ACOUSTIC FACIES AROUND THE INTRUSIVE COMPLEX OF SALAHNAMA AND PANDANG ISLANDS, MALACCA STRAIT

AKUSTIK FASIES DI SEKITAR KOMPLEKS INTRUSI PULAU SALAHNAMA DAN PULAU PANDANG, SELAT MALAKA

Subarsyah[1*], Ali Albab[1], Shaska R. Zulivandama[1], Eko Saputro[1], Arif Ali[1], Imam Setiadi[1], Muhammad Zulfikar[1], Faris Nauval Rasyid[1], Riza Rahardiawan[1]

[1] Marine Geological Institute, Indonesia

*Corresponding author:

(Received 16 April 2025; in revised from 17 April 2025; accepted 29 December 2025)

DOI : 10.32693/bomg.40.2.2025.938

ABSTRACT: Salahnama and Pandang Islands lie on the main range of the granite province; both islands are located in the Sunda Shelf, Malacca Straits. These islands are composed of intrusive rocks from Berhala. The rock's existence will offer a significant contribution to the distribution of surface sediments in the surroundings. The sea dynamics and the geometry of the Malacca Strait will also have an impact on the seabed. Apart from that, global factors such as sea level changes will lead to transformation of the depositional environment and subsurface geology in the strait. Geological conditions of the seabed surface and subsurface can be understood and interpreted based on the acoustic characteristics and reflector patterns of a seismic section. Then, based on the acoustic character and reflector pattern, an acoustic facies can be defined. Seismic data measurements have been carried out around Salahnama and Pandang Islands in 2024. Based on the results of the seismic section, the acoustic facies in the study area are classified into 6 (six), which include AF I – AF VI. Seabed morphological features in the form of sand dunes were identified in the first acoustic facies (AF I); this feature is formed due to geometric aspects, surface currents, and bottom current's which may or may not be triggered by tidal vortices. Acoustic Facies II (AF II) is characterized by sandwave or ripple marks formed by strong seabed currents. AF III was formed after the Last Glacial Maximum (LGM) ended and the depositional environment returned to a shallow marine environment, characterized by a transparent pattern in the seismic section. The erosional truncation at the upper boundary of AF IV indicates a change in the depositional environment from shallow marine to coastal or terrestrial environments during the Last Glacial Maximum period. AF V is acoustic bedrock, and AF VI is characterized by a chaotic pattern, which is interpreted as granitic intrusive rocks.

Keywords: Berhala, Facies, Acoustic, Salahnama and Pandang

***ABSTRAK**: Pulau Salahnama dan Pandang terletak pada jalur utama granit, kedua pulau berlokasi di Paparan Sunda, Selat Malaka. Kedua pulau ini tersusun atas batuan intrusif Berhala, keberadaan pulau-pulau ini akan memberikan kontribusi yang signifikan terhadap sebaran sedimen permukaan di sekitarnya. Dinamika laut dan geometri Selat Malaka juga akan memberikan pengaruh terhadap kondisi geologi dasar laut, selain itu faktor global berupa perubahan muka air laut akan memberikan perubahan terhadap lingkungan pengendapan dan geologi bawah permukaan di Selat Malaka. Kondisi geologi permukaan dasar laut dan bawah permukaan dasar laut saat ini dapat dipahami dan diinterpretasikan berdasarkan karakter akustik dan pola reflektornya dari suatu penampang seismik. Kemudian berdasarakan karakter akustik dan pola reflektor dapat didefinisikan suatu akustik fasies. Pengukuran data seismik telah* *dilakukan di sekitar Pulau Salahnama dan Pandang pada tahun 2024. Berdasarkan penampang seismik yang dihasilkan, akustik fasies di area studi diklasifikasikan menjadi 6 (enam) yang meliputi; AF I – AF VI. Fitur morfologi dasar laut berupa gumuk pasir teridentifikasi pada akustik fasies pertama (AF I), fitur ini terbentuk akibat aspek geometri, arus permukaan dan arus bawah permukaan yang mungkin terpicu tidal vortis ataupun tidak. Akustik Fasies II (AF II) dicirikan dengan sandwave atau ripple mark yang terbentuk akibat arus dasar laut yang kuat. AF III terbentuk setelah Last Glacial Maximum (LGM) berakhir dan lingkungan pengendapan kembali menjadi lingkungan laut dangkal, dalam penampang seismik dicirikan dengan pola transparan. Ketidakselarasan berupa erosional truncation pada batas atas AF IV merupakan indikasi dari perubahan lingkungan pengendapan dari laut dangkal menjadi lingkungan Pantai atau terrestrial selama perioda Last Glacial Maximum. AF V merupakan batuan dasar akustik dan AF VI dicirikan dengan pola chaotic yang diinterpretasikan sebagai batuan intrusi granitic.*

Kata Kunci: *Berhala, Fasies, Akustik, Salahnama dan Pandang*

INTRODUCTION

Salahnama and Pandang Islands are situated in the Sunda Shelf which is part of the relatively stable core 'Sundaland', (Gorsel, 2018). On the Sunda Shelf two significant geological events contribute to the formation of acoustic facies around the intrusive complex of these two islands, in addition the impact of recent ocean dynamics; such as currents, tides and waves.

