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Organic Thermal Maturity Based on Color Index of Halang Formation, Banyumas Basin, Central Java, Indonesia

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ABSTRACT - Analysis of palinomorfs and foraminfera fossils was carried out on two samples taken from the claystone layer of the Halang Formation. This analysis was conducted to evaluate the thermal maturity of the sample as well as to determine its age and depositional environment. Both samples contained poor amounts of pollen, spores, dinnoflagellate and diatom, but they contained very abundant foraminifera. Pollens, spores, dinnoflagellates and diatom in these two samples were mostly black or blackish, gray to dark brown in color. The color of the foraminifera tests also mostly dark gray. No index fossils were found in the pollen assemblages. However, the presence of *Spinizonocolpites echinatus*, *Monoporites annulatus* and *Pinuspollenites* type indicates the samples are not older than the Paleocene. The foraminifera assemblage in both samples indicates that the age of the samples is Early Pliocene. The lack of pollen grains and spores and the abundance of foraminifera indicate that the depositional environment of the two samples was offshore. The presence of *Melonis pompiliodes*, *Cibicidoides wuellerstorfi*, and *Bulimina affinis* indicates that these samples were deposited in a lower slope/lower bathyal environment. The color of the pollen, spore, dinoflagellate, diatom, and foraminifera fossils indicates the degree of thermal maturity of the samples have reached a mature or dry gas (barren) level. The high level of thermal maturity of relatively young Halang Formation is supposed to be related to the presence of post-depositional volcanic activities.

Keywords: halang formation, pollen, spores, thermal alteration, thermal maturity index.

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INTRODUCTION

Based on the Geological Map of the Majenang Sheet with a scale of 1:100,000 (Kastowo & Suwarna 1996), the Pangandaran Sheet (Simandjuntak & Surono 1992), the Banyumas Sheet (Asikin et al. 1992) and LEMIGAS (2005), the Banyumas Basin is composed of Oligocene to Pliocene rock Formations. Several previous reports discussed the possibility of a hydrocarbon system in the Banyumas Basin (e.g., Muchsin et al. 2002; Noeradi et al. 2006;

Satyana 2006; Subroto et al. 2006; Armandita et al. 2009). Mulhadiyono (1973), (LEMIGAS 2005), and Armandita et al. (2011) presumed the Gabon/Jambang Formation, Kalipucung Formation, and the Rambatan Formation as reservoir rocks for hydrocarbons, indicated by the presence of some hydrocarbon seepages. However, the source rock for the hydrocarbon system in this basin needs to be better recognized. The main problem in determining source rock in this basin is that the distributions of biomarkers of Paleogene and Neogene rock formations are comparable (Subroto et al. 2007). The lack of geochemical data is one of the reasons for the poor understanding of the petroleum system in the Banyumas Basin. Subroto et al. (2007) excluded the possibility of the Halang Formation as the source rock even though the Halang Formation bears the best resemblance of biomarkers to the hydrocarbon seeps found in the Banyumas Basin. Subroto assumed that the Halang Formation would still need to reach a sufficient level of thermal maturity due to its relatively young geological age. Instead, he concluded that the hydrocarbon source rock in the Banyumas Basin is the Middle to Late Eocene Wungkal Formation, which has characteristics similar to those of the Halang Formation.

The Halang Formation is a pile of turbidite sediments deposited from the bottom to the middle of an underwater fan (Setiawan 2018). This formation consists of alternating sandstone, claystone, marl, and tuff, with breccia insertions. The bottom of this formation is composed of calcareous sandstone with marl and breccia inserts. The middle part consists of alternating calcareous sandstones and marl, with breccia, calcarenite, and tuff inserts. The upper part comprises calcareous sandstone with insertions of tuff, breccia/conglomerate sandstone, siltstone, and marl. Foraminifera plankton are found in marl layers at the bottom and top of this formation. Foraminifera fossil assemblages at the bottom of this formation indicate Late Middle Miocene to Early Late Miocene (N15 and N16) ages. Foraminifera assemblages at the top of this formation show the age of the Late Miocene to Early Pliocene. Thus, the age of the Halang Formation is Late Miocene to Early Pliocene (N15 – N18). Based on the benthic foraminifera assemblages, this formation is supposed to have been deposited in the upper bathyal environment. However, Asikin et al. (1992) and (Kastowo & Suwarna 1996) argue that the depositional environment of this formation is a shallow open sea (neritic). The Kumbang Formation and Tapak Formation were unconformably deposited on the Halang Formation.

Despite the Halang Formation's relatively young geological age, the increasing post-Mio-Pliocene volcanic activities might have facilitated its thermal maturity, as (Armandita et al. 2009) discussed. The hydrothermal process or the overburden of volcanic materials due to these volcanic activities might have played a role in the thermal maturity of hydrocarbons in the Halang Formation. Fossil color index will be applied to assess the thermal maturity of Halang Formation. Fossil color index has been widely used as an indicator in determining the level of thermal maturity based on thermal alteration (e.g., Spina et al. 2018; Jiang et al. 2016; Goodhue & Clayton 2010; Pross et al. 2007; Yule et al. 2000; Marshall & Yule 1999; Haseldonckx 1979). This research generally aims to identify traces of thermal maturity of rocks in microfossil discoloration. Specifically, this study aims to determine the level of thermal maturity of the Halang Formation based on the color index of foraminifera and palynomorphs. Moreover, the age and depositional environment of the Halang Formation were also reassessed based on fossils of foraminifera and palynomorph assemblages.

METHODOLOGY

The geology of the study site is composed of Halang Formation, Kumbang Formation, Tapak Formation, and alluvial deposits. Several studies have reported the presence of gas seepage around the site (e.g. Hadimuljono & Yensusnimar 2021; Sutadiwiria et al. 2022). Near the study site, a gas seepage was found (Figure 1). The sample for this study was taken from a stratigraphic profile of the Halang Formation exposed in Gunung Wetan Village, Jatilawang District, Banyumas (Figure 1).

The Halang Formation outcrop was observed at several points in Gunung Wetan Village, Jatilawang District, Banyumas. The results of these observations are presented as a composite stratigraphy of the Halang Formation (Figure 2). Two samples, 18RL05E and 18RL05 G, were taken for microfossil analysis. Both samples are black organic claystone stratigraphically located above the vesicular basalt lava unit.

