

Research article

**Depositional Environmental Evolution of Nyalindung Formation based on Paleontology Molluscan Study, Ciodeng Area, Sukabumi, West Java, Indonesia**Riset Geologi dan Pertambangan  
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(<http://creativecommons.org/licenses/by-nc-sa/4.0/>).**Aswan<sup>1</sup>, Elina Sufiati<sup>2</sup>**<sup>1</sup>Paleontology and Quaternary Geology Research Group, Department of Geological Engineering, Faculty of Earth Sciences and Technology, Institute of Technology Bandung (ITB), Jl. Ganesha 10 Bandung, Indonesia  
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**ABSTRACT** This research was conducted to understand and identify changes in the depositional environment of the Nyalindung Formation in the Ciodeng area, Sukabumi, based on mollusk paleontology and lithological associations. Paleontological study of mollusks to interpret the depositional environment becomes important due to the scarcity or absence of foraminifera in mollusk bearing rocks. Foraminifera is commonly used to determine depositional environment. The results of this mollusk paleontology study and lithological associations show at least sixteen changes in depositional environment. The environmental changes range from rivers, mangroves, beaches, tidal areas, shallow marine nearby the coast, shallow open marine, and relatively deeper marine. The depositional environmental changes shown by this section might be related to tectonic activity and global sea level fall that occurred since the early Late Miocene to Pleistocene. The sedimentary units in this section are also characterized by predominant fluvial, mangroves, beach, and tidal in the upper layers.

**INTRODUCTION**

There are many mollusk fossil outcrops in Indonesia, especially on the island of Java, such as in Paleogene, Neogene, and Quaternary deposits. Several genera of mollusk fossils can be used as indicators of depositional environment, and even some of them can be used as an age index fossil. The study of mollusk paleontology is quite important because in recent years, there have been only a few articles published on the results of molluscan paleontology studies in Java, including Sufiati (2012) in Banten, Prasetyo *et al.* (2012) in several sites in West and Central Java, Sufiati (2013) in Bumiayu and Cirebon, Aswan *et al.* (2013) in Sumedang, Aswan *et al.* (2015) in the Bobotsari Basin, Purwokerto and its surroundings, Aswan *et al.* (2017) which investigated the age of several

mollusk fossil-containing deposits on the island of Java, Aswan *et al.* (2018) in the Cisaat River in Bumiayu, and Sari *et al.* (2019) in Bayah, Banten province. The research on molluscan paleontology is also significant because rocks that contain mollusk fossils generally lack foraminifera contain, whereas foraminifera are usually used to determine the depositional environment. Therefore, these mollusk fossils will be the main keys to indicate the depositional environment, especially in mollusc-containing rock units that contain scarcity or absence of foraminifera.

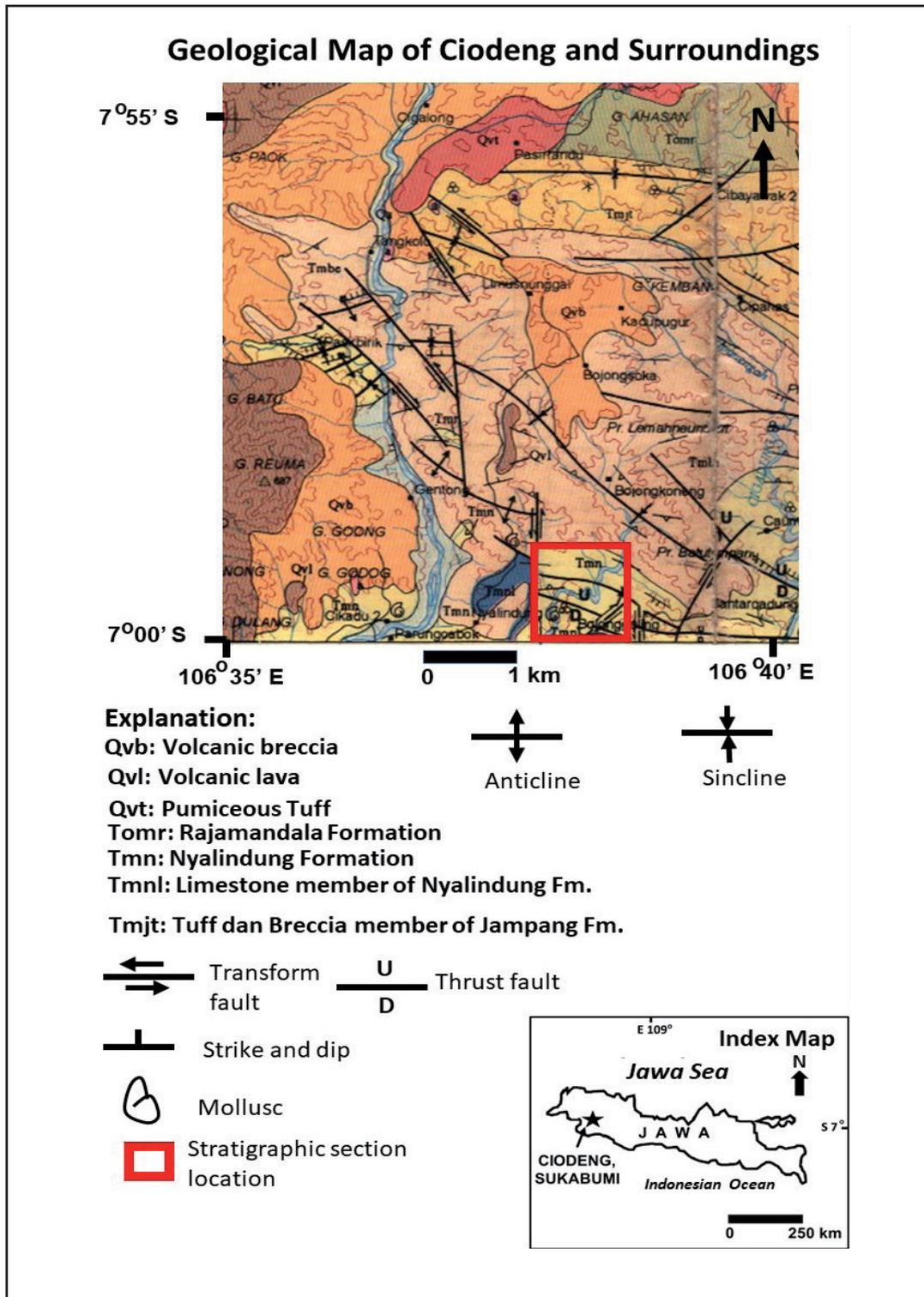
This Ciodeng River section is in Ciodeng Village, Tonjong Village, Pelabuhan Ratu sub-district, Sukabumi Regency, West Java Province, along the Ciodeng River and its surroundings, having coordinates 07° 00' 00"– 06° 59' 20" South Latitude and 106° 37' 30" - 108° 38' 00" East Longitude (Figure 1). The Nyalindung Formation in the Ciodeng area is also crucial from the stratigraphic point of view of mollusk fossils in Jawa because it is the location of the Odengian Stage developed by Oostingh (1938). The Odengian Stage is one of the stratigraphic levels in the distribution of the Javanese Neogene Stage based on the mollusk index fossil compiled by Oostingh (1938). This Odengian level is equivalent to the Tortonian (Late Miocene) on the international geological time scale with *Turritella angulata cramatensis* as an index fossil (Oostingh, 1938). The distribution of the Javanese Neogene Stages based on mollusk fossils is still used today to determine the age of deposits containing mollusk fossils. However, no research that has updated the sequence of stages compiled by Oostingh (1938).

