DISTRIBUTION OF SUBSURFACE SEDIMENTATION AS A POTENTIAL MINERAL PLACER DEPOSITS IN SOUTH BINTAN ISLAND WATERS

SEBARAN SEDIMENTASI BAWAH PERMUKAAN SEBAGAI POTENSI ENDAPAN MINERAL PLACER DI PERAIRAN SELATAN PULAU BINTAN

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ABSTRACT : Bintan Island is one of the areas traversed by the Southeast Asian granitoid belt which is known to have the potential for heavy mineral placer deposits. Due to the dwindling presence of heavy mineral placer deposits in land areas, it is necessary to explore in water areas. Delineation of deposits accommodation of heavy mineral placer in the defined area are requires subsurface imaging investigations. The method used in this subsurface mapping is a single channel seismic method with a total of 179 lines from northeast-southwest and west - east directions. The results of this seismic record are then interpreted as the boundaries of the seismic facies unit and distributed using the kriging method. Furthermore, the thickness calculates by using the assumption velocity of 1600 m/s.

Based on the facies unit boundaries that have been interpreted, the quaternary sediments that formed in the study area are divided into 2 types of units, namely: Unit 2 which is estimated to be fluvial - transitional sediment, and Unit 1 which is estimated to be transitional - shallow marine sediment. There is also a difference in thickness patterns in these two units, where Unit 2 shows a pattern of sediment thickening that resembles a paleochannel trending northeast - southwest, while Unit 1 is relatively uniform.

From the results of this study, it can be said that the area that has potential of heavy mineral placer deposits is in the west-center of the southern waters of Bintan Island. Where the potential for heavy mineral placer deposits should be in the paleochannel deposits that are part of Unit 2.

Keywords: Quaternary Sediments, Heavy Mineral Placer Deposits, Rare Earth Elements, Southern Waters of Bintan

ABSTRAK : *Pulau Bintan merupakan salah satu wilayah yang dilalui oleh jalur granitoid Asia Tenggara yang dikenal memiliki potensi keterdapatan mineral berat plaser. Akibat keberadaan mineral berat plaser di wilayah daratan semakin menipis, maka dilakukan pencarian potensi tersebut di wilayah perairan. Delineasi wadah mineral berat plaser pada area ini memerlukan penyelidikan citra bawah permukaan.*

Pemetaan bawah permukaan ini menggunakan metode seismik single channel dengan jumlah lintasan sebanyak 179 lintasan dari timurlaut - baratdaya dan barat - timur. Hasil rekaman seismik ini kemudian diinterpretasi batas-batas unit fasiesnya dan disebar dengan menggunakan metode kriging. Selanjutnya dihitung ketebalannya dengan menggunakan asumsi cepat rambat 1600 m/s.

Berdasarkan batas unit fasies yang telah diinterpretasi sedimen kuarter yang terbentuk di daerah penelitian terbagi menjadi 2 jenis unit yaitu: Unit 2 yang diperkirakan merupakan sedimen fluvial - transisi, dan Unit 1 yang diperkirakan sebagai sedimen transisi - laut dangkal. Terlihat pula adanya perbedaan pola ketebalan sedimen pada kedua Unit ini, dimana Unit 2 menunjukkan adanya pola penebalan sedimen menyerupai paleochannel berarah timurlaut - baratdaya sedangkan pada Unit 1 relatif terlihat seragam.

Dari hasil penelitian ini dapat disimpulkan bahwa daerah yang memiliki potensi endapan mineral berat plaser berada di Barat ke tengah daerah perairan selatan Pulau Bintan. Dimana potensi endapan pembawa mineral berat plaser seharusnya berada pada endapan paleochannel yang merupakan bagian dari Unit 2.

Kata Kunci: *Sedimen Kuarter, Endapan Mineral Berat Plaser, Unsur Tanah Jarang, Perairan Selatan Bintan*

INTRODUCTION

Southeast Asia is one of the areas traversed by the granitoid route that carries economically heavy minerals. Where this granitoid line stretches for 3000 km from Burma to West Kalimantan, not passing through Bintan Island and the surrounding waters (Cobbing, 2005). As it is known that the distribution of these granitoids is not only on land, but also spreads to the waters (Zulfikar et al., 2020). The presence of placer-heavy minerals on land through which the Southeast Asian granitoid route passes is limited. This forces geological explorers to look for new reserves in territorial waters. The mineral placer deposits exploration is intrinsically linked with the mineral deposit accommodation. We need to find this heavy minerals placer deposit accomodation that contain fairly large mineral placer accumulation.

The objectives of this study are to investigate the presence of accommodation of heavy mineral and rare earth elements deposits in South Bintan Island Waters based on subsurface sedimentary pattern by using single-channel seismic data interpretation. Data analysis was performed by identifying reflector configuration patterns and those continuity. Where sediment units that are estimated to have the potential for placer mineral deposits are generally sediment units located just above the acoustic basement (granite??) or unit 2 with a paleovalley or paleochannel shape. These characterizes (paleovalley/ paleochannel) showed alluvial deposits and generally has potential to contain placer minerals (Arifin, 2011; Raharjo, 2007).

The study area is located in the southern waters of Bintan Island, part of East Bintan District, Bintan Regency, Riau Islands Province. It lies within the latitude 86,874.34 mN to 93,664.28 mN and the longitude 441,499.37 mE to 456,751.02 mE (Figure 1). Geographically, it is part of northern hemisphere UTM Zone 48 N.

