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RESEARCH ARTICLE

Trace Fossils Of The Selorejo Formation, Rembang Zone, North East Java Basin, Indonesia

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Abstract

The Rembang Zone of the North East Java Basin is a zone that develops as a petroleum system and is one of the areas with Indonesia's largest oil reserves. One of the lithologies in the Rembang Zone is a sedimentary rock carbonated as a marker of marine sediments. The outcrop is continuous and rich in trace fossils, especially in the Ledok and Selorejo Formations. The existence of trace fossil outcrops is crucial for the learning process of earth science, biology, and other sciences, but recently these outcrops have been closed and have become damaged. Their numbers are decreasing due to community mining activities, so unique research on trace fossils in the Rembang Zone must be done immediately. This research aims to discover the variation of trace fossils found in the Selorejo Formation. The methods used are field mapping, measured stratigraphic measurements, rock sampling, and laboratory analysis (sedimentology, petrography, and paleontology). The research shows trace fossils in *Planolites, Helminthopsis, Thalassinoides, Conichnus, Chondrites, Macaronichnus, Bergauria, Ophiomorpha, Skolithos, Terebellina, Palaeophycus,* and *Asterosoma*.

Keywords: *Trace fossils, Ichnofacies, Rembang zone, North East Java basin.*

1. Introduction

The Ledok and Selorejo Formations are located in the Rembang Zone, North East Java Basin, located between the Randublatung Depression Zone and the Java Sea to the north, which extends for 400 km with a width of 120 km from Semarang to Madura. In the Rembang Zone are sedimentary rocks of thick Cenozoic age, containing fossils and continuous outcrops from the Eocene to the Pleistocene. Based on lithological characteristics from old to young, they are arranged of Pre-Tertiary-aged Rocks, and the Formation of Ngimbang, Kujung, Prupuh, Tuban, Tawun, Ngrayong, Bulu, Wonocolo, Ledok, Mundu, Selorejo, Paciran, Lidah, and Undak Solo were successively deposited on top of them. (Pringgoprawiro, 1983) (Choiriah, Prasetyadi, Yudiantoro, et al., 2020b) .

The Rembang Zone has continuous stratigraphy and good potential for research in the development of earth sciences. The Rembang zone was deposited in a shallow to deep marine environment, which causes marine organisms to develop quite well in this zone. Many kinds of fossils exist in this zone, such as mollusk fossils, foraminifera, and evidence of the interaction of living things recorded as trace fossils. Rocks containing trace fossils have recently become rare because residents have excavated many outcrops, which are used for house foundations, roads, backfill, and for public facilities. This zone is known for the presence of the largest oil field out of the 300 fields managed by Pertamina.

The research location will be selected in formations that have abundant trace fossils, namely the Ledok and Selorejo Formations rocks. The rock in this formation is dominated by limestone, a gas and oil reservoir in the North East Java Basin (Husein, 2016). Trace fossil research is carried out directly in the research area to obtain data on the number of densities and variations of trace fossils, analyze rock porosity, and changes in the depositional environment (ichnofacies) in the area depositional. The purpose of this research is to:

1. Determining the variation of trace fossils on the MS trajectory
2. Divide the ichnofacies based on the variety of trace fossils found.

This research focuses on trace fossils taken systematically on the most ideal measured stratigraphic path, continuous and good outcrop, with a distance and area of rock layers of about ±1 m^2 so that a representative level of accuracy, density, and variation of trace fossils will be produced. Research on trace fossils comprehensively in the Rembang Zone has not been carried out.

2. Physiography and Regional Stratigraphy

According to Bemmelen,1949 (Fig. 1), it is included in the Rembang Anticlinorium or Rembang Zone, an undulating plain area with hills interspersed with alluvial plains.

The Ledok Formation consists of predominantly coarse to very fine carbonate rocks, alternating limestones and calcarenite, sandy limestones, sandstones, marl, and many glauconite minerals area at the top, and the limestone thins upwards. The developed sedimentary structures that developed were bedding, mega cross-bedding, and bioturbation/trace fossils (Fig. 3). The Ledok Formation is NN10-NN12 (Late Miocene), based on the last occurrence of *Discoaster hamatus and Discoaster quinqueramus*. The depositional environment at the Outer Neritic (100-200) m, based on the presence of *Oolinia apiculata* and *Pseudoclavulina humilis*. The thickness of the unit is 297 m (Choiriah, Prasetyadi, Yudiantoro, et al., 2020a). The stratigraphic of the study area is focused on the Ledok Formation and the Selorejo Formation (top Mundu) (Fig. 2).