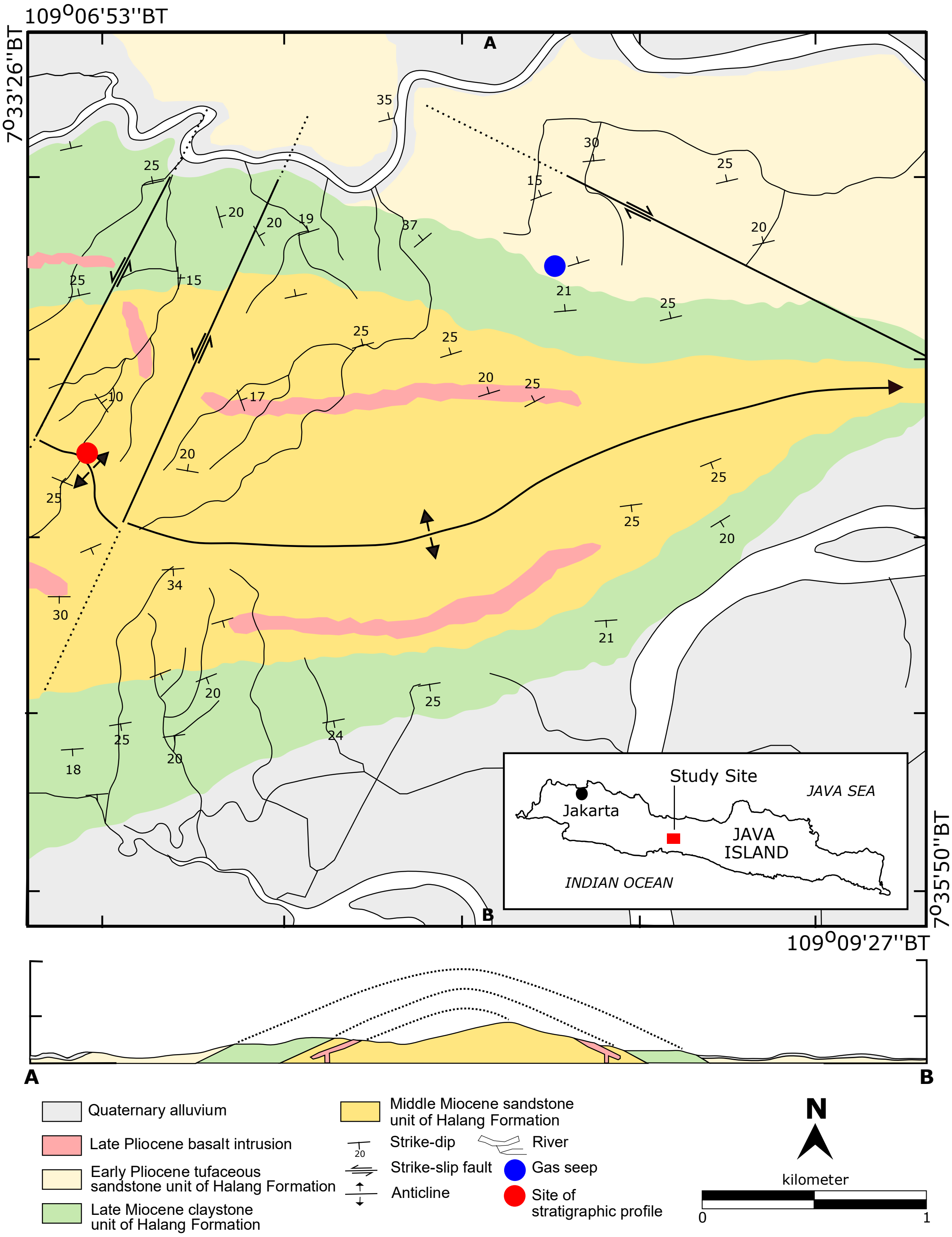

Figure 1
A simplified geological map of the study site (modified from Izati et al., 2013) shows the location of the stratigraphic profile from which samples for this study were collected (red circle).

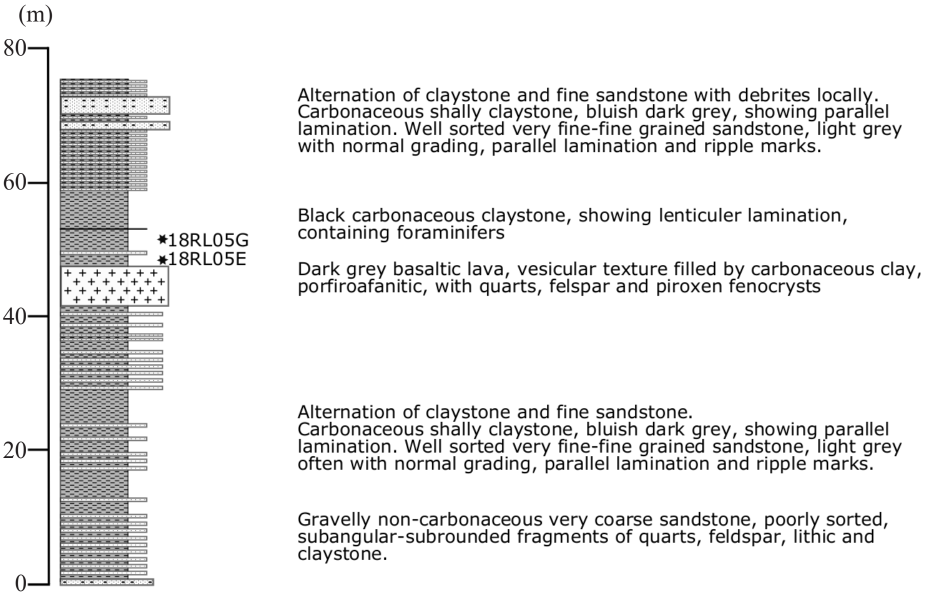

Figure 2
A composite stratigraphic profile of the Halang Formation in the study area (*after* Setiawan 2018).

Both samples were prepared using standard palynological preparation methods. HCl was used to remove carbonate content, HF to remove silica, KOH to remove humic acid, and $ZnCl_2$ to separate light minerals from heavy minerals. The residue is then processed with acetolysis solution, a mixture of H_2SO_4 and $(CH_3CO)_2O$ to remove cellulose. The remaining residue was made into a pollen glass slide using glycerin jelly as a medium. The palynomorph content, including foraminifera lining in one glass slide, was identified and counted for each sample. Pollen and spore identification referred to (Belonzi et al. 2020) and (de Vernal 2014); photographs for each palynomorph specimen were carried out using transmission light using a light microscope with a magnification of 1000x. Photographs of palynomorph specimens were visually compared with the pollen/spore color index chart (TAI-Thermal Alteration Index) developed by (Staplin 1969). Rank assessment of sporomorphs under transmitted light follows (Pearson 1984), expressed as a TAI, from 1 to 4 or 5.

Foraminifera sample preparation was performed using the swirling technique to separate the clay from the sand grains. Foraminifers in both samples were identified under a light microscope. The age of the sample was determined based on the planktic foraminifera fossils. The depositional environment of the sample was estimated based on the assemblage of benthic foraminifers. Photographs using transmitted and reflected light were carried out with an Olympus BX53 light microscope. Foraminifera photographs taken using reflected light were used to evaluate the Foraminifera Color Index (FCI). The FCI follows (McNeil et al. 1996).

RESULT NAD DICUSSION

Foraminifera, Other Fossils and Minerals

The residues of both samples are dark in color, composed of planktonic foraminifera fossils and abundant pyrite minerals, a few small benthic foraminifera, ostracodes, and radiolaria (Figure 3). The sample also comprises lithic fragments, minerals calcite, sulfur, and zircon. The well-preserved foraminifera shells, ostracodes, and radiolaria are dark gray on reflection lighting. With light transmission, the light was still able to penetrate the walls of the test foraminifera, showing only a tiny portion of the foraminifera chambers lled with sediment or minerals (see Figure 3). Foraminifera assemblages consist of juvenile to adult foraminifera. The diversity of foraminifera fossils is relatively high. Both samples have similar types and compositions of grains. Dark sediment or minerals lled some of the foraminiferal chambers. Fourteen planktic foraminifera and three species of benthic foraminifera were identified in both samples (Figure 4). The genus *Globorotalia* is abundant in both samples. We identified several reworked fossils in the two samples: *Rotalia beccarii*, *Lagena* spp., and *Pyrgo* sp.