The present geology of the region is characterized mainly by a granitic belt. These Southeast Asian granitic intrusions are classified into four provinces; the Eastern Province, Main Range Province, Western Province, and the Volcanic Arc Suite (McCourt et al., 1996; Cobbing, 2005). The Eastern Province was initiated by subduction of the Palaeo-Tethys beneath the Cathay Islands which is a composite of the South China, North China, Indochina, West Sumatra, and West Burma plates. The Main Range Province is influenced by the collision of the Sibumasu and the East Malaya-Indochina plates, in contrast the Western Province is related to subduction Ceno Tethys (Metcalfe, I., 2013). The Final province, which is geographically restricted to the Barisan Mountains, exhibits a wide range of composition, (Cobbing, 2005). Salahnama and Pandang Islands are assumed to be located within the granite formations of the Main Range Province (Figure 1).

In the geological maps published by the Indonesian Center of Geological Survey (Bennette, et. al 1981), these two islands are constructed by intrusive rocks from the Berhala Region. The age of the Berhala intrusion is estimated to be Middle Permian. Cobbing (2005) suggested that the Main Range Province granite may have formed 247 to 143 million years ago, or between the Jurassic and Triassic periods. Therefore, the Berhala intrusion may be younger than previously thought.

Sea level changes during the Last Glacial significantly impacted to formation of acoustic facies around these intrusive complexes, The Sunda Shelf was fully exposed and connecting mainland Southeast Asia with Sumatra, Java and Borneo, (Bird, et. all, 2005, Figure 2). During the Last Glacial, Sundaland experienced erosion and a terrestrial environment.

Identifying acoustic facies is a valuable approach for understanding recent geological conditions, as well as the geological processes and sea dynamics that impact the current state of the seabed. In this publication we will examine various acoustic facies around the intrusive complexes of Salahnama and Pandang Islands to gain insights into recent geological conditions and the processes involved.

The geological fact that channels formed during the Last Glacial Period in this region is fascinating, considering that the presence of channels is often associated with the potential for placer minerals. One of the important acoustic facies that can be used to analyze the potential of mineral placers is the acoustic facies within a channel. It would be very valuable to be able to analyze the acoustic facies character within the channel to identify the potential for placer minerals

Study Area

The study area is situated on the waters of the of Salahnama and Pandang Islands, within the narrow and shallow part of the Malacca Straits. It covers approximately 168 km2 and is defined by the coordinates Longitude 99^o 37.5' E to - 99^o 47.5' E and Latitude 3^o 29' N - to 3^o 19' N (see Figure 3).

METHODS

The analysis and identification of acoustic facies were primarily conducted on single channel seismic data, complemented with seabed surface samples. A total of 353 km of survey lines were analyzed, consisting of 285 km, including 23 northeast-southwest lines spaced at 0.5 and 1.0 km, and 68 km of 5 northwest-southeast lines, spaced at 2 to 3 km. Ninety grab samples were collected for this study, as illustrated in Figure 4. These data were obtained from a marine mapping project conducted by Marine Geological Institute of Indonesia. The boomer seismic energy of a 300 joules was generated by an Applied Acoustic Boomer System, which was fired at a fixed spacing of 20 m and recorded at a sweep duration of 250 milliseconds.

The analysis and interpretation of seismic dataset were carried out by the using SonarWiz7 software. The seismic profile was converted from two ways time to depth using an acoustic speed assumption of 1600 m/s. The identification of acoustic facies was defined based on their internal and external reflector configuration/geometry, reflection strength, penetration depth and lateral continuity and were then classified into several categories. The analysis of this data focused on identification of granitic rock on seismic profile.