Geologically, the rock units found in the research area are part of the Nyalindung Formation (Tmn) on the Bogor Sheet Geological Map, according to Effendi *et al.* (2011), which is characterized by glauconitic sandstone, calcareous, greenish; claystone, marl, sandy marl, conglomerate, breccia, limestone, and tuffaceous marl which are rich in mollusk fossils. This unit is unconformably overlain by Quaternary Volcanic Breccia (Qvb) and Volcanic Lava (Qvl).

Recently there has been no research on the depositional environment of the Nyalindung Formation rock units in the Ciodeng River section, either based on the mollusk fossil content or based on other studies. Some findings on the Nyalindung Formation include Clements and Hall (2007), who stated that the Cimandiri Formation (the rock unit of the Nyalindung Formation which was previously considered a part of the Cimandiri Formation) is a shallow marine and terrestrial deposit.

Aswan and Ozawa (2006) discussed changes in the depositional environment of the Nyalindung Formation in the Middle Miocene age interval dominated by the tidal and shallow marine environment. Aswan *et al.* (2017) explained the age of the Nyalindung Formation in the Ciodeng section and its age equivalence compared to other rock units on the island of Java which also contain mollusk fossils. Firmansyah *et al.* (2017) studied the carbonate sandstones of the Nyalindung Formation in the Loji area (Simpenan sub-district of Sukabumi regency). They concluded that the depositional environment is shallow marine based on its foraminifera content.

Putri (2019) studied the paleoecology of the depositional environment of the Nyalindung Formation in the Cijarian River. Merle and Landau (2020) examined the presence of the *Eofarvatia* fossil in the Nyalindung Formation as evidence of the continuity of the Tethys shallow marine system during the Neogene in the Indo-Pacific region. Kesuma (2020) researched paleo-currents during the deposition of the Nyalindung Formation in the Cigalaras River section. Besides, the very limited content of foraminifera fossils in the Nyalindung Formation often causes difficulties determining the depositional environment. Therefore, the study of the evolution of the depositional environment of the Nyalindung Formation in the Ciodeng area based on mollusk paleontological analysis is



**Figure 1.** Geological map of the Ciodeng area and its surroundings, as well as the location of the stratigraphic cross-sectional measurement of the Nyalindung Formation in the Ciodeng area (in the red box in the south-central part of the map), Sukabumi Regency, West Java, Indonesia. This map is part of the Bogor Geological Map Sheet (Effendi *et al.*, 2011).

important to complement paleontological data from rock units as the part of the Neogene Stages in Java Island. This research aims to determine the depositional environment of the Nyalindung Formation based on paleontological studies of mollusks and their lithological associations by following the stratigraphic measuring section data on the Ciodeng River section in the Ciodeng area. The results of the depositional environment studies are also expected to provide an overview of changes in sea level at the beginning of the Late Miocene, which affects changes in mollusk fossil associations during the Nyalindung Formation deposition in the research section.