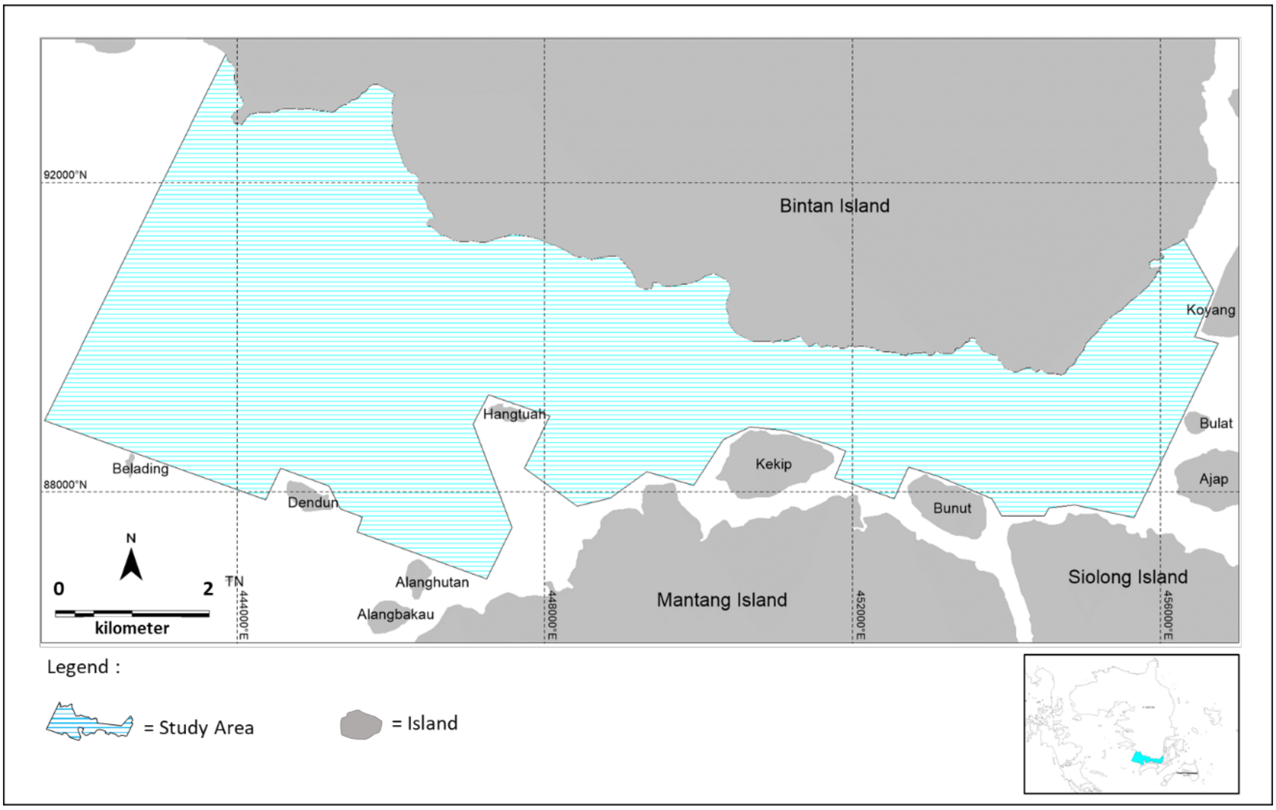

Figure 1. Study area

Geology of Bintan Island and its surroundings

According to Kusnama (1994) Bintan Island and its surroundings are part of the Riau Archipelago which is generally composed of intrusive igneous rocks in the form of granite and diorite of pre-tertiary (Triassic) age. This breakthrough rock is the oldest rock on the mainland of Bintan Island with enough to dominate about 40% of the total land on Bintan Island (Figure 2).

In a small part in the southwest part of Bintan Island, the Goungon Formation is deposited which dominates almost all parts of the mainland of Bintan Island. The Goungon Formation is composed of white tuffaceous sandstone, fine to medium grained, has a parallel laminated structure. In addition, there are also siltstones and dacitan tuff and feldspathic lithic tuff, smooth, white in color and locally interspersed with tuffaceous sandstones. This formation was deposited in a fluviatile environment and is Pliocene - Pleistocene in age. Then

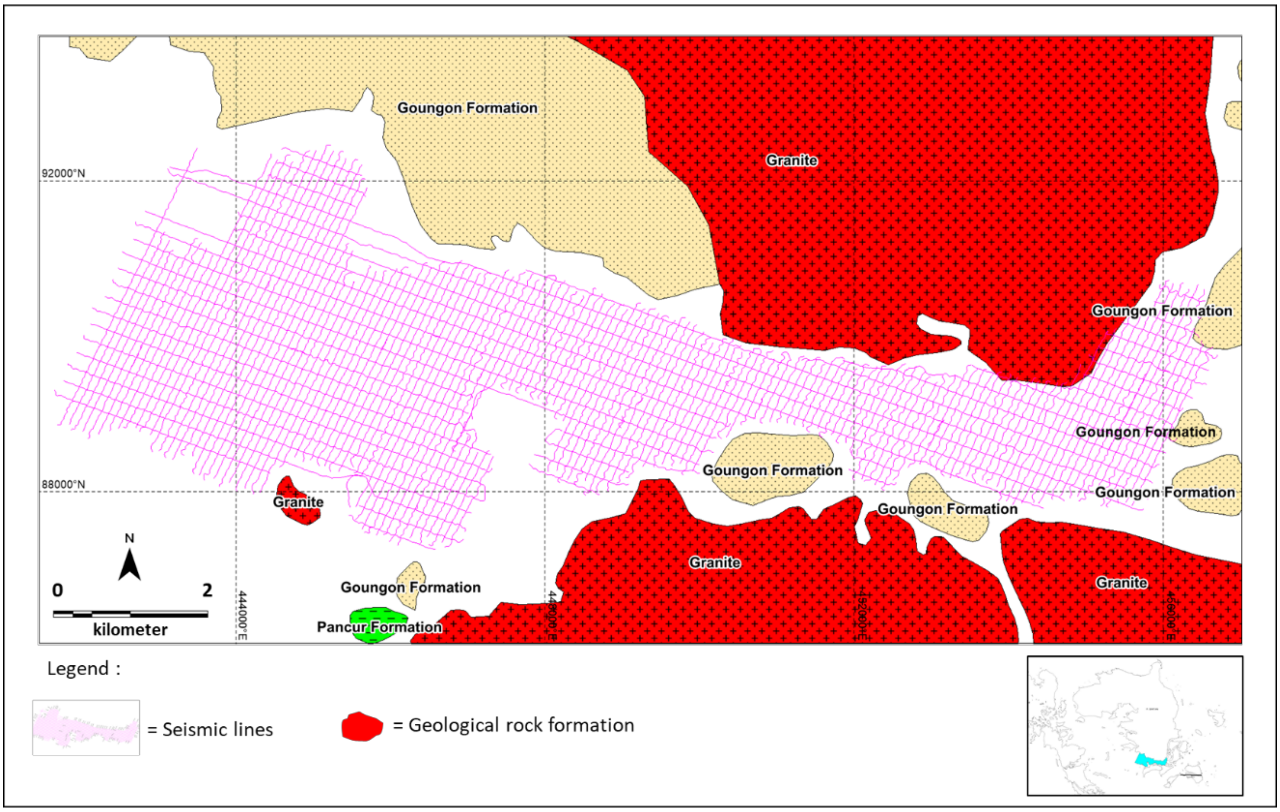

Figure 2. Geological rock formation (Kusnama, 1994) and seismic lines map

sedimentary rocks of Cretaceous age were found, namely the Pancur Formation and the Semarung Formation. The Pancur Formation is composed of claystone/shale with a reddish color with a pencil structure, in some places there are inserts of well-layered and well-separated quartz sandstone. This formation is not aligned with the granite rock which is thought to be the acoustic bedrock in the Bintan Island area. Meanwhile, the Semarung Formation is composed of medium-coarse grained arcose sandstones, well consolidated and there are claystone inserts with light gray color and thin layers. The Semarung Formation was deposited in a terrestrial environment until the transition which also overlaps with the Pancur Formation.

