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Characteristics of Carbonate Facies and Depositional Environment of Tapak Formation in the Ajibarang Area, Central Java, Indonesia

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***Abstract*—The limestone of Tapak Formation is well exposed in the Ajibarang area and its surroundings, Central Java, Indonesia. Very intensive mining activity is a very serious threat to this limestone. Hitherto, the geological study on this limestone is still very limited. The objective of this study was to investigate the characteristics of these limestone facies and their sedimentation. This research consists of field and laboratory (petrography and micropaleontology) analysis. The results showed that the limestone of the Tapak Formation consisted of three facies: planktonic packstone, algal foraminifera packstone, and foraminifera algal packstone. Planktonic packstone facies are composed of bioclastic fragments in a micro matrix. The fragments were dominated by planktonic foraminifera consisting of a genus of *Globigerina, Globigerinoides, Globorotalia,* and *Orbulina*. Benthic foraminifera and radiolarians were also identified. Sedimentation from planktonic packstone facies was estimated to occur in the deep marine environment. Algal foraminiferal packstone facies are composed of bioclastic fragments in a micro matrix. Large algae and large foraminifera dominated the fragments. Algae were from the type of red algae, consisting of *Lithophyllum, Corallina, and Rhodolite.* Foraminiferal algal packstone and algal foraminiferal packstone that were observed in the studied area were characterized by the abundance of large foraminifera and interpreted to be deposited in the upper reef slope. We interpreted that the limestone in the study area was deposited in the upper reef slope to the lower reef slope environments. We hope that the information we provided here is useful for petroleum system study in Central Java, Indonesia.**

***Keywords*—Limestone; facies; sedimentation; Tapak Formation Ajibarang Indonesia.**

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I. Introduction

In the southwest of Ajibarang City, Central Java, the limestone of Tapak Formation is exposed up to around 7.5 km in length. The existence of limestone in this area gives a significant aspect to the surrounding community by utilizing it as raw material for building the foundation. The geology of this limestone, however, has not been intensively studied. For this reason, a limestone study in this area was carried out to determine the characteristics of limestone, including the types of facies and their sedimentation. Fauzielly and Hamdani [1] studied the depositional environment of the limestone-based on the Ca and Mg content and concluded that the type of calcite carbonate was deep marine sediments. Tapak Formation can be divided into two parts [2]. The upper part of the Tapak Formation is composed of reef and clastic limestone, with the lower part of the Tapak Formation is composed of intercalation of sandstone and siltstone. Amin [3] identified that the depositional environment of Tapak Formation ranged from tidal to deep marine. Based on sedimentary facies and microfossil content, Rizal [4] identified that the upper part of the Tapak Formation is characterized by alternating sandstone, siltstone, and mudstone, with fining and thinning upward sequence. Rizal [4] also identified that the sandstone of the upper part of the Tapak Formation could play as reservoir potential, as this sandstone has 10 to 15% porosity. Ma'arif [5] studied the lower part of the Tapak Formation and identified it was deposited as part of the deep sea levee and middle fan channel. The detailed information and history of hydrocarbon exploration in the Tapak Formation is still not adequate [4]. This study on the limestone of the Tapak Formation will provide more information about the petroleum system in Central Java, Indonesia.

Everywhere in the world, carbonate facies study is very important not only for the petroleum system (e.g. [6]–[11]) but also for hydrology and climate history [12], [13]. This highlights the necessity of this carbonate facies study of the Tapak Formation. In Indonesia, there were some carbonate facies and sedimentation studies. For example, the Tertiary carbonate reefs in the Madura Strait were primarily influenced by the tectonic framework [14]. Fifariz [15] studied the carbonate shelf evolution of the Kujung Formation. The shallow carbonate of the Parigi Formation was identified as underground gas storage [16]. The sediment composition and facies of coral reef islands in the SW Sulawesi were studied by Jansen [17]. Meanwhile, the modern isolated carbonate platforms in the Kepulauan Seribu Complex were studied by Utami [18], [19], and they found that the carbonate platforms are composed of four facies. Recently, Utami [20] studied the mineralogic and isotopic fingerprint of equatorial carbonates with the study case from the Kepulauan Seribu Complex.

The integration of biostratigraphy and seismic reservoir characterization was used by Gold [21] to identify the carbonate platform facies in eastern Indonesia. The depositional model of carbonate facies in the Salawati Basin was studied by Silalahi [22] using seismic interpretation. In NW Borneo, 3D seismic and geomorphology were used to identify the development of isolated carbonate platforms [23]. In the Bird's Head Region, West Papua, the carbonate drowning successions was studied intensively by Gold [24].

The research area in the Banyumas sub-basin is regionally situated in a basin system bounded by two horizontal fault structures, namely the Karangbolong Fault and the NW-SE trending Gabon Fault [21], [25]. Regionally, the other structure that bounded this basin was the Miocene NE - SW normal fault (half-graben). The development of this graben was started by regional tectonics at the end of the Oligocene, where it was preceded by a horizontal fault movement directed at NW-SE [25].

