Shallow Subsurface Sediment Characteristics of Northern Obira Coastal Based on Georadar Facies Interpretation

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Abstract. The Georadar (GPR) as a non-destructive technique has been used extensively for geological research. The study was conducted in order to identify coastal sediment characteristics of northern Obi coastal area by performing GPR radar facies analysis. The model of GPR used was Sirveyor 20 with MLF antenna frequency 40 Mhz, penetration depth was 10 meter, and Radan 5 as processing software which include time zero correction, spatial filtering, deconvolution, migration, adjustment amplitude and signal gain. Data interpretation describes georadar image/radargram based on radar facies methodology. The result showed three differences of radar facies unit. The radar facies unit can be divided into 2 facies units in which there are 2 other sub-units, namely unit 1A, 1B, 2A and 2B. Radar facies characterized by medium-high amplitude, continuous parallel-subparallel, medium-weak reflector. At the top part down to 3.75 m is Unit 1A that intersects with 1B. Below 3.75 – 7.75 m depth interval is Unit 2A, and unit 2B is from 7.75-10 meter depth interval. Unit 1 is interpreted as Quartenary alluvium (Qa) and unit B is Woi Formation (Tmpw). Radar facies characteristic indicated the differences of the geological unit.

1. Introduction
The Obi Islands are groups of islands in the Southern Moluccas. Those islands are located in the north of Buru Island and Seram Island. Obira Island is the largest of the archipelago. Other islands are Can Island and Tapa Island, located in the northern of Obira Island, Obilatu Island and Belang-Strip Island in the west part, Gomumu Island in the south, and Tobalai Island in the east of Obira Island.

The general method often used to determine subsurface condition is drilling method. However this method has the disadvantage of a high price, time consuming and destructive method. Although the results obtained are more complete for engineering purposes. The other method is Ground Penetrating Radar/Ground Probing Radar (GPR). GPR also known as Georadar, is one of the geophysical non-destructive and non-invasive techniques for measuring physical properties of
geological materials [1, 2, 3]. GPR requires less setup/survey time [4], easy to operate [5], and able to describe the shallow subsurface geology at high resolution [6, 7].

GPR describes shallow subsurface stratigraphy based on physical properties changes, particularly the differences in conductivity and dielectric properties that indicate different subsurface layers, structures, or sediment units [2, 4]. The radargram allows us to interpret and visualize the opaque ground [3]. Interpretation of radar facies data is frequently used in the interpretation of shallow subsurface geological feature/condition [8, 4], such as identify lithology and subsurface sediment [9, 10, 11, 12, 13, 14, 15], land subsidence [16, 17], geological structure [18, 19, 20].

In order to understand subsurface geology, GPR method has performed in Obira coastal area. The main purpose of this study is to describe the characteristic of subsurface sediment based on georadar facies interpretation.

2. Method

The study area was located in the northern coastal area of Laiwui Village and Jikotamu Village, Obi District. Two lines of georadar data were collected, namely L01 with north-south direction (across to the coastline) as far as 650 m and L02 as far as 2380 m from west to the east (parallel and across to the coastline) (Figure 1).

![Figure 1. The area of study (red squares), blue lines are GPR lines, i.e. L01: GPR measurement Line 01 and L02: GPR measurement Line 02](image_url)
2.1 Regional geology of Obira Island

Regionally, the Obi area is included in the Obi Basin [21], which was formed due to three plates’ geodynamic movement. According to [22] the stratigraphy of the Obi area began with the emergence of ultramafic and metamorphic rocks during the Triassic-Jura period, then the Loleobasso Formation was deposited during Jura, while the Tertiary sediments of the Obi area began in the Oligo-Miocene which was characterized by the deposition of the Fluk Formation and the Bacan Formation, followed by volcanic activity, diorite intrusion and gabbro. Afterwards the Woi, Obit and Anggai Formations were deposited in the Mio-Pliocene. These fluctuations have continued until now, which is shown by the formation of coastal steps and the growth of coral limestone accompanied by volcanic activities. On Obira Island, there are various mineralization including nickel and copper found in ultramafic rock, iron sand deposits found at the mouth of the Lele River. Limestone is abundant in Obira Island (Figure 2).