Above the Triassic-aged granite, andesite rocks are formed with the composition of plagioclase, hornblende, and biotite. This rock has a porphyritic texture with a base mass of micro-crystalline feldspar and is generally fresh rock. This andesite rock is estimated to be in the Early Miocene to Late Miocene age. Above these andesite rocks above the Goungon Formation, alluvium of Holocene age was deposited which was composed of sand, yellowish red with a composition of quartz, feldspar, hornblende and biotite which is a remnant of granite erosion. This alluvium unit is the result of river and coastal deposits that cover unconformably above the Goungon Formation or older rocks. All rock formations in the study area are shown in the regional stratigraphic table (Figure 3).

Quaternary Sediments of Bintan Island and its surroundings

At the age of the quarter around 12,000 - 15,000 years ago during the Last Glacial Maximum (LGM), Bintan Island was still part of the Sunda Shelf which stretched from China to Madura Island and East Kalimantan. At that time, the waters of Bintan Island and its surroundings were still in the form of land, around which many ancient river patterns developed that flowed into the South China Sea (Hanebuth et al., 2002; Molengraaff & Weber, 1921; Pucha?a et al., 2011;

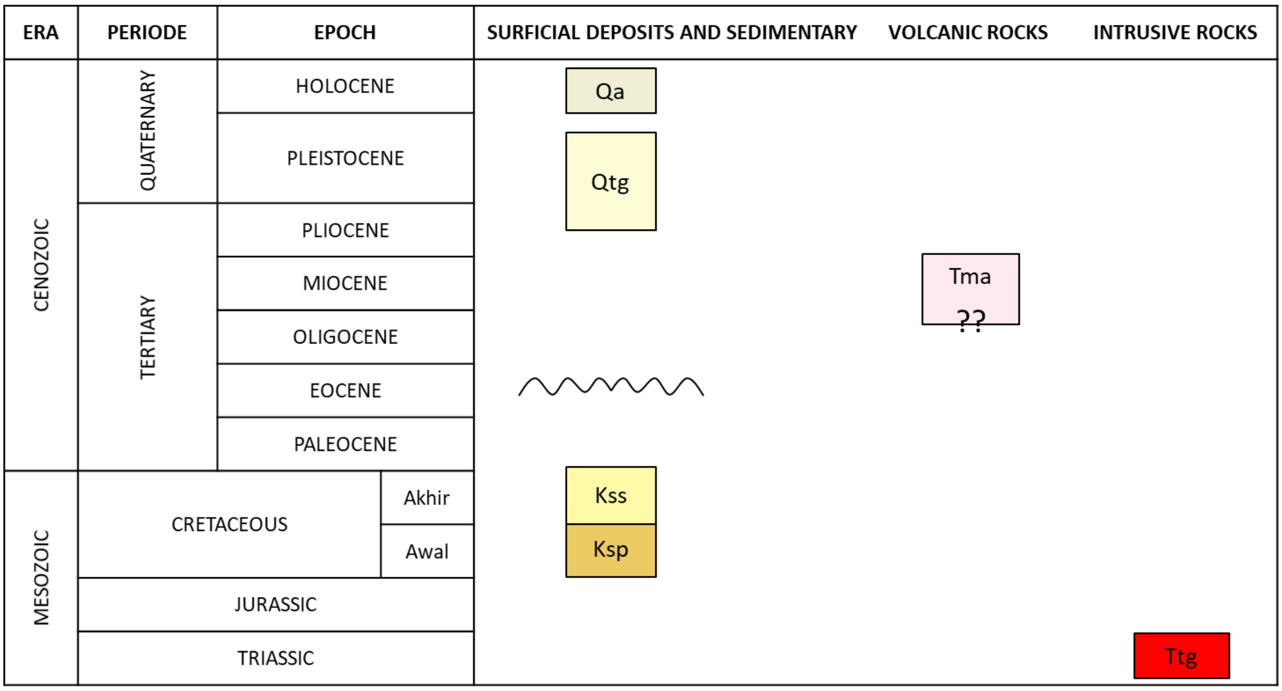

Figure 3. Regional stratigraphy of Bintan Island and surroundings (Kusnama, 1994)

Sathiamurthy & Rahman, 2017; Solihuddin, 2014; Voris, 2000).

Pre-quaternary rocks that located on Bintan Island and its surroundings are dominated by Triassic-aged granite. This granite rock is thought to be a large batholith body. In some places, the body of this batholith were intruded again by andesite at the Oligocene - Miocene age. All of these rocks then undergo a weathering process and were eroded by the drainage system or the evolving fluvial system. Thus, all of the eroded materials were transported and deposited. The sedimentary materials that transported from the previous rock were accumulate in deposit trap (valley). These area have a relatively low morphology compared to the source rock. This process continues until the Last Glacial Maximum occurs and causes global land sinking by sea level rise.

The sinking that occurred during the Last Glacial Maximum caused sea levels rise to covered fluvial depositional patterns. The sea level which was originally under 120 meters from the sea level today, tends to rise until the depositional environment which was originally a terrestrial environment turns into a marine environment. This includes the southern waters of Bintan Island and its surroundings. Terrestrial depositional facies, which were originally rocks older than the quarter, were later covered by transitional and marine facies.

Heavy Minerals and Rare Earth Elements Potential on Bintan Island

The entire area that traversed by Southeast Asian granitoid belt has potential for presence heavy mineral placer deposits. These deposits were formed from fragments of granitoid rocks that carry heavy minerals. Cobbing (2005) classifies that the Granitoids in Bintan Island are I-type granitoids. Genetically, Winter (2001) considers that this I-type granite is a granite that formed by partial melting of mafic mantle igneous material from subduction zones which results in the formation of breakthrough rock with a distinctive chemical composition.

Previous research stated that the I-type granitoids have heavy mineral potential such as Cu and Mo, which were formed from volcanic arc granite (Pearce et al., 1984). Moreover, Setiady and Sarmili (2005) stated that seabed sediments and coastal sediments in the waters around Batam Island and the western part of Bintan Island contain various metallic minerals. These heavy minerals are magnetite, ilmenite, monazite, cassiterite, hematite, etc. This is allegedly due to the deposition of placer minerals resulting from the breakdown of granite rocks on Batam Island and Bintan Island.

In addition, as is well known, most of Bintan Island is rich in bauxite content. Where this bauxite is found in clay from weathered granite with a high alumina content (Rohmana et al., 2007; Yusuf et al., 2005). The formation of bauxite is due to very intense weathering, causing the lateritized zone of granite to be enriched by bauxite and deposited above the source rock. Even in the northern and eastern parts of Bintan Island, a rock structure in the form of Corestone is formed which is a sign of fairly massive granite weathering (Hutabarat et al., 2016).