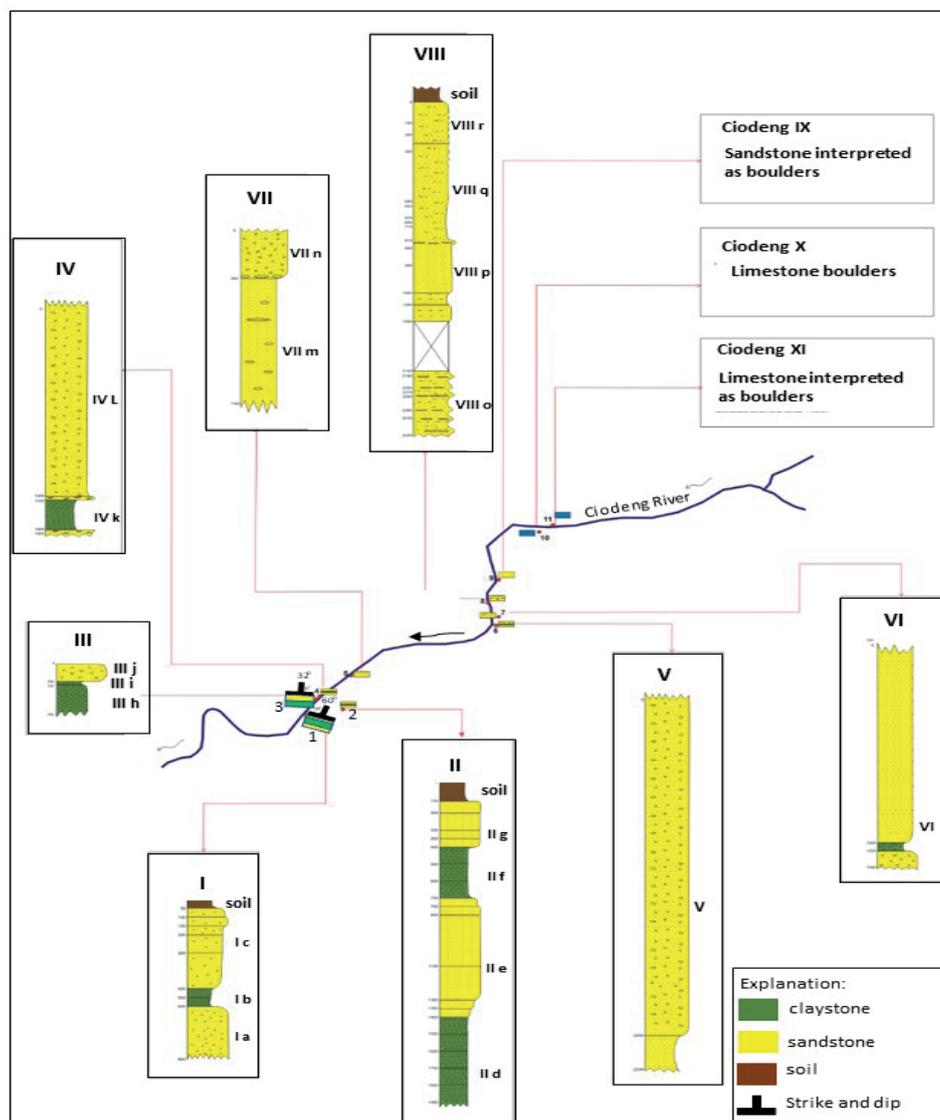
## RESEARCH METHODOLOGY

This research is conducted through field observations using qualitative and quantitative methods such as 1) stratigraphic measuring section along Ciodeng River and megascopic sedimentological analysis of each rock layer; 2) collecting data on the mollusks fossil content from each sedimentary layer contained in the stratigraphic column, and; 3) the determination of the depositional environment of each sedimentary layer based on the association of mollusk fossils, especially based on the in-situ fossil content and lithological associations if no mollusk fossils were found in a rock layer. The identification of mollusk fossils refers to Aswan and Ozawa (2006), Oostingh (1938), and Sufiati *et al.* (2013). The interpretation of the depositional environment of mollusk fossils for each layer follows Okutani (2000) and Aswan and Ozawa (2006). Mollusk fossils used to analyze the depositional environment are prioritized only based on insitu mollusk fossils. The fossils criteria are based on their taphonomic aspect, namely the position of the long axis of the Gastropod class fossil that is parallel to the position of the rock layers, as well as the condition of intact shells. The in-situ criteria for mollusk fossils from Class Pelecypoda uses taphonomic aspects viewed from the position of umbo facing upwards to the horizontal position of the sedimentary rock layer and the condition of intact shells. Some parts of the Ciodeng River section are covered by thick vegetation and soil with wide distributions. Thus the measurement results are divided into eight stratigraphic columns (it cannot be made into one continuous stratigraphic column) named Location Point I to VIII with twenty detailed observation points for examining the depositional environment (Figure 2). The results of depositional environment interpretation are used to reconstruct sea-level changes during the deposition of the Nyalindung Formation in the research area. The determination of the oldest (bottom) layer to the youngest (topmost) layer is based on the measurement of the position of the rock layers at Location Points I and III, where the direction of the slope is relative to the northeast (Figure 2). The sequence of stratigraphic cross-sectional measurements from Location I to VIII also consistently moves from southwest to northeast or from the oldest to the youngest.