Ultramafic Rock: Consists of: Serpentinite, pyroxenite and harsburgit. Serpentinite is greenish-gray in color consisting of serpentine, olivine, pyroxene, chromite, magnetite and iron oxide. Pyroxenite is light gray-greenish consisting of: pyroxene, olivine, magnetite and chromite. Harsburgite is yellow-green in color consisting of: pyroxene (enstatite), olivine and ore. The rock is heavily crushed, containing quartz and calcite veins; very strong welding and pengerpentinened. Locally found diorite and gabbro cracks that containing pyrite. The age is considered to be pre-Tertiary.

Bacan Formation: Consists of: Breccias and lava inserted with tuffaceous sandstones and greenish-gray claystones. The breccia has andesite, basalt and a little red chert component. The lava is greenish-gray, andesitanic, propylated, calcite and quartz fine veins. The sandstone and claystone contained of foraminifera, including Globorotalia kulgeri Bolli, Globigerina venezuelana Hedberger; Austritilina howchini Schlumberg, showing a Lower Oligo-Miocene age, with its thick is more than 1,000 m. It is exposed on Central Obira Island and Obilatu Island. The upper part is exposed to the Fluk and Menindih Formations incompatible with ultramafic rocks.

Woi Formation: Consists of sandstones, conglomerates and marl. Gray sandstones, medium segregated, tuff. Conglomerate is gray in color, composed of andesite crust, basalt and limestone. Marl is gray in color, contains of foraminifera and mollusks.

Aluvium: Consists of mud, loam, sand, and gravel as beach and river deposits. Scraps of coral were found on small islands north of Obira Island.

Figure 2. Geological map of the study area
General method used to understand shallow subsurface geology in this study is GPR technique with radar facies analysis. GPR also known as Electromagnetic Subsurface Profiling (ESP) 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 [5].

The GPR utilizes electromagnetic wave backscattering emitted through the surface ground. An intermediate antenna Velocity of transmission and backscattering of electromagnetic wave is very fast and stated in nanosecond time unit [23]. The GPR 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 (Figure 4). An electromagnetic pulse transmitted through the ground, and the return time of the reflected pulse is recorded [2], and the system will measure the time elapsed between wave transmission and reflection. This process is repeated at short intervals while the antenna is in motion, and the 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 color scale [24].

The depth of GPR was obtained with formula:

$$D = \frac{c \cdot t}{2 \cdot \varepsilon r}$$

D: Depth, c: speed of light in vacuum (0.3 m/ns), t: signal travel time, \(\varepsilon r\): dielectric constant [1]. Basically, the depth of radargram is shown in time travel, i.e. nanosecond (ns), but it could be displayed in meter as well. Based on result of experience and literature in many coastal radargram data in Indonesia, the conversion from ns to meter is about 20 ns = 1 meter [9, 10, 11, 12, 16, 20].

Figure 3. Stratigraphy column in the study area
Figure 4. Principles of GPR method [26].

GPR system used in this study was SIRVeyer 20 model of GSSI product that includes mainframe and a toughbook as processing and storing data, cable and Multi-Level Frequency (MLF) type that are the transmitter and receiver antenna were separated by 1 m distance (standard offset). The MLF antenna was set as 40 MHz with depth penetration was 10 and 20 meters. Supporting equipment includes accumulator GPS, camera, and stationary.

Generally, processing steps of GPR data processing include data conversion to use digital format, removing or minimizing direct wave from air to the surface, setting and adjusting amplitude and gain, static data adjustment for removing elevation distinction, data filtering, and velocity analysis [26]. The data were processed in Radar 5 software of GSSI product. GPR data processing steps include time zero correction that 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 processing GPR data follow standard processing setted by [26]. The final step was interpretation of GPR data.

The GPR data interpretation was based on radar facies interpretation, which the concept was based on methodology applied to seismic stratigraphy surveys [8]. Radar facies characteristics were interpreted based on the internal configuration and continuity of reflections, as well as on reflection termination patterns [27] and generally characterized on the basic of shape, amplitude, continuity and internal reflection configuration and external form [28, 29] following the approach applied by [6, 26, 30].