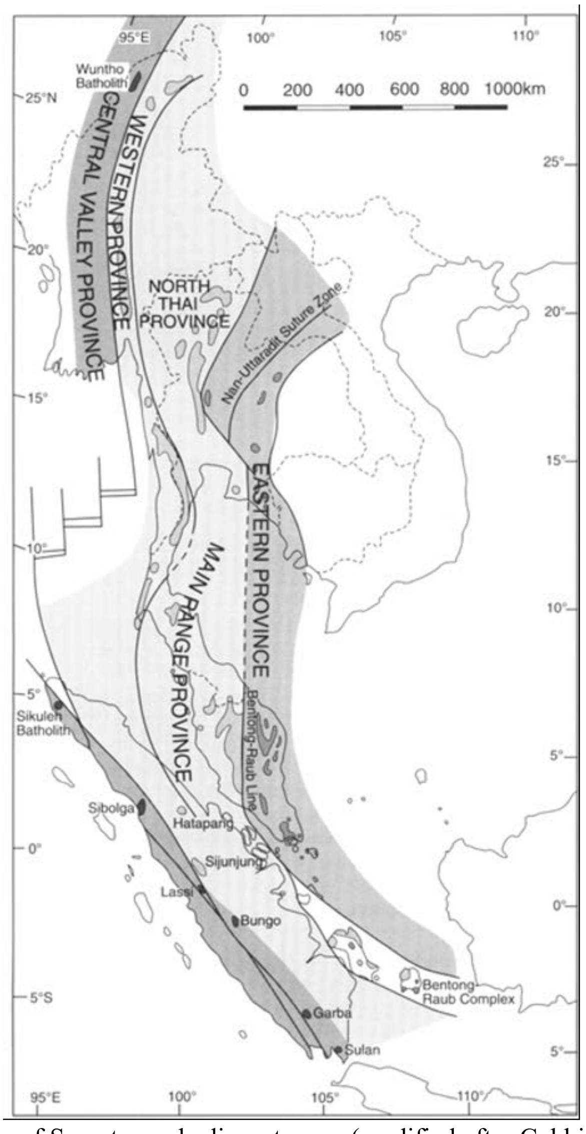


Figure 1. Granitic provinces of Sumatra and adjacent areas (modified after Cobbing et al. 1992 and McCourt et al. 1996).

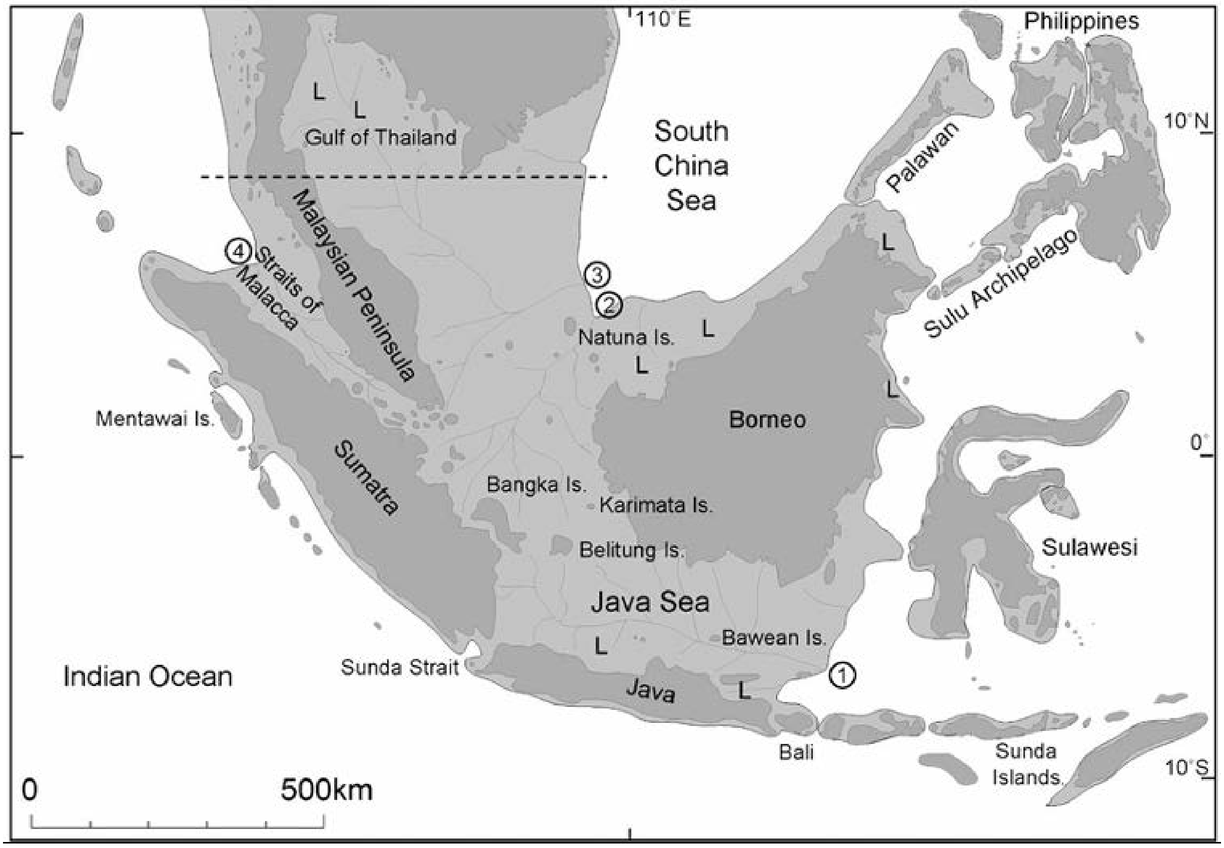


Figure 2. Sundaland at the Last Glacial Maximum, showing the modern distribution of land in dark grey and the additional land exposed during the LGM in light grey (adapted from Voris, 2000).

