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Characteristic of Shallow Subsurface Quaternary Sediment in Nongsa Isle, Part of Putri Islands, Batam, Based on Georadar Data Interpretation

Karakteristik Sedimen Kuarter Bawah Permukaan Dangkal di Pulau Nongsa, Bagian dari Pulau Putri, Batam, Berdasarkan Interpretasi Data Georadar

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ABSTRACT: Nongsa Isle belongs to Putri Islands in Batam, is the outermost island that need to be protected either from natural hazards and anthropogenic factor. Therefore, this study was conducted by performing Ground Penetrating Radar analysis, in order to understand the geological condition particularly sedimentology and its process. We used Sirveyor 20 GPR equipment type with MLF antenna frequency 40 Mhz and Radan 5 as processing software, which include time zero correction, spatial filter, deconvolution, migration and adjustment of amplitude and signal gain. Data interpretation was conducted based on radar facies methodology that describes georadar image/radargram. The study result showed differences of sedimentary facies based on three differences of radar facies units, with the first layer (unit 1) is the youngest unit has thicknesses ranging from 3.5 – 5 m that characterized by parallel, strong reflector, high amplitude and continuous reflector configurations, unit 2 from 5 – 11 meter of depth, indicates parallel reflector pattern with medium-high amplitude and continuous, and unit 3 which is the oldest unit with thickness until penetration limit (11 – 20 m), characterized by a configuration of sub parallel – hummocky reflectors that are undulating, low-medium amplitude reflectors. Based on radar facies characteristics such as reflector configuration, reflection amplitude, and reflection continuity, the differencies of depositional facies are changes from fluvial – coastal plain.

Key words: GPR, radar facies, Nongsa Isle, Batam, subsurface sediment

ABSTRAK: *Pulau Nongsa adalah bagian dari Pulau Putri, Batam, merupakan pulau terluar yang harus dijaga baik dari bencana alam maupun dari faktor antropogenik. Oleh karena itu studi ini dilakukan dengan melakukan analisis Ground Penetrating Radar (GPR), bertujuan untuk memahami kondisi geologi terutama sedimentologi dan proses-prosesnya. Kami menggunakan peralatan GPR tipe Sirveyor 20 dengan antena MLF frekuensi 40 MHz dan software Radan 5 untuk pemrosesan data, yang mencakup koreksi titik nol permukaan, spasial filter, dekonvolusi, migrasi, serta pengaturan amplitude dan penguatan sinyal. Interpretasi data georadar dilakukan dengan penafsiran radar fasies, yang menunjukkan gambaran citra georadar/radargram. Hasil studi menunjukkan perbedaan fasies sedimen yang ditunjukkan oleh tiga tipe perbedaan unit fasies radar, yaitu unit 1 yang merupakan fasies paling muda dengan ketebalan 3,5 - 5 meter, yang ditunjukkan dengan karakter fasies paralel, refleksi kuat, amplitudo tinggi dan konfigurasi reflektor menerus, unit 2 dari kedalaman sampel 5 – 11 meter, ditandai fasies berkarakter pola refleksi paralel dengan amplitudo sedang-tinggi dan kontinyu, dan unit 3 adalah fasies tertua dengan ketebalan sampai batas penetrasi georadar (11-20 m), ditandai dengan konfigurasi reklektor sub paralel-bergelombang, amplitudo rendah-medium. Berdasarkan karakter fasies radar seperti konfigurasi reflektor, amplitudo reflektor dan kontinyuitas reflektor, menunjukkan bahwa fasies pengendapan pada daerah penelitian mengalami perubahan dari arah daratan ke arah laut.*

Kata kunci: *GPR, fasies radar, Pulau Nongsa, Batam, sedimen bawah permukaan*

INTRODUCTION

Nongsa, Putri Besar and Putri kecil are 3 small islands belong to Putri Islands or Nongsa Isle after island toponym verification (Figures 1). The islands lie in the most northwest tip of Indonesia Archipelago, as the outermost land of Singapore. Its coastal line has been changed significantly (Geurhaneu and Susantoro, 2016), and it is prone to abrasion hazard (Hernawan *et al.* 2018). As the outermost island, Putri Islands are need to be protected, both from natural hazards and anthropogenic impact. For that, it is necessary to understand the oceanography, geology and sedimentological process of the islands. One parameter to understand the geology of the area is studying subsurface lithology. From this information we could understand the sedimentological process, hence we get information which factors influences the study area.

In order to understand the subsurface lithology of certain area, geophysical methods can also be applied which offer *non*-destructive and non-invasive techniques for measuring physical properties of geological materials (Chlaib *et al.*, 2014; Sjöberg *et al.*, 2015; Ferreira, 2019). Ground penetrating radar (GPR) is one of geophysical methods which able to describe the shallow subsurface geology. It has been developed as a tool for shallow subsurface geological survey at high resolution (van Heteren *et al.*, 1998, Moysey *et al.*, 2006) and has been used extensively in geological research, including to identify lithology and subsurface sediment (Budiono and Latuputty, 2008; Budiono, 2013a; 2013b; Noviadi, 2014; Jatmiko *et al.*, 2016; Elfarabi *et al.*, 2017), geological structure (Somantri *et al.*, 2016; Shofyan *et al.*, 2016; Budiono *et al.*, 2010), and land subsidence (Budiono *et al.*, 2012; Raharjo dan Yosi, 2017).