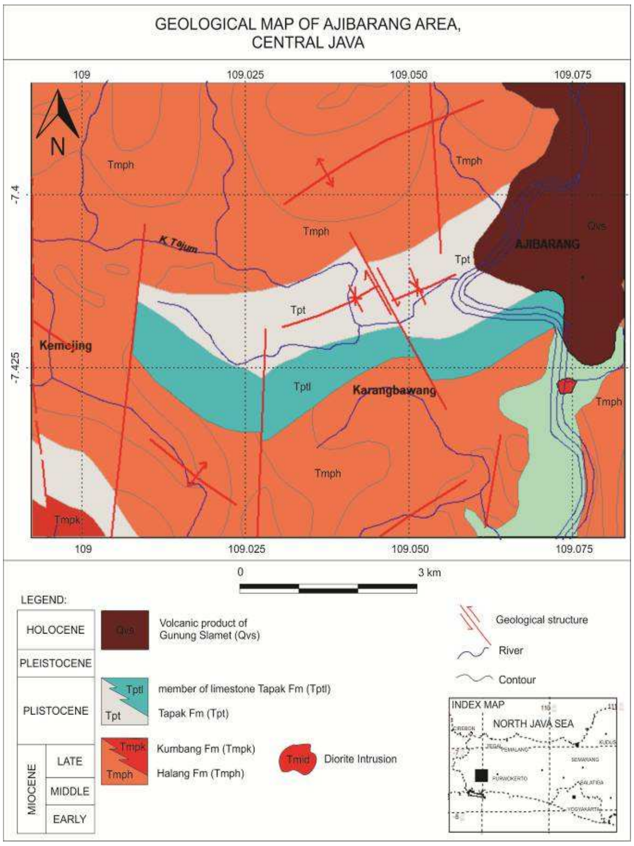

Fig. 1 Geological map of Ajibarang areas and surrounding [2].

Based on the geological map of the Purwokerto area ([2], Fig. 1), the oldest rock in the study area is the Halang Formation (Tmph) that consists of andesitic sandstones, tuffaceous conglomerates, and marls. Based on planktonic foraminifera, the age of this formation was Middle Miocene. In some areas, the Tapak Formation was deposited interfingering with the Halang Formation. The upper part of the Tapak Formation consists of limestone, sandstone, and green marl with pieces of mollusks. Tapak Formation is Pliocene aged [2]. The volcanic product of Selamet Volcano (Qvs) is the youngest rock in the study area and consisting of volcanic breccias, lavas, and tuffs.

II. Materials and Method

The research design used is field observation and limestone sampling for petrographic and micropaleontological analysis. During the field observations, measured sections of Tapak Formation limestone were conducted in Karangbawang, Darma, and Kemojing areas. Spot observations were conducted at specific locations in Darma, Darma Kradenan, and Kemojing. Table 1 showing the detailed name of the measured section and spot location.

TABLE I
DETAIL OF MEASURED SECTIONS AND SAMPLING LOCATIONS AND THE FACIES NAME AT EACH SITE

No	Location	Transect	Name of site	Facies
1	Karangbawang	MS1	KB1A, B, C	Planktonic Packstone
2	Darma	MS2	DR1, 2, 3 DR1A, B, C, D, E	Planktonic Packstone
		-	DA1,2,3,4	
3	Kemojing	MS3	KJ1,2,3	Foraminifera Algal Packstone
			KJ4,5,6,7,8	Algal Foram Packstone
			KM1,2	
		-	KM3	Planktonic Packstone
4	Darma Kradenan	-	DR2,3,4,5,6,7, 8	Planktonic Packstone

The locations of measured section and spot sampling locations can be seen in Fig. 2. The total samples for laboratory analysis were 33. For micropaleontological analysis, foraminifera were microfauna used as an indicator in this study. Analyzes were performed using standard methods, which using a solution of hydrogen peroxide (H_2O_2 3%) in sample preparation [26] to remove organic matters [27]. Samples were sieved by a 63 µm mesh, the residues oven-dried at <60°C, weighed and sieved into 63–150 µm and >150 µm size fractions [28].

Samples were subdivided into a number of splits using a standard splitter, and ~300 specimens were picked and counted [29], [30]. The petrographic analysis describes the texture (grain size, sorting, and contacts), sedimentary structures (laminations, bioturbation), and framework grain composition.

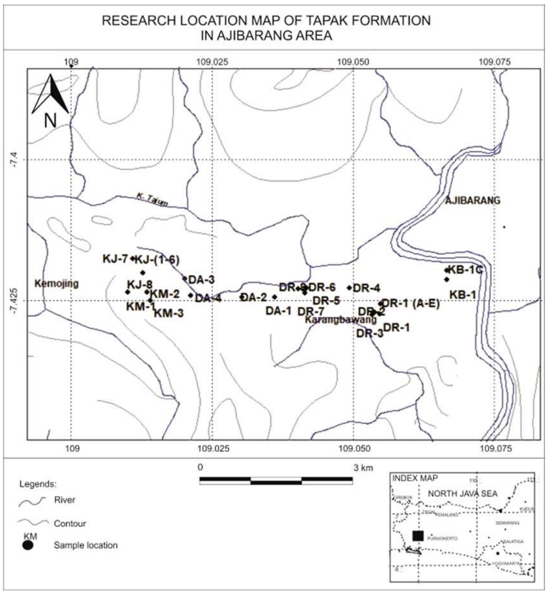

Fig. 2 Map of observation locations and carbonate sampling in the study area.

