MJFAS
Malaysian Journal of Fundamental and Applied Sciences



RESEARCH ARTICLE

# Characterization of Ground Penetrating Radar Reflection Patterns in the Peatlands of Kubu Raya Regency, Indonesia

**Mentari Adelia Lumban Tobing[a], Muhardi[a,*], Hans Andreas Elmaury Siregar[b]**

[a]Geophysics Study Program, Universitas Tanjungpura, 78124, Pontianak, Indonesia;
[b]Center for Mineral, Coal, and Geothermal Resources, 40122, Bandung, Indonesia

**Abstract** Ground Penetrating Radar (GPR) is a geophysical method that uses electromagnetic waves to map utilities and subsurface layers. It transmits electromagnetic waves, reflects them when they contact the medium, and then records them. Peatlands have unique properties, characterized by low density due to their composition of partially decomposed organic matter and a very high water storage capacity of up to 90% of the total volume. This research aims to interpret the reflection patterns in the subsurface layer of peatland areas. This research used a Plug-in Cobra GPR SE70 system operating at 80 MHz. The research location was in Rasau Jaya Sub-district, Kubu Raya Regency, Indonesia. Data acquisition in the field applied ten tracks with lengths varying from 162 m to 287 m. The data processing consisted of several stages, namely static correction, subtract-mean (dewow), Butterworth bandpass, background removal, average subtraction, and manual gain. The results showed that the reflection patterns on the peat layer showed random/irregular diffraction and undulated (hummocky) with high amplitude. In contrast, the reflection patterns on the clay layer showed parallel to wavy patterns with low amplitude. The results also showed that the peat layer thickness at the research location ranged from 1.07 m to 2.78 m. These findings serve as an essential reference for GPR surveys using the same approach in other areas to improve carbon reserve estimates and assess hydrological risks in peatlands of Kubu Raya Regency.

**Keywords**: Dielectric Contrast, Ground Penetrating Radar, Peatland, Reflection Patterns.

## Introduction

Peatland area in Indonesia is about 14.91 million ha spread out in Sumatra 6.44 million ha (43%), in Kalimantan 4.78 million ha (32%), and in Papua islands 3.69 million ha (25%) [1]. Peat soils on the island of Kalimantan are estimated to have originated in the early Holocene period, and the peat age in West Kalimantan is estimated to be around 4,300 years [2]. One of the areas in West Kalimantan with a large amount of peatland is Kubu Raya Regency, which has an area of 829,969.17 ha [3]. Peatlands in an area are essential in storing carbon, regulating the water cycle, and supporting biodiversity. However, peat's unique physical and chemical properties challenge further management to understand its internal structure effectively and efficiently.

Peatlands in Kubu Raya Regency play crucial ecological roles as carbon sinks, water regulators, and biodiversity supporters [4]. However, their management is often hampered by the unique physical and chemical characteristics of peat, particularly in efforts to identify its internal layer structure. Geophysical surveys using the Ground Penetrating Radar (GPR) method offer a solution to overcome this challenge [5], [6]. This method utilises differences in electromagnetic wave responses to identify peat and other layers [7]. Knowledge of GPR reflection patterns enables clear visual identification, resulting in accurate subsurface stratigraphic maps to support data-driven land management [8]. The limited application of GPR for peatland mapping in Kubu Raya Regency is the primary rationale for this research.

The GPR method can identify the soil's physical properties, which can help with subsurface exploration [5], [9]. This method sends electromagnetic waves into the subsurface, which are then reflected back by recording the signal's amplitude, resulting in a picture of the subsurface conditions [10], [11]. Peat layers have unique characteristics, which can produce different reflection patterns from other soil layers [5].

***For correspondence:**
muhardi@physics.untan.ac.id

**Received:** 29 Sept. 2025
**Accepted:** 28 Feb. 2026

Therefore, the interpretation of GPR data on peat layers is essential as it can provide a precise understanding of the internal structure of peat effectively and efficiently [12], [13]. This research is also necessary for developing a more accurate method of mapping peat layer thickness for sustainable land management.

This research was conducted to observe the description and amplitude response of GPR data on peat and clay layers in Rasau Jaya Sub-district, Kubu Raya Regency. This research is expected to provide information for other researchers regarding the reflection characteristics of GPR data amplitude in peat and clay layers. Identifying the type of GPR reflection configuration can give a clearer picture of peat thickness, hydrological conditions, and subsurface soil layers [7]. This information is essential to support sustainable land management, reduce the risk of peatland fires, and prevent subsidence. In addition, the results of this identification can also be used for more efficient land use planning and mitigation of environmental impacts from human activities, thus maintaining the ecological functions of peatlands as carbon stores and water cycle controllers.