The age of the rock unit under study, referring to Aswan *et al.* (2017), is in the early interval of the Late Miocene. Aswan *et al.* (2017) found the age of the rock unit based on the analysis of planktonic foraminifera from sediment samples taken from location points VII and VIII. Determining the age of this rock unit is important to find out the main cause of sea-level changes that occurred during the deposition of the Nyalindung Formation in the Ciodeng area.

## RESULTS

The following is a discussion of the determining the depositional environment results from each measured stratigraphic cross-section at Ciodeng, based on their molluscan and their lithological associations (from the bottom rock layer (oldest) to the top (youngest)):



**Figure 2.** Stratigraphic column of the Nyalindung Formation along the Ciodeng River, Ciodeng area

### Location point I

The outcrop at location point 1 is a layer of sedimentary rock with a thickness of  $\pm 9$  meters. The outcrop generally consists of gravelly sandstone with claystone interbedded and contains many mollusk fossils in the upper part of claystone and sandstone. The strike and dip of this layer are  $N 290^{\circ} E/60^{\circ}$ .

The lowest part of this sedimentary outcrop is sandstone (Ia), medium-coarse grained, conglomeratic - gravelly with a fragment size of 0.5-4 cm, and no mollusk fossils found. The thickness is  $\pm 3$  meters. The lowest layer of sediment at location 1 is interpreted as being deposited in a river environment based on its coarse to very coarse grain and non-calcareous characteristics.

The layer is covered by claystone (Ib) in gray color with a thickness of about 1 meter. In this layer, many mollusk fossils are found with some specific types: *Turritella*, *Dentalina*, *Trochus tjilonganensis*, *Oliva subulata - odengensis*, *Nassa*, *Natica (Natica) rostalina*, and *Paphia paratapes*.

The association of mollusk fossil species indicates a shallow open marine depositional environment (1-5 meters depth).

The upper part (below the soil layer) at this site consists of a layer of sedimentary rock thickness of about 5 meters. This sandstone layer is medium-coarse sandstone (Ic), gravelly, gray-brown color, and contains many mollusk fossils. The identified mollusk fossils include *Turritella*, *Babylonia*, *Paphia paratapes*, *Dentalina*, *Nassarius*, *Anomalocardia (A.) squamosa antiquata*, *Chicoreus anguliferus*, *Nassa*, *Conus*, *Corbula*, and *Ostrea*. The mollusk fossil association indicates a shallow marine depositional environment nearby the coast (0-1 meters depth) which is influenced by the river system, indicated by the gravel content of the sandstone.

## Location point II

The thickness of the stratigraphic cross-section measured at location II is ±19 meters. In general, lithology consists of two claystone layers intercalation and two sandstone layers covered by soil at the top. Mollusk fossils are abundant in both claystone layers, while at the bottom and top sandstone layers, there are no mollusk fossils.

In the lower layer of sandy claystone (IIId) (5 meters of thickness), there are abundant mollusk fossils that characterize open shallow marine, including *Turritella*, *Bufonaria (Bursa)*, *Nassa*, *Paphia*, *Conus*, *Babylonia*, and *Natica*. After deposition of claystone (IIId), calcareous and tuffaceous sandstone (IIe) is deposited, and it does not contain mollusk fossils with a thickness of 7 meters. This sandstone depositional environment is interpreted as still in shallow marine with volcanic activity that does not support mollusk life. Therefore, the mollusk fossils cannot be found in this layer. In this sandstone layer, the interpretation of the shallow marine environment is based on its carbonate content, while the volcanic effect is indicated by its tuffaceous characters.

The depositional environment again changes to a tidal environment indicated by the presence of *Columbella* and *Ostrea* mollusk fossils in the upper claystone layer (IIIf) with a thickness of 3 meters.

The upper part of the stratigraphic column at this location is characterized by a layer of coarse sandstone amalgamated and conglomeratic and non-calcareous (IIg) with a thickness of 2.5 meters. The coarse grain lithological association reflects high energy depositional environment. It is interpreted that this rock layer was deposited in a fluvial/river environment.

## Location point III

The stratigraphic column at location point III has ±3 meters thickness located in N 272° E/32°. At the bottom, there is a soft-slightly hard sandy claystone (IIIh) with a thickness of 2 meters, containing many mollusk fragments, including *Turritella javana*, *Ranella*, *Paphia (Paratapes)*, *Nassarius*, *Conus odengensis*, *Murex*, and several mollusks from Pectinidae and Arcidae groups. The species association indicates a shallow open marine depositional environment. On top of it, it is exposed sandy conglomerate (IIIj) with a thickness of 1 meter, dark gray in color, slightly hard-compact, non-calcareous, and no mollusk fossils are found. Lithological associations reflect a strong streambed depositional environment are indicated by coarse clastics grain, indicating a river depositional environment. Between claystone and conglomerate, a thin layer of claystone (IIIi) is fine, locally slightly sandy, soft, non-calcareous, and no mollusk fossils are found. This rock layer with a thickness of 10 centimeters is estimated as floodplain sediment as part of river system.

