Study on the Use of Ground-Penetrating Radar Technique to Recognize Tin deposits in Bangka Island

Wahyudi W. Parnadi¹*, Sarwo. S. Amin¹, Mohamad N. Heriawan², Rizandi G. Parnadi³

¹Department of Geophysical Engineering, Institut Teknologi Bandung
²Department of Mining Engineering, Institut Teknologi Bandung
³Wifra Geo Energi, Jl. Sangkuriang S-8 Bandung 40135, Indonesia

*Author correspondence: wahyudi@gf.itb.ac.id

Abstract. Bangka Island, which is situated in the east of Sumatra, is included in the Indonesian tin belt, spanning from the Malayan Peninsula to the southeast direction until Bangka Island. After ten years of exploitation, intensive exploration to locate new tin deposits is needed to add new tin reserve from available resources. This research is aimed at applying Ground-Penetrating Radar (GPR) technique to recognize tin deposits at some location onshore. GPR method is selected among other geophysical methods due to its potential to image subsurface effectively, both in time and campaign cost. GPR Mala RAMAC system equipped with 100 MHz antenna came to use. Three blocks of 200m x 200m area comprising of around 9 in-line and 9 cross-line profiles were investigated. The acquired data were then processed using careful processing steps, including dewow, Butterworth bandpass as well as f-k filtering to avoid information loss. The processed data were then analyzed by using nine characteristic frequencies which are determined in frequency as well as in time domain. With the aid of borehole log data from all of measurements locations, we recognize specific signature associated with Tin layers at depths of 5 - 10 meters.

Key words: Ground-Penetrating Radar; tin deposits; characteristic frequency; Bangka Island; Indonesian tin belt

1. Introduction

Bangka island is included in the Indonesian tin belt, spanning from Malayan Peninsula to the southeast direction until that island, that is the most important primary-granite as well as the secondary product of tin mineralization in Indonesia. Two types of tin deposits are recognized in Bangka Island, i.e. primary tin deposits and alluvial tin deposits, which are mined in the form of open pit mining and hydraulic mining respectively. Vast artisanal mines, which in most cases belong to illegal activities, have impacted the reclamation area to become damaged, spotted and resulting in the declining of the amount of tin reserves owned by the mining company that has concession to the area. After ten years of exploitation, intensive exploration to locate new tin deposits is needed to add new tin reserve from available resources. A fast, accurate, and cost effective method to image subsurface tin deposits is therefore required.

Ground Penetrating Radar (GPR) is one of geophysical methods that can provide high resolution image of the subsurface in efficient and effective ways. Study on the use of GPR technique has been carried out in mineral exploration [1, 2]. Mapping of subsurface is easily obtain in a rapid
and economical ways [3]. Induced Polarization (IP) has been also applied in recognizing tin deposits in the study area. Since its result was unsatisfactory and the potential use of GPR should be explored, only GPR technique comes into use through this study.

In this research, GPR is applied to detect and delineate interface between alluvial deposits and underlying granitic rocks representing paleochannels.

2. Geology Regional of Bangka Island

The geological structures observed on the South Bangka sheet are straightness, crease and cesarean [4]. The straightness is mainly on granite with diverse directions. Folds are found in sandstone and claystone formations of Tanjung Genting and Ranggam formations with a slope of 18 - 75 degrees. The fold axis is approximately to be Northeast-Southwest. Two types of fault that developed in the area are the horizontal fault and normal faults. Horizontal fault is directed Northeast-Southwest, while the normal faults is directed Southeast-Northwest.

Tectonic activity is interpreted to take place since the Perm is marked by the formation of the Malihan Pemali complex. In the Early Trias there was a decline and deposition of Tanjung Genting formation in a shallow marine environment [5]. Then at the End of Jurassic Trias End lifting took place and followed by breakthrough Granite Klabat. Beginning Miocene Middle-Pliocene early deposition too place with the formation of Ranggam in the fluvial environment. Further alluvial removal and precipitation in rivers, swamps and beaches took place on the Holocene. The main mineral resource in South Bangka is white tin, with additional minerals such as monazite, zircon, xenotim, ilmenite, magnetite and pyrite. Tin deposits exist as primary and secondary tin deposits. Primary tin deposits are found in gneissic granite bodies in Sepat Mountain near Lubuk Besar, whereas secondary tin deposits exist along ancient river channels.