## Materials and Methods

The research was conducted on peatlands in Rasau Jaya Sub-district, Kubu Raya Regency, West Kalimantan Province, Indonesia. Measurements in this research were conducted using 10 tracks, with the distribution and design as shown in Figure 1. These tracks varied in length from 162 m (L2) to 287 m (L10), as shown in Table 1. Data acquisition in the field used a Plug-in Cobra GPR SE70 system with an operating frequency of 80 MHz. This was chosen as its theoretical maximum penetration depth in ideal conditions (up to 8 m) sufficiently exceeds the expected peat depth at the research location (up to 3 m) [14]. Additionally, the 80 MHz frequency provides an optimal balance between resolution and penetration for identifying the peat-clay boundary [11]. It provides the depth necessary to penetrate all peat layers and has sufficient resolution to identify the characteristic reflection patterns that differentiate peat from clay layer.

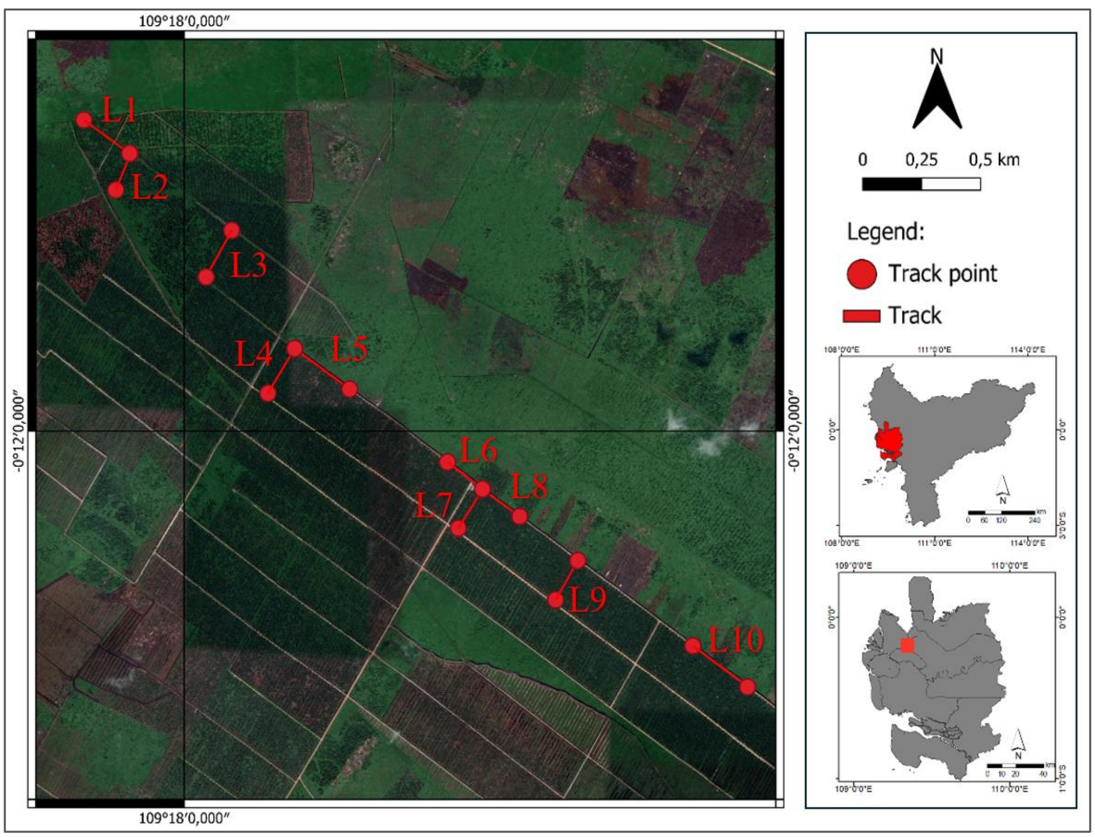


**Figure 1.** Research location on peatlands in Rasau Jaya Sub-district, Kubu Raya Regency

**Table 1.** The length of each track applied

| Tracks | Track length (m) |
|---|---|
| L1 | 238 |
| L2 | 162 |
| L3 | 221 |
| L4 | 216 |
| L5 | 286 |
| L6 | 186 |
| L7 | 190 |
| L8 | 192 |
| L9 | 188 |
| L10 | 287 |

The principle of using the GPR method is like the reflected seismic method in identifying facies and subsurface sequences. The GPR system consists of a signal generator, a transmission antenna (Tx), and a receiving antenna (Rx). The transmitting antenna generates radio waves at high velocity through the medium and back to the receiving antenna. Electromagnetic waves' transmission and return occur very quickly in nanosecond time units. Components of the radar system and interpreted section of the subsurface layer in the GPR method are presented in Figure 2.