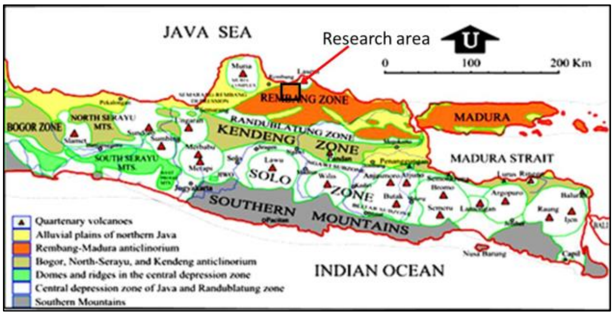

Fig. 1. Physiography of East Java and research area in Black box (Van Bemmelen, 1949)

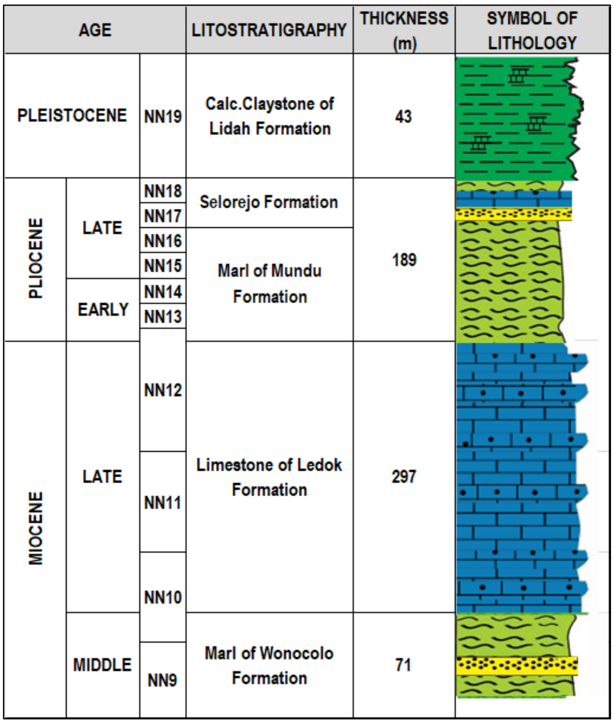

Fig 2. Stratigraphy of the Ledok and Selorejo Formation on the Nglebur River (Choiriah, Prasetyadi, Yudiantoro, et al., 2020b).

The Selorejo Formation is composed of alternations between foraminiferal grainstone and packstone which are partially glauconitic in nature with marl limestone to sandy limestone, with a type location in Selorejo village near Cepu. The thickness of this unit reaches 100 m (Husein, 2016).

The Selorejo Formation is the upper part of the Mundu Formation. The Mundu Formation comprises white and bluish marl, sandstone containing abundant foraminifera, and some mollusk shells. Mundu Formation (top) has some layers. They are layers of sandstone limestone, massive structures, and parallel layers, which are the Selorejo Formation. The age of the Mundu Formation is NN12-NN16 (Early Pliocene to Middle Pliocene) according to nannofossil analysis, namely the late appearance of *Discoaster quinqueramus* and *Discoaster brouweri* (Choiriah et al, 2020). Trace fossils are structures produced in substrates ranging from unlithified sediments to sedimentary or organic rock matter (including shell, bone, wood, and peat) by the activity or growth of organisms. Trace organisms can be grouped into categories depending on the type of substrate and mode of origin (Knaust, 2021).

Fig. 3. Trace fossils in sandy limestone of Ledok Formation (Choiriah, Prasetyadi, Kapid, et al., 2020)

3. Methods

The research was carried out through geological capture and field data collection including, lithostratigraphic data, lithofacies, ichnofacies, and rock sampling, which were then used for fossil analysis in the laboratory.

3.1 Trace Fossils.

Trace Fossils or Ichnofossils were appearances or expressions of changes in depositional structures in sedimentary rocks by organisms when organisms were still alive. Often the organisms that produce these structures leave no skeletal remains, so the products of the activity of these organisms are known as "trail" fossils.