#### **Location point IV**

The stratigraphic column generated from sedimentary rock outcrops at location point IV is + 14.2 meters thick. At the bottom, there is a rock layer dominated by sandy claystone (IVk) with a thickness of 2 meters, gray in color, locally gravelly, and there are fragments of mollusk fossils from the Bivalvia Class: *Dosinia*, *Arca*, *Scapharca*, and *Paphia* (*Parataptes*); and from Gastropod Class: *Turritella*, *Ranella*, *Murex*, *Nassarius*, *Natica*, *Conus*, *Babylonia*, and gastropods from the Fusidae group. The mollusk species association indicates a shallow open marine depositional environment. The upper part rock layer is conglomeratic coarse sandstone (IVL) with a thickness of 12.2 meters, dark gray in color, slightly hard-compact, and no mollusk fossils found. Lithological associations are coarse grain clastic and non-calcareous, reflecting a non-marine environment, and are deposited with high energy flow so that they are interpreted as fluvial/river deposits.

#### **Location point V**

The measured stratigraphic cross-section of sediment outcrop in this site has  $\pm$  22 meters of thickness. The outcrop consists of conglomeratic coarse sandstone with a thickness of 20 meters. There is a medium sandstone layer underneath, brownish-gray in color, slightly hard, and no mollusk fossils with a thickness of 2 meters. Viewed from the lithological association, it is medium to coarse sandstone, conglomeratic and non-calcareous, reflecting a non-marine depositional environment with a high energy flow as fluvial/river environment. This river depositional environment is interpreted as a continuation of the upper depositional environment of location IV (Layer IVL). These two rock layers reflect the same depositional environment.

#### **Location point VI**

The thickness of the sediment layer at location point VI is  $\pm$ 13.5 meters. The bottom layer consists of coarse conglomeratic sandstone, and on top, there is a thin layer of claystone, and the top layer is carbonaceous sandstone with medium grain size. In the sequence of rock layers at this point, no mollusk fossils were found. The lithological association is dominated by coarse clastics from medium sandstone to conglomeratic coarse sandstone, supported by carbonaceous and non-calcareous characteristics, it is interpreted that this rock layer was deposited in a fluvial/river environment. These three rock layers reflect the same depositional environment of fluvial system.

#### **Location point VII**

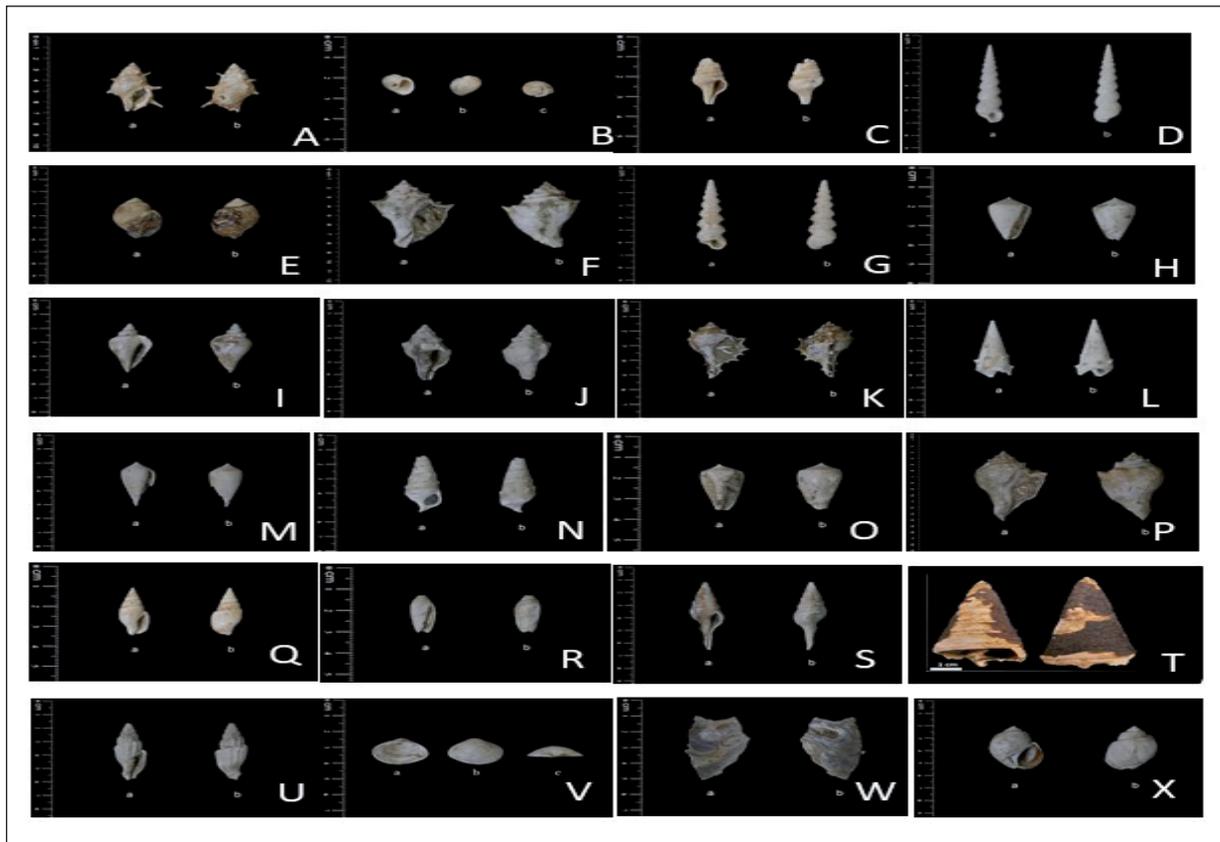
The thickness of the sedimentary rock layer at location VII is about 11 meters. The lower lithology consists of medium-coarse sandstone (VII<sub>m</sub>) thickness of 8 meters, locally containing hard carbonate nodules and very coarse sandstone lenses bound by calcite cement. This sandstone is also calcareous, and some leaves fossils found which have become black carbon. Mollusk fossils are *Arca*, *Nassarius*, *Ostrea*, small *Natica*, *Perna viridis*, and *Telescopium*. The fossil content indicates the depositional environment of mangroves. The sediment layer above shows a fluvial depositional environment/strong river stream, characterized by coarse to very coarse sandstone (VII<sub>n</sub>) with a thickness of 3 meters, conglomeratic, dark gray in color, slightly hard, and non-calcareous. In this rock layer, no mollusk or other fossils are found.