Similar to other geophysical methods including seismic, magnetic, resistivity and gravity, GPR describes near surface stratigraphy based on changes in physical properties particularly the differences in conductivity and dielectric properties which indicate different subsurface layers, structures or sediment units (Al-Syukri *et al.*, 2006; Sjöberg *et al.*, 2015). Compared to other geophysical methods described above, GPR offers higher resolution and requires less setup/survey time (Al-Syukri *et al.,* 2006). GPR is easy to operate (Busby *et al.*, 2004) and it can provide a 3-D pseudo image of the subsurface and depth estimates. The radargram allow to interpret and visualize the opaque ground (Ferreira, 2019). Although penetration depth of GPR is considerably less than that of shallow seismic methods, however GPR penetrates deep enough (several meters) to study near-surface geological features (Al-Syukri *et al.,* 2006). Therefore, GPR method had been chosen to be applied to this study in order to understand the subsurface geology of the Putri Islands.

GPR uses high frequency of electromagnetic waves to create high resolution imagery, making it possible to recognize sedimentary structure through patterns and termination of reflector. The interpretation of radar facies from GPR data is frequently used in the interpretation of near surface geological feature/condition (Tamura *et al.*, 2016; Al-Syukri *et al.*, 2006).

Regional Geology of Batam and Bintan Island (South of Putri Islands)

Putri Islands is located in the northeast of Batam Island, within Singapore Strait. According to geological map, Batam region lies in the western Sumatra granite area, as a part of tin belt from mainland Thailand - Malaysia to Bangka - Belitung. This tin belt is known as the Tin Belt of Sumatra and belongs to the main range and eastern range of tin belt-bearing granites (Kusnama*,* 1994). Such geological conditions causing the waters of Batam to be rich with the potential of placer minerals and heavy minerals (economic value). Source of the placer minerals and heavy minerals from granite rocks in the tin belts found in the southern part (Batam and Bintan) which have been deformed and weathered (Figure 1) (Kusnama, 1994). Batam Island is composed of four type of sediments are:

Qa: Alluvium, in the coastal and river area, which consist of sand, yellowish red, composed mainly of quartz, feldspar, hornblende and biotit, may be a result of weathered granite erosion. This alluvium is also composed of conglomerate which is composed by granite, pebbles, metamorphics and sandstone, unconsolidated. From the other side, this alluvium shows swamp deposit, and coastal deposits. This alluvium has Holocene Age.

QTg: Goungan Formation, is a sedimentary rock formation deposited during Pliocene – Pleistocene. This formation consists of white tuffaceous sandstone, fine-medium grained, parallel lamination, and siltstone is commonly found, dacitic tuff and feldspatic lithic tuff, white, fine grained, locally alternating with tuffaceous sandstone, that show parallel and cross lamination, reddish white tuff and grey siltstone which is slighty carbonaceous and contain plant remains.

Tg: Granit, deposited in Tertiary Age particularly Late Triassic. This unit has reddish – greenish grey color with coarse grained. It contains of feldspar, quartz, hornblende and biotite as primary minerals with mostly are primary texture. Based on location and mineral

