and source rock to be established.

ACKNOWLEDGMENT

The authors would like to thank the Institute for Research and Community Service at Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia, for providing funds for this research.

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