In addition to the potential for heavy minerals, Bintan Island also has a high potential for rare earth elements. Irzon and Abidin (2017) mention that granite rocks in the north of Bintan Island have a high content of rare earth elements. Where regionally, Kusnama (1994) stated that, the granite in the north of Bintan Island has similarities with the granite in the south of Bintan Island. The identification of placer mineral deposits using a seismic stratigraphic interpretation approach in the waters will provide clues to the drilling target and delineation of the boundary of the placer mineral deposits (Batchelor, 1979). Batchelor's succeeded in exploring placer minerals (in this case offshore tin), with the concept that the potential of placer minerals deposits is not only in young alluvium valleys (which are the result of onshore source rock deposits). But it is also located in the old sedimentary facies which is a subsurface heavy mineral-bearing rock deposit. These event occurred before the last glacial maximum period, when Sundaland still exist. So the thickness stratigraphic unit distribution becomes important.

METHODS

The subsurface geological conditions in this study were identified using shallow reflected seismic. The total number of lines acquired as a result of 179 routes stretching from the western waters of the south of Bintan Island and the east of the southern waters of Bintan Island, while the northern and southern parts of the research area are located in the strait between the south of Bintan Island and the north of Mantang Island. The intervals between lines are range from 100 - 200 m with the main line direction relative to the northeast - southwest as many as 135 lines and a cross-section with a west - east direction as many as 44 lines. The length of each track ranges from 150 meters - 4400 meters.

Single-channel seismic reflection using a typical single plate boomer sound source with a total power of 300 joules to produce sound waves at every 0.5 seconds of shot interval. Such waves propagate towards the seabed and are reflected back to the streamer hydrophone. Parameter of these wave propagation contains information about the properties of the subsurface. Seismic recording executed by using Sonarwiz 5 software with the ouput of digital data recorded in the SEG-Y format (filename extension .sgy)

The data outputting from seismic acquisition has been further processed to enhance the quality of seismic images by denoising technique using band-pass filtering. These band pass filtering processes was settings with following frequency limitation: low cut frequency 20 Hz, low pass frequency 750 Hz, high cut frequency 150 Hz and high pass frequency 1500 Hz. All of these processed are used over a range of 256 samples. To sharpen the resolution of the seismic image we used a gain setting of 3x10-4 dB.

From there on, we did the interpretation of sedimentary unit boundaries (horizon) based on characteristics of seismic facies that derived from reflector configuration of seismic profile (Mitchum, et al., 1977 in Veeken, 2007). After that, we created an isopach map that illustrates the stratigraphic thickness pattern between an upper and lower horizon. We consider kriging as a fitted geostatistical method to be used in predicting spatial distribution of these horizons. Furthermore, to determine the distribution of sediment unit thickness in meters (isopach), we used a time to depth conversion with a velocity assumption around 1540 m/s for seabed (water velocities) and 1600 m/s for subsurface sediment (Puchala, 2011) . The whole processing and interpretation was performed by Sonarwiz and Petrel software.

RESULTS

Total of 179 seismic lines that have been interpreted in this study area. The track consists of a main line with a northeast - southwest direction, and a crossline with a west - east direction. Based on the reflector configuration analysis from the seismic records, there are 3 seismic horizons that bounded 2 seismic facies units above the acoustic basement with various thickness patterns and markedly different distribution patterns. These 3 horizons are presumed to be quaternary sediments consists of the seabed (horizon 1), bottom unit 1 (horizon 2) and acoustic basement (horizon 3).

Seismic Correlation Surface and Seismic Facies Unit

Seismic Correlation Surface

The interpretation of the three horizons then correlated as a surface, which were distribute throughout the entire area. The result of this seismic horizon interpretation shows the paleogeographic pattern in the area. Each horizon has a difference pattern, horizon 3 shows a depth pattern that is relatively different from the recent bathymetry. This surface shows the steep highs countours and the other place shows a continuous valley. Meanwhile, horizon 2 does not show a significant difference in depth pattern from horizon 1 which is the current bathymetry.

Seismic Facies Unit

Based on the results of the correlation between the surface area boundaries, the study area is divided into 3 seismic facies units, namely:

Facies Unit 3 / Acoustic Basement

This facies unit is the oldest facies in the study area. Top of this unit overlain by the surface of bottom unit 2 and the bottom boundary of these unit appear clear despite the used of maximum penetration during seismic acquisition.

The reflector characteristics in the entire seismic records of this unit shows a weak frequency, subparallel - chaotic, and moderate amplitude. Based on the reflector pattern, this unit can be divided into 2 types, namely acoustic basement which is estimated as bedrock (granitoid?) and sedimentary rock. Acoustic basement is generally dominates the whole area characterized by chaotic and hyperbolic reflector patterns (Figures 4 and 5). Meanwhile, facies unit 3 which is a sedimentary rock appears relatively subparallel - chaotic reflector pattern. The thickness range of this facies unit cannot be identified because the lower boundaries of this unit cannot be known.

records of this unit shows a moderate frequency, subparallel - chaotic, and medium amplitude. It is estimated that the sediment deposited is a medium-coarse fraction sediment resulting from the previous rocks weathering whose transportation process is not too far from the source rock. In some places, continuous valley that forming a paleochannel were also found (Figures 6 and 7). The depositional pattern that developed in this unit is thought to be a fluvial - transitional depositional facies. The thickness range of this facies unit is quite high, ranging from 0.75 - 30 meters.