Foraminifera and petrographic analyzes were carried out at the Sedimentology Laboratory, Research Center for Geotechnology LIPI, Bandung, Indonesia. The method flowchart can be seen in Fig. 3.

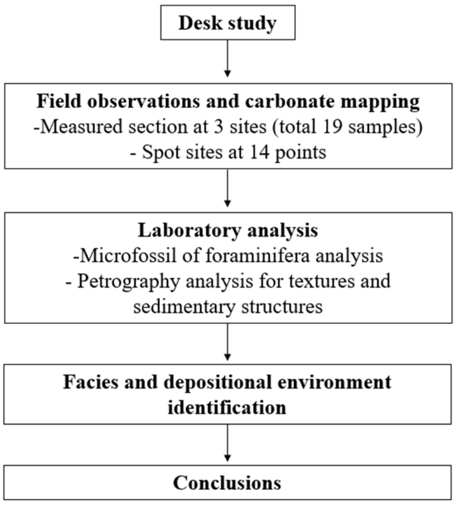

Fig. 3 Research flowchart for this carbonate facies and depositional environment study.

III. Result and Discussion

Field and laboratory observations showed that the limestone of Tapak Formation consists of three facies: planktonic packstone facies, algal foraminiferal packstone facies, and foraminiferal algal packstone facies.

A. Planktonic packstone facies

These planktonic packstone facies were distributed in the Darma Kradenan area at DR 4, DR 5, DR 6. In the Darma area, these facies distributed at the spot location of DA 2, and DA 3. In Kemojing, the spot site that these facies can be observed was at KM 3. Along the measured sections in Karang Bawang area, these facies can be observed at KB 1A and KB 1C. Fig. 4A showing the description of these facies along the measured section in Karangbawang. The long-measured sections at the Darma Kradenan area are distributed at DR 1A, DR 1B, DR 1C, DR 1D, DR 1E, DR1, and DR 2. The description of this facies in Darma Kradenan can be seen in Fig. 4B.

The planktonic packstone facies were characterized by layers of yellowish white to brownish-yellow colored packstone, layered well on 5-20 cm in thickness. Foraminifera was abundant in these facies. Sedimentary structures of crossbedding (e.g., Fig. 4A) and lenticular type were observed.

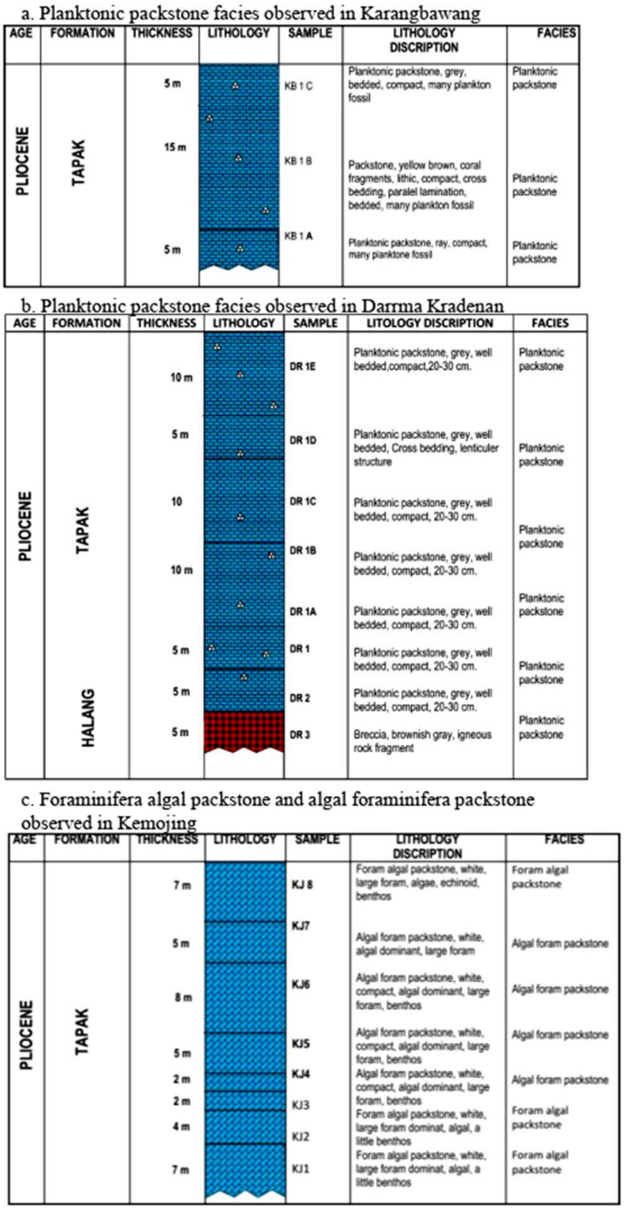

Fig. 4 Facies description of facies observed in the measured section. A. Planktonik packstone facies. B. Algal packstone facies. C. Foraminiferal algal packstone and foraminifera packstone facies.