The morphological description and classification of trace fossils (ichnotaxobase) are based on several relevant aspects directly related to bioerosion development and mechanism. Ichnotaxobase is thought to be applied to the trace fossils of vertebrates and invertebrates (Pirrone et al., 2014). This classification for naming trace fossils is based on 1) general morphology; 2) bioglyphs; 3) filling; 4) branching; 5) pattern of events; and 6) emplacement location (Fig. 4). The genus name is based on trace fossils by Alan R & P. Johnson, 1975 in (Choiriah et al., 2022) of Table 1.

Table 1 Genus name based on trace fossils by Alan R & P. Johnson, 1975 in (Choiriah et al., 2022)

Crawling	Feeding	Grazing	Dwelling	Escape	Resting
Vertebrates	*Asterosoma	*Helminthopsis	*Arenicolites	(Telichichnus)	*Bergaueria
	***Chondrites**	***Zoophycus**	**(Bergaueria)**	**(Monocraterion)**	***Conichnus**
	*Macaronichnus	*Cosmosaphe	(Conichnus)	(Diplocraterion)	
	Muensteria		**Cylindrichnus**		
	***Planolites**		*Diplocraterion		
	*Rhizocorallium		***Monocraterion**		
	***Rossella**		*Ophiomorpha		
	*Telichichnus		**Paleophycus**		
	(Zoophycus)		*Skolithos		
	(Thalassinoides)		***Terebellina**		
			*Thalassinoides		

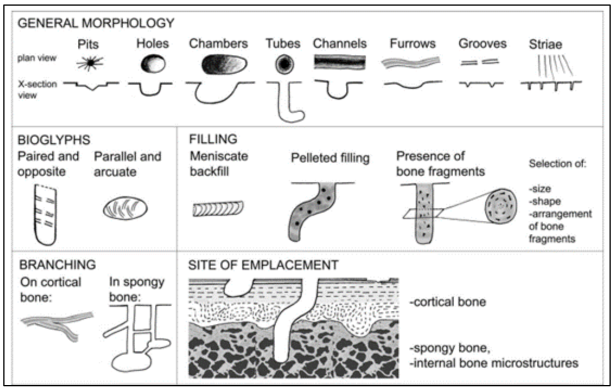

Fig. 4. Diagram illustrating the most common attributes of ichnotaxobases for bioerosion trace fossils in bones and their terminology (Pirrone et al., 2014)

Seilacher (2007) in his research used trace fossils for paleoecological reconstruction; introduction of the depositional environment, trace-fossil evolution, and ichnostratigraphy and concluded that deep-sea track fossils are different from shallow sea track fossils (Knaust, 2017). The main controlling factors for the distribution of trace fossils are climate change, water discharge, changes in water circulation, and the position of water turbidity (Díez-Canseco et al., 2015). Trace fossils can be classified in various ways for different purposes. The existence of trace fossils is one factor in cavities in rock formations. Each type of trace fossil will be associated with variations in lithofacies, sedimentation processes, rock types, and the depth of the settling site are associated with some aspects of geology like rock facies spreads, rock sources, paleobathymetry, trace fossils, and sedimentation processes (Pramunita,Siska W., Pandita, Hita., Rizqi, 2020)

3.2. Stratigraphy of Gadu and surrounding areas

The lithological variation of the Selorejo Formation, is composed of calcareous sandstone, sandy limestone, bioclastic limestone, marl, and sandy marl (Fig. 5). This unit was deposited in a shallow marine environment.

Fig. 5. Outcrop of lithological variations

The Limestone Selorejo Unit and the Selorejo Sandy limestone Unit are rock units composed of calcareous sandstone, sandy limestone, bioclastic limestone, marl, and sandy marl, deposited in a shallow marine environment. The status of the Selorejo sandstone unit is proposed to be the Selorejo Formation, with the Late Pliocene age ranging from NN17-NN18 (Late Pliocene), marked by the late appearance of the nannofossils of *Discoaster surculus,* and *Discoaster brouweri.*

The Selorejo Formation was deposited in a shallow marine environment, aged NN17-NN20 (Pliocene to Pleistocene), and has hyposaline salinity as indicated by a decrease in nannofossils, namely the number of Sphenolithus abies followed by an increase in Helicosphaera carteri (Santoso et al., 2014).