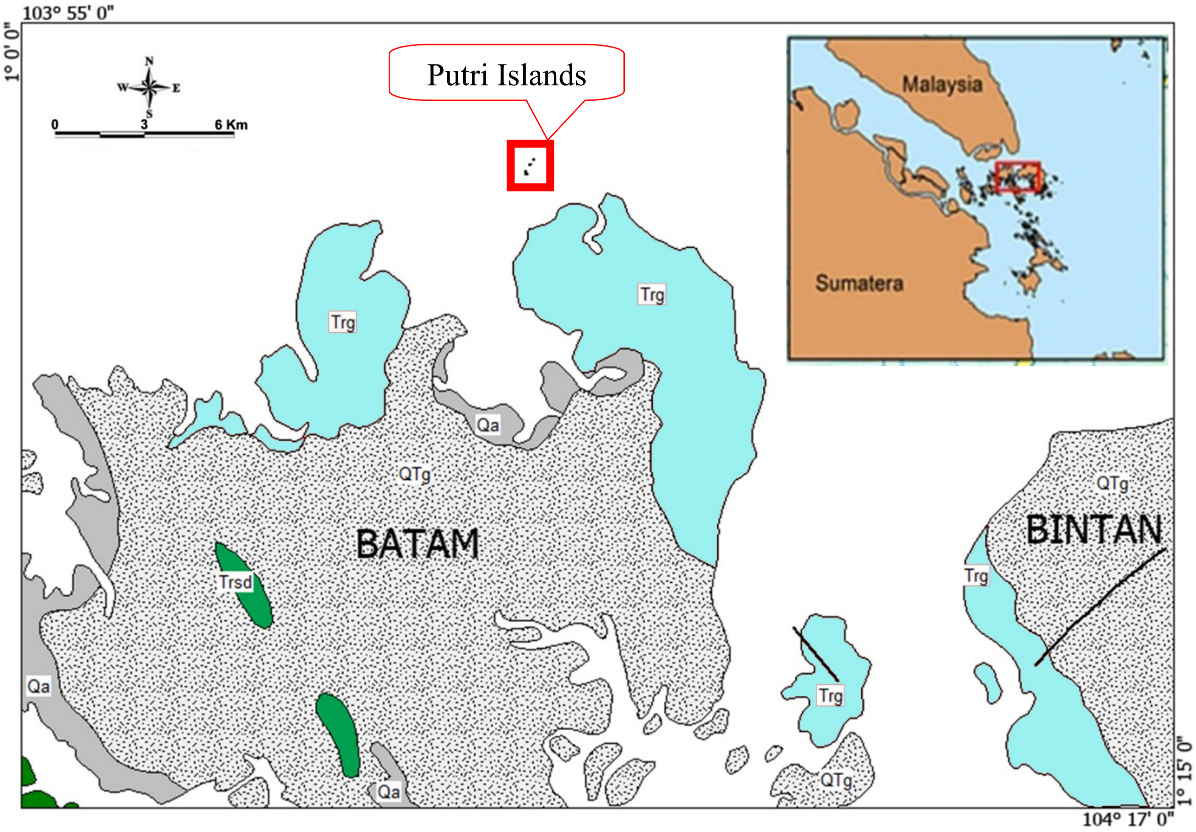


Figure 1. Geological map of Tanjungpinang (Kusnama, 1994).
Remarks: Qa : Alluvium, QTg: Goungan Formation, Trg: Granit, Trsd: Duriangkang Formation. Red square is the study area.

composition, it can be grouped into Kawal Granite Pluton in Bintan Island and Nongsa Granite Pluton in Batam Island. The Granite Unit are appeared on the part of the beach and forming a cape. Whereas the bay narrowed by previous rock sedimentation, that forming quartz alluvial deposits.

Trsd: Duriangkang Formation, dark grey shale with pencil structure, brittle and slightly carbonaceous, alterated with quartz sandstone, light grey, micaceous, poorly sorted and well consolidated.

Geology of Putri Islands and the surrounding waters

According to Hernawan *et al* (2018) Putri Islands consists of 3 islands namely Nongsa Isle, Putri Besar Isle, and Putri Kecil Isle. The Putri Islands composed by Holocene – Pleistocene Sedimentary, Middle Miocene – Late Miocene Conglomerate of various material and Late Trias Granite. Nongsa Isle is dominated by Holocene-aged sand, but in some of the surrounding waters there are limestone reefs. Putri Besar Isle is dominated by conglomerates with various materials. This conglomerate was allegedly a part of the Tanjungkerotang Formation, which was of Middle Miocene-Late Miocene age. The waters around it have variation in the distribution of quaternary sediments such as limestone reefs, clayey sand, sand, and gravel and boulder of loose material. Putri Kecil Island are believed to be based by granite rocks to form a steep morphology. Local geological map is shown in Figure 2.

METHOD

For this study, to understand subsurface geology, we performed GPR method particularly in Nongsa Isle. Administrativelly, It is located in Batam Area, Riau Islands Province (Figure 1 and 2). Two lines of measurements are conducted, are L 01 (with a track line of 150 m length and parallel to the coastline) and CL 01 (with a track line of 50 m length and accross to the coastline).

The GPR method was based on transmitting of electromagnetic wave into the earth and capturing electromagnetic wave that transmitted, reflected and scattered by subsurface structure and anomalies beneath the surface of the earth. The reflected and scattered electromagnetic waves were received by the receiving antenna on the earth surface (Busby *et al.*, 2004). The technique is known as Electromagnetic