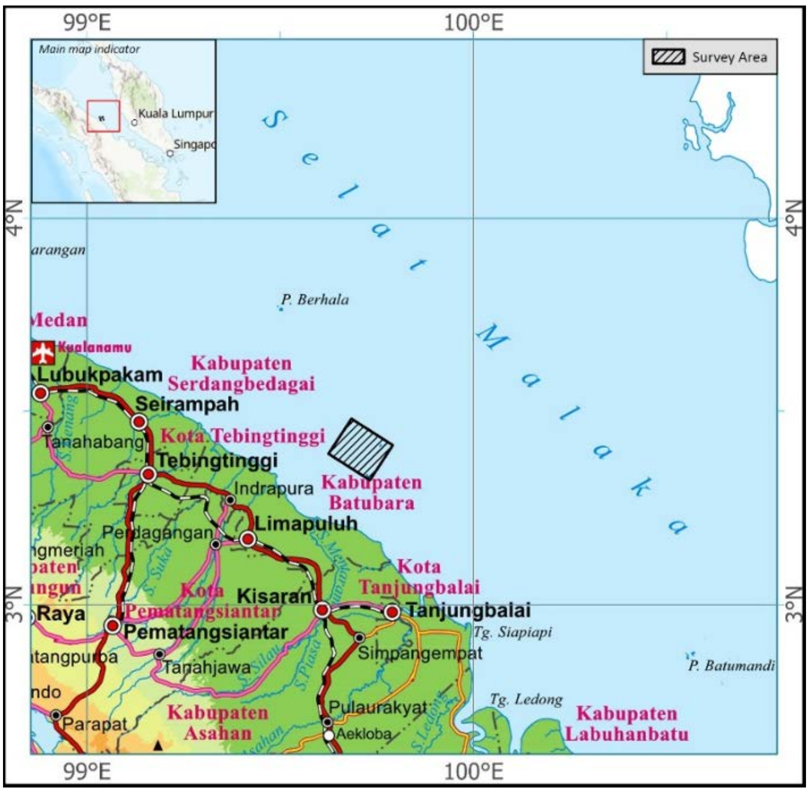


Figure 3. Study area, Malacca Straits

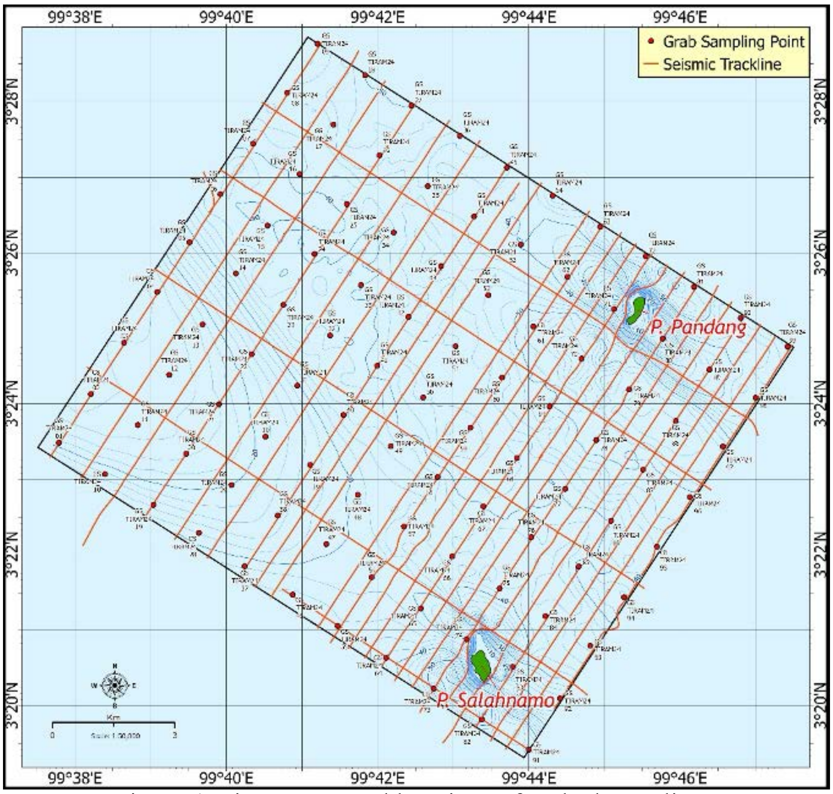


Figure 4. Line survey and locations of seabed sampling

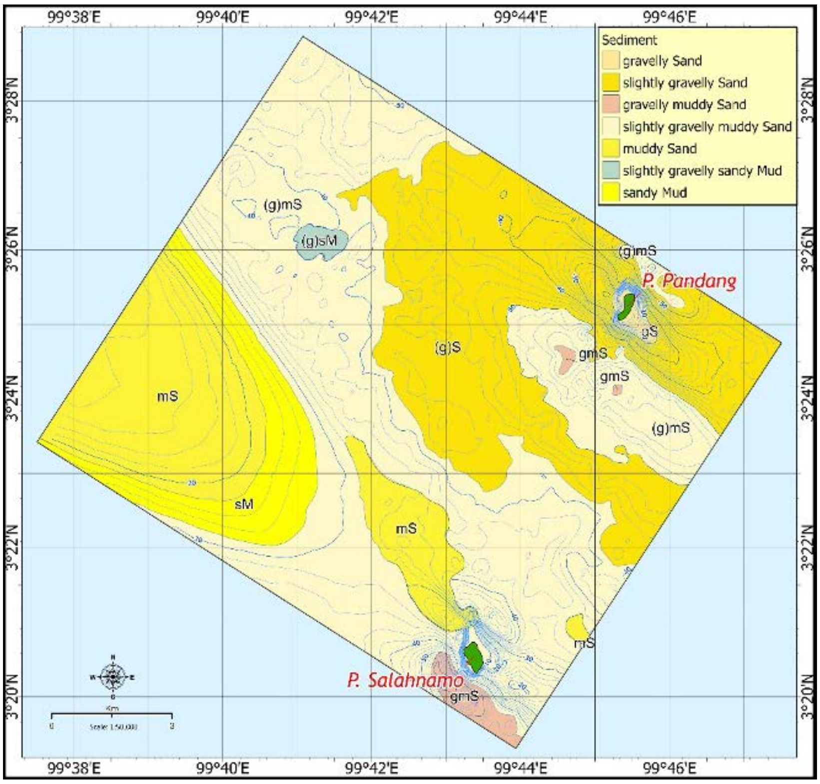


Figure 5. Distribution of Surficial Sediments

RESULTS AND DISCUSSION

Acoustic facies classification is done based on differences acoustics character, sediment types and geomorphological patterns, (Novak, et. al, 2020 and Schulten, et. al, 2023), six acoustic facies (AFI~AFVI) can be identified in this study based on these variations. The acoustic characters are described in detailed on the Table 1 and are illustrated in Figure 6 and Figure 7. The six identified acoustic characters include: gently oblique prograding reflectors, prolonged, transparent, divergent, deformed and chaotic types. The characteristics are generally correlated with sedimentary properties and bottom conditions during sedimentary process.

Acoustic Facies I

This facies is represented by gently oblique prograding reflectors is distributed in the northwestern part of study area. The sea bottom condition identified are smooth and mounded, which can be interpretated as a sand bank. This sand bank likely formed in the Malacca Straits due to its geometric configuration and the influence of surface and bottom currents, potentially triggered by tidal vortices. Tidal vortices are chain of spiral eddies that occur in the environment where strong tides and currents flow through straits. Acoustic blanking has also been identified in these acoustic facies, Indicating the accumulation of significant organic material. The orientation of sand banks is parallel to the shoreline, with an approximate length of 10 to 12 km. This facies was identified in unit I of seismic section (Figure 7). The facies may consist of muddy sand and gravelly muddy sand as shown in Figure 5.

Acoustic Facies II

Facies II, is characterized by a prolonged type, a prolonged type of acoustic facies is characterized by a strong, long-lasting, and often high-amplitude seafloor reflection with very little to no sub-bottom penetration (Dowdeswell, et. al, 2014), is distributed from the center to the northeast part of the study area. The prolonged type is characterized by the disappearance of acoustics signals downward. On seismic profiles, the facies shown irregular surfaces associated with the existence of bedforms of sand waves (Table 1). Depositional sand waves may be associated with strong bottom currents in the center of Malacca Straits.