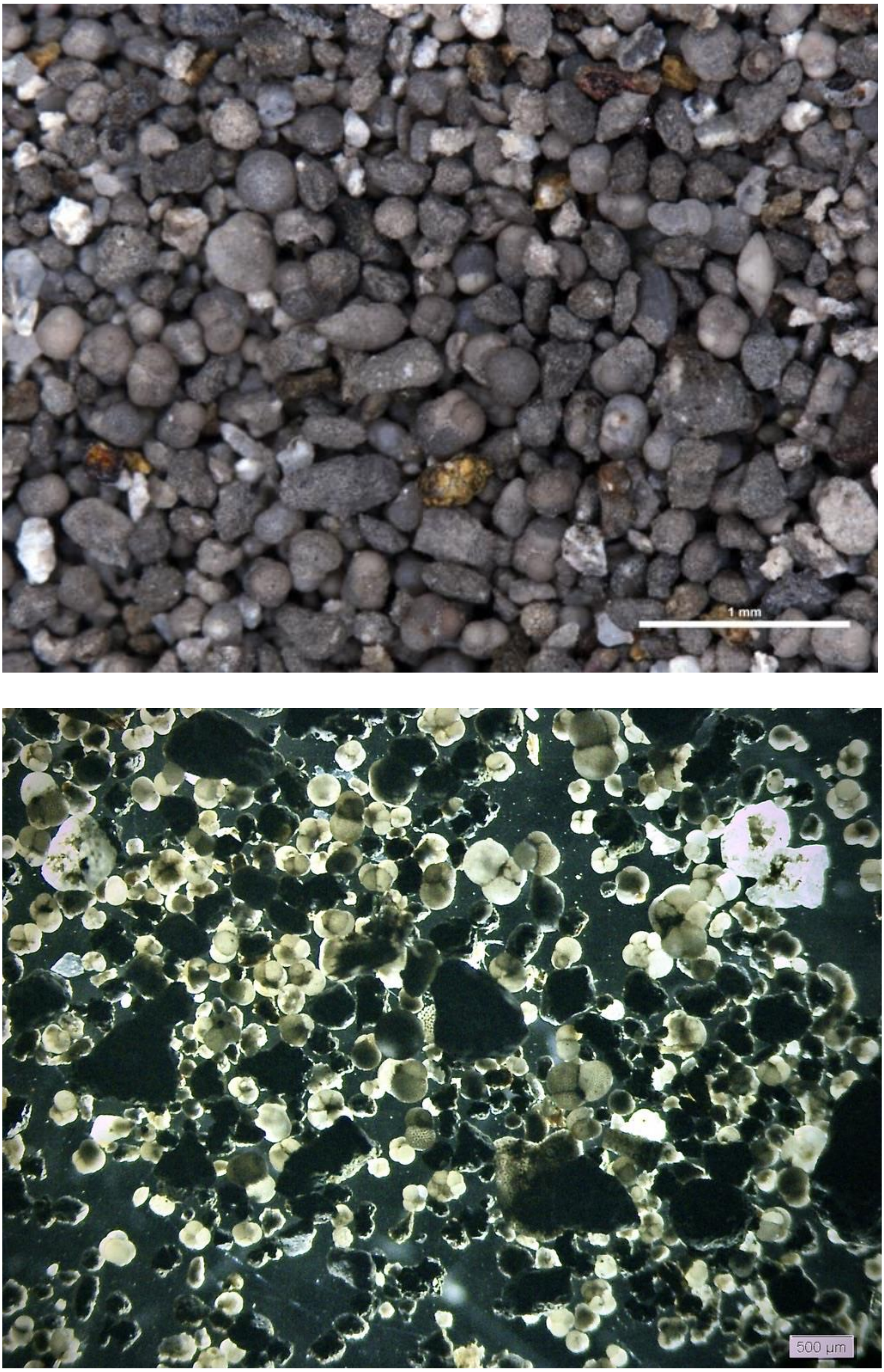

Figure 3
Washed samples photographs were taken under reflection light (above), and transmission light (below).

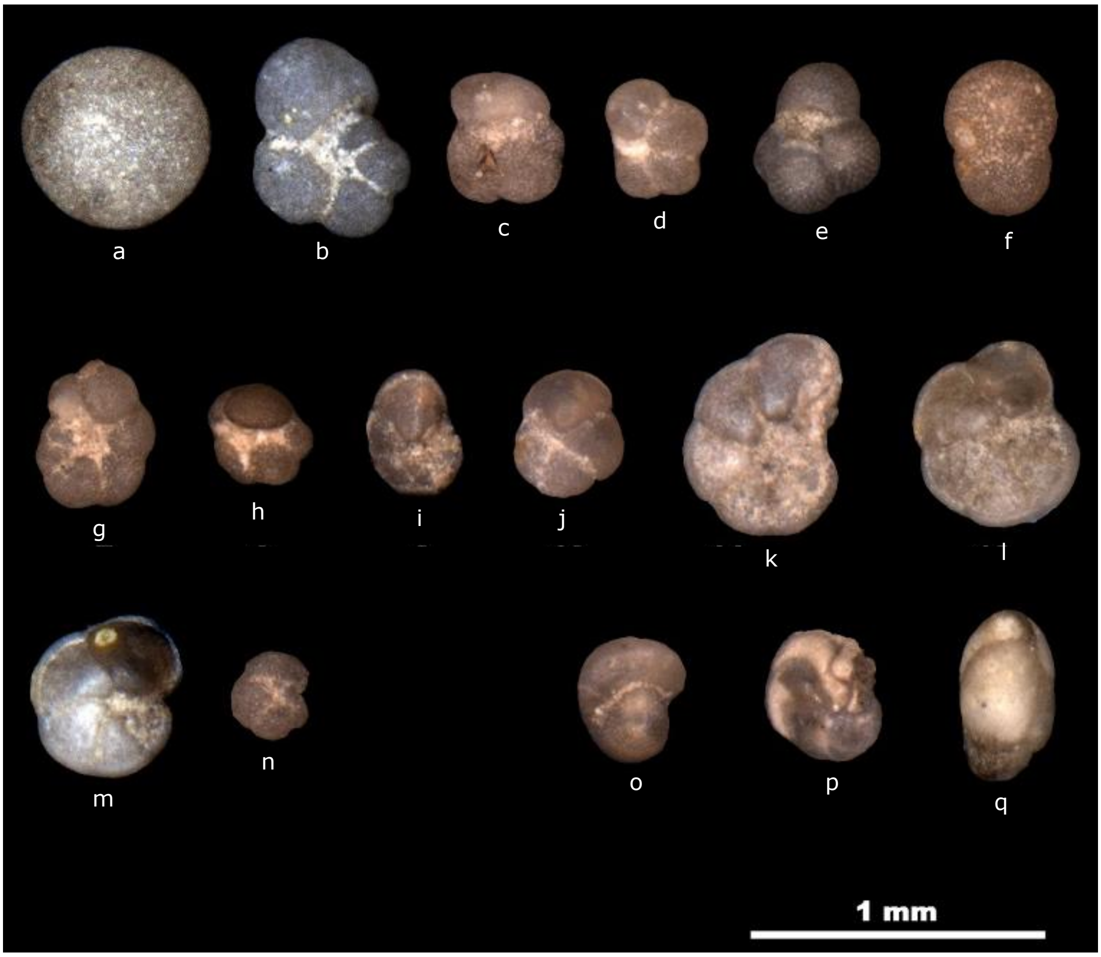

Figure 4
Planktic and benthic foraminifera species present in both samples: a. *Orbulina universa* (d'Orbigny); b. *Hastigerina siphonifera* (d'Orbigny); c. *Globigerinoides obliquus extremus* (Bolli & Bermudez); d. *Globorotalia acostaensis acostaensis* (Blow); e. *Sphaerodinellopsis seminulina* (Schwager); f. *Orbulina bilobata* (d'Orbigny); g. *Globorotalia humerosa humerosa* (Takayanagi & Saito); h. *Globoquadrina altispira altispira* (Cushman & Jarvis); i. *Globorotalia merotumida* (Banner & Blow); j. *Globorotalia scitula* (Brady); k. *Globorotalia plesiotumida* (Banner & Blow); l. *Globorotalia menardii menardii* (Parker, Jones & Brady); m. *Globorotalia pseudomiocenica* (Bolli & Bermudez); n. *Globoquadrina dehiscens* (Chapman, Parr & Collins); o. *Melonis pompilioides* (Fichtel & Moll); p. *Cibicidoides wuellerstorfi* (Schwager); q. *Bulimina affinis* (d'Orbigny).