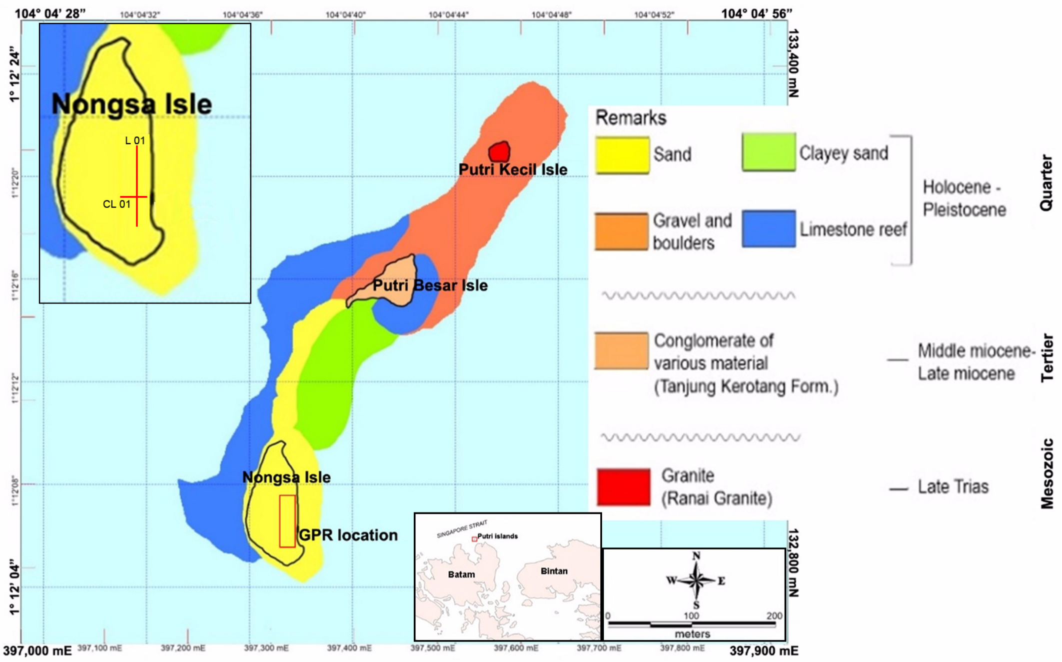


Figure 2. Geological map of Putri Islands (Hernawan *et al.*, 2018). Red rectangular is the location of GPR at Nongsa Isle, the GPR lines (L 01 and CL 01) are indicated by red lines in the inset.

Subsurface Profiling (ESP) and is the electrical analogue of seismic sub-bottom profiling technique used in marine geology (Budiono *et al.*, 2012). The system utilizes electromagnetic wave backscattering emitted through the surface ground with an intermediate antenna (Figure 3). Velocity of transmission and backscattering of electromagnetic wave is very fast and stated in nanosecond time unit (Allen, 1979).

An electromagnetic pulse is transmitted through the ground and the return time of the reflected pulse is recorded. The resolution and penetration depth of radar signal depends on the characteristics of transmitted pulse and antenna choices, which usually range between 10 and 1000 MHz. Higher frequencies will yield a higher resolution but a smaller penetration depth; however, the penetration depth will also depend on dielectric and conductive properties of ground material (Sjöberg *et al.*, 2015).

The ground penetrating radar antenna transmits a short electromagnetic pulse of radio frequency into the medium. When the transmitted wave reaches an electric interface, a part of the energy is reflected back while the rest continues its course beyond the interface. The radar system will then measure the time elapsed between wave transmission and reflection. This is repeated at short intervals while the antenna is in motion and output signal (scan) is displayed consecutively in order to produce a continuous profile of the electric interfaces in the medium. The profile is shown in grey or colour scale (Silvast and Wiljanen, 2008).

GPR systems use discrete pulses of radar energy. These systems typically have the following four components, i.e.: 1) a pulse generator which generates a

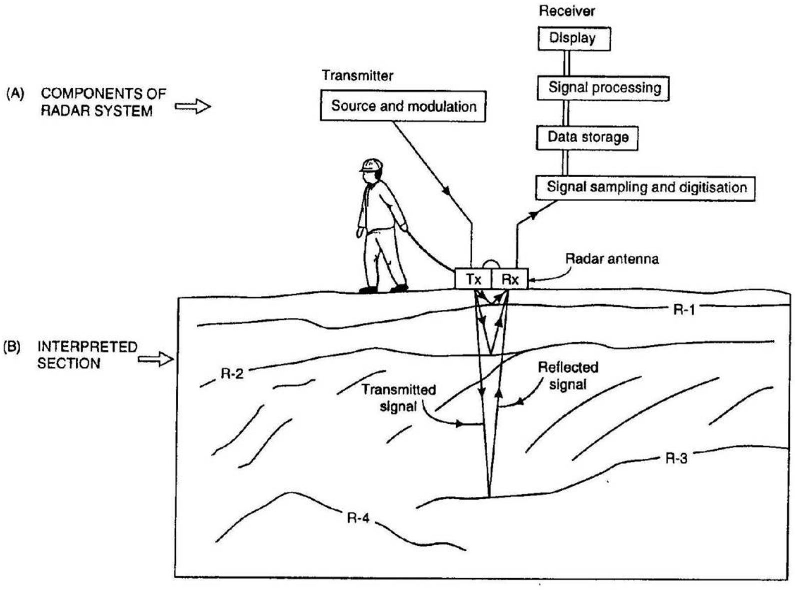


Figure 3. Working principles of GPR method (Reynold, 1997).

single pulse of a given frequency and power, 2) a transmitter antenna, which transmits the pulse into the medium to be measured, 3) a receiver antenna, which collects the reflected signals and amplifies the signal, 4) a sampler which captures and stores the information from receiver antenna (Silvast and Wiljanen, 2008). In this study, measurement were made with SIRVeyor 20 model of GSSI product that include mainframe and toughbook as processing and storing data, cable and MLF (Multi Level Frequency) type as separated transmitter and receiver antenna. The transmitting and receiving antennas were held at a constant distance of 1 m (common offset) and an accumulator was stored in transmitter antenna as source of pulse generator. The MLF antenna was setted as 40 MHz with 30 meter of depth penetration. Supporting equipment include accumulator (used as power supply like batere for mainframe and toughbook), survey wheel, GPS, meter roll, camera and stationary.

Normally, georadar data processing include some steps, i.e.: data conversion to use digital format, removing or minimalizing direct wave from air to the surface, setting and adjusment of amplitudo and gain, static data adjusment for removing elevation distinction, data filtering and velocity analysis (Beres dan Haeni, 1991).

The data were processed in Radar 5 software of GSSI product. The first step of processing data was time zero correction. This process will remove direct wave in the air between antenna and ground surface. The next processes were spatial filter, deconvolution, migration and adjustment of amplitude and gain. The final step was interpretation of GPR data.