The interpretation is carried out on the radargram to determine the boundaries and thickness of the peat layer. It requires wave propagation velocity, which is identified based on the thickness of the peat layer obtained from the drill data and the travel time of the radar waves from the source to the target and back to the source (two-way travel time). The wave propagation velocity is obtained using Equation (1).

$$v = \frac{2d}{t} \quad (1)$$

where:
$v$ = radar wave propagation velocity (m/ns)
$d$ = layer boundary depth (m)
$t$ = radar wave travel time (ns)

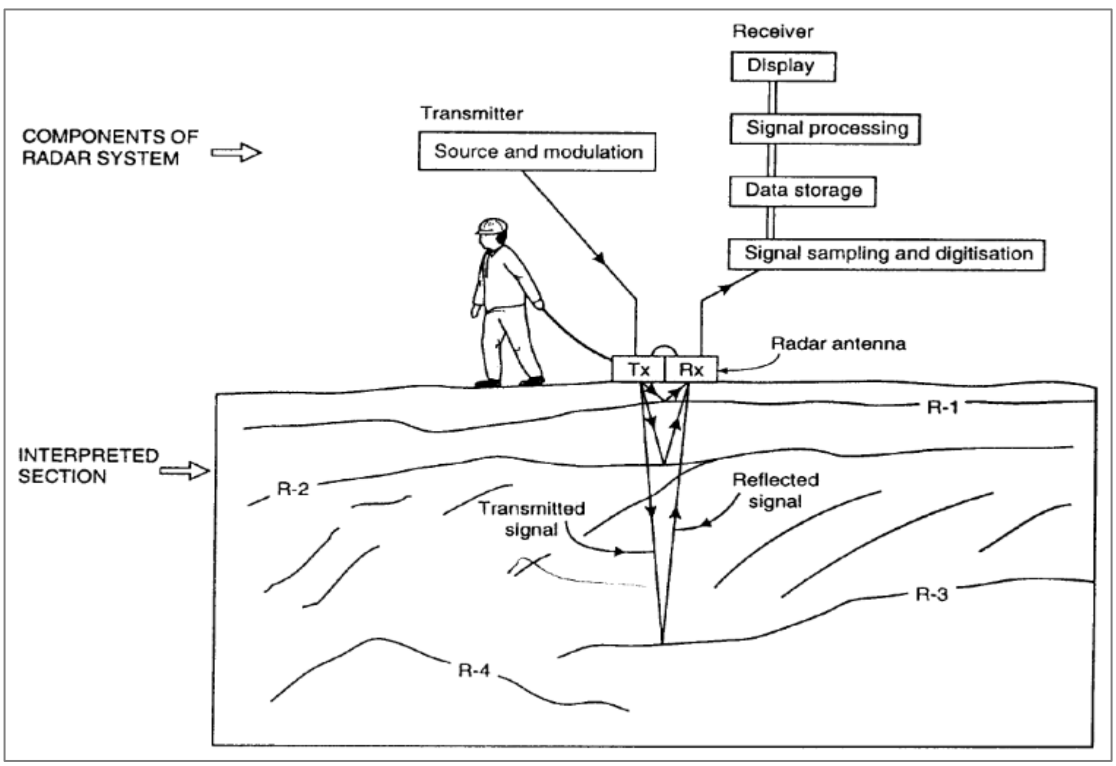


**Figure 2.** Component of radar system and interpreted section on subsurface layer [10]

GPR data processing is conducted through several stages, each with its specific purpose: static correction, subtract-mean (dewow), Butterworth bandpass, background removal, average subtraction, and manual gain. Static correction aims to remove time-zero (Tz) before the following data processing stage, as direct signals are unrelated to the subsurface conditions. Dewow removes very low frequencies recorded on the radargram by applying a time window filter based on the filtered spectrum. Using Butterworth bandpass, a bandpass filter is applied to clean the data from unnecessary frequencies (noise). Background removal aims to remove common environmental elements from the data so that anomalous material is more easily visible. Subtracting the average are applied to remove random signals and low-frequency traces. Manual gain is used to amplify the signal on each trace independently. This process is essential because signals weaken as they pass through the ground; some signal is lost to the environment (attenuation), and some are reflected to the receiver [15]. Therefore, signal amplification is required to maintain data quality as depth increases [10], [11].