3. Result and discussion
The study area is an area where quaternary deposits are intensively formed with a terrestrial depositional environment. This is indicated by the presence of alluvial deposits (Figure 5). Quaternary Terrestrial deposits are recorded in the radar facies.
Figure 5. Alluvium deposit in the study area

3.1 Facies Radar

Subsurface structures can be seen using various geophysical methods, e.g. the Grobe Probing Radar (GPR). This GPR principle has similarities to seismic where the waves are emitted below the surface and then received back by a receiver showing distinctive reflector patterns. This reflector pattern is then called the radar facies (Figure 6). The facies radar that offers the same reflector pattern in 1 deposition unit is then interpreted using the seismic stratigraphic principle.

The reflector configuration in the study area shows two different radar facies units. Each radar facies unit has two radar facies sub units in it. These radar facies units are as follows:

Unit 1
This unit is a facies unit which has the characteristics of a strong reflector - medium, parallel - subparallel, with medium - high amplitude. Unit 1 is further divided into 2 Sub-Units, namely Sub-Unit 1A and Sub-Unit 1B.

- Sub-Unit 1A
  This sub-unit is characterized by a strong, continuous parallel, high amplitude reflector. This unit has a depth ranging from the surface to 0.5 meters down. Then this unit is recognized again at a depth of 1.5 - 2.5 meters.

- Sub-Unit 1B
This sub-unit is characterized by medium-high amplitude, continuous parallel-subparallel reflectors. This unit is limited at the top by the lower limit of Unit 1A from a depth of 0.5 to 1.5 meters and below. Similar to Sub-Unit 1A, this unit is identified again at a depth of 2.5 - 3.75 meters.

Unit 2
This unit is a facies unit which is characterized by a medium-weak, parallel-subparallel, medium-weak reflector with medium amplitude. Unit 2 is further divided into two Sub-Units, namely Sub-Unit 2A and Sub-Unit 2B.

- **Sub-Unit 2A**
  This sub-unit is characterized by medium, parallel reflector - continuous subparallel with medium amplitude. This unit is the last unit on the radar record which is limited by the lower part of Unit 1B from 3.75 - 7.75 meters depth.

- **Sub-Unit 2B**
  This sub-unit is characterized by a weak reflector, parallel - continuous subparallel with medium amplitude. This Sub-Unit is the last Sub-Unit on the radar record, the lower part of which is limited by the maximum GPR penetration limit.

Deposition Sub-Units 1A and 1B appear to be repeated in Unit 1, this is similar to the field observations (Figure 7) which shows the repetition pattern in the lithology.

![Figure 7. Surface lithology in the study area](image-url)
3.2 Interpretation of GPR Radar Unit
The subsurface conditions based on the recorded GPR data illustrate the occurrence of two different facies units that each of them has several sub-units. These sub-units can be recognized on the L01 (Figure 8) and L02 (Figure 9) trajectories. The difference in facies units might be due to changes in the depositional environment. Previous research [22] based on surface lithological observations indicated that the research area traversed by the two trajectories was Quaternary Alluvium. The results of the field review show that there is a change in texture, that is a smooth upward laminate (Figure 7). This might be influenced by changes in seawater inundation which appear to be increasingly intensive.

![Figure 8. Interpretation of L01 georadar record](image-url)
Sub-Unit 1A is the youngest sedimentary layer, where the upper limit of Sub-Unit 1A is the surface of the treaded soil while the lower boundary of Sub-Unit 1A is the upper limit of Sub-Unit 1B. This sub-unit has the characteristics of a strong, continuous parallel, high amplitude reflector. This sub-unit can be interpreted as sediment deposited in an environment where the sediment supply rate and current are relatively constant. Allegedly the depositional environment plays a dominant role in the fluvial direction but has begun to have an influence from the sea. This is shown by the very firm parallel reflector pattern. Strong reflectors with a parallel pattern generally show a relatively fine grain size texture, however in this depositional condition there is also coarse grain size sediment. This sub-unit has a clear and continuous coating area which can be seen from the continuity of the reflector. The thickness of this Sub-Unit 1A ranges from 0.5 - 1 meter. When compared with the results of previous studies [22], this Sub-Unit 1A is still included in the Quaternary Alluvium (Qa).