The grab samples indicate that the surficial sediments on these facies varies from gravelly muddy sand to gravelly sand as shown in Figure 5.

Acoustic Facies III

This acoustic facies is represented by transparent characters. Transparent characters only found in the subsurface unit, known as unit III. These transparent acoustic facies commonly consist of homogenous material. In the Malacca Strait, the most likely depositional environment for these characters to occur is shallow marine. The deposition in the marine environment has repeatedly occurred in the Sundaland due to flooding events started during the Middle Pleistocene (Susilohadi, et. al, 2024).

Acoustic Facies IV

The acoustic facies IV, acoustic facies within the channel, can be divided into three different acoustic facies. Facies IV (a) is characterized by a low lateral continuity of reflector and divergent – clinoform reflectors. Divergent reflector character commonly indicates a lateral sediment variation during the depositional or that the depositional surface tilted progressively (Deng, et.al 2024) but in this study area the lateral variation during the depositional was the most likely cause these acoustic facies. High amplitude and low lateral continuity indicate terrigenous deposition such as inter-bedded channel sands and shales. Terrigenous sediments are commonly made up of sand, mud, and silt, and are usually related to the composition of their source rocks (Cullers and Podkovyrov, 2002).

Facies IV (b) is characterized by chaotic-like reflectors within the channel fill, a chaotic acoustic signature is interpreted as a mixture of sediments, including coarse gravel and heavy minerals, which create an irregular internal structure that reflects seismic waves in a disorganized manner. Facies IV (c) is characterized by homogeneous/transparent reflectors within a channel that might indicate a finer-grained, less mineral-rich sediment, like silt or clay. An erosional truncation is identified at the top of the facies boundary which may an indicator of an erosion during the eustatic depression of sea level fall. During the Last Glacial Maximum (LGM) sea level fall by ~ 120 meters and fully exposed the Sunda Shelf.

Acoustic Facies V

Acoustic facies V is represented by a transparent character. Transparent acoustic reflection in this facies is believed due to weaker acoustic energy and is defined as the acoustic basement.