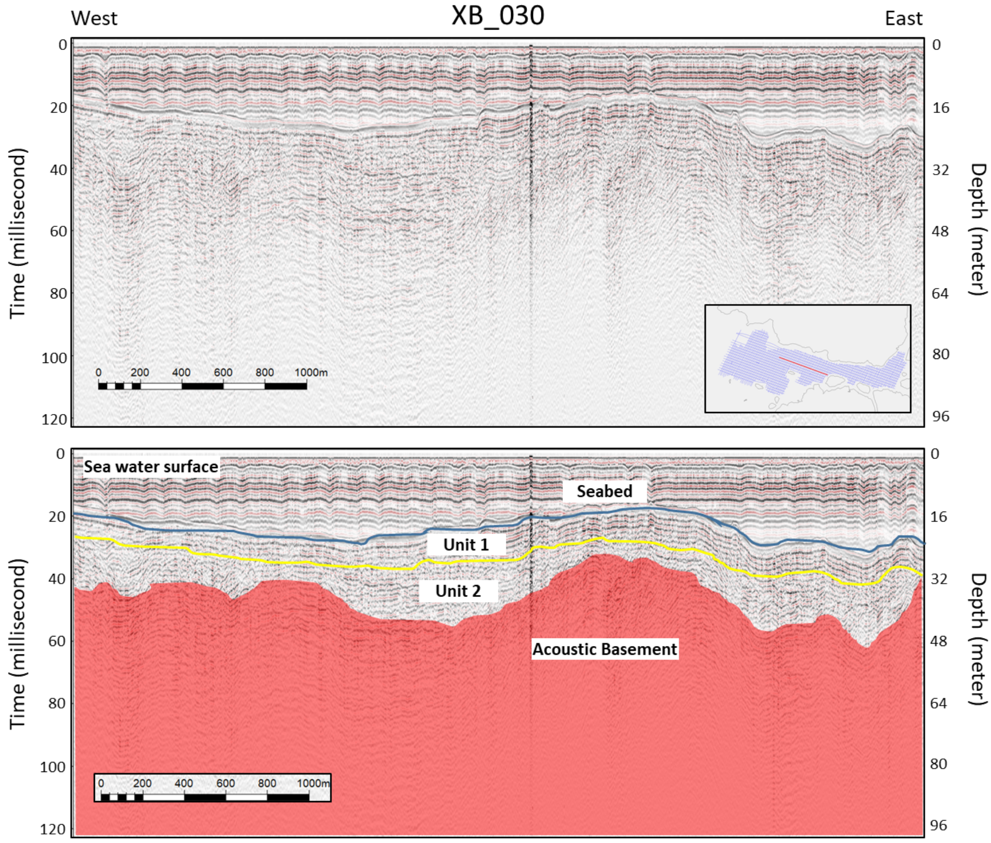

Figure 4. Interpretation of seismic line XB_030

Facies Unit 2

This facies unit is a sedimentary facies whose top is bounded by the surface of the bottom unit 1/top unit 2 (horizon 2) and the bottom is bounded by surface of bottom unit 2/top unit 3 (horizon 3) which is presumably sedimentary rock. In some places there are directly adjacent to the acoustic basement with reflector patterns in the form of chaotic and relatively hyperbolic shapes sticking up like granitoids.

The reflector characteristics in the entire seismic

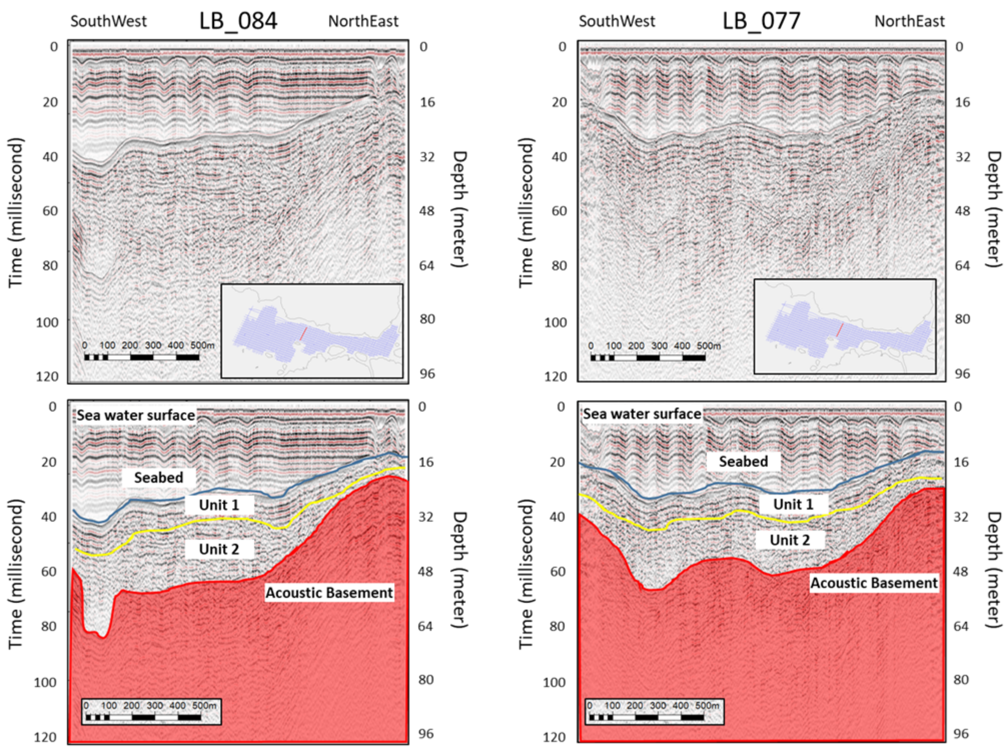

Figure 5. LB_084 and LB_077 seismic lines interpretation

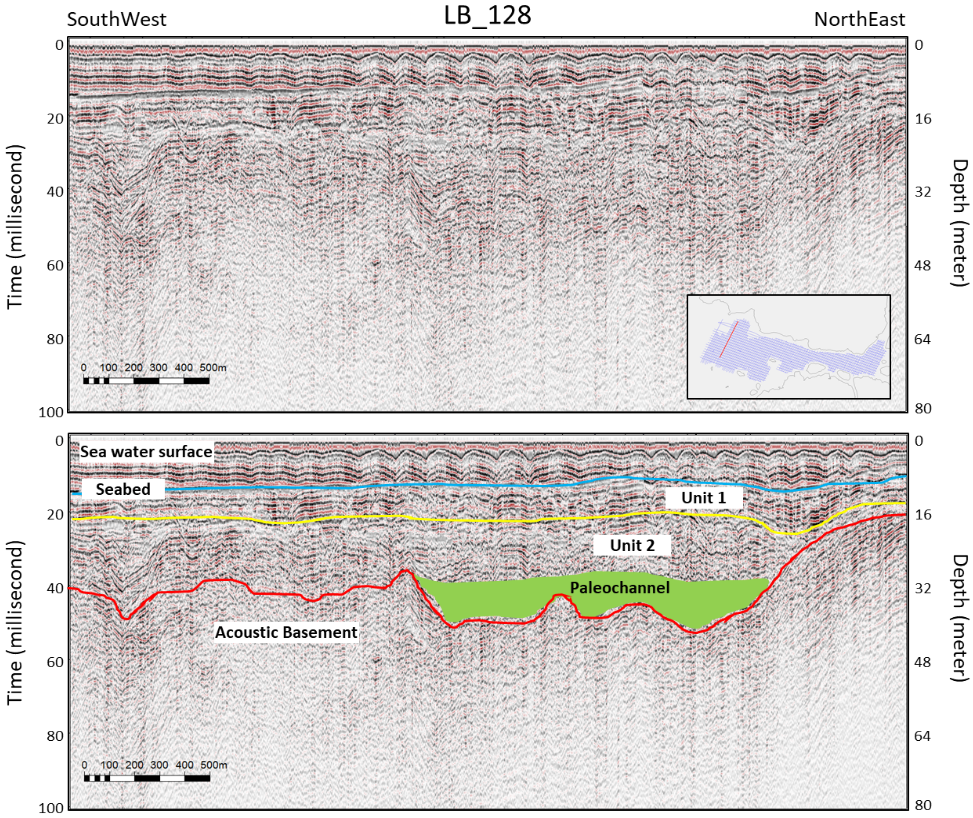

Figure 6. LB_128 seismic line interpretation

Facies Unit 1

This facies unit is the youngest facies unit or recent sedimentary facies which is bounded at the top by the seabed and at the bottom by the bottom unit 1/top unit 2.