This formation was unconformably deposited on the marl of the Mundu Formation and was conformable closed by the Lidah Formation claystone unit. A decrease in the global sea level caused the unconformable that occurred at the end of the Pliocene. The Selorejo member, which consists of interbedded thin layers of limestone with calcarenite, very rich in planktonic foraminifera fossils, was deposited in the Late Pliocene-Plistocene, which is the effect of a regression/sea shrinkage process or concurrent with sediment folding in the North East Java Basin.

The Selorejo Formation has four ichnofossil classes, namely (*Thalassinoides, Arenicolites, Planolite, and Rhizocorallium)* and based on ichnofacies and lithofacies data, the Selorejo Formation was deposited in a shallow marine environment accompanied by waves and storms (Santoso et al., 2014).

3. Result & Discussion

From the results of collecting trace fossil data on the MS Sungai Gadu section, trace fossils were obtained from *Planolites, Helminthopsis, Thalassinoides, Conichnus, Chondrites, Macaronichnus, Bergauria, Ophiomorpha, Skolithos, Terebellina, Palaeophycus,* dan *Asterosoma.*

1. *Planolites,* straight to slightly or markedly undulate and meandrous, rarely branched, cylindrical or subcylindrical or irregularly developed, unlined burrows, walls smooth to transversely or obliquely annulate.

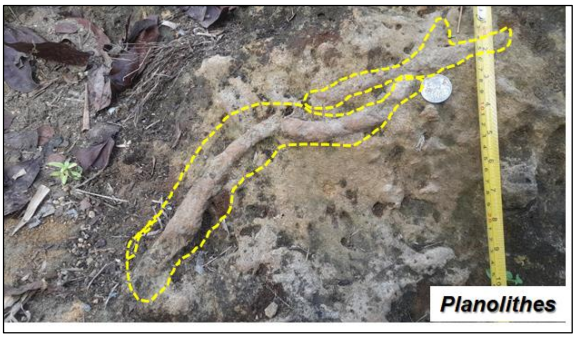

Fig 6. *Planolites*

Planolite is an ichnofossil, which is associated with shallow marine sediments under low to moderate energy conditions (Pemberton and Frey, 1982).

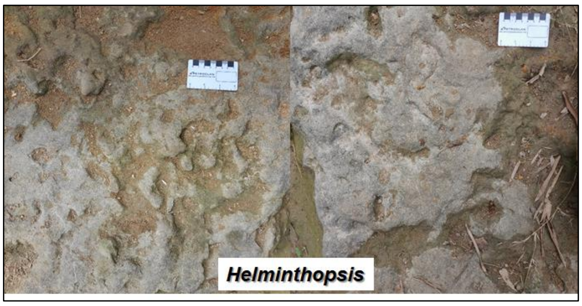

Fig 7. *Helminthopsis*

2. *Helminthopsis* is a tubular, cylindrical, and simple burrow. This burrow is elongated in shape and unbranched. There are entanglements and irregular indentations. Trace fossils of *Cruziana* and *Helminthopsis* include Ichnotaxa of the *ichnofacies Scoyenia*, *wormlike, nematode, notostracans, myriapods*, and arthropods which are interpreted as deposits

in a meandering flow environment, in point bar sediments and fluvial (Metz, 2022).

3. *Thalassinoides* are the reason for the relatively large burrow. This burrow consists of a section with smooth walls and cylindrical. This fossil branches in a pointed shape like the letter "Y" to thick as the letter "T." This fossil is usually found enlarged at the branch.

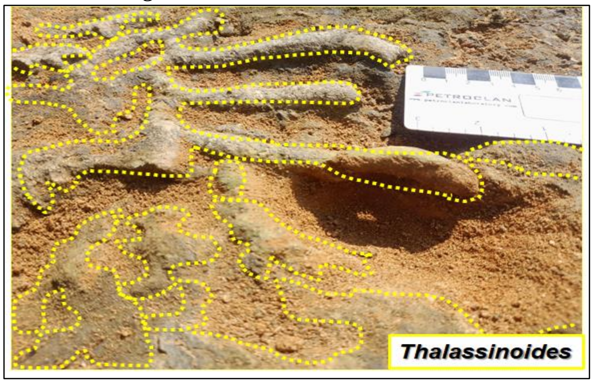

Fig.8. *Thalassinoides*

4. *Conichnus,* this trace fossil, is short to long and upright/vertical, shaped like a pointed/cone at the end. The shape of the burrow is round, cylindrical-sub cylindrical, smooth, with a smooth base. The feature in the field is like round bulge-like papillae. It is a cone-shaped burrow made by sea anemones, occurs in medium-grained, criss-cross sandstones, and is often found in shallow seas (Desai & Saklani, 2015).