The depth of GPR was obtained by the reflection arrival time and the profiles can be obtained by multiple offsets (Chlaib *et al.*, 2014), with formula:

$$D = \frac{c\,.\,t}{2\sqrt{\varepsilon r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

D: Depth, c: speed of light in vacuum (0.3 m/ns),
t: signal travel time, εr: dielectric constant.

Basically, the depth of radargram is shown in time travel, i.e. nanosecond (ns), but it’s could be displayed in meter as well. Based on result of experience in many coastal radargram data in Indonesia, the conversion from ns to meter is about 20 ns = 1 meter (Budiono and Latuputty, 2008; Budiono *et al.*, 2010; Budiono *et al.*, 2012; Budiono, 2013a; 2013b; Noviadi, 2014).

The interpretation of GPR data was based on radar facies interpretation, which the concept is based on methodology applied to seismic stratigraphy surveys (Tamura *et al.*, 2016). Identifying radar facies is an important criterion for geophysical characterization of sedimentary deposits (Cassidi, 2009). Radar facies characteristics were interpreted based on the internal configuration and continuity of reflections, as well as on reflections termination patterns (Shan *et al.,* 2015) and generally characterized on the basic of shape, amplitude, continuity and internal reflection configuration and external form (Chowksey *et al.*, 2011; Ekes and Hickin, 2001) using the approach applied by Beres and Haeni (1991), van Heteren *et al.* (1998), Beres *et al.* (1999) (Figure 4).

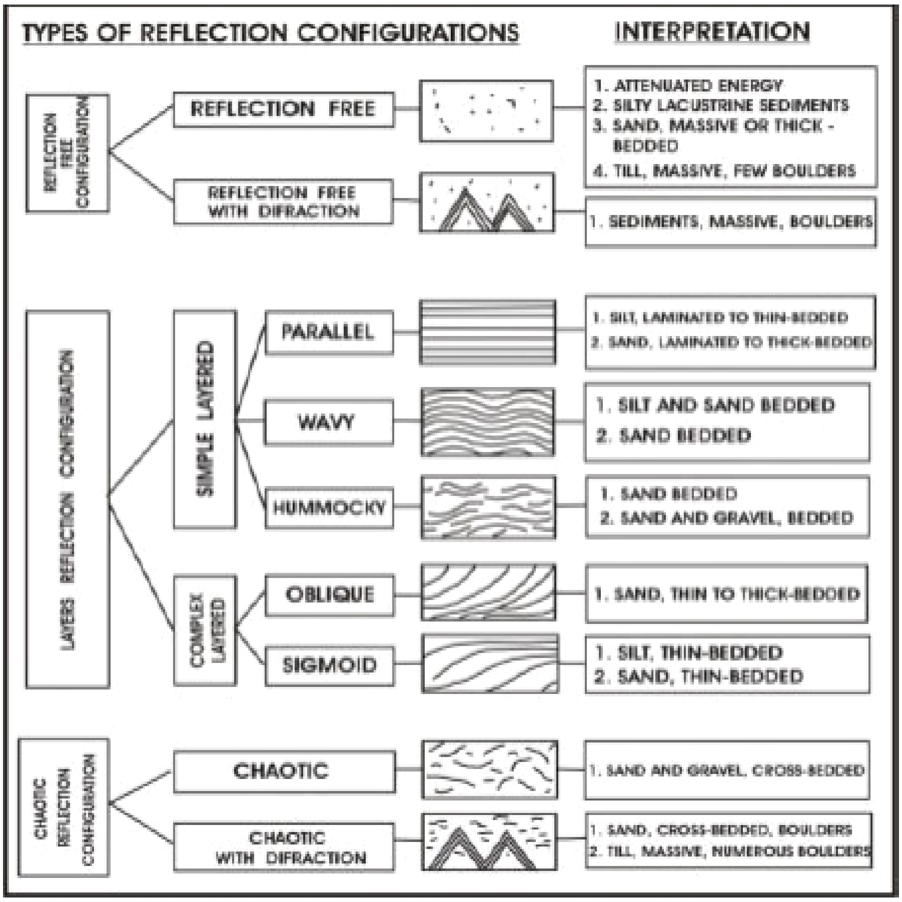


Figure 4. Type of reflection configuration (Beres and Haeni, 1991).

RESULT

The two lines (L01 and CL 01) of GPR measurement indicate relatively homogenous result. The raw data of recorded georadar is shown as image, known as radargram, with direct wave in the top of image (Figure 5a). The first step of processing is eliminated from the direct wave in radargram, so surface level (0 meter) is shown in top of radargram (Figure 5b). Next processing of georadar data has been described in method and shown in available mode that make it easier to interpret data as shown in Figure 7.

Radar Facies:

The analysis of radar facies is similar with seismic facies analysis procedure. The subsurface analysis related to the stratigraphic radar procedure was based on sequence identification and facies. The radar facies was resulted from GPR data set analysis that was consisted in the identification of individual radar facies. These facies were grouped into radar unit based on radar reflector configuration pattern in this study area, which can be used for interpretation of depositional environment (Jatmiko *et al.*, 2016; Budiono, 2013b).