This unit has the characteristics of high frequency, the dominant reflector pattern is simple parallel continuous with a small part there is subparallel, and the amplitude is medium - high. This is allegedly due to the sediment deposited at this time is sediment resulting from the deposition of a shallow marine environment which tends to be influenced by tides and waves and has not been well compacted.

The sediments in this unit are estimated to be dominated by fine fraction sediments and in some places there are also sediments dominated by shell fragments (Nurdin et al., 2020). This is due to the good lighting and nutrition of the environment, making it a good place for molluscs and coral reefs to grow. In addition, this also shows that the depositional environment in the area is dominated by tides and waves where this environment is in a

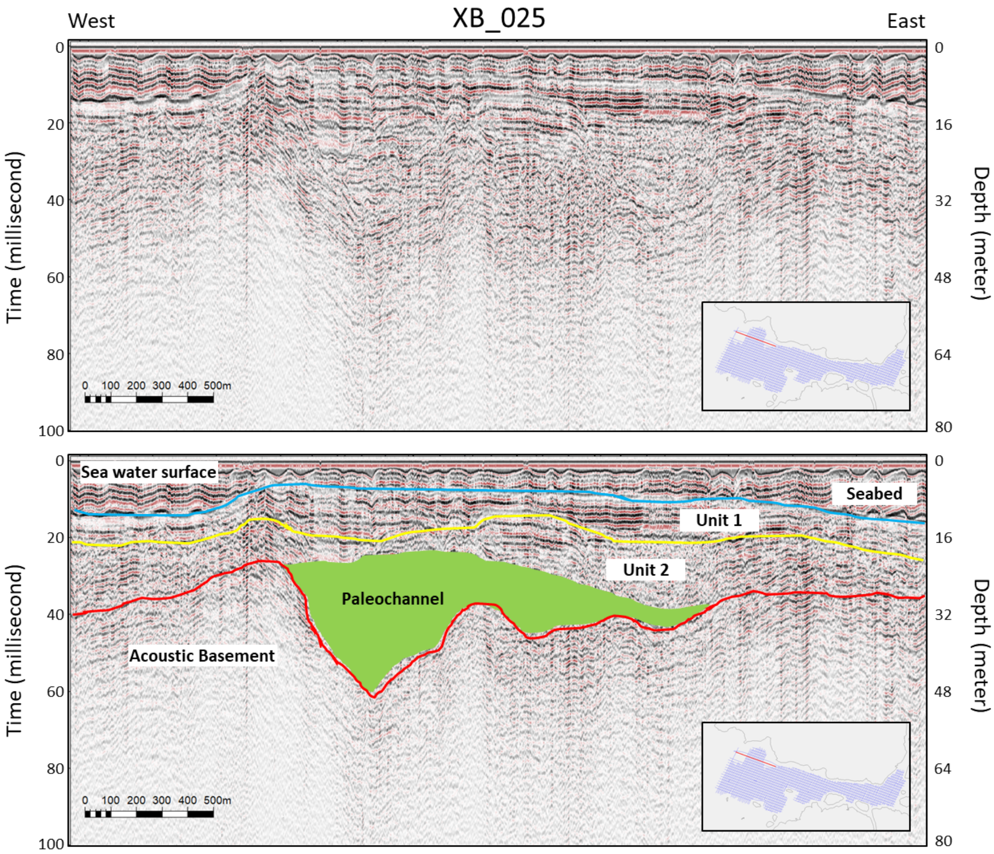

Figure 7. XB_025 seismic line interpretation

coral reefs do not like places where the water is cloudy, which is a dominant feature of fluvial deposition. The thickness range of this unit ranges from 1 - 13.5 meters.

DISCUSSIONS

Sediment Distribution Pattern in the Southern Waters of Bintan Island

The distribution of quaternary sediments in the Southern Waters of Bintan Island shows patterns of thinning and thickening of sediments in unit 1 and unit 2. However, the tendency of sediment thickening or thinning in unit 1 and unit 2 is different. This is because the depositional facies in each unit are different, so the depositional patterns are different.

Quaternary sediments Unit 2

Unit 2, which is estimated to be a fluvial-transitional depositional facies unit, shows a varied thickness pattern with a wide range ranging from 0.75 - 30 meters (Figure 8). If we look at the pattern of unit 2 sediment thickness formed in the study area, there are differences in the pattern between the west - center of the study area and the east - center of the study area.

The farther from the mainland, the thickness pattern is relatively uniform. While there is also sediment thinning up to 2 meters, this is allegedly due to the acoustic basement in the area being closer to the surface. However, the sediment in central to eastern study area more thinner than central to western study area. This can be seen from the influence of rock resistance to weathering. So that the fluvial sedimentation that is formed is not well developed. In regionally, Kusnama (1994) provides a formation boundary in the south of Bintan Island between the west and the east. The western part is dominated by the Goungon Formation (Qtg), while the eastern part is dominated by Triassic-aged granite (Trg).

Overall, the thickness pattern in unit 2 shows a relatively diverse sediment thickness. Where in the central - western part of the study area, thickening of the sediment is seen with patterns resembling paleochannels which are closely related to fluvial deposits. Meanwhile, in the center - east study area sediment depletion is seen. Which is estimated to be in this area a relatively high level that is still resistant to weathering. This indicates the unit of this part is terrestrial depositional system. Where the terrestrial