Fig 9. *Conichnus*

5. *Chondrites,* this trace fossil has small burrows and is "dendritic" branched. The burrows's walls are smooth and regularly patterned but must be symmetrical. The walls of the burrow are not interconnected. The burrow diameter varies. Chondrites are modern trace fossils associated with marine environments, with good oxygen, disoxic, and limited space, so they are considered highly tolerant ichnotaxons (Baucon et al., 2020).

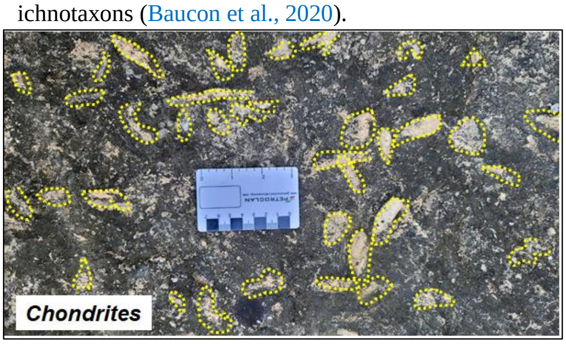

Fig 10. *Chondrites*

6. *Macaronichnus* is a trace fossil of compact shape, dense and thin (sub-vertical to sub-horizontal), cylindrical, smooth, and porous, and with a circular cross-section. The diameter of the burrows ranges from 2 to 5 mm and the shape is elongated, tortuous, and unbranched. Macaronichnus is usually identified as an unbranched, cylindrical, sub-horizontal burrow from a few millimeters to 15 mm in diameter. Macaronichnus is primarily found in shallow coastal and shallow subtidal deposits but also occurs in deep-sea sediments (Dorador et al., 2021)

7. *Bergaueria* is a trace fossil that is short in size, round in shape, and protruding to the surface like a burrow. The shape of the burrow is vertical, with an elliptical base. Bergaueria (sea anemone) is an ichnofossil in the form of a burrow, found in marine environments, in muddy layers whose deposition is heavily influenced by the presence of brackish water (Wroblewski & Gulas-Wroblewski, 2021)

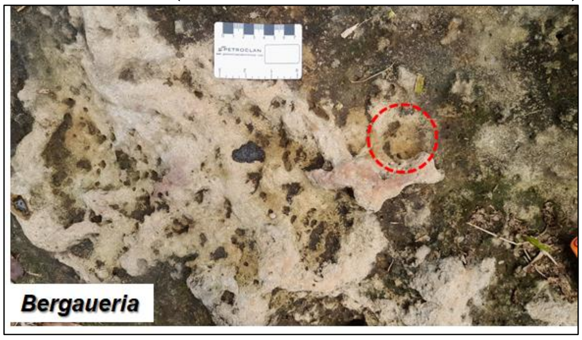

Fig. 11. *Bergaueria*

8. *Ophiomorpha* is a trace fossil in the form of burrows, which are simple to very complex. Ophiomorpha-bearing sandstones were deposited at the end of the transgressive system in a series of stratigraphy. The appearance of *Ophiomorpha* indicates the entry of the sea into the paralic system (Nagy et al., 2016).