Palynology

In small amounts, pollen, spores, and diatoms were present in both samples (Table 1). The type of palynomorphs present are *Pinnuspollenites* sp., *Monoporites annulatus* (Gramineaea type), *Spinizonoclopites echinatus* (*Nypa fruticans* type), *Acrostichum aureum* type, *Cyathea* type, *Pteris* type, *Laevigatosporites*, *Verrucatosporites*, *Psilatriporites*, *Poriporapollenites*, unidentified trilete spores, *Botryococcus braunii*, dinoflagellates, diatomae and foraminifera test lining. (Table 1, Figure 5, 6, 7, 8). The count of foraminifera test lining exceeds palynomorp. All observed fossils show dark brown, blackish brown, gray or black colors.

Color Index

Visual evaluation of the color range of the foraminifera fossil assemblage of the Halang Formation based on the FCI chart (above) is presented in Figure 5. The comparison shows that the color range of the assemblage is FCI <7 and mainly in a range of 3-6. This range suggests a % Ro value of ~0.5-1.5, according to (Hartkopf-Fröder et al. 2015). Thus, the FCI data indicates that the thermal maturity of the Halang Formation is at the mature to dry gas/barren level.

Figures 5, 6, 7, and 8 visually compare fossil color with a color index chart. The thermal alteration color index chart used as a reference follows Staplin (1969) after being interpreted by Pearson (1984).

Pollen, spores, dinoflagellates, and foraminifera test linings were present in both samples and showed different colors. The color of pollen and spores was in the range of TAI 3 to 4- with % Ro 1.0-2.0 values. Some pollen and spore specimens are somewhat tricky to colorize but are estimated to have a TAI index between 3 and 3-, as shown in Figure 5 (a.1, b-2, d), Figure 6 (b-1 and b-2), Figure 7 (a-1, c-1, and c-2). The color of the foraminifera test lining is in the Thermal Alteration Index (TAI) range of 3 to 4- with a % Ro 1.0 – 2.0 value. The color of dinoflagellate fossils is in the range of TAI 3 to 4- with % Ro 1.0 – 2.0 values. Thus, we can assume the thermal maturity of the fossils in the two samples is at the mature to dry gas/barren level.

Table 1
Palynomorph fossils in sample 18RL05E and 18RL05G.

Palynomorph Fossil	Total Specimen (grain)	
	Sample 18RL05E	Sample 18RL05G
Pinuspollenites sp.	2	4
Monoporites annulatus (Gramineae type)	3	7
Spinizonocolpites echinatus (*Nypa fructicans* type)	1	2
Acrostichum aureum type	1	1
Cyathea type	2	4
Pteris type	2	6
Laevigatosporites	2	5
Triletsporites	4	-
Periporatepollenites	-	1
Psilatriporites	-	1
Verrucatosporites	-	3
Botryococcus braunii	5	3
Dinoflagelates	-	3
Diatomae	3	-
Foraminefera Test Lining	45	56

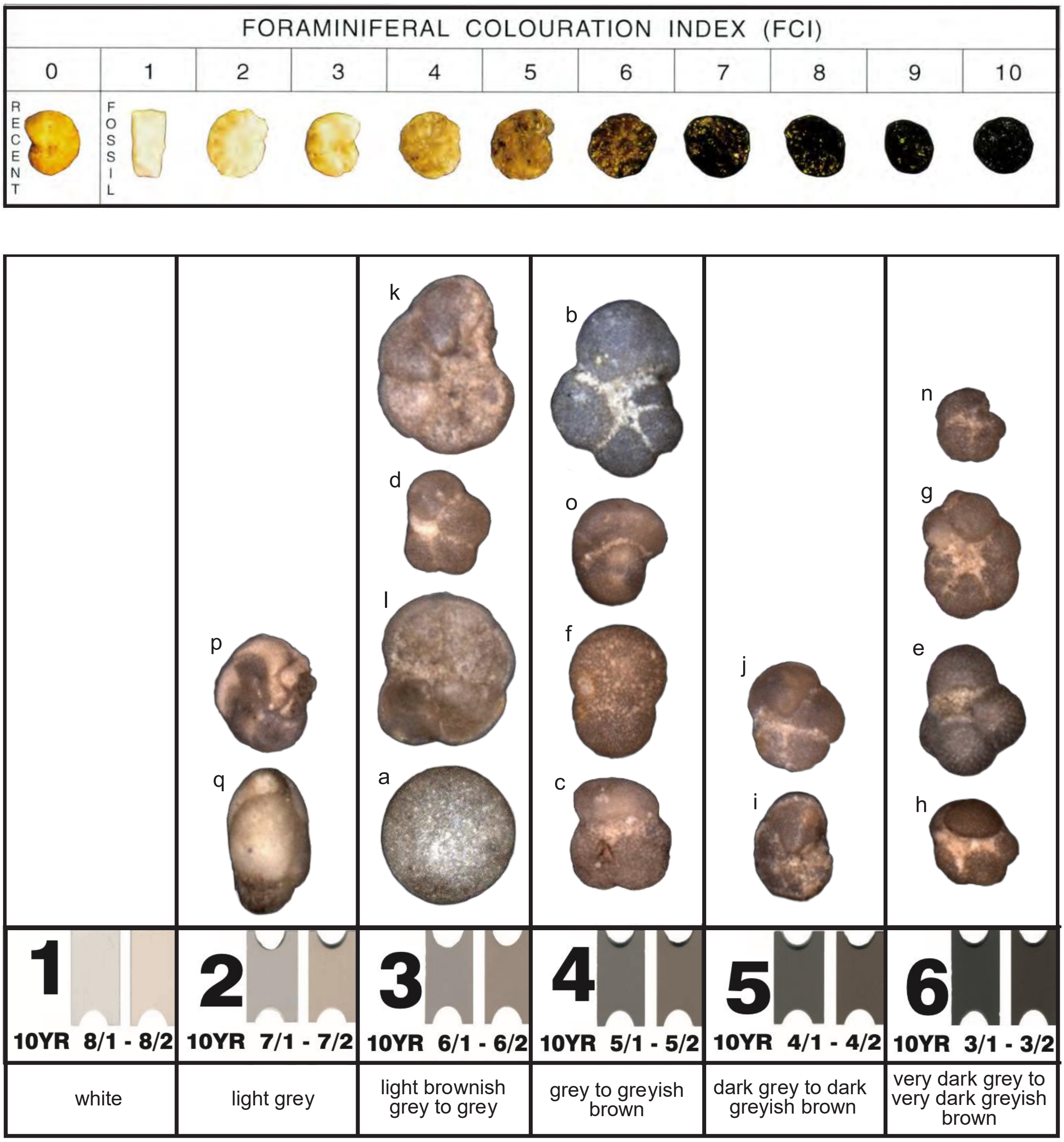

Figure 5
Visual evaluation of foraminifera assemblage of Halang Formation based on FCI chart (above) as suggessted by McNeil et al. (1996). The color range of the assemblage shows FCI <7 and mostly in a range of 3-6. Codes and fossil names are listed in Figure 4.