### Location point VIII

At point VIII the sedimentary rock outcrop mostly consists of sandstone with a thickness of ± 25.3 meters. The strike and dip of this rock layer are N 250° E/30°. The lowest layer is clayey fine sandstone (VIIIo) with a thickness of 5 meters, gray in color, slightly soft, contains a lot of plant remains (carbon streak). Based on the lithological association of clayey fine clastics and plant remains, it is interpreted that the depositional environment is mangrove. The upper rock layer consists of medium sandstone (VIIIp) with a 6 meters thickness. The mollusk fossils are dominated by bivalve fragments which indicate a beach environment. Above this VIIIp sandstone layer, the clayey sandstone was found again (VIIIq) with a thickness of 10 meters with brownish-gray in color, containing mollusk fossils dominated by *Strombus* sp. In this clay sandstone layer, there are gastropod *Strombus* sp. and *Balanus* Arthropod fossils found, the association of the two fossils indicating a tidal environment. The lithology at the , top of point VIII consists of clayey medium sandstone (VIIIr), which shows a relatively deeper open marine environment. The deeper marine environment (about 5-30 meters depth) in this sandstone layer is shown by , the gastropod fossils *Babylonia spirata* and *Lophiotoma indica*. The thickness of this VIIIr layer is 4.3 meters.

### DISCUSSION

The depositional environment determination of the Nyalindung Formation along the Ciodeng River, which was deposited at the beginning of the Late Miocene, shows that there have been at least sixteen changes in the depositional environment. This research is conducted mainly based on the association of mollusk fossils and their lithology. Some of the mollusk fossils found in this research section can be seen in Figure 3. The summary and illustrations of changes in the depositional environment are shown in Table 1 and Figure 4. In Table 1, the changes in the depositional environment can be traced from the oldest rock layers found in column I and the bottom row with the letter 'a)' and top position indicated younger age, marked with the letter 'b)' and 'c)'. The younger stratigraphic position is shown in column II from the bottom row to the top and until the youngest layer in column VIII, marked with the letter 'r)'.



**Figure 3.** Some mollusk fossils found in the research section A. *Bursa (Bufonaria) spinosa*; B. *Natica rosalina*; C. *Pleurotoma odengensis*; D. *Turritella javana*; E. *Babylonia canaliculatus*; F. *Melongena gigas*; G. *Turritella cramatensis*; H. *Conus djajariensis*; I. *Strombus (Labiostrombus) triangulates*; J. *Siphonalia dentifera*; K. *Chicoreus anguliferus*; L. *Faunus (Lampasia) palabuanensis*; M. *Conus cinereus*; N. *Faunus odengensis*; O. *Conus hardi*; P. *Melongena ponderosa*; Q. *Columbela* sp.; R. *Oliva odengensis*; S. *Lophiotoma indica*; T. *Telescopium* sp.; U. *Vexillum jonkeri*; V. *Paphia (Paratapes) sp.*; W. *Ostrea* sp.; X. *Babylonia spirata*.

**Table 1.** The depositional environment of the Nyalindung Formation in the Ciodeng area, Sukabumi, from the oldest (I) to the youngest (VIII) rock layer. Note: the depth range of “relatively deeper marine” is 5-30 meters and “open shallow marine” is 1-5 meters depth.