Observation of thin sections of DR 1, DR 1E and DR 4 showed that the texture was packstone with poorly sorted bioclastic granules floating in a micric matrix. Bioclastic granules were dominated by planktonic foraminifera consisting of genus Globigerina, *Globigerinoides, Globorotalia*, and *Orbulina* (e.g., Fig. 4B). There was also a small number of large foraminifera, benthic foraminifera, and Radiolaria. Porosity type of this facies were intraclast, interclast and moldic type.

B. Algal Foraminiferal Packstone Facies

This facies were formed mainly by large algae and foraminifera. This facies were white-colored, compact with thickness ranging from 30 to 50 cm. Observation of thin incisions showed that the texture of these facies is characterized by bioclastic grains in the matrix. These facies composed of poorly sorted bioclastic grains that consist of red algae from the types of *Lithophyllum, Corallina* and *Rodolith*. In several layers, the number of *Rodoliths* was very prominent (e.g., Fig. 5C and 5D). Large foraminifera, especially *Operculina* sp, *Amphistegina* sp. and *Calcarina* sp were abundant. Benthic foraminifera, echinoid, and a few foraminifera of *Halimeda* were identified. Porosity type of this facies included intraclast, and interclast types. These facies were distributed in the Kemojing along the measured section of MS3 at sites of KJ5, KJ6, KJ7, KM1 and KM 2. Fig. 4C showing the thickness and description of this facies.

C. Foraminiferal Algal Packstone Facies

These facies composed of poorly moderately sorted bioclastic grains in a micric matrix. The texture of this facies was packstone texture, white-colored, and compact. Bioclastic granules dominantly consisted of large foraminifera, algae fragments, echinoids, a few benthic, and briozoa. The porosity type of this facies included interparticle, intraparticle, and moldic porosity. These facies contained huge number of large foraminifera of Operculina sp., Amphistegina sp and Calcarina sp. These facies were observed in the measured sections in Kemojing (MS 3) area (e.g., Fig. 4C) at KJ1, KJ2, KJ3, KJ4 and KJ8. Fig. 5E showing the outcrop of foraminfera algal packstone facies at site KJ 3. A huge number of large foraminifera can be seen from the thin section as shown in Fig. 5F.

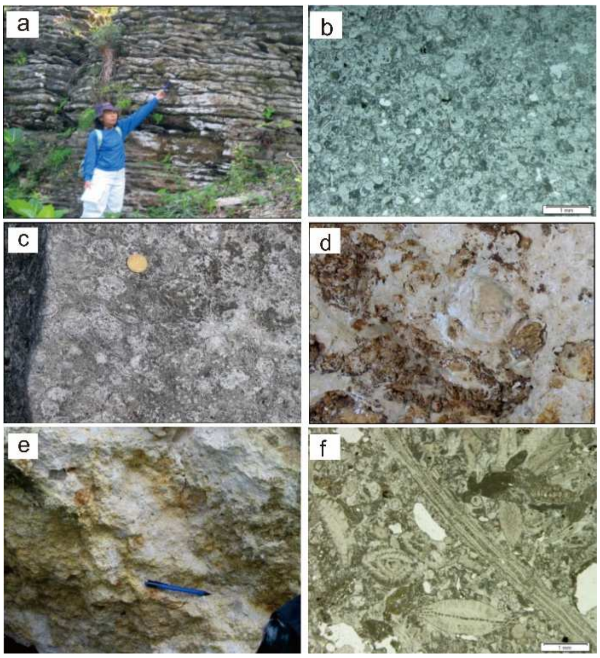

Fig. 5 A. Well layered of planktonic packstone facies. B. Abnundant planktonic foraminifera of planktonic packstone facies. C. The occurrence of *rodolith* in the algal foraminiferal packstone. D. Close-up of algae in the algal foraminiferal packstone. E. Outcrope of foraminifera algal packstone facies at site KJ 3. F. Thin section of a sample of foraminifera algal packstone facies taken from site KJ 1 showing abundant large foraminifera.

Limestone of Tapak Formation members in the study area consisted of three facies: planktonic packstone facies, algal foraminiferal packstone facies and foraminiferal algal packstone facies. By referring to the characteristic of these facies, the depositional environments of this limestone can be interpreted (e.g. [31]–[33]. Planktonic packstone facies was characterized by having 5 to 20 cm thick layers with parallel lamination, cross-bedding, and lenticular sedimentary structures. These facies are composed of bioclastic fragments in a micro matrix. The fragments were dominated by planktonic foraminifera consisted of a genus of *Globigerina, Globigerinoides, Globorotalia,* and *Orbulina*. Benthic foraminifera and radiolarians were also identified. Sedimentation from these facies was estimated to occur in the deep-sea environment.