3. Theory of Ground Penetrating Radar (GPR)

Propagation of electromagnetic waves, which is valid for GPR, is based upon Maxwell equations. Maxwell’s equations are composed of four differential equations that state the relationship between electric field and magnetic field, which also states the direction of propagation, transmission, reflection and also diffraction on the wave electromagnetic [6]. The equations are

$$\nabla \cdot E = \frac{\rho}{\epsilon} \quad (1)$$
$$\nabla \cdot B = 0 \quad (2)$$
$$\nabla \times E = -\frac{\partial B}{\partial t} \quad (3)$$
$$\nabla \times B = \mu \sigma E + \varepsilon \mu \frac{\partial E}{\partial t} \quad (4)$$

where:
- $E$ = Electric field strength (V/m)
- $B$ = Magnetic Induction (Wb/m² or Tesla)
- $\mu$ = Magnetic permeability (H/m)
- $\sigma$ = Electrical Conductivity (mS/m)
- $\varepsilon$ = Electrical permittivity (F/m)
- $\rho$ = resistivity (Ωm).

The velocity of electromagnetic waves medium is given by [7]

$$v_m = \frac{c}{\sqrt{\varepsilon_r}} \quad (5)$$

And in vacuum, the propagation velocity of electromagnetic waves $c$ is
where:
\[ c = \text{Speed of light (3x10}^8 \text{ m/s)} \]
\[ \varepsilon_0 = \text{Electricity permittivity of free space (8.84x10}^{-12} \text{ F / m)} \]
\[ \mu_0 = \text{Magnetic permeability of free space (1.26x10}^{-6} \text{ H/m)} \]
\[ \varepsilon_r = \text{Relative permittivity (no unity)} \]

4. The Characteristic Frequency

The characteristic frequency is the frequency of the identifier as a characteristic of a wavelet or signal. A wavelet or signal can be represented by its characteristic frequency which can be determined in frequency domain as well as in time domain.

In the frequency domain there are 5 characteristic frequencies, i.e. center frequency \( f_{\text{center}} \), frequency variance \( f_b \), RMS frequency \( f_{\text{RMS}} \) that are determined in power spectrum and centroid frequency \( f_{\text{centroid}} \) and variance \( \beta \) that are determined in amplitude spectrum [8]:

\[ f_{\text{center}} = \frac{\int_{-\infty}^{\infty} f P(f) df}{\int_{-\infty}^{\infty} P(f) df} \]
\[ f_b = \sqrt{\int_{-\infty}^{\infty} (f - f_{\text{center}})^2 P(f) df / \int_{-\infty}^{\infty} P(f) df} \]
\[ f_{\text{RMS}} = \sqrt{\int_{-\infty}^{\infty} f^2 P(f) df / \int_{-\infty}^{\infty} P(f) df} \]
\[ f_{\text{centroid}} = \frac{\int_{-\infty}^{\infty} f S(f) df}{\int_{-\infty}^{\infty} S(f) df} \]
\[ \beta = \frac{\int_{-\infty}^{\infty} (f - f_{\text{centroid}})^2 S(f) df}{\int_{-\infty}^{\infty} S(f) df} \]

where \( P(f) \) is power spectrum of frequency \( f \).

There is a more sophisticated method to determined characterizing frequency in time domain. We adopt here equivalent bandwidth \( (\Delta f) \), mean frequency \( f_m \), lower cut-off frequency \( f_l \) and higher cut-off frequency \( f_h \) [8, 9]:

\[ \Delta f = \frac{a_m}{2E} \]
\[ f_m = \frac{1}{2W} \]
\[ f_l = f_m - \frac{\Delta f}{2} = \frac{1}{2} \left( 1 - \frac{P_a}{2} \right) \]
\[ f_h = f_m + \frac{\Delta f}{2} = \frac{1}{2} \left( 1 + \frac{P_a}{2} \right) \]

Where, \( P_a = \text{Resolving power}, a_m = \text{Maximum amplitude signal}, E = \text{signal energy}, f_m = \text{center frequency}, \) and \( W = \text{the width of main lobe} \).