The radargram interpretation process is conducted to determine the boundaries and type of material in each soil layer. Therefore, the thickness of the peat layer and the type of layer below can be identified. Soil layers have different dielectric constants and different reflection configuration patterns. These patterns are reflection facies analysis correlated with the available lithological data. The types of reflection configurations of each layer will indicate the characteristics of each layer with typical materials [16]. Figure 3 shows the relationship between the type of reflection configuration and its interpretation [8].

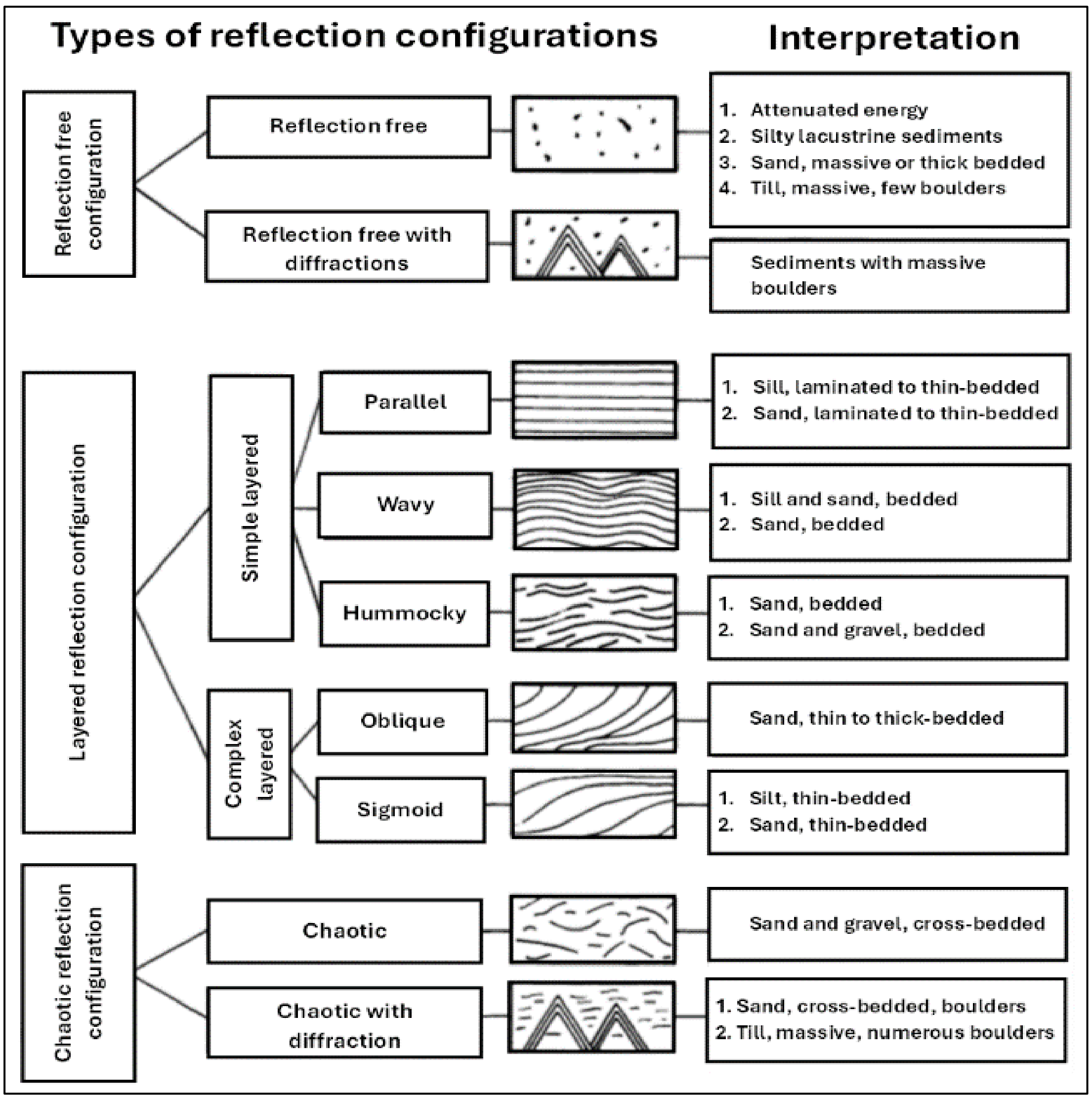


**Figure 3.** Types of reflection configurations and its interpretation [8]

## Results and Discussion

Figure 4 shows the radargrams on track L1 and L6, showing the types of reflection configuration interpreted as peat layer and clay layer. The part of the radargram that shows medium to high positive and negative amplitude (blue, purple, green, and red) is interpreted as a peat layer. Radargrams in peat layers are characterized by amplitude reflections with random/irregular diffraction and undulated (hummocky). The part of the radargram that has a low amplitude and zero value (yellow) is interpreted as a clay layer. The radargram amplitude of the clay layer shows characteristic small wavy reflections with some repetition of a uniform pattern (parallel to wavy). This shows that the clay layer is indicated by a relatively lower amplitude when compared to the peat layer. The pattern was consistent on all tracks, both on peat and clay layers.