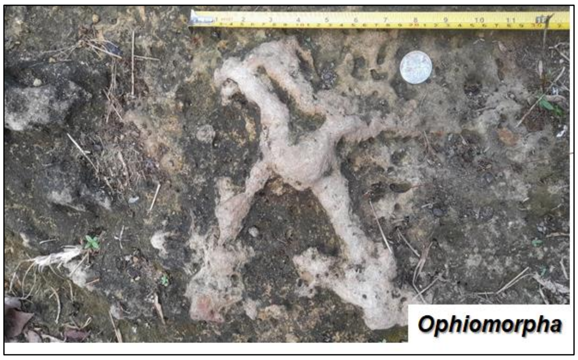

Fig. 12. *Ophiomorpha*

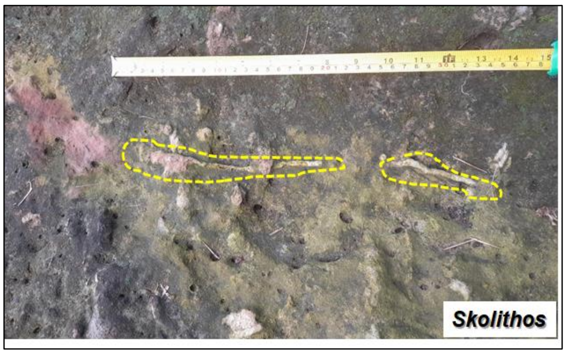

Fig. 13. *Skolithos*

9. *Skolithos* the structure of this fossil trace, has no branches. The shape is upright to oblique shape, and straight to slightly curved. The shape of the burrow is round, cylindrical to subcylindrical, often found in a row, and sometimes the top is funnel-shaped. The outer wall is smooth to rough and indistinct, and some specimens have internodes, the burrow diameter varies. Skolithos, often found in crevasse splay sediments, consists of red-brown, grayish-green, and locally diverse sediments with abundant downstream regime structures but little overflow regime structure (Zhou et al., 2019).
10. *Terebellina* is sizeable tubular trace fossil whichthat is straight to curved. The shape of this fossil trace is also narrow unbranched, and elongated, at both ends, it is usually open. At the ends, there may be transverse bulkheads or internal partitions. The walls are composed of agglutin. These fossil traces are commonly found with thick burrow walls, and the inside is composed of spongy spicules, grains of sand, and silt. The constituent materials can come from a mixture of materials mixed with organic cement. The aperture hole is located at the end of the wider diameter. Terebellina subcylindrical, vertical, curved burrows to soft and firm with circular to shaped cross-sections are commonly found in the ichnofacies Cruziana in offshore, marine environments (Choiriah et al., 2022).

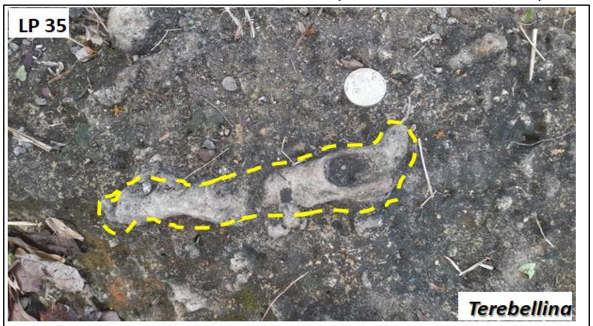

Fig.14. *Terebellina*

11. *Palaeophycus* is a branched but also unbranched trace fossil. In physical form, the surface is smooth, has an ornament, and is lined. This fossil trace is cylindrical; most of the burrows are horizontal. The burrow diameter varies, with unstructured fillings and the same lithology as the source rock of the trace fossils. Palaeophycus, Zoophycos, Chondrites, Lorenzinia, and Spirorhaphe ichnofossil were found in the submarine fan distal facies associated with high intensity indicating low energy and low sedimentation rates (Widiatama & Santy, 2022).

Fig 15. *Palaeophycus*

12. *Asterosoma* is rounded and elongated, has a bulbous middle region, all taper at one end and some at both ends, and many have several smaller branches fanning from the end. Several individual burrows form a fan or radiate from the same point with e a central tube. The trace fossils such as Asterosoma reflect open ocean conditions (Gilbert et al., 2019).

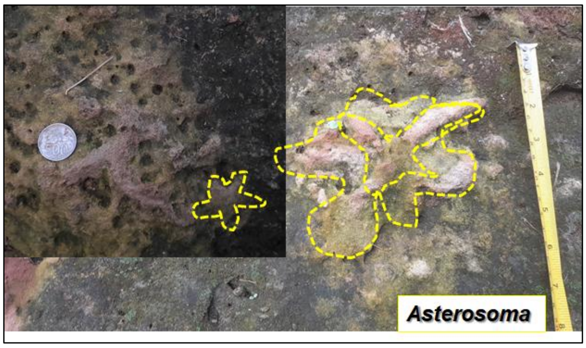

Fig 16. *Asterosoma*

Conclusion

The trace fossils that have been identified are 12 fossils, namely: *Planolit, Helminthopsis, Thalassinoides, Conichnus, Chondrites, Macaronichnus, Bergauria, Ophiomorpha, Skolithos, Terebellina, Palaeophycus, and Asterosoma*. The presence of trace fossils indicates that the depositional environment is in the shallow marine area along the coast with low to high energy on sandy lithology. This research is a preliminary study, which will continue to determine the value of porosity in each type of trace fossil and its benefits in the petroleum system.

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