Detailed explanation about the equivalent bandwidth can be found in [6]. Figure 1 shows 9 characteristic frequencies determined from arbitrary signal.
5. Result and Discussion

GPR Mala RAMAC system equipped with 100 MHz antenna came to use. Three blocks of 200m x 200m area comprising of around 9 in-line and 9 cross-line profiles were investigated. The acquired data were then processed using Reflexw software. Careful processing steps, including dewow, Butterworth bandpass filtering as well as f-k filtering to avoid information loss were carried out. The data were f-k filtered by eliminating velocity \( v < 0.02 \text{m/ns} \) and \( V > 0.22 \text{m/ns} \). The latter was applied to eliminate scattering from objects at surface like trees and bush.

Two layers can be identified from figure 2 and figure 3. The first layer is indicated as tin containing alluvial layer and the second layer denotes granitic rocks as bedrock. The processed data are then analyzed through its characteristic frequency. There are characteristic frequencies differences between tin containing alluvial layer and underlying granitic rocks. Frequency variance \( f_b \) of traces from tin-containing layer lies in the range 8 MHz to 53 MHz, whilst that of bedrock lies between 36 MHz until 78 MHz.

From calculation of characteristic frequencies of some traces representing tin containing layer and underlying granitic rocks (figures 2 & 3, table 1), it can be shown that frequency variance \( f_b \) values trend to show significant differences rather than other characteristic frequencies. It is concluded that the frequency variance \( f_b \) can be used as aid tool to distinguish between tin-containing layer and underlying granitic rock in the study area. The use of other characteristic frequencies for that purposes is very challenging.
Figure 2. Radargram from line 1. Yellow line shows the interface between alluvial layer and granitic rocks.

Figure 3. Radargram from line 3. Yellow line shows the interface between alluvial layer and granitic rocks.

Table 1. Calculation of characteristic frequencies for line 1 and line 3

| No Trace | A7-D7 Trace 550 | A7-D7 Trace 150 | B3-D9 Trace 500 | B3-D9 Trace 1500 |
|---------|-----------------|-----------------|-----------------|-------------------|
| Bagian  | 1-200 300-400   | 1-260 281-600   | 1-230 321-600   | 1-200 201-600     |
| F_centered | 68.9 107.3     | 82.2 102.7     | 91.2 86        | 74.4 82.8         |
| Ib      | 8.8 72         | 15.9 77.3      | 52.5 70.7      | 20.2 36.6         |
| Frms    | 9.4 12.4       | 9.2 12.6       | 11 12          | 8.9 9.9           |
| Tau     | 1.5 1.3        | 3.8 1.4        | 1.1 1.4        | 1.4 1.2           |
| F_centroid | 90.9 150.7    | 95.1 146.5     | 132.6 138.4    | 88.5 132.4        |
| Delta f | 16.9 7.1       | 31.6 9.1       | 2.5 7.8        | 7.5 3.9           |
| Fm      | 0.003 0.012    | 0.003 0.012    | 0.003 0.012    | 0.003 0.012       |
| F1      | -8.1 -5.2      | -15.8 -4.5     | -1.2 -5.9      | -5.7 -1.9         |
| F2      | 8.4 3.5        | 15.8 4.5       | 1.2 3.0        | 8.7 1.9           |
We also found from other research in this area, that borehole log data from all of measurements locations are showing specific signature associated with tin-containing alluvial layers at depths of 5 - 10 meters.

6. Conclusion
Based on Ground-Penetrating Radar (GPR) acquired with 100MHz antenna in Bangka Island, we analyzed 9 characteristic frequencies from some traces representing radargram obtained from measurement in the prospect area, the frequency variance $f_b$ shows significant differences rather than other characteristic frequencies. $f_b$ values from traces of tin-containing alluvial layer lie in the range of 8MHz – 53MHz, whilst that of granitic rocks as bedrock lie in the range 36MHz – 78 MHz. These differences in $f_b$ values can be used as aid tool to differentiate between tin-containing alluvial layers and underlying granitic rocks. With the aid of borehole log data from all of measurements locations, we recognize specific signature associated with tin-containing alluvial layers at depths of 5 - 10 meters.

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