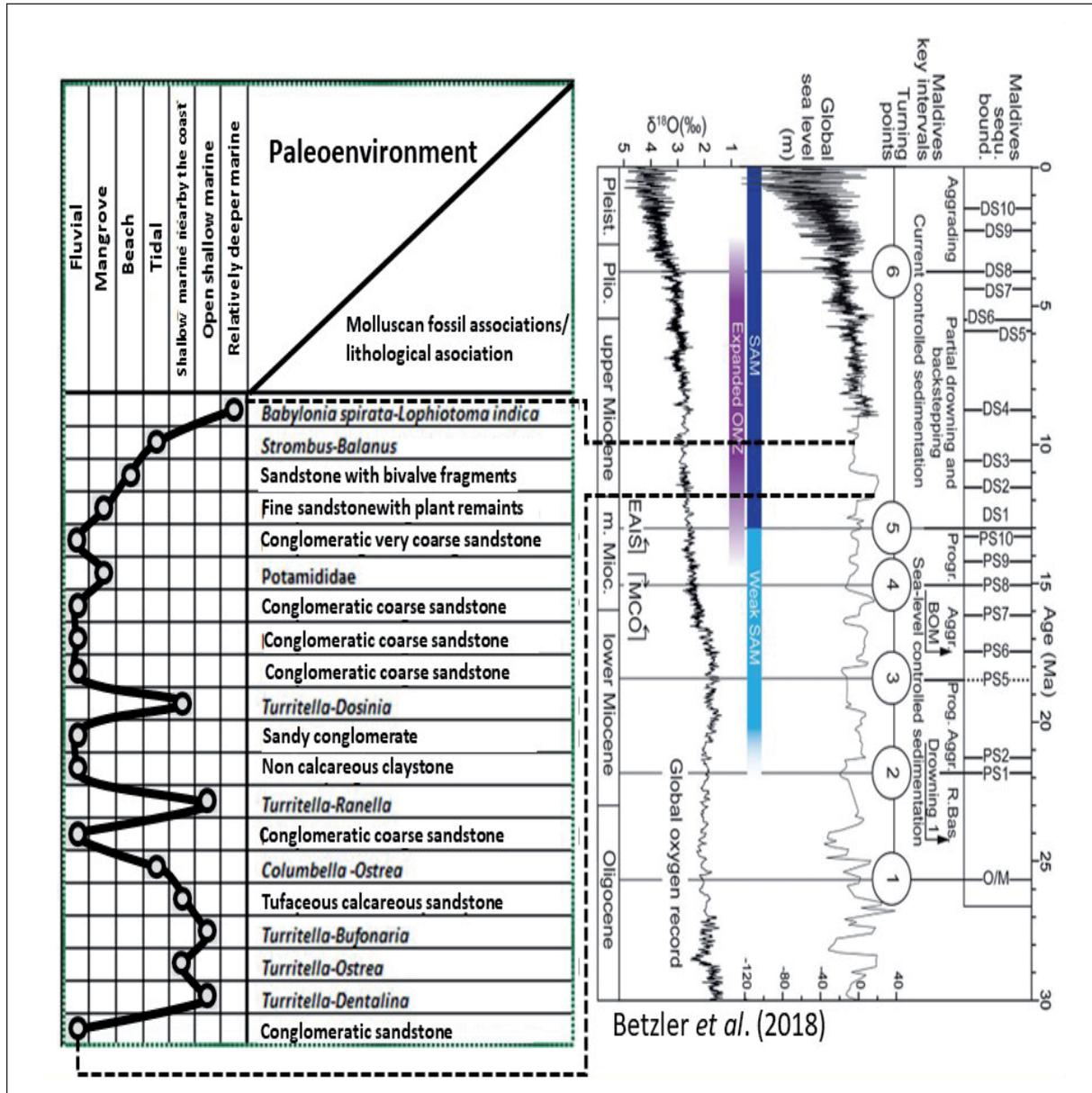
If there is a continuous similarity of depositional environments in successive columns, it will not be considered as a new change of depositional environment. The example of this case is the “fluvial” depositional environment in layer IVL, the “fluvial” depositional environment in Column V, and the “fluvial” depositional environment in Column VI. They will only be considered as one depositional environment

Stratigraphic Order							
I	II	III	IV	V	VI	VII	VIII
	g) Fluvial						r) relatively deeper marine
c) Shallow marine nearby the coast	f) Tidal	j) Fluvial					q) Tidal
b) Open shallow marine	e) Shallow marine nearby the coast	i) Fluvial (flood plain)	L) Fluvial			n) Fluvial	p) Beach
a) Fluvial	d) Open shallow marine	h) open shallow marine	k) Shallow marine nearby the coast	Fluvial	Fluvial	m) Mangrove	o) Mangrove

Although in Table 1 it is written 20 (twenty) depositional environments, for the same depositional environment which is continuous in the next column, it is not counted as a change in the depositional environment.

In Figure 4, it can be seen that there are sixteen changes in the depositional environment (a total of seventeen observed depositional environments) from the oldest (bottom row) to the youngest layer (top row). The determination of mollusk association name is based on the dominant genus and is in-situ in a layer or based on the depositional environmental index mollusk fossils. If there are transported mollusk fossils, they cannot be used to determine the association name, such as *Ostrea* found in layer VIIIm. *Ostrea* is considered a transported fossil from the tidal area as its habitat because of other dominant mollusk fossils in this layer are those living in the mangrove environment. However, there is an exception for transported fossils which are used as the basis for determining the depositional environment, such as determining the depositional environment of layer VIIIp. In this VIIIp layer, the mollusk fossils found are transported fragments commonly found in the coastal areas. If the determination can detect the name of the fossil species, then the

association name includes the name of the genus and species, such as *Babylonia spirata-Lophiotoma indica*. Only the genus name is used if the species name cannot be identified. The exception to the naming of this mollusk association is in layer VIIIq, where *Balanus* sp. is taken from Arthropoda Phylum as an index fossil of the tidal environment.



**Figure 4.** Changes in the depositional environment of the Nyalindung Formation in the Cideng area, Sukabumi Regency, West Java based on mollusk fossil and lithological associations (left figure) and the approximate interval (interval is delimited by two dotted lines) compared to the global sea level in the early Late Miocene (right figure) based on Betzler *et al.* (2018).