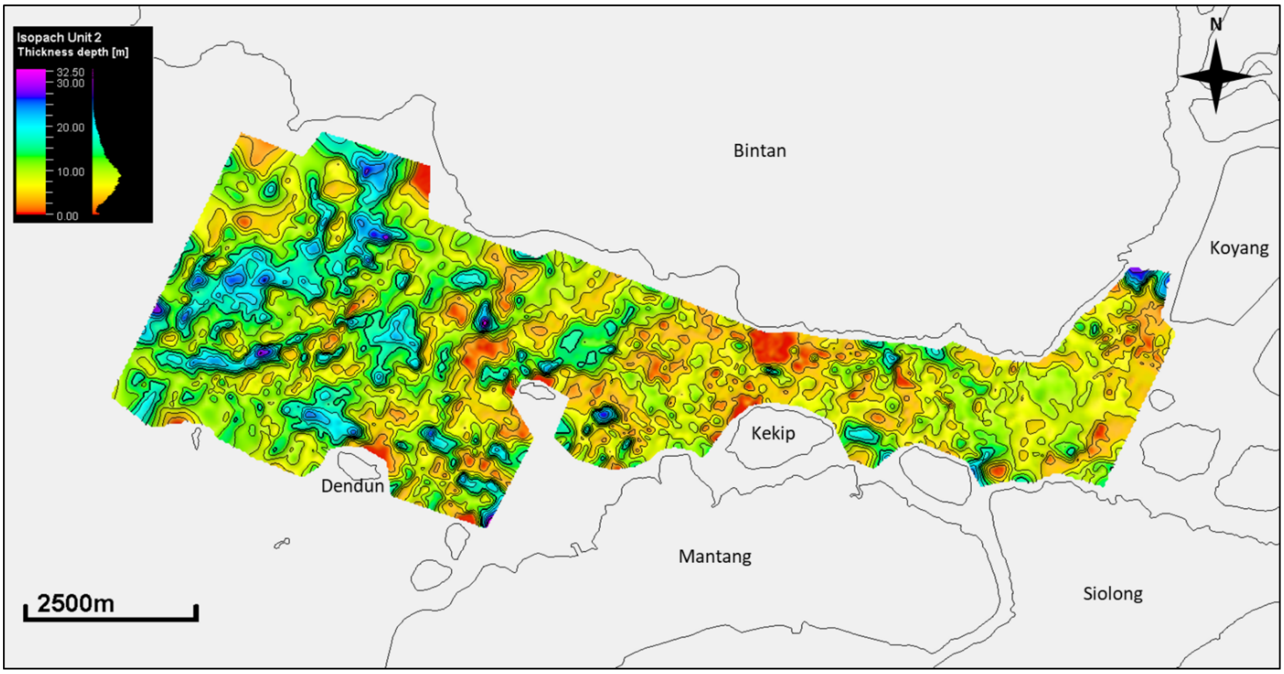

Figure 8. Unit 2 isopach map

In the central to western part of the study area, sediment thickening occurs with a pattern resembling a paleochannel. The sediments formed were relatively thickened towards southwest of the study area. This paleochannel is thought to be a fluvial deposit-forming groove which then continues to the larger main river.

In the central to eastern part of the study area, the dominant sediment thickness pattern ranges from 3 - 7.5 meters. In some places close to the mainland, there is a thickening of up to 20 meters, this is allegedly due to the influence of sedimentation from rivers on the mainland.

depositional system allows the formation of paleochannel patterns.

According to Voris (2000), in the period before last glacial maximum, there were 4 large rivers formed in Southeast Asia, namely the North Sunda River, Siam River, Malaca River and South Sunda River. Sediments originating from these large rivers flow from the highlands and then head towards the open sea. The presence of paleochannels seen in the study area is estimated to lead to one of the two major rivers, namely the North Sunda River or the Siam River. Judging from its geographical location, this paleochannel tends to join the North Sunda River to the South China Sea.

Quaternary Sediment Unit 1

This unit is interpreted as a transitional - marine facies unit. It has simple parallel - subparallel reflector patterns which show a non-varied thickness pattern with a shorter range that ranging from 1 - 13.5 meters (Figure 9). The thickness pattern in this Unit 1 sediment shows a different pattern in the middle - east part of the study area compared to the western part of the study area.

pattern. In addition, there is also sediment depletion up to 1 meter. This is presumably due to the reduced accommodation space caused by the basement acoustics getting closer to the surface. This pattern is relatively similar to the thickness pattern in Unit 2. Where the sediment tends to follow the shape of its accommodation space (same as its Unit 2).

Overall, the thickness pattern in unit 1 shows a fairly wide spread of sediment. It is shows these unit is a part of shallow marine depositional system (same as the current environmental conditions). Where this shallow marine

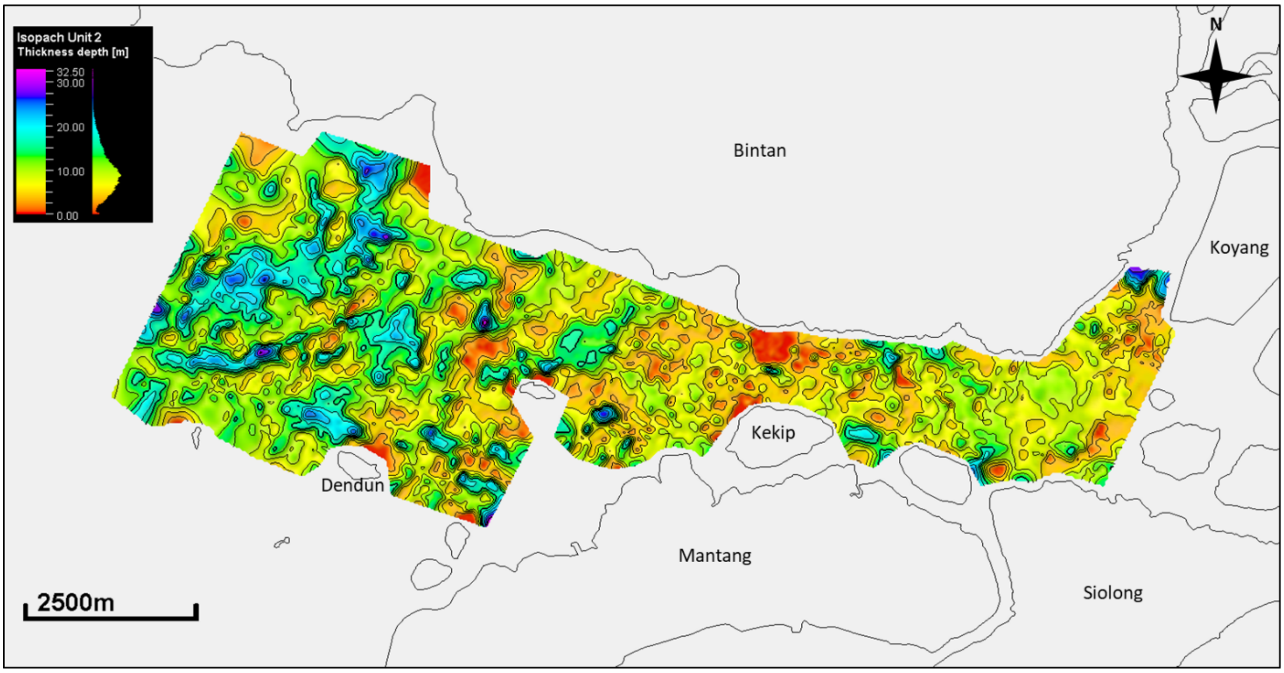

Figure 9. Unit 1 isopach map

The pattern of sediment thickness in the middle - west of the study area shows a dominant thickness with range between 4 - 8 meters. However, in west and central part there are close to the main river in Bintan Island or Mantang Island has a sediment thickening pattern up to 12 meters. This is allegedly due to the influence of sedimentation from the rivers. The farther from these river has a uniform thickness pattern. On the other hand there is also sediment depletion up to 3 meters. This is allegedly due to the basement acoustics in the area closer to the surface. Thus, the accommodation space for the sediment is getting shallower.

Meanwhile, in the central - eastern part of the study area has a thinner pattern than central - west study area with dominant pattern of sediment thickness ranges from 3 - 6 meters. However, in some places that are close to river in mainland showing the same pattern as the mid-west area. It can be seen from a thickening up to 12 meters. We interpreted there cause of the sedimentation from the main rivers on the mainland affects the sedimentation pattern. The farther from the mainland, shows a uniform thickness

deposition system is dominated by tides and waves.