Algal foraminiferal packstone facies are generally layered with thicknesses ranging from 30 to 50 cm. These facies are composed of bioclastic fragments in a micric matrix. The fragments were dominated by large algae and large foraminifera. Algae were from the type of red algae, consisted of *Lithophyllum, Corallina* and *Rodolith*. In some layers, the number of *Rodolith* was prominent. Large foraminifera, especially *Operculina* sp, *Amphistegina* sp., *Calcarina* sp., were observed in these facies. *Halimeda* (in small amounts), echinoid and benthic foraminifera were also identified in these facies. The algal foraminifera packstone facies was interpreted to have been deposited in the shallower area compared with packstone planktonic facies. However, both facies were deposited in the deep-sea environment. The dominance of red algae is an indication of a low deposition rate environment [34].

Foraminiferal algal packstone and algal foraminiferal packstone observed in Kemojing area characterized by the abundant of large foraminifera and interpreted to be deposited in the upper reef slope. The occurrence of Halimeda supports this conclusion. In this study, *Halimeda* was abundantly observed in algal foraminiferal packstone facies in the Kemojing area. In general, *Halimeda* is an indicator of the lagoon environment, even though this genus is also present in reef front to reef slope environment [35], [36]. In Indonesia, *Halimeda* was abundantly observed in the reef front environment of Wonosari Formation [37]. Praptisih [38] observed the occurrence of Halimeda in the algal foraminifera packstone facies of Parigi Formation in Karawang, West Java, Indonesia. Beside Halimeda, Praptisih [38] was also observed the abundance of red algae of *Rodolith* in this facies. In addition, *Rodolith* also identified in the Middle Miocene carbonate in the NW Tranylvanian basin, Romania [10]. The highly abundant of *Halimeda* and *Rodolith* indicated that these facies were formed in the back reef part of shallow marine environment. Algal foraminiferal packstone of Parigi Formation in Cirebon, West Java, Indonesia was also characterized by the abundance of *Rodolith* and *Halimeda* [39]. *Halimeda* dominantly occurred in Miocene tropical carbonate platform slopes in southern Spain that contain classical reef-slope facies [40]. Large foraminifera that indicates this typical packstone facies was also observed by Consorti [41] in Sakarya Zone, Turkey, and in the Carribean island of Bonaire [42].

The abundant planktonic foraminifera characterize planktonic packstone facies observed in the Darma area, limestone that layered with some part cross-bedded, interpreted as deposited in the lower reef slope environment. This characteristic was similar with the facies identified in the carbonate of Qom Formation in Iran [35]. Foraminiferal algal packstone facies of Kelapanunggal Formation in Cibinong, West Java is characterized by dark grey claystone intercalated with the packstone [33]. Another feature recognized in these facies was the cross-bedding structure. This condition shows that the deposition of this environment has been mixed with clastic sediments. Praptisih [33] Janßen [43] observed the abundance of *Halimeda* in these facies, indicating that these facies formed in shallow marine environments. Based on this data, it was interpreted that the depositional environment of this foraminiferal algal packstone facies was the back reef lagoon [33].

Many researchers have pointed out the importance of the occurrence of *Rodolith*. The relation of ocean warming and acidification with the occurrence of *Rodolith* has been studied by Martin and Hall-Spencer [44]. As in this research, *Rodolith* is prominently observed in the algal foraminiferal packstone; more detailed studies need to be conducted in the future to observe its relation to ocean warming and acidification during the Miocene age. Furthermore, Aguirre [45], [46] stated that *Rodolith* is one of the most abundant components in carbonate platforms that can be found in the low intertidal zone to the depth over 150 m [47], [48].

As discussed above, *Halimeda* is abundant observed in the foraminiferal algal packstone. In this study, the occurrence of this species is yet to be discussed in more detail. A further detailed study is very important as *Halimeda* can also provide meaningful information on the past ocean condition. Some previous studies identified that the response of ocean acidification could be traced by the occurrence of *Halimeda* [49]–[55].

IV. Conclusion

We investigated the sedimentological characteristics of the limestone of the Tapak Formation in the Ajibarang area, West Java, Indonesia. Thus, we concluded that this formation consists of planktonic packstone facies, algal foraminiferal packstone facies, and foraminiferal algal packstone facies. Based on the sedimentological characteristics and the fossil content, we interpreted that these facies were deposited in the lower reef slope to the upper reef slope environment. The sedimentological characteristics of the limestone of Tapak Formation have similar characteristics with the limestone's facies in other locations in Java. We hope that the information we provided here will be very useful for petroleum system study in Central Java, Indonesia. We proposed a further detailed study on the occurrence of Rodolith and Halimeda that found abundantly and characterize different facies of Tapak Formation. This further detailed study will provide information on the Miocene Ocean conditions.

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References

[1] L. Fauzielly and A. H. Hamdani, "Analisis lingkungan pengendapan batugamping berdasarkan distribusi unsur kimia di daerah Cidora, Kecamatan Ajibarang, Kabupaten Banyumas, Jawa Tengah," *Bull. Sci. Contrib. Geol.*, vol. 13, pp. 202–212, 2015.