Based on the different georadar data reflection configurations (Figure 6), there are three radar facies units which are characterized by differences in the radar facies of units 1, 2, and 3 in sequence, namely:

Unit 1

The radar facies are characterized by parallel, strong reflector, high amplitude and continuous reflector configurations. This unit is from the surface down to 4 - 5 meters.

Unit 2

This second radar facies is characterized by a parallel reflector pattern with medium-high amplitude and continuous. This layer is below Unit 1 with sharp contact, down to a depth around 11 - 12 meters.

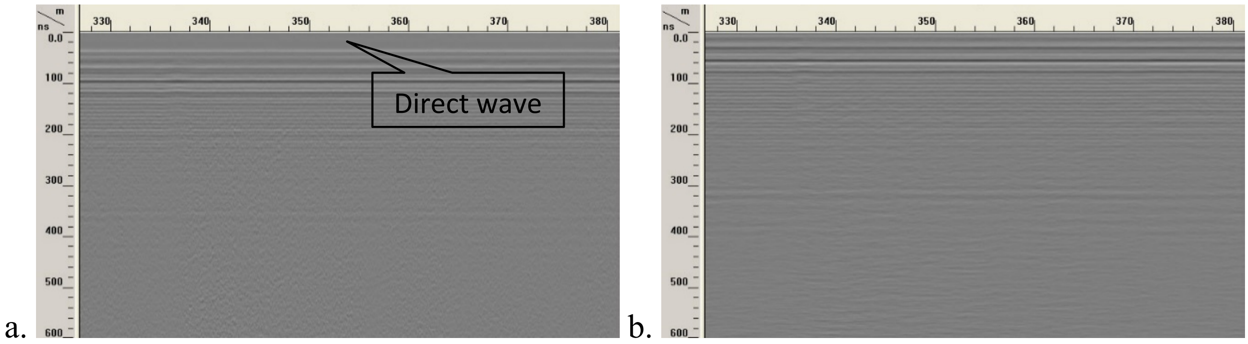


Figure 5. Raw data of recorded GPR L-01 (a) with direct wave and (b) non direct wave.

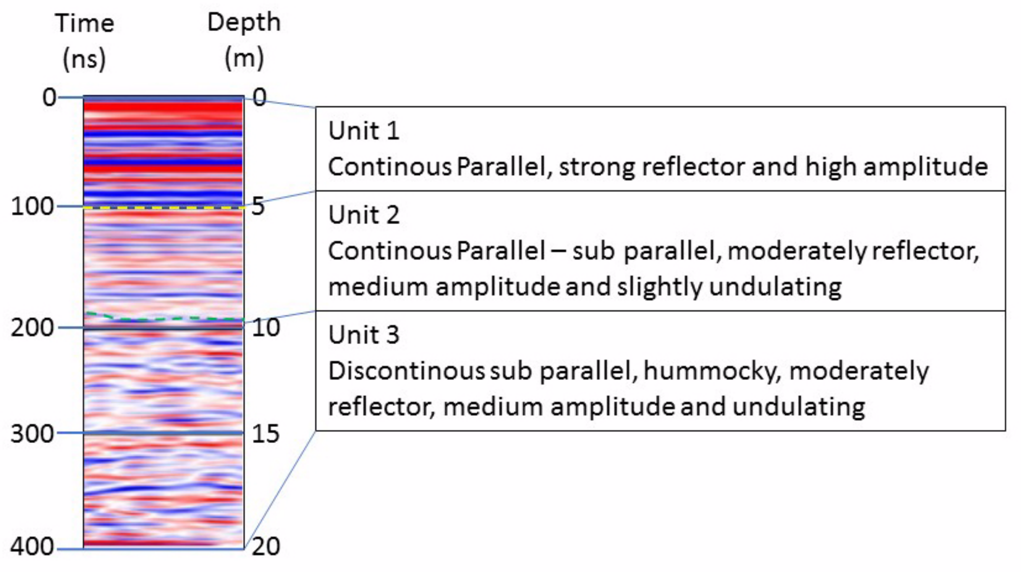


Figure 6. Resumed of radar facies of the GPR record derived from Line L01 and Line CL 01.

Unit 3

The radar facies are characterized by a configuration of sub parallel – hummocky reflectors that are undulating, low-medium amplitude reflectors. This facies is at the lowest layer below Unit 2 down to a depth 30 meter (maximum penetration).

DISCUSSION

Interpretation of GPR Radar Unit

Distribution of facies radar in identifying subsurface geological conditions on Putri Island needs to be done so that the differences in the depositional environment or facies of Pulau Putri composing rock and its geological potential are known. Based on the results of previous studies, Pulau Putri is composed of Quaternary Tuffaceous Sandstone Formation (Kusnama, 1994) which is of course a sedimentary rock with a fluvial depositional environment. Conditions in the past (Quaternary Age) indicated that the waters around Putri Islands are part of Sundaland. At the time the Quaternary was part of the mainland until the end of the global glaciation period 9000 years ago appeared (Sathiamurthy and Voris, 2006). However, based on the results of the P3GL investigation (2005) showed that during the Pleistocene - Holocene (Quaternary), Putri Islands are composed of reef limestone and coarse to fine fragments of sediment. This indicates that during this Quaternary time there were evolution of depositional environment from fluviatil into marine (Hernawan *et al.*, 2018). Based on the interpretation of radar facies georadar data (Figure 7) that widely applied (e.g. by Beres and Haeni, 1991; Jol and Smith, 1991; Huggenberger, 1993; Bristow, 1995; van Overmeeren, 1998; van Heteren *et al.*, 1998; Noviadi, 2014; Budiono and Latuputty, 2008; Budiono, 2013a; 2013b, etc.) which interpreted subsurface geological in the several coastal zone based on GPR data, the conditions of subsurface lithology at the study area is described as follows (Figure 7):