The Potential of Heavy Mineral Placer Deposits or Rare Earth Elements in the Southern Waters of Bintan Island

Based on consideration of sediment thickness and paleochannel pattern in Unit 2, which develops in a northeast-southwest direction with acoustic basement that shallow to the surface. The area that has greater potential is in central to west area. Where in this area Unit 2 has paleochannel as a mineral placer deposit accommodation, even more location of the source rock (acoustic basement) not too far away from the deposits. Regarding the type and amount of mineral content, further research is needed using drill data and laboratory analysis.

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CONCLUSION

- Quaternary sediment deposits in the Southern Waters of Bintan Island consist of 2 units, namely: Unit 1 which is shallow marine sediments with a predominance of fine fractions and Unit 2 which is fluvial - transitional sediments with a dominance of medium - coarse fractions.
- Areas that have the potential for heavy mineral placer deposits are the western – central areas of the Southern Waters of Bintan Island. The potential for this heavy mineral placer deposit is in the paleochannel deposits which are part of Unit 2.

REFERENCES

Arifin, L., 2011. Identifikasi Alur Sungai Purba dan Endapan Plaser di Perairan Lembar Peta 1612 Kalimantan Selatan. Jurnal Sumber Daya Geologi.

Batchelor, B.C., 1979. Geological Characteristics of Certain Coastal and Offshore Placers as Essential Guides for Tin Exploration in Sundaland, Southeast Asia. Geol. Soc. Malaysia, pp.283-313.

Cobbing, E. J., 2005. Granites. In Sumatra: Geology, Resources and Tectonic Evolution (Vol. 31, pp. 54-62). Geological Society.

Hanebuth, T. J., Stattegger, K., & Saito, Y., 2002. The stratigraphic architecture of the central Sunda Shelf (SE Asia) recorded by shallow-seismic surveying. Geo-Marine Letters, 22(2), 86-94. https://doi.org/10.1007/s00367-002-0102-1.

Hutabarat, J., Syafri, I., Sulaksana, N., Sukiyah, E., Fauzielly, L., & Sudradjat, A., 2016. Fenomena Pelapukan Granit "Corestones" di Daerah Bagian Timur dan Utara Pulau Bintan. Seminar Nasional Ke - III Fakultas Teknik Geologi Universitas Padjadajran.

Irzon, R., & Abidin, H. Z., 2017. Kandungan Unsur Tanah Jarang pada Granit Putih Kemerahan dari Daerah Lagoi dan Perbandingan dengan Batuan Sejenis di tempat lain. Jurnal Geologi Dan Sumberdaya Mineral, 18(3), 137-146.

Molengraaff, G. A. F., & Weber, M., 1921. Proceedings Royal Academic Amsterdam. XXIII, 395-427.

Nurdin, N., Zulfikar, M., Kamiludin, U., Setiady, D., Mustafa, M. A., Setyanto, A., Widiatmoko, H. C., Setiadi, I., Hans, D. Z., Piranti, S. A., Aryanto, N. C. D., & Haryanto, A. D. (2020). Upaya Penambahan Potensi Cadangan Mineral Strategis Kelautan di Jalur Granitoid Tahap-1 (Lokasi: Bintan Selatan dan Sekitarnya, Kabupaten Bintan, Provinsi Kepulauan Riau). Pusat Penelitian dan Pengembangan Geologi Kelautan, Bandung, Badan Penelitian dan Pengembangan Energi dan Sumberdaya Mineral, Kementerian Energi dan Sumberdaya Mineral. Internal report, 88p. Unpublished.

Pearce, J. A., Harris, N. B. W., & Tindle, A. G., 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. Journal of Petrology, 25(4), 956-983. https://doi.org/10.1093/petrology/25.4.956.

Pucha?a, R. J., Porbski, S. J., ?liwi?ski, W. R., & August, C. J., 2011. Pleistocene to Holocene transition in the central basin of the Gulf of Thailand, based on geoacoustic survey and radiocarbon ages. Marine Geology, 288(1-4), 103-111. https://doi.org/10.1016/j.margeo.2011.08.007.

Raharjo, P., & Arifin, L., 2007. Identifikasi Alur Purba Berdasarkan Seismik Pantul Dangkal di Perairan Bangka Utara Lembar Peta 1114. Jurnal Geologi Kelautan. Vol. 5 (2), 165-176.

Rohmana, Djunaedi E.K, & M.P, P., 2007. Inventarisasi Bahan Galian. Proceeding Pemaparan Hasil Kegaitan Lapangan Dan Non Lapangan, 1-14. http://psdg.bgl.esdm.go.id/kolokium 2007/KONSERVASI/Prosiding-Bintan.pdf.

Sathiamurthy, E., & Rahman, M. M., 2017. Late quaternary paleo fluvial system research of sunda shelf: A review. Bulletin of the Geological Society of Malaysia, 64(December), 81-92. https://doi.org/10.7186/bgsm64201708.

Setiady, D., & Sarmili, L., 2005. Keterdapatan Beberapa Mineral Berat Di Perairan Pulau Bintan Dan Sekitarnya Sebagai Hasil Rombakan Dari Sedimen Holosen Asal Paparan Sunda. Jurnal Geologi Kelautan, 3(3), 1-7. https://doi.org/10.32693/jgk.3.3.2005.126.

Solihuddin, T., 2014. A Drowning Sunda Shelf model during Last Glacial Maximum (LGM) and Holocene: A review. Indonesian Journal on Geoscience, 1(2), 99-107. https://doi.org/10.17014/ijog.v1i2.182.

Veeken, P. C. H., 2007. Handbook of Geophysical Exploration: Seismic Exploration. In Elsevier (Vol. 37). https://doi.org/10.1016/S0950-1401(07)80025-5.

Voris, H. K., 2000. Maps of Pleistocene sea levels in Southeast Asia: Shorelines, river systems and time durations. Journal of Biogeography, 27(5), 1153-1167. https://doi.org/10.1046/j.1365-2699.2000.00489.x.

Winter, J. D., 2001. An Introduction to Igneous and Metamorphic Petrology. Prentice Hall.

Yusuf, A. F., P, M. R., Sayekti, B., & Awaludin., 2005. Inventarisasi dan Penyelidikan Bahan Galian Industri Kabupaten Kepulauan Riau, Provinsi Kepulauan Riau. Proceeding Pemaparan Hasil Kegiatan Lapangan Dan Non Lapangan, 1-5.

Zulfikar, M., Aryanto, N. C. D., Nur, A. A., & Syafri, I., 2020. Study of Granitoid Distribution at Toboali Waters, Bangka Belitung Province: Seismic data interpretation approach. Bulletin of the Marine Geology, 35(2), 53-64. https://doi.org/10.32693/bomg.35.2.2020.681