[2] M. Djuri, H. Samodra, T. C. Amin, and S. Gafoer, "Geological Map of Purwokerto and Tegal Sheet, Java, scale 1: 100.000," Bandung, 1996.

[3] M. H. A. Amin and B. K. Susilo, "Lingkungan pengendapan Formasi Tapak daerah Samudra, Kabupaten Banyumas, Jawa Tengah," in *Applicable Innovation of Engineering and Science Research*, 2019, pp. 252–259.

[4] Y. Rizal, W. D. Santoso, A. Rudyawan, R. A. Tampubolon, and A. A. Nurfarhan, "Sedimentary facies and hydrocarbon reservoir potential of sand flat in the upper part of Tapak Formation in Banyumas Area, Central Java," *Ris. Geol. dan Pertamb.*, vol. 28, pp. 251–263, 2018.

[5] S. G. Ma'arif and M. I. Novian, "Mekanisme dan Dinamika Sedimentasi Formasi Tapak Bagian Bawah di Daerah Kalisalak, Kecamatan Margasari, Kabupaten Tegal, Provinsi Jawa Tengah," 2015.

[6] G. Kontakiotis, L. Moforis, V. Karakitsios, and A. Antonarakou, "Sedimentary facies analysis, reservoir characteristics and paleogeography significance of the Early Jurassic to Eocene Carbonates in Epirus (Ionian Zone, Western Greece)," *J. Mar. Sci. Eng.*, vol. 8, no. 9, 2020.

[7] E. S. Sallam, M. M. Afife, M. Fares, A. . van Loon, and D. A. Ruban, "Sedimentary facies and diagenesis of the Lower Miocene Rudeis Formation (southwestern offshore margin of the Gulf of Suez, Egypt) and implications for its reservoir quality," *Mar. Geol.*, vol. 413, pp. 48–70, 2019.

[8] R. Atmadibrata, D. Muslim, R. F. Hirnawan, and A. Abdurrokhim, "Characteristics of Arun carbonate reservoir and its implication to optimize the most potential gas resource zone in Arun gas field, Aceh, Indonesia," *Indones. J. Geosci.*, vol. 6, pp. 209–222, 2019.

[9] F. L. Valencia and J. C. Laya, "Deep-burial dissolution in and Oligocene-Miocene giant carbonate reservoir (Perla Limestone), Gulf of Venezuela basin: implications on microporosity development," *Mar. Pet. Geol.*, vol. 113, pp. 104–144, 2020.

[10] R. Chelaru, E. Sasaran, T. Tamas, R. Balc, I. . Bucur, and G. Ples, "Middle Miocene carbonate facies with rhodoliths from the NW Transylvanian Basin (Valenii Somcutei Cave, Romania)," *Facies*, vol. 65, no. 4, 2019.

[11] S. Banerjee, S. Khanolkar, and P. K. Saraswati, "Facies and depositional settings of the Middle Eocene-Oligocene carbonates in Kutch," *Geodin. Acta*, vol. 30, no. 1, pp. 119–136, 2018.

[12] M. Ingals, C. M. Frantz, K. E. Snell, and E. J. Trower, "Carbonate facies-specific stable isotope data record climate, hydrology, and microbal communities in Great Salt lake, UT," *Geobiology*, vol. 18, no. 5, pp. 566–593, 2020.

[13] B. Dyer, A. C. Maloof, S. J. Purkis, and P. M. (Mitch) Harris, "Quantifying the relationship between water depth and carbonate facies," *Sediment. Geol.*, vol. 373, pp. 1–10, 2018.

[14] W. Ran *et al.*, "Formation and evolution of the Tertiary carbonate reefs in the Madura Strait Basin of Indonesia," *Geology*, vol. 37, pp. 47–61, 2019.

[15] R. Fifariz, X. Janson, C. Kerans, and B. Sapiie, "Carbonate-shelf evolution during the Oligocene to Early Miocene: insights from shelf architecture, lithofacies, and depositional models of the Kujung Formation, offshore East Java, Indonesia," *J. Sediment. Res.*, vol. 90, no. 8, pp. 796–820, 2020.

[16] E. G. Sirodj, E. Sunardi, B. G. Adhiperdana, and I. Haryanto, "Shallow carbonate for underground gas storage in West Java, Indonesia," *J. Pet. Technol.*, vol. 10, no. 2, pp. 19–25, 2020.

[17] A. Jansen, A. Wizemann, A. Klicpera, D. W. Satari, H. Westphal, and T. Mann, "Sediment composition and facies of coral reef islands in the Spermonde Archipelago, Indonesia," *Front. Mar. Sci.*, vol. 4, no. 144, 2017.

[18] D. A. Utami, L. Reuning, and S. Y. Cahyarini, "Satellite- and field-based facies mapping of isolated carbonate platforms from the Kepulauan Seribu Complex, Indonesia," *Depos. Rec.*, vol. 4, pp. 255–273, 2018, doi: 10.1002/dep2.47.

[19] D. A. Utami and A. R. Hakim, "Carbonate sedimentology of Seribu Islands patch reef complex: a literature review," in *IOP Conference Series: Earth and Environmental Science*, 2018, p. 012013.