Sub-Unit 1B is a sediment layer deposited under Sub-Unit 1A, where Sub-Unit 1B is bounded at the top by the lower limit of Sub-Unit 1A and the lower part is limited by the upper limit of Sub-Unit 1A or the upper limit of Sub-Unit 1A. This sub-unit has the characteristics of medium-high-amplitude, continuous parallel-subparallel reflectors. This unit can be interpreted as sediment deposited in an environment where the sediment supply velocity and current are quite strong, because it is characterized by the presence of sub-parallel reflector patterns. It is indicated that the depositional environment plays a dominant role in the fluvial direction. Medium reflectors with a parallel - subparallel pattern usually show a relatively medium - coarse texture of the sediment grain size. This sub-unit has a clear and continuous coating area which can be seen from the continuity of the reflector. The thickness of this Sub-Unit 1B ranges from 1 - 1.25 meters. When compared with the results of previous studies [22], Sub-Unit 1B is still included in the Quaternary Aluvium (Qa).

Both Sub-Unit 1A and Sub-Unit 1B belong to the similar depositional facies’ unit, namely the Facies 1 Unit, where the facies 1 unit is considered a facies unit that a fluvial deposition is slightly affected by the sea above it (Sub-Unit 1). Sub-Units 1A and 1B are repeated, due to the influence of the sea level changes. Compared to the previous studies, these depositional characteristics are in

**Figure 9. Interpretation of L02 georadar record**

![Interpretation of L02 georadar record](image-url)
accordance with the characteristics of Quaternary Alluvium (Qa) which is composed of mud, loam, sand, gravel and gravel as coastal and river deposits [22]. Meanwhile, under Unit 1, other facies units were developed.

Sub-Unit 2A is a layer of sediment deposited under Unit 1, wherein Sub-Unit 2A is bounded at the top by the bottom of Unit 1 / Sub-Unit 1B (2nd loop) and the bottom is limited by the upper limit of Sub-Unit 2B. This sub-unit has the characteristics of a weak reflector, parallel - continuous subparallel with medium amplitude. This sub-unit can be interpreted as sediment deposited in an environment where the sediment supply rate is fairly constant but the current is strong enough. It is indicated that the depositional environment plays a dominant role in the fluvial direction. Weak reflectors with a parallel - subparallel pattern generally show a relatively moderate - coarse texture of the sediment grain size. This sub-unit has a clear and continuous coating area which can be seen from the continuity of the reflector. This 2A Sub-Unit has a thickness of up to 4 meters. When compared with the results of previous research [22], this Sub-Unit 2A can be classified into the Woi Formation (Tmpw).

Sub-Unit 2B is a layer of sediment deposited under Sub-Unit 2A, the upper part is limited by the lower limit of Sub-Unit 2A and the lower part is limited by the maximum penetration of the GPR device. This sub-unit has the characteristics of a weak reflector, parallel - continuous subparallel with medium amplitude. This unit can be interpreted as sediment deposited in an environment where the sediment supply rate is fairly constant but the current is strong. It is indicated that the depositional environment plays a dominant role in the fluvial direction. A weak reflector with a parallel - subparallel pattern usually shows a relatively fine - coarse texture of the sediment grain size. This sub-unit has a clear and continuous coating area which can be seen from the continuity of the reflector. The thickness of this Sub-Unit 2B is up to 2.25 meters. When compared with the results of previous studies [22], Sub-Unit 2B is included in the Woi Formation (Tmpw).

Both Sub-Unit 2A and Sub-Unit 2B belong to the same depositional facies unit, namely the Facies 2 Unit, where the Facies 2 Unit is presumably a facies unit of fluvial deposition unit. When compared with previous studies, these depositional characteristics are in accordance with the characteristics of the Woi Formation which is composed of sandstones, conglomerates, and marl [22].

4. Conclusion
The radar facies unit is divided into two facies units in which there are two other sub-units. This might be due to the difference in texture, resulting the differences in the reflection of the reflected waves. This difference in reflection configuration can be recorded on GPR in sufficient detail, although the lithology below the surface is still in the similar rock formation.

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