The third layer (Unit 3) is the oldest facies that have a thickness more than 20 meters. This facies is characterized by a hummocky reflector configuration at the top and a chaotic in the bottom with a discontinuous trend, moderate reflector contrast with moderate amplitude, and a fairly dominant undulation pattern. This layer is thought to be a sedimentary rock formed in the presence of large depositional energy and strong currents. The characteristics of sediments formed in this facies are thought to have a coarse grain size. If correlated with previous studies, this facies is comparable to Conglomerate Various Material (Hernawan *et al*, 2018) as a part of Tanjungkerotang Formation (Tmpt) (Kusnama, 1994).

The second layer (Unit 2) is a facies at a depth of 5-11 meters with thicknesses ranging from 5-6 meters. This facies is characterized by a parallel-subparallel reflector configuration, medium amplitude and in some reflectors undulating and continuous. This layer is interpreted as a sediment that has a stable accommodation and a constant sedimentation velocity.

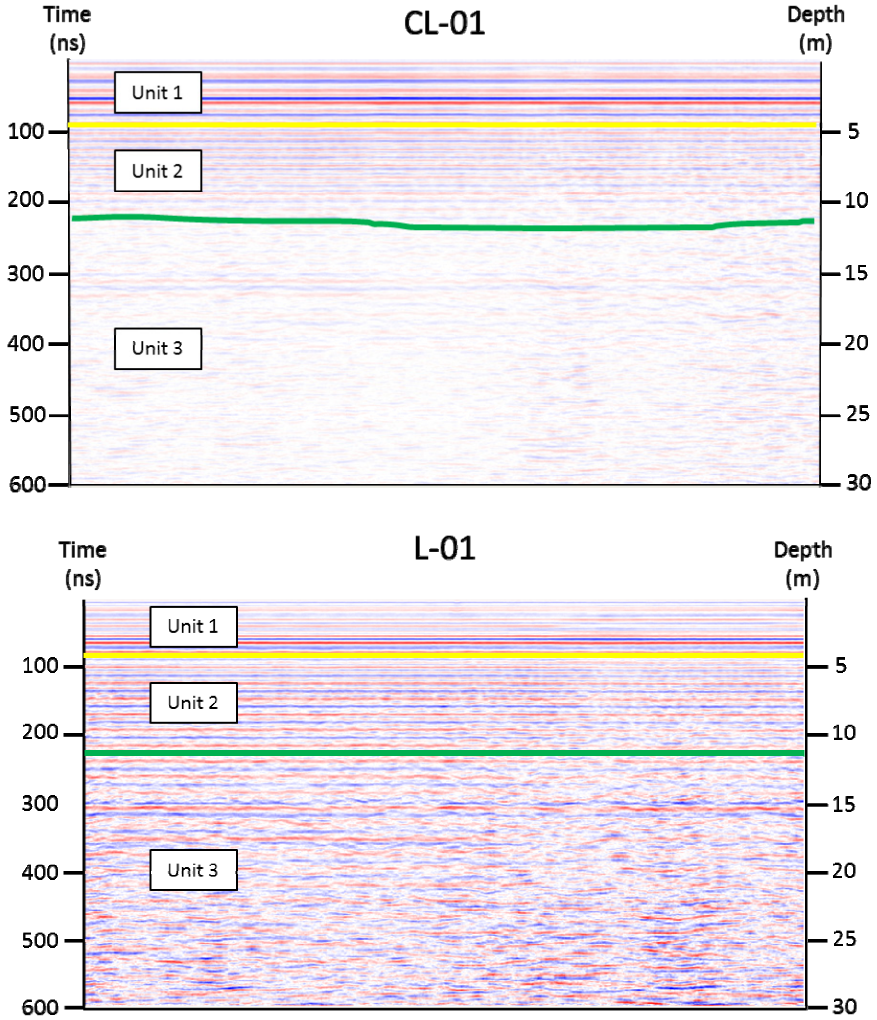


Figure 7. Georadar data record view on Line L-01 and CL-01 (2D)