Acoustic Facies VI

Facies VI is characterized by chaotic reflection pattern. In this study area, this characters associated with granitic intrusive rocks which made up the Islands of Salahnama and Pandang. The rocks can be identified not only on the sea bottom but also on the subsurface, the appearance rock on the seabed manifested by formation of rocky bottom.

The sea dynamics and geometry of Malacca Straits have a significant contribution to recent geological processes; the developments of morphological features such as sand banks and ripple marks are evidence of their contribution. Meanwhile, the granitic belt plays a role as a sediment supplier especially for coarser sediments in the study area, granitic intrusive bodies can be easily identified on the seismic section. Regarding sea dynamics, some features that are important to understand further is the mechanism of sand bank formation that is identified as the acoustic facies I (AFI).

Sea level changes associated with the Last Glacial had an impact on changes in the depositional environment. Depositional environment changes occurred from shallow marine to coastal or terrestrial environments primarily during the transition from Pleistocene to Holocene Epochs. In the seismic section, this change can be easily recognized by erosional truncation.

CONCLUSSIONS

Acoustic facies analysis provides a fast and effective method for characterizing and understanding geological history also identifying potential resources. Acoustic facies I provide evidence on how sand banks can form in the straits through a sea dynamic. Acoustic facies II provide an overview of how sedimentary structures can be formed by strong bottom current and wave. Analysis of acoustic facies, within the channel as seen in the acoustic facies four, can contribute information related to the potential of mineral placers. Chaotic-like reflectors within the channel (acoustic facies IV) have a greater potential of placer mineral rather than divergent-clinoform and homogenous-transparent reflector. Therefore, knowledge of acoustic facies can be used to identify channels that have the potential for placer minerals.

ACKNOWLEDGEMENTS

The authors are indebted to the head of the Marine Geological Institute of Indonesia (MGI) for permission to use the seismic data from this institute. The authors thank to team leader and all members of teams of mineral survey and mapping at Tanjung Tiram Waters, Malacca Straits. The authors also would like to thank all those who have helped and supported this research.

REFERENCES

Bennette, J.D., M.C. Bridge, N.R. Cameron, A. Djunuddin, S.A. Ghazali, D.H. Jeffery, W. Kartawa, W.Keats, N.M.S. Rock dan S.J. Thompson, 1981. *The Geology of the Langsa Quadrangle, Sumatra, Skala 1:250.000.* Pusat Penelitian dan Pengembangan Geologi, Direktorat Jenderal Pertambangan Umum, Departemen Pertambangan dan Energi.

Bird, I. M., Taylor, D., and Hunt, C., 2005. Palaeoenvironments of insular Southeast Asia duringthe Last Glacial Period: a savanna corridor in Sundaland. *Quaternary Science Reviews*: 2228-2242.

Cobbing, E.J., Mallick, D.I.J., Piteld, P.E.J. & Teoh, I.H., 1986. The granites of the Southeast Asian Tin Belt. *Journal of the Geological Society of London*, 143, 537–550.

Cobbing E.J., Pitfield, P. E. J., Darbyshire, D. P. F. AND Mallick, D. I. J., 1992, The granites of the South-East Asian tin belt. *Overseas Memoir 10 British Geological Survey.*

Cobbing, E.J., 2005, Granites, Barber, A.J., Crow, M.J., Milsom, J.S., Sumatra: Geology, Resources and Tectonic Evolution, *Geological Society, London*.

Cullers, R. L., and Podkovyrop, V. N., 2002. The source and origin of terrigenous sedimentary rocks in the Mesoproterozoic Ui group, southeastern Russia. *Precambrian Research* 117 157-183 – Elsevier.

Dowdeswell, J.A., Hogan, K.A., Cofaigh, C. O., Fugelli, E.M.G., Evans, J., Noormets, R., 2014. Late Quaternary ice flow in a West Greenland fjord and cross-shelf trough system: submarine landforms from Rink Isbrae to Uummannaq shelf and slope. *Quartenary Science Review*, 292-309.

Deng, X., Huang, K. and Li, X., 2024. Sedimentary Characteristics and Evolution of the Late Miocene to Quaternary Tributary Channels in the Head of Bounty Channel, *New Zealand. Appl. Sci* 14 6160.

McCourt, W.J., Crow, M.J., Cobbing, E.J., Amin, T.C., 1996. *Mesozoic and. Cenozoic plutonic evolution of SE Asia: Evidence from Sumatra, Indonesia*. Geol. Soc.

Metcalfe, I., (2013). Gondwana Dispersion and Asian Accretion: Tectonic and. Paleogeographic Evolution of Eastern Tethys. *Australian Journal of Earth*.

Mollengraaff, G.A.F., 1921. Modern Deep-Sea Research in the East Indian Archipelago. *Geographical Journal* 57, 95–121.