[20] D. A. Utami, L. Reuning, M. Hallenberger, and S. Y. Cahyarini, "The mineralogic and isotopic fingerprint of equatorial carbonates: Kepulauan Seribu, Indonesia," *Int. J. Earth Sci.*, 2021, doi: https://doi.org/10.1007/s00531-020-01968-9.

[21] D. P. Gold, F. Baillard, R. Rathore, Z. Zhang, and S. Arbi, "An intergrated biostratigraphic, seismic reservoir characterisation and numerical stratigraphic forward modelling approach to imaging drowned carbonate platforms; a case study from eastern Indonesia," *Geol. Soc. London Spec. Publ.*, vol. 509, 2020, doi: https://doi.org/10.1144/SP509-2019-88.

[22] E. Silalahi, Y. Putri, R. Sitinjak, D. Miraza, and M. S. T. Ozza, "Seismic interpretation and depositional model of Kais-Lower Klasafet reservoirs in Walio Area of kepala burung PSC, Salawati basing, West Papua, Indonesia," *J. Phys. Conf. Ser.*, vol. 1363, 2018.

[23] K.K.Ting, Y.E.Tan, E.Chiew, E. L. Lee, A.N.Azudin, and N. A. Ishak, "Assessing controls on isolated carbonate platform development in Central Luconia, NW Borneo, from a regional 3D seismic facies and geomorphology investigation," *Geol. Soc. Spec. Publ.*, vol. 509, 2020.

[24] D. P. Gold, P. M. Burges, and M. K. BouDagher-Fadel, "Carbonate drowning successions of the Bird's Head, Indonesia," *Facies*, vol. 63, no. 25, 2017, doi: doi.org/10.1007/s10347-017-0506-z.

[25] N. Muchsin *et al.*, "Miocene Hydrocarbon System of the Southern Central Java Region," in *Proceedings of the 31st Annual Convention Indonesian Association of Geologists*, 2002, pp. 58–67.

[26] P. S. Putra and S. H. Nugroho, "Distribusi Foraminifera Bentonik Hidup dalam Hubungannya dengan Sedimen Dasar Laut di Selat Sumba, Nusa Tenggara Timur," *J. Geol. dan Sumberd. Miner.*, vol. 20, pp. 17–26, 2019.

[27] M. M. Key Jr, A. M. Smith, N. J. Phillips, and J. S. Forrester, "Effect of removal of organic material on stable isotope ratios in skeletal carbonate from taxonomic groups with complex mineralogies," *Rapid Commun. Mass Spectrom.*, vol. 34, no. 20, p. e8901, 2020.

[28] E. Lo Giudice Cappelli and W. E. Austin, "Size matters: analyses of benthic foraminiferal assemblages across differing size fractions," *Front. Mar. Sci.*, vol. 6, no. 752, 2019.

[29] A. Damanik, K. A. Maryunani, S. H. Nugroho, and P. S. Putra, "Rekonstruksi perubahan suhu permukaan laut berdasarkan kumpulan foraminifera di Perairan Utara Papua, Samudra Pasifik," *Bull. Geol.*, vol. 4, no. 1, pp. 496–504, 2020.

[30] R. D. W. Ardi *et al.*, "Last Deglaciation—Holocene Australian-Indonesian Monsoon Rainfall Changes Off Southwest Sumba, Indonesia," *Atmosphere (Basel).*, vol. 11, no. 932, 2020, doi: 10.3390/atmos11090932.

[31] J. J. Wilson, *Carbonate Facies in Geologic History*. New York: Springer-Verlag, 1975.

[32] E. Flügel, *Microfacies of Carbonate Rocks: Analysis, Interpretation and Application*. Berlin, Heidelberg: Springer-Verlag, 2014.

[33] P. Praptisih and K. Kamtono, "Carbonate Facies and Sedimentation of the Klapanunggal Formation in Cibinong, West Java," *Indones. J. Geosci.*, vol. 1, pp. 175–183, 2014.

[34] E. Mohammadi, "Sedimentary facies and paleoenvironmental interpretation of the Oligocene larger-benthic-foraminifera-dominated Qom Formation in the northeastern margin of the Tethyan Seaway," *Paleoworld*, 2020, doi: doi.org/10.1016/j.palwor.2020.06.005.

[35] J. L. Wray, *Calcareous Algae (Developments in Palaeontology and Stratigraphy)*. Elsevier Science, 1977.

[36] W. Renema, "Large benthic foraminifera in low-light environments," in *Mesophotic coral ecosystems*, Springer, Cham., 2019, pp. 553–561.

[37] M. S. Siregar, P. Praptisih, Kamtono, and M. M. Mukti, "Reef facies of the Wonosari Formation, south of Central Java," *Ris. Geol. dan Pertamb.*, vol. 14, pp. 1–17, 2004.

[38] P. Praptisih, "Fasies, lingkungan pengendapan dan sifat fisik (kesarangan dan kelulusan) batuan karbonat Formasi Parigi di daerah Pangkalan Karawang, Jawa Barat," *J. Geol. dan Sumberd. Miner.*, vol. 17, pp. 205–215, 2016.