Note: the depth range of “relatively deeper sea” is 5-30 meters and “open shallow sea” is 1-5 meters. Some fluvial environments that remain unchanged are illustrated as they originate from different stratigraphic columns. This also shows long fluvial depositional environment interval.

If there is a continuous similarity of the depositional environment in successive columns, it will not be counted as a new change of depositional environment. The example of this case is the “fluvial” depositional environment in layer IVL, the “fluvial” depositional environment in Column V, and the “fluvial” depositional environment in Column VI. They will only be counted as one depositional environment (Table 1).

At some locations that are stratigraphically higher than the rock sequences at point VIII (to the east of point VII in Figure 2), limestone lithology is embedded among other rock boulders (Figure 2 locations IX, X, and XI). In this research, the depositional environment of these limestones is not discussed because their stratigraphic position cannot be ascertained, and their status may only be loose boulders embedded among other rock boulders. Changes in the depositional environment of the Nyalindung Formation in the Cideng River section, which is in the early Late Miocene age, are related to changes in sea level due to tectonic influences and global climate change. The changes in the depositional environment, according to Ohneiser *et al.* (2015) and Betzler *et al.* (2018), are triggered by global sea-level changes. According to Betzler *et al.* (2018), the global sea level began to decline from the beginning of the late Miocene until the Pleistocene age. The sea level decrease caused by the earth’s cold climate reached its peak by the end of the Pleistocene age, marked by the glaciations process. The sea-level change and the global sea-level change curve, according to Betzler *et al.* (2018), had been started since the beginning of the Late Miocene. The details can be seen in Figure 4.

Indications of earth surface cooling that began in the Late Miocene is also stated by Eichler *et al.* (2021), who studied the earth’s climate based on the analysis of benthic foraminifera from the Oligocene to the Recent age. Apart from Eichler *et al.* (2021), Ng *et al.* (2021), who examined the conditions of the Atlantic Ocean during the Late Miocene age, also stated that global cooling had been detected since the Late Miocene. The increasingly shallowing sea level is characterized by the dominance of the depositional environment of rivers, mangroves, beaches, and tidal at younger stratigraphic intervals. Although the upper part of the studied stratigraphic interval is characterized by a relatively deep marine environment (5-30 meters), the previous interval shows the dominance of much shallower depositional environments such as fluvials and mangroves.

Several previous researchers who have studied the intervals of the lower Middle Miocene of Nyalindung Formation generally concluded that shallow seas dominated the depositional environment. The researchers include Aswan and Ozawa (2006), Clements and Hall (2007), Firmansyah *et al.* (2017), Putri (2019), Merle and Landau (2020), and Kesuma (2020). Based on the findings on the Nyalindung Formation in the Cideng River section at the beginning of the Late Miocene, it can be seen that there are indications of shallowing sea level due to environmental changes compared to the Middle Miocene interval. This relatively shallowing environment is characterized by a predominantly fluvial/river and mangrove depositional environment in the upper stratigraphic interval.

Associated with tectonic activities at the beginning of the Late Miocene in the western part of Java, based on Clements and Hall (2007), the research location is part of the emergent volcanic arc in the southern area. The studied rock units are thought to have been deposited at the end of the volcanic activities waning period that began in the Middle Miocene before the volcanic arc shifted to the northern part of Java Island in the Late Miocene (Clements and Hall, 2007). The shallow marine environment, and transition of the mangrove to the land (fluvial/river) where the

Nyalindung Formation in the Cideng River section was deposited, is also predicted to be influenced by its tectonic position in the emergent volcanic arc. This emergent volcanic arc in the southern part of Java Island started in the Oligocene and continued to the Late Miocene age (Clements and Hall, 2007).

The tectonic effect on sea level dropped due to a decreasing temperature in the Pacific, and Indonesian Oceans is also explained by Kuhnt *et al.* (2004). According to Kuhnt *et al.* (2004), the collision between Australian and Southeast Asian continents affected reducing the flow of warm streams from the equator to higher latitudes. This collision is estimated to start about 25 million years ago and is thought to global cooling. This cold climate of course, influences the decrease in sea level during the deposition of rock units in the studied area.

## CONCLUSIONS

Paleontological studies of mollusks and lithological associations of the Nyalindung Formation on the Cideng River section, Cideng area, Sukabumi Regency, West Java have supported the interpretation of changes in the depositional environment during this rock unit deposited in the early Late Miocene. In this research, there are at least sixteen changes in the depositional environment indicated by changes in the association of mollusk fossil content and/or lithology. In general, the evolution of the depositional environmental ranges is around fluvial, mangroves, beaches, tidal areas, shallow seas near the coast, shallow open seas, and relatively deeper seas. At younger rock intervals, river and mangrove environments appear more often than marine, nearshore, and open seas.

The evolution of the Nyalindung Formation interval depositional environment is influenced by tectonic activities and global sea-level changes in the early Late Miocene age during the deposition of this rock unit. Global sea level indicates a shallowing trend from the Late Miocene to the Pleistocene. This global sea level dropped following some other findings that show that river and mangrove environments are more commonly formed at younger rock intervals than to the emergence of shallow open sea environments or shallow seas near the coast.

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