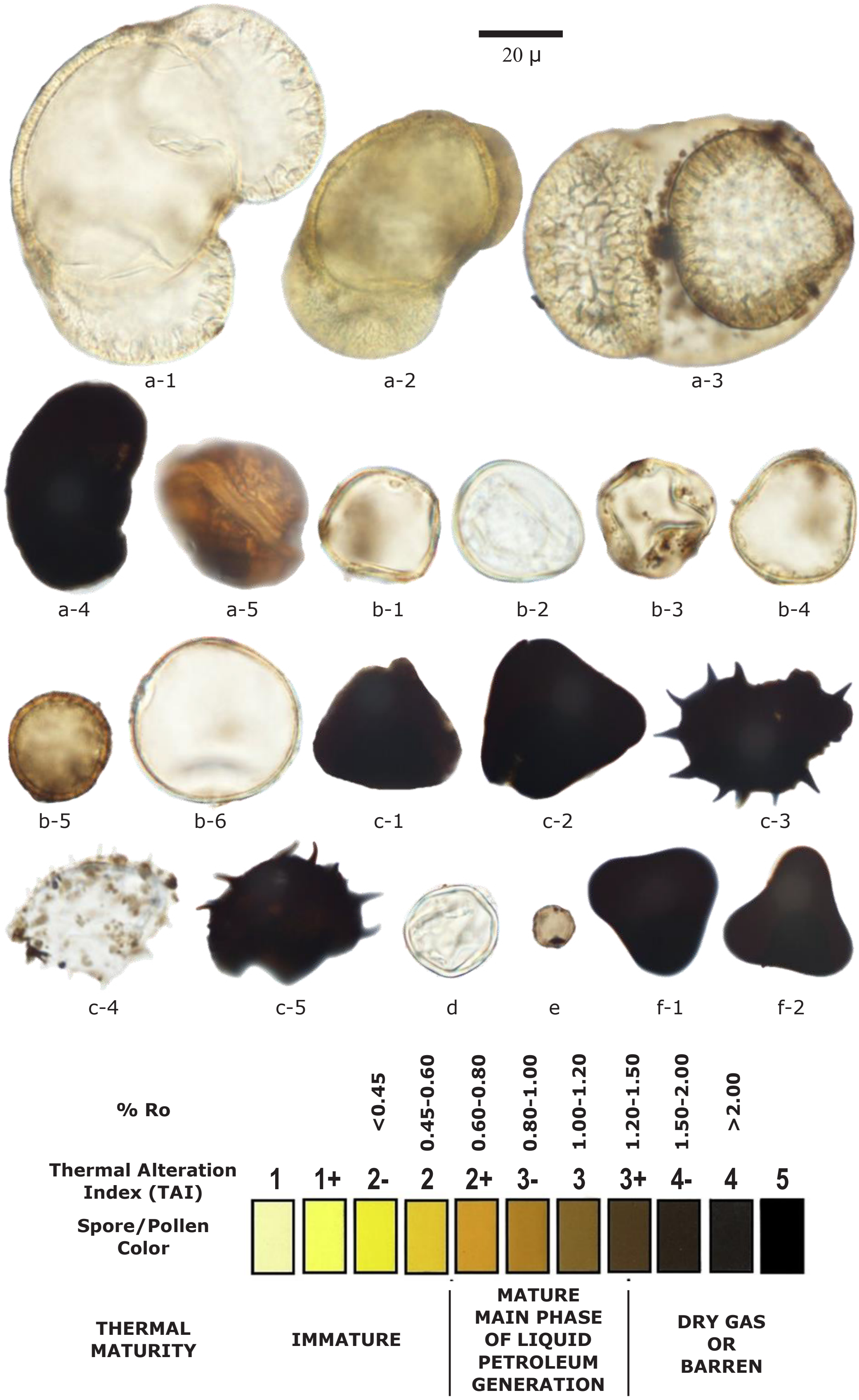

Figure 6
Fossil of pollens, spores, lining foraminifers and dinnoflagellates in sample 18RL05G: (a) *Pinnuspollenites* type, (b) *Monoporites annulatus* type, (c) *Spinizonocolpites echinatus* type, (d-e) unidentified pollen, (f) *Cyathea* type.