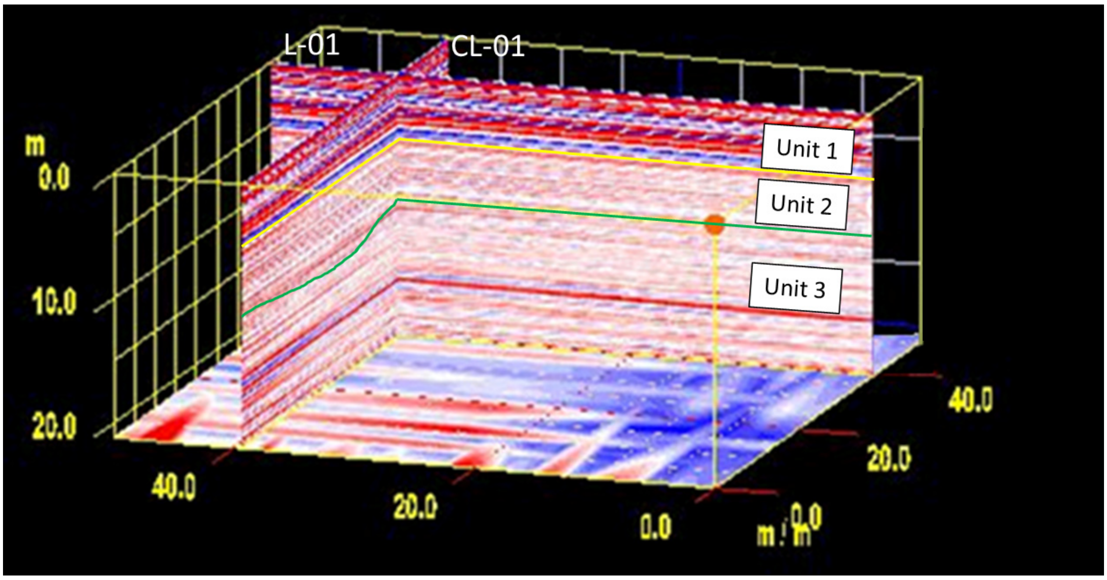
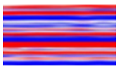
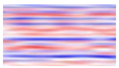


Figure 8. Fench Diagram view on Line L-01 and CL-01 (3D)

Sea level rise impact observed in this unit, reflected by the undulation on the bottom which was allegedly affected due to the deposition energy which is quite large with moderate currents. Derived from this condition the characteristics of the sediment formed in this facies are thought to have a fine-to-medium sand grain size. If correlated with previous studies, this facies is comparable to the Goungon Formation (QTg) (Kusnama, 1994).

The first layer (Unit 1) is the youngest facies that have thicknesses ranging from 4 - 5 meters. This facies is characterized by a parallel reflector configuration, high and continuous amplitude from the upper limit of the layer to the lower limit of the layer. This shows that the deposition process that occurred has a stable accommodation with a constant sedimentation speed. The parallel reflector pattern usually indicates that depositional energy occurs is relatively low with a fairly quiet current. In addition, observing the shape of a strong reflector with high amplitude, this shows that characteristics of the sediment in this facies are thought to have a very fine-to-fine sand grain size. If correlated with previous studies, this facies is comparable to Aluvium (Qa) (Kusnama, 1994) with depositional environment similar to the present condition, namely the coastal area. The beaches in this area are dominated by sandy beaches with relatively flat morphology (Hernawan *et al.*, 2018). All of these patterns can be seen on Table 1.

Table 1. Relation Between Radar Facies Changes with Depositional Facies Changes

Unit	Georadar Recording	Reflection Configuration	Reflection Continuity	Reflection Amplitude	Grain Size Assumption	Depositional Facies
1		Simple Parallel	Continuous	High	Very fine – Fine sand	Coastal Plain transgression ↗
2		Parallel, slightly undulating	Continuous	High to medium	Fine sand – Medium sand	Transition Zone transgression ↗
3		Parallel-Subparallel undulation, discontinuous	Discontinuous	Low to medium	Coarse sand	Fluvial

Relation between depositional facies in Units 1-3

It can be seen from the reflector pattern on radar facies that the pattern formed indicates a change in the depositional environment. Depositional environment changes that has an impact to grain size of the Quaternary sediments in the study area. Hanebuth (2002) states that the Sunda Shelf is currently undergoing a phase of transgression starting from the Holocene period 11,000 years ago to the present day. This is due to the period of sea level rise that has occurred and lead to the submerged of the Sundaland, so that the plain which was originally land has become a transitional environment - shallow marine. In unit 3 reflect the coarse sand sediment grain size, characterized by a dominantly discontinuous and undulating reflector pattern. This pattern indicates that the depositional facies in this unit are terrestrial (fluvial) facies. Unit 2 shows a continuous parallel pattern with a low – medium amplitude, it shows transformation of depositional facies into transition zone. Marine influence indication is reflected by fining grain size to be medium – fine sand sediment. The last unit as the youngest depositional facies (Unit 1), this unit is characterized by a continuous parallel with strong amplitude reflector pattern dominated. This unit is the same unit as the present condition, which is a sandy beach area (Hernawan *et al.*, 2018) with very fine sand - fine sand sediment grain size. The deposition process that occurred from Unit 1 - 3 illustrates the influence of sea level rise (transgression), causing a change in depositional facies from fluvial – coastal plain (Table 1). This is correlated with the previous research by (Solihuddin, 2014) that Sunda Shelf was drowning during Last Glacial Maximum process until present.

CONCLUSION

The GPR method has successfully interpret the depositional facies that reflected in radar facies. Based on reflection pattern such as reflection configuration, reflection amplitude, and reflection continuity the depositional facies of the study area are interpreted as fluvial – coastal plain that might be related to the end of the Last Glacial period that lead to sea level rise.

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