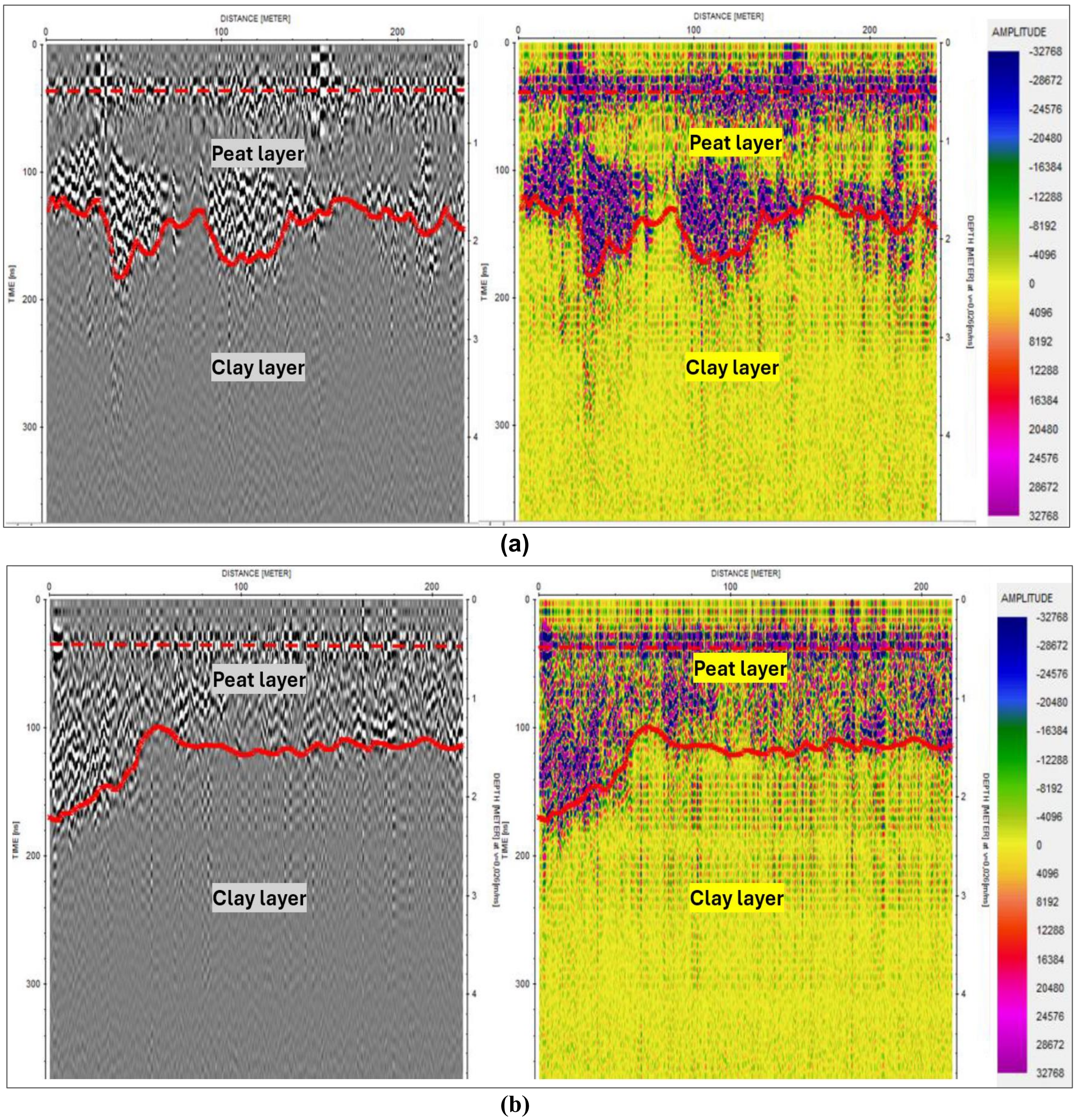


**Figure 4.** Example of displaying types of reflection configurations on a radargram; tracks L1 (a) and L6 (b)

The soil layer on each track is predicted to have different water content. This is indicated by the different radargram amplitudes on each track even though they are in the same layer. Reflection amplitudes appear stronger (higher contrast) in layers with higher water content due to the increased dielectric contrast, whereas layers with lower water content produce weaker (lower contrast) amplitudes. The amplitude display on the radargram is also affected by the length of the track and the number of traces. The shorter the track, the more sloping the amplitude displayed on the radargram. Overall, the interpretation results for track length and peat thickness are shown in Table 2.

**Table 2.** The peat thickness identified for each track

| Tracks | Peat thickness (m) |
|---|---|
| L1 | 1.55 – 2.36 |
| L2 | 1.28 – 2.78 |
| L3 | 1.07 – 2.37 |
| L4 | 1.29 – 2.23 |
| L5 | 1.38 – 2.03 |
| L6 | 1.50 – 2.12 |
| L7 | 1.37 – 1.99 |
| L8 | 1.56 – 1.95 |
| L9 | 1.07 – 2.26 |
| L10 | 1.45 – 2.22 |

The difference in reflected amplitude observed between peat and clay layers can be correlated with variations in water content and dielectric properties, as explained by the basic electromagnetic principles underlying the GPR method. The amplitude of electromagnetic wave reflections at the interface between two layers is directly correlated with the reflection coefficient, which is determined by the difference in electrical impedance or relative dielectric constant between the two materials [11]. Water content is a key factor because water has a very high dielectric constant, so an increase in water content will significantly increase the material's relative dielectric constant [10]. Water-saturated peat layers (water content >80%) can have a very high relative dielectric constant, whereas even when saturated, compacted clay soils typically exhibit a moderately high but comparatively lower dielectric constant.

Radargrams in peat layers exhibit random and hummocky diffraction, as shown in Figure 5. Peat layers contain organic matter at varying levels of decomposition, leading to significant changes in their dielectric properties [17]. This can increase the potential for amplitude reflection in areas with significant dielectric changes. The high dielectric constant of water-saturated peat layers, in contrast