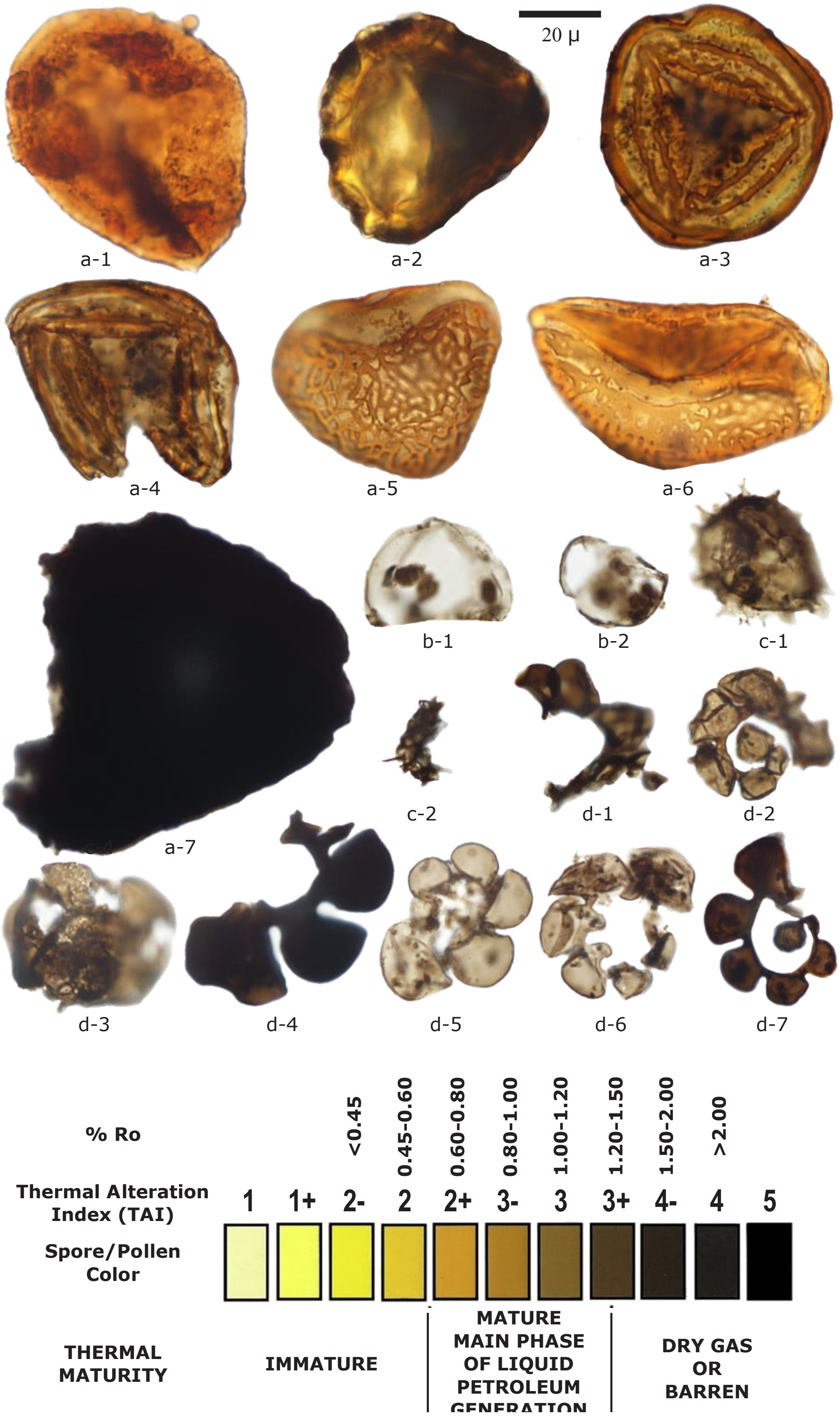

Figure 7
Fossil of pollens, spores, lining foraminifers and dinnoflagellates in sample 18RL05G: (a) *Pteris* type, (b) *Laevigatosporites* type, (c) Dinnoflagellate, (d) Foraminifera lining.

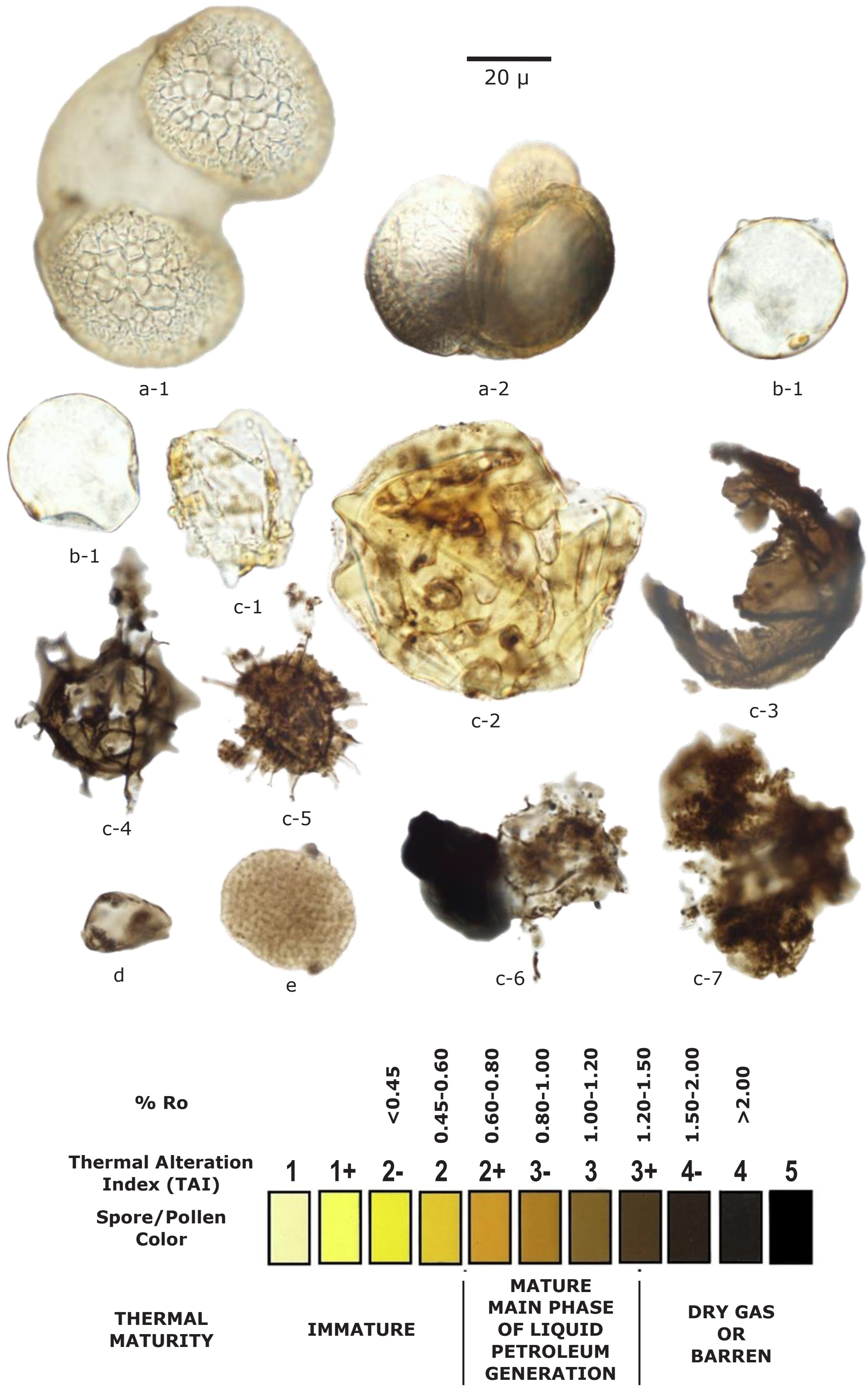

Figure 8
Fossil of pollens, spores, lining foraminifers and dinnoflagellates in sample 18RL05E: (a) *Pinnuspollenites* type, (b) *Monoporites annulatus* type, (c) Dinoflagellates cysts, (e) *Ficus* type, (e) unidentified pollen.