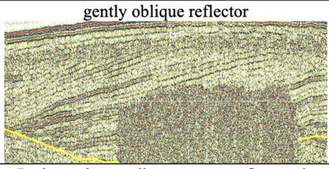
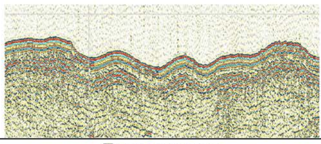
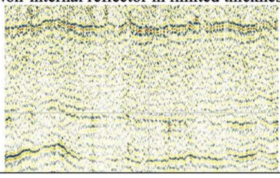
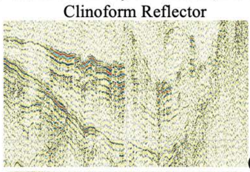
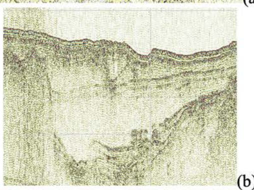
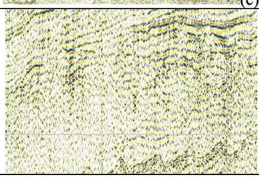
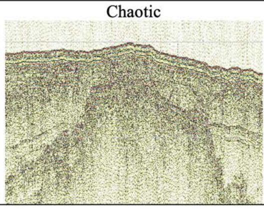
Novak, A., Smuc, J., Poglajen, S., and Vrabec, M., 2020. *Linking the high-resolution acoustic and sedimentary facies of a transgressed Late Quaternary alluvial plain (Gulf of Trieste, northern Adriatic)*, 419.

Schulten, I. Micallef, A., Krastel. S., Urlaub, M., Gutescher, M. A., and Kopp, H., 2023. *Reconstruction of the 1908 Messina gravity flow (central Mediterranean Sea) from geophysical and sedimentological data*, 459.

Susilohadi, Novico, F., Husson, L., Rahardiawan, R., Prabowo, H., Widodo, J., and Sudjono, E. H., 2024. Quaternary deposition and erosion in the northeastern Sunda Strait: An interplay between sea level, tectonics, and magmatic activity. *Journal of Asian Earth Sciences* X 12.

Van Gorsel, J.T. 2018. *Bibliography Of the Geology of Indonesia and Surrounding Areas Edition 7.0.* https://vangorselslist.com.

Table 1. **Six Acoustic Facies Defined at Study Area**

Acoustic Facies	Acoustic Character/Types	Sediments/Rock	Bottom Condition & Geomorphology	Sedimentary Environments	Interpretation
AFI	gently oblique reflector 	Muddy Sand/Gravelly Muddy Sand	Elongated Shaped Smooth and Mounded Bottom Sand Bank Features	Tidal Vortice along The Straits	Sand banks formed probably due to geometrical aspect and tidal vortices. In several parts below the sand bank was identified acoustic blanking due to presence of gas which is believed to be biogenic in origin.
AFII	Prolonged type, disappearance of acoustic signals to down direction 	Gravely Muddy Sand – Gravely Sand	Irregular Surface, Sand Wave, Mega Ripple, Rocky Bottom.	Coastal – Shelf Sea	Absorbing of acoustic signals by irregular bottom condition, medium to coarse sediments including gravel and shell fragment. Sand wave and mega ripple identified in the northeast. The appearance this sediment structures associated with strong currents (in the middle of the straits).
AFIII	Transparent type Non-internal reflector in limited thickness 	Homogeneous Sediments	-	Shallow Marine	Transparent acoustic reflection commonly occurred due to penetrating of acoustic signal to soft homogeneous sediments.
AFIV	Low lateral continuity of reflector, Divergent-Clinoform Reflector  (a)  (b)  (c)	Terrigenous Sediments	-	Terrigeneous Depositional	(a) Divergent-clinoform reflectors indicate that there were lateral variations in depositional rates or that the depositional surface tilted progressively. (a) High amplitude and low lateral continuity indicate terrigenous deposition such as inter-bedded channel sands and shales. (b) Chaotic-like reflectors within the channel fill, a chaotic acoustic signature is interpreted as a mixture of sediments, including coarse gravel and heavy minerals, which create an irregular internal structure that reflects seismic waves in a disorganized manner. (c) Homogeneous/Transparent reflectors within a channel might indicate finer-grained, less mineral-rich sediment, like silt or clay.
AFV		Sedimentary Rocks	-	Shallow Marine	Transparent acoustic reflection in these facies occurred due to weaker acoustic energy
AFVI	Chaotic 	Granitic Intrusive Rocks	Irregular Surface, Rocky Bottom	-	Intrusive granitic rocks identified in the survey area by chaotic character as an internal reflector.