[39] P. Praptisih, M. S. Siregar, K. Kamtono, M. Hendrizan, and P. S. Putra, "Fasies dan lingkungan pengendapan batuan karbonat formasi Parigi di daerah Palimanan, Cirebon," *Ris. Geol. dan Pertamb.*, vol. 22, pp. 33–43, 2012.

[40] J. Reolid, C. Betzler, V. Singler, C. Stange, and S. Lindhorst, "Facies variability in mixed carbonate-siliciclastic platform slopes (Miocene)," *Facies*, vol. 63, no. 11, 2017, doi: https://doi.org/10.1007/s10347-016-0489-1.

[41] L. Consorti and F. Koroglu, "Maastrichtian-Paleocene larger foraminifera biostratigraphy and facies of the Sahinkaya Member (NE Sakarya Zone, Turkey):insights into the Eastern Pontides arc sedimentary cover," *J. Asian Earth Sci.*, vol. 183, 2019, doi: https://doi.org/10.1016/j.jseaes.2019.103965.

[42] J. C. Laya *et al.*, "Controls on Neogene carbonate facies and stratigraphic architecture of an isolated carbonate platform – the Caribbean island of Bonaire," *Mar. Pet. Geol.*, vol. 94, pp. 1–18, 2018.

[43] A. Janßen, A. Wizemann, A. Klicpera, D. Y. Satari, H. Westphal, and T. Mann, "Sediment Composition and Facies of Coral Reef Islands in the Spermonde Archipelago, Indonesia," *Front. Mar. Sci.*, vol. 4, no. 144, May 2017, doi: 10.3389/fmars.2017.00144.

[44] S. Martin and J. M. Hall-Spencer, "Effects of Ocean Warming and Acidification on Rhodolith/Maërl Beds," in *Rhodolith/Maërl Beds: A Global Perspective*, R. Riosmena-Rodríguez, W. Nelson, and J. Aguirre, Eds. Springer, Cham., 2017, pp. 55–85.

[45] J. Aguirre, J. C. Braga, and D. Bassi, "Rhodoliths and rhodolith beds in the rock record," in *Rhodolith/Maërl beds: A global perspective*, Springer, Cham., 2017, pp. 105–138.

[46] J. Aguirre *et al.*, "Middle eocene rhodoliths from tropical and mid-latitude regions," *Diversity*, vol. 12, no. 3, 2020, doi: 10.3390/d12030117.

[47] F. Rendina *et al.*, "Distribution and Characterization of Deep Rhodolith Beds off the Campania Coast (SW Italy, Mediterranean Sea)," *Plants*, vol. 9, no. 985, pp. 1–17, 2020, doi:10.3390/plants9080985.

[48] R. C. Pereira and R. da Gama Bahia, "Rhodoliths: Can its importance on a large scale be promoted by a microscale and invisible phenomenon?," *Front. Mar. Sci.*, 2021, doi: doi:http://dx.doi.org/10.3389/fmars.2021.630517.

[49] Z. Wei *et al.*, "Increased irradiance availability mitigates the physiological performance of species of the calcifying green macroalga Halimeda in response to ocean acidification," *Algal Res.*, vol. 48, p. 101906, 2020.

[50] Z. Wei *et al.*, "Effects of plant growth regulators on physiological performances of three calcifying green macroalgae Halimeda species (Bryopsidales, Chlorophyta)," *Aquat. Bot.*, vol. 161, p. 103186, Feb. 2020, doi: 10.1016/j.aquabot.2019.103186.

[51] K. E. Peach, M. S. Koch, P. L. Blackwelder, D. Guerrero-Given, and N. Kamasawa, "Primary utricle structure of six Halimeda species and potential relevance for ocean acidification tolerance," *Bot. Mar.*, vol. 60, no. 1, pp. 1–11, 2017.

[52] K. E. Peach, M. S. Koch, P. L. Blackwelder, and C. Manfrino, "Calcification and photophysiology responses to elevated pCO2 in six Halimeda species from contrasting irradiance environments on Little Cayman Island reefs," *J. Exp. Mar. Bio. Ecol.*, vol. 486, pp. 114–126, Jan. 2017, doi: 10.1016/j.jembe.2016.09.008.

[53] C. McNicholl *et al.*, "Ocean acidification effects on calcification and dissolution in tropical reef macroalgae," *Coral Reefs*, vol. 39, no. 6, pp. 1635–1647, 2020.

[54] A. Prathep, R. Kaewsrikhaw, J. Mayakun, and A. Darakrai, "The effects of light intensity and temperature on the calcification rate of Halimeda macroloba," *J. Appl. Phycol.*, vol. 30, no. 6, pp. 3405–3412, 2018.

[55] B. C. V. Narvarte, W. A. Nelson, and M. Y. Roleda, "Inorganic carbon utilization of tropical calcifying macroalgae and the impacts of intensive mariculture-derived coastal acidification on the physiological performance of the rhodolith Sporolithon sp.," *Environ. Pollut.*, vol. 266, Nov. 2020, doi: 10.1016/j.envpol.2020.115344.