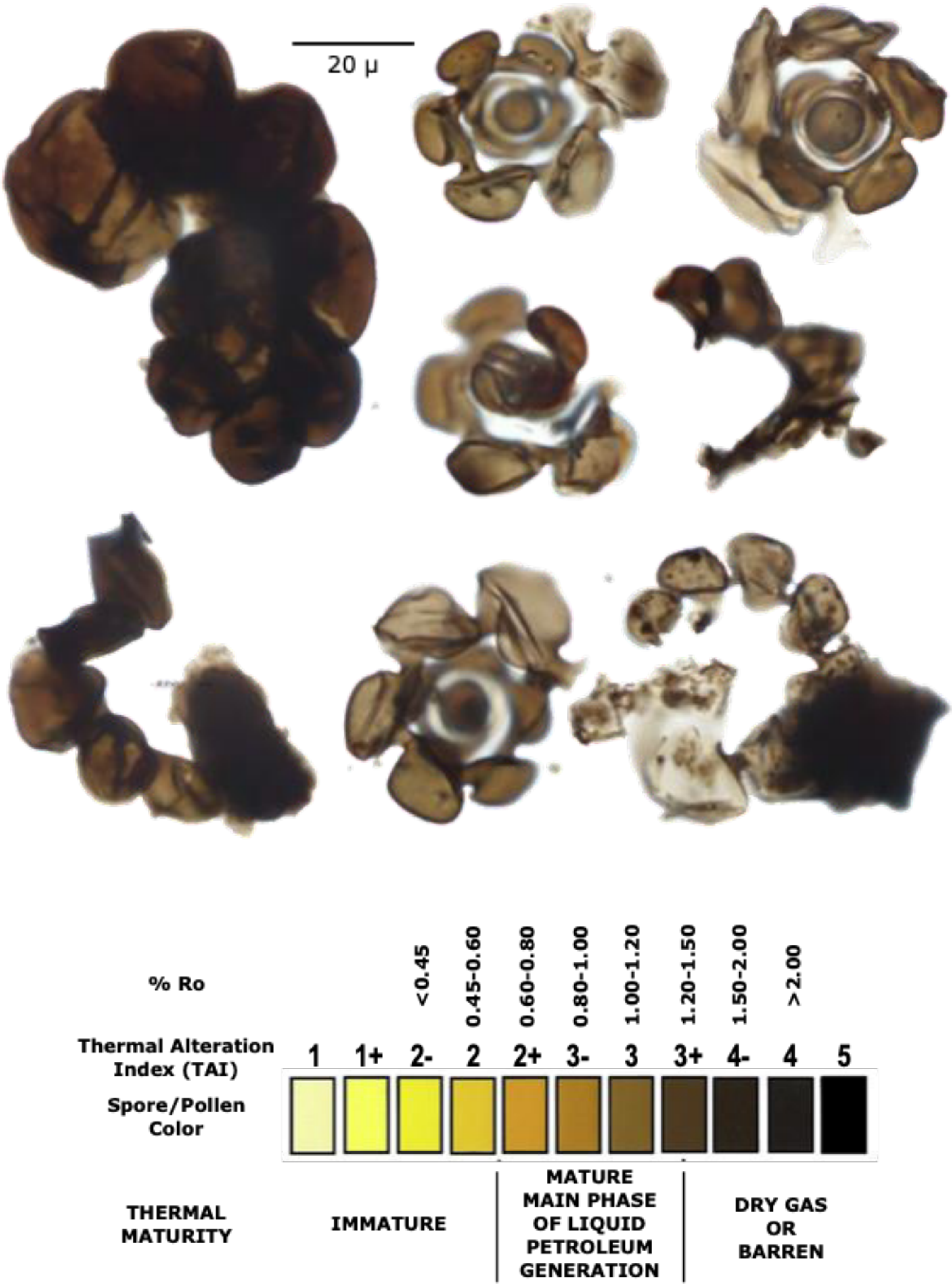

Figure 9
Fossil of lining foraminifers in sample 18RL05E.

Discussion

Age and Depositional Environment

Index pollen fossils were not present in both samples. According to (Morley 1991), the *Monoporites annulatus*, *Spinizonocolpites echinatus*, and *Pinuspollenites* types in both samples indicate an age not older than the Paleocene. The low content of pollen and spores and the abundance of foraminifera test lining indicate an offshore depositional environment. However, the assemblage of planktic foraminifera fossils in sample 18RL05E indicates an Early Pliocene age at the end of zones N17 to N18 (Blow 1969). The assemblage of planktonic foraminifera fossils in sample 18RL05G indicates an Early Pliocene age in the N19 zone (Blow 1969). Thus, both samples were deposited in the Early to Late Pliocene Period in the zone N17-N19. Accordingly, the age of the Halang Formation is Early Pliocene in the N17-N19 zone.

The two samples contained *Melonis pompiliodes*, *Cibicidoides wuellerstorfi*, and *Bulimina affinis*. According to (Rauwerda et al. 1984), the presence of these species indicated a lower slope/lower bathyal depositional environment at a depth of 1000 m.

Halang Formation in the Petroleum System of the Banyumas Basin

In both samples, pollen, spores, dinoflagellates, and foraminifera test lining showed dark color in a glass slide under a transmission light microscope. This color is a trace for post-deposition processes. Two possible processes can be the cause, namely thermal alteration and impurities. Thermal alteration is a term for changes in the physical characteristics of organic materials due to heating and high pressure after deposition. This phenomenon is easily observed in pollen fossils in coal seams (Hartkopf-Fröder et al. 2015; Gutjahr 1966). Impurities are the presence of other material that covers the surface or seeps into the fossil after deposition. Impurities can occur due to the presence of hydrocarbons along with cracking and migration processes. The bitumen covers the surface and seeps into the fossil, lling in the fossil chambers and making the fossil appearance darker. Thermal alteration may occur when a heat source heats the fossil-bearing rocks. The higher the heating temperature, the darker the color of the fossil.

Only fossils with a color index reference can be used as a qualitative indicator of Thermal Maturity. Among others are pollen spores and foraminifera. Staplin (1969) initially proposed pollen and spores' thermal alteration color index. Pollen and spores in both samples have a TAI range of 3 to 4- with % Ro 1.0 – 2.0 values. The pollen and spores TAI in both samples indicate that the Halang Formation might have been in a mature to dry gas level. These values are comparable with the FCI value, which is mainly in a range of 3-6 and implies that despite its young age, Halang Formation might have undergone sufficient thermal heating. What processes might have facilitated this heating?

The presence of pyrite and sulfur minerals in moderate abundance in both samples may be related to the thermal alteration of the fossils. The presence of basalt in the stratigraphic profile (Figure 2) can indicate a heating source if this basalt is a sill. The presence of vesicular structures within the basalt indicates that this basalt is lava. Consequently, after depositing the two samples, the heating source may be related to the volcanism process. Possible related volcanism is volcanism after forming a structural high during the Mio-Pliocene, as (Armandita et al. 2009) discussed. Hydrothermal processes and the overburden of volcanic materials may have facilitated the maturation of the hydrocarbons due to a higher geothermal gradient.

On the other hand, the difference in color of fossils in the same sample may exclude the possibility of thermal alteration as the cause of fossil discoloration. Another process that can cause the discoloration of fossils is impurities caused by hydrocarbons. The possibility of these impurities is indicated by the presence of hydrocarbon seepages around the sampling site (see Figure 1). Indication of impurities also appeared during pollen preparation. The soaked samples extracted the bitumen to oat on top of the water. Thus, the dissimilarity of fossil coloration supports the occurrence of the post-depositional impurities process rather than heat alteration. In the case of fossils, differences in the absorption capacity of each fossil to impurities can cause color differences. If this is the case, the dark colors of the palynomorph fossils and the foraminifera test linings further indicate that part of the Halang Formation may have become reservoir rock.

CONCLUSION

The age, depositional environment, and thermal maturity of the Halang Formation have been evaluated based on foraminifera and pollen-spore assemblages. This evaluation suggests an age of Early Pliocene (N17-N19 zone) and a depositional environment of 1000 m below the sea level of the Halang Formation. The pollen-spore assemblage suggests a TAI value of 3 to 4- with a % Ro of 1.0-2.0. The foraminifera assemblage suggests an FCI value of 2-6 with a % Ro of 0.5-1.5. These suggest the thermal maturity of the Halang Formation is at the mature to dry gas/barren level.

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GLOSSARY OF TERMS

Symbol	Definition
TAI	Thermal Alteration Index
FCI	Foraminifera Colour Index
%Ro	Vitrinite Reflectance
HCl	Hydrogen Fluoride
HF	Hydrofluoric Acid
KOH	Potassium Hydroxide
$ZnCl_2$	Zinc Chloride
H_2SO_4	Sulfuric Acid
$(CH_3COO)_2O$	Acetic Anhydrite

REFERENCES

Alaug, A.S., 2010, Source rocks evaluation, hydrocarbon generation and palynofacies study of late cretaceous succession at 16/G-1 offshore well in Qamar Basin, eastern Yemen. Arabian Journal of Geosciences. DOI 10.1007/s12517-010-0182-6.

Armandita, C., Mukti, M.M. & Satyana, A.H., 2009, Intra-arc trans-tension duplex of Majalengka to Banyumas area : prolific petroleum seeps and opportunities in West-Central Java border. Proceedings, Indonesian Petroleum Association, Thirty-Third Annual Convention & Exhibition, IPA09-G-173.