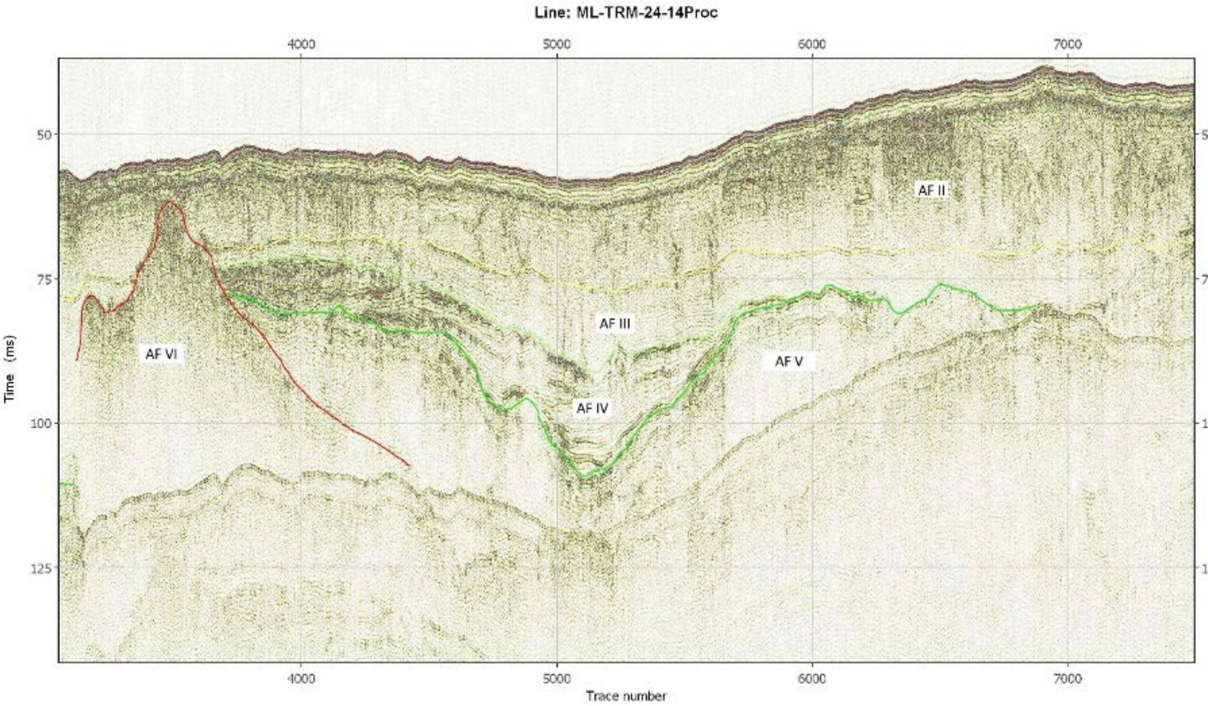


Figure 6. Seismic section line 14 and interpretation of acoustic facies within the line

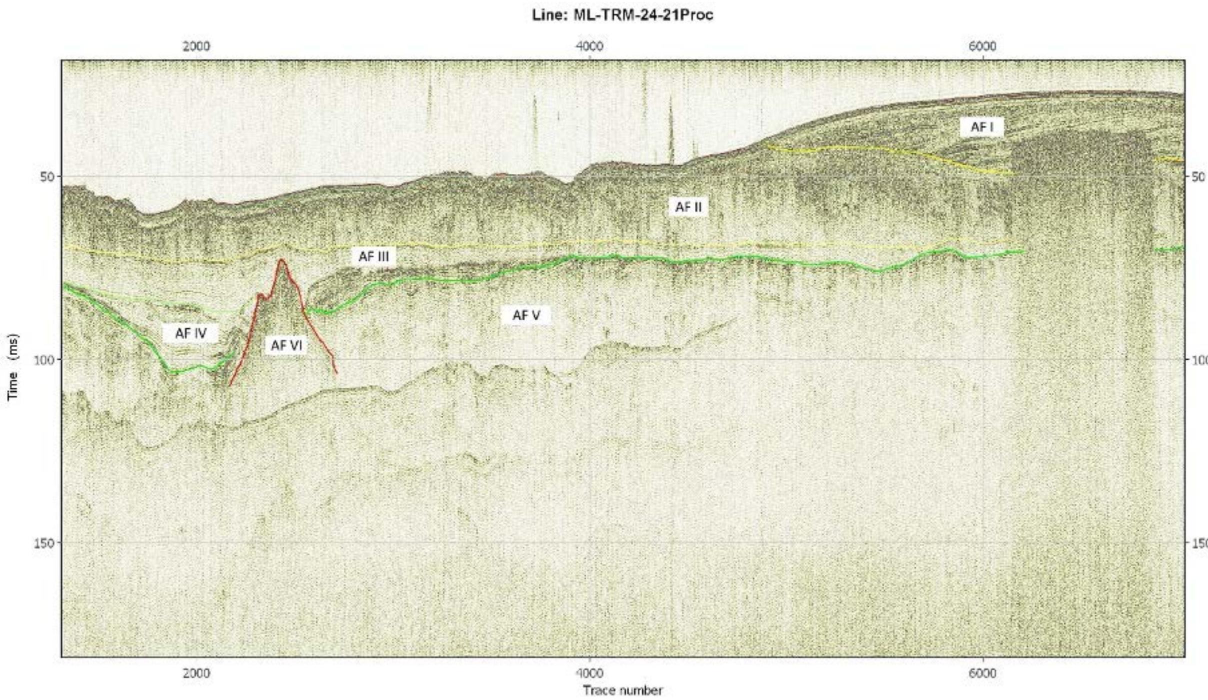


Figure 7. Seismic section line 21 and interpretation of acoustic facies within the line