to the lower dielectric constant of the underlying clay, causes radar waves to experience significant velocity changes at the boundary, resulting in a high impedance contrast [18]. This high impedance contrast leads to a high reflection coefficient, causing a significant portion of the radar wave energy to be reflected to the GPR antenna, which is recorded as strong amplitude reflections. The porous and heterogeneous structure of peat can also amplify reflection signals due to variations in material density and composition [6]. Therefore, peat produces clearer and stronger reflection signals in GPR radargrams [11]. In addition, some peat layers contain a high proportion of fine-grained material from decomposing plants, leading to scattering of the reflected waves.

The low-amplitude reflection in the radargram at the research location is interpreted as a clay layer, as shown in Figure 6. The amplitude of the radargram in the clay layer shows weak wavy reflection with several repetitions of the same pattern (parallel to the wavy). This shows that a lower-amplitude reflection than the peat layer indicates the clay layer. The clay layer is generally homogeneous, resulting in a relatively stable radar response. It is characterized by weak GPR amplitude reflections due to its high water-absorbing and retaining capacity. The high water content in clays increases their electrical conductivity, significantly dampening radar waves as they propagate through the material [19]. In addition, clay layers can have a high dielectric constant when saturated (though often still lower than saturated peat), which slows the propagation velocity of radar waves, resulting in weaker reflected wave energy at the GPR antenna [20]. The dispersion of the waves within the clay also results in attenuation and dispersion of the power, weakening the returning reflection signal [21]. Therefore, GPR amplitude reflections in clay soils are usually lower than in peat layers.

This result shows a consistent pattern based on the characteristic GPR reflection between peat and clay on each track, increasing the reliability of non-destructive subsurface mapping in tropical peatlands. In similar conditions and peat characteristics at other locations, it provides a reference for GPR surveys to differentiate peat from clay in tropical environments. It offers essential subsurface data to improve carbon stock estimates and assess hydrological risks in the peatlands of Kubu Raya Regency.