Armandita, C., Satyana, A.H., Mukti, M.M. & Yuliandri, I., 2011, Trace of the translated subduction in Central Java and its role on the Paleogene basins and petroleum system development. Proceeding JCM Makassar, The 36th HAGI and 40th IAGI Annual Convention and Exhibition.

Asikin, S., Handoyo, A., Prstistho, B. & Gafoer, S., 1992, Geologic Map of Banyumas Quadrangle, Jawa. Pusat Penelitian dan Pengembangan Geologi, Bandung, Indonesia.

Bellonzi, T.K., Dutra, F.V., de Souza, C.N., Rezende, A. A. & Gasparino, E.C., 2020, Pollen types of Sapindaceae from Brazilian forest fragments: apertural variation. Acta Bot. Bras., 34(2).

Blow, W.H., 1969, Late Middle Eocene to Recent Planktonic Foraminifera Biostratigraphy. Conv Planktonic Micro Fossils, Leid Nederland, E.J., Vol 1, Geneva.

De Vernal, A., 2014, Palynology (Pollen, Spore, etc). Encyclopedia of Marine Geosciences, 1-11.

Goodhue, R. & Clayton, G., 2010, Palynomorph Darkness Index (PDI) – a new technique for assessing thermal maturity. Palynology 34, 147-156.

Gutjahr, C.C.M., 1966, Carbonization meaurements of pollen-grains and spores and their application. Leidse Geologische Mededelingen, Vol. 30, 1-29.

Hadimuljono, J.S. & Yensusnimar, D., 2021, Heavy oil seepage characteristic in Cipari area, Banyumas Central Jawa. Scientific Contributions Oil & Gas, Vol. 44(3), 161-171.

Hartkopf-Fröder, C., Königshof, P., Littke, R. & Schwarzbauer, J., 2015, Optical thermal maturity parameters and organic geochemical alteration at low grade diagenesis to anchimetamorphism: A review. International Journal of Coal Geology 150–151, 74–119.

Haseldonckx, P., 1979, Relation of palynomorph color and sedimentary organic matter to thermal maturation and hydrocarbon generating potential.

CCOP Technical Bulletin 6, 41-53.

Izati, C.N., Putra, A.H.A., Gibran, A.K., Saputro & S.D. Karunia, W.O., 2013, Distribution of gas seep near subsurface and its type using electrical method and geochemical análisis in Jatilawang, Banyumas. Proceedings, Indonesian Petroleum Association, Thirty-sevent Annual Convention & Exhibition, IPA13-SG-115.

Jiang, D., Robbins, E.I., Wang, Y. & Yang, H., 2016. Spore/Pollen Fossil Coloration and Petroleum Source Rock Quality. In: Jiang, D., Robbins, E.I., Wang, Y., Yang, H. (Eds.), Petrolipalynology. Springer Berlin Heidelberg, 123-127.

Kastowo & Suwarna, N., 1996, Geological Map of the Majenang Quadrengle, Jawa, skala 1:100.000. Pusat Penelitian dan Pengembangan Geologi, Bandung.

Lemigas, 2005, Summary on Petroleum Geology of Indonesia's Sedimentary Basins, Prepared for Patra Nusa Data. Jakarta.

Marshall, J.E.A. & Yule, B.L., 1999, Spore color measurement. In: Jones, T.P., Rowe, N.P. (Eds.), Fossil Plants and Spores: Modern Techniques. Geological Society, London, 165-168.

McNeil, D.H., Issler, D.R. & Snowdon, L.R., 1996, Colour alteration, thermal maturity, and burial diagenesis in fossil foraminifers, Ottawa, Geological Survey of Canada Bulletin 499, 34p.

Morley, R.J., 1991, Tertiary stratigraphic palynology in Southeast As.ia: current status and new directions. Geol. Soc. Malaysia, Bulletin 28, 1-36.

Muchsin, N., Ryacudu, R., Kunto, T.W., Sribudiyani, Yulihanto, B., Wiyanto, B., Nurjayadi, A. Rahardjo, K. & Riandra, F., 2002, Miocene hydrocarbon system of the southern Central Java region. Proceedings the 31st Annual Convention of Indonesian Association of Geologists, 58-67.

Mulhadiyono, 1973, Petroleum Possibilities of The Banyumas Area. Jakarta, Indonesian Petroleum Association (IPA).

Noeradi, D., Subroto, E.A., Wahono, H.E., Hermanto, E. & Zaim, Y., 2006, Basin evolution and hydrocarbon potential of Majalengka-Bumiayu transpression basin, Java Island, Indonesia. Proceedings AAPG International Conference and Exhibition, Perth. Soft file CD version.

Pearson, D.L., 1984, Pollen/Spore Color Standard, Version #2. Phillips Petroleum Company, Exploration Project Sec- tion. Bartelsville, Oklahoma.

Pross, J., Pletsch, T., Shillington, D. J., Ligouis, B., Schellenberg, F. & Kus, J., 2007, Thermalalteration of terrestrial palynomorphs in mid-Cretaceous organic-rich mudstones intruded by an igneous sill (Newfoundland Margin, ODP Hole 1276A). International Journal of Coal Geology, 70, 277-291.

Rauwerda, P.J., Morley, R.J. & Troelstra, S.R., 1984. Assessment of Depositional Environment and Startigraphy on the Basis of Foraminiferal Paleoecology. Robertson Research Private Limited, Singapore.

Satyana, A.H., 2006, New insight of Tectonics of Central Java, Indonesia and its petroleum implications. Proceedings AAPG International Conference and Exhibition, Perth. Soft file CD version.

Setiawan, R., 2018, Laporan Internal Pendahuluan. Pusat Survei Geologi, Badan Geologi.

Simandjuntak, T.O. & Surono, 1992, Geologic Map of Pangandaran Quadrangle, Jawa. Bandung. Pusat Penelitian dan Pengembangan Geologi, Bandung, Indonesia.

Spina, A., Vecoli, M., Riboulleau, A., Clayton, G., Cirilli, S., Michele, A.D., Marcogiuseppe, A., Rettori, R., Sassi, P., Servais, T. &Riquier, L., 2018, Application of Palynomorph Darkness Index (PDI) to assess the thermal maturity of palynomorphs: A case study from North Africa. International Journal of Coal Geology, 188, 64-78.

Staplin, F.L., 1969, Sedimentary organic matter, organic metamorphism and oil and gas occurrence. Bull. Canadian Petroleum Geology 17, 47–66.

Subroto, E.A., Wahono, H.E., Hermanto, E., Noeradi, D. & Zaim, Y., 2006, Re-evaluation of the petroleum potential in Central Java Province, Indonesia: Innovative approach using geochemical inversion and modelling. Proceedings AAPG International Conference and Exhibition, Perth. Soft file CD version.

Subroto, A.S., Noeradi, D., Priyono, A., Wahono, H.E., Hermanto, E., Praptisih & Santoso, K., 2007, The Paleogene Basin within the Kendeng Zone, Central Java Island, and implications to hydrocarbon prospectivity. Proceedings, Indonesian Petroleum Association Thirty-first Annual Convention & Exhibition, IPA07-G-091.

Sutadiwiria, Y., Purwasatriya, E.B., Cahyaningratri, P.R., Syavitri, D., Maulani, M., Giovany, A.A. & Ramadhan, A.K., 2022, Scientific Contributions Oil & Gas, Vol. 45(3), 153-167.

Yule, B.L., Roberts, S. & Marshall, J.E.A., 2000, The thermal evolution of sporopollenin. Organic Geochemistry 31, 859–870.