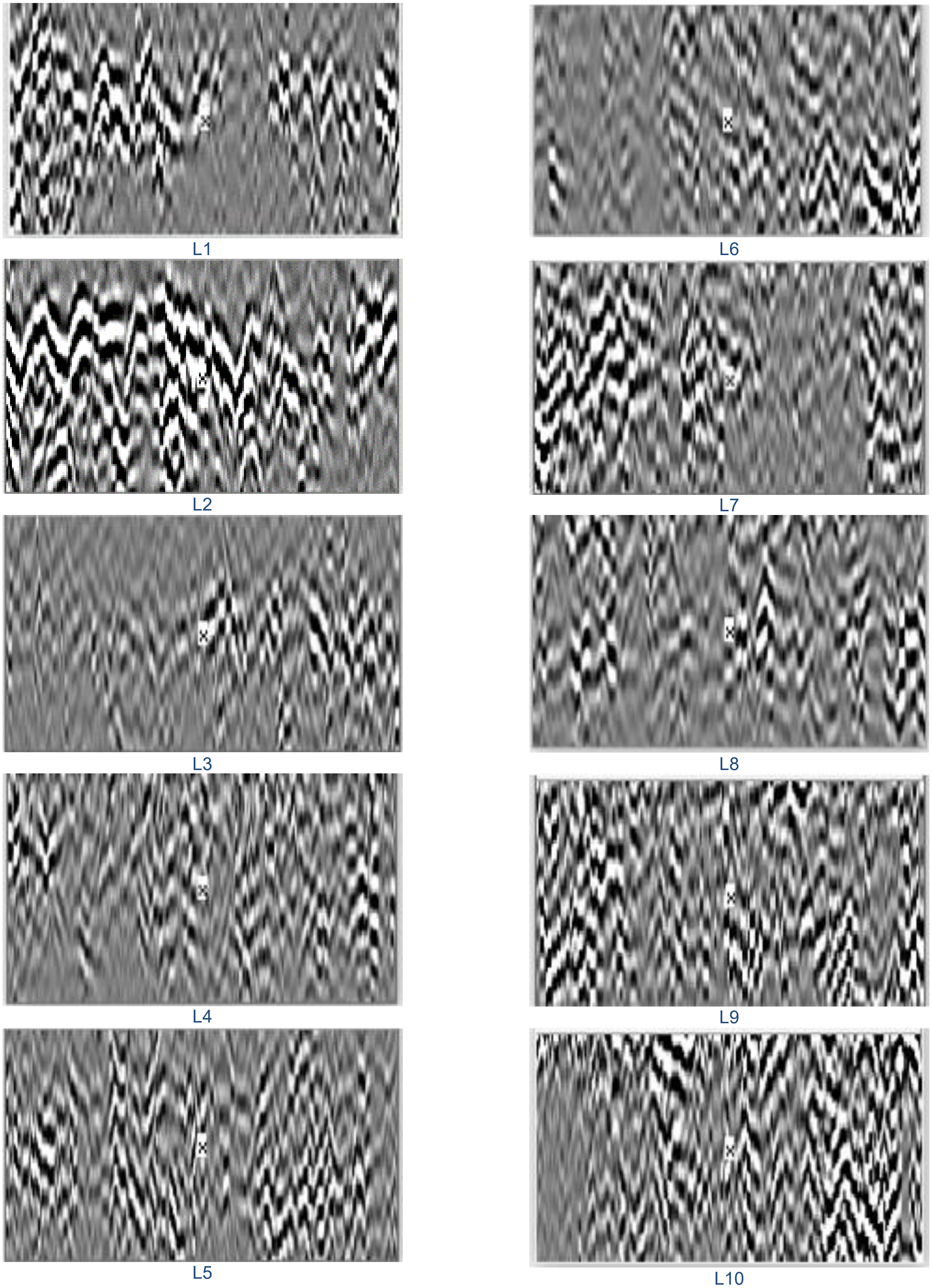


**Figure 5.** The types of reflection configuration that is interpreted as peat layer

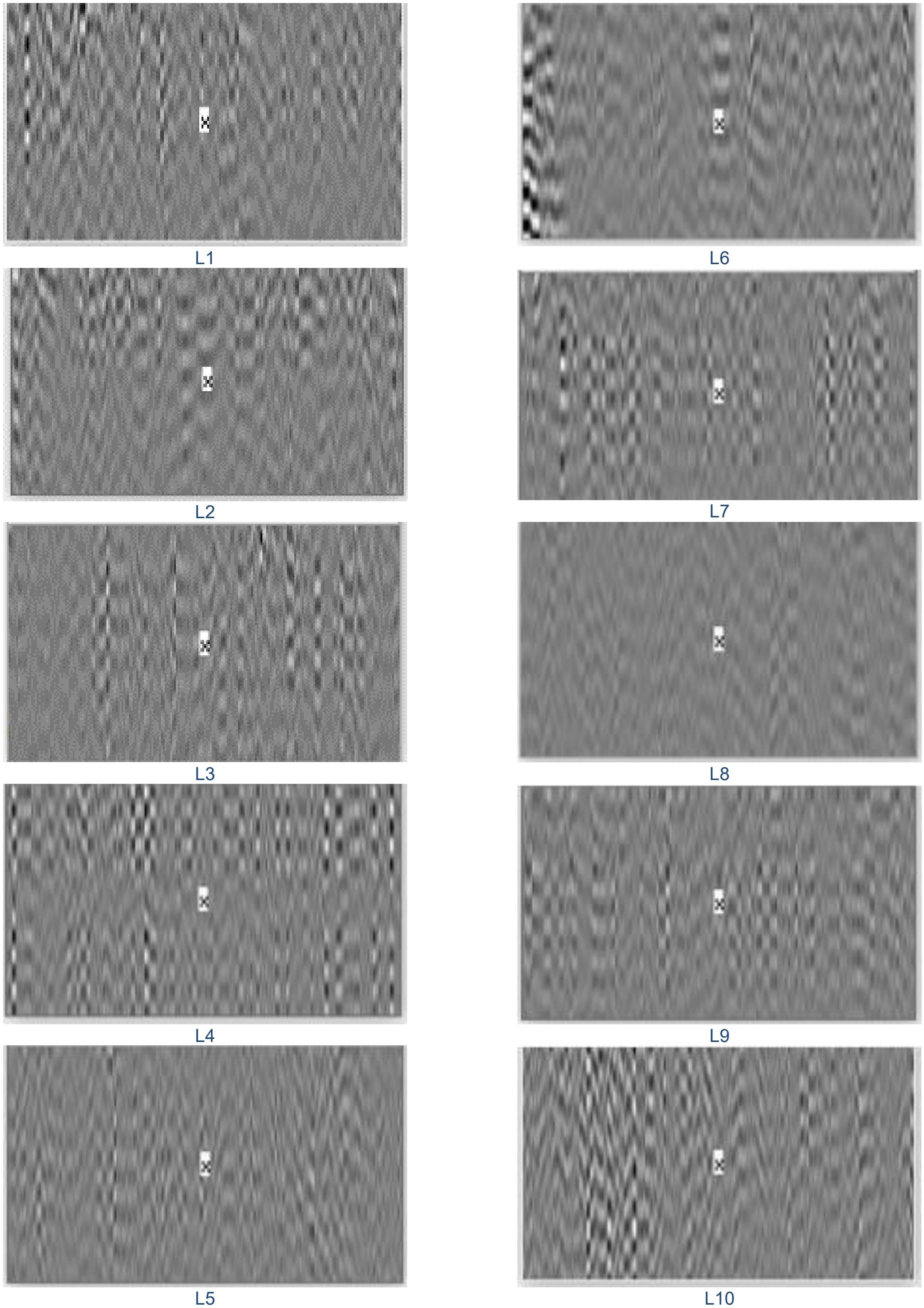


**Figure 6.** The types of reflection configuration that is interpreted as clay layer

# Conclusions

This research successfully identified GPR reflection patterns of the subsurface layers of peatlands in Kubu Raya Regency. The peat layer is clearly differentiated by its reflection pattern, characterized by random/irregular and undulated (hummocky) with high amplitude. In contrast, the underlying clay layer exhibits parallel to wavy reflections with low amplitude. The results also showed that the peat layer thickness at the research location ranges from 1.07 m to 2.78 m. These reflection patterns are characteristic of the physical properties of peat and clay layers. The peat layer is heterogeneous, rich in organic matter, and produces strong reflections, while the clay layer is homogeneous, more conductive, and produces weak reflections. These results provide a reference for GPR surveys to differentiate peat from clay in tropical environments and provide essential subsurface data to improve carbon stock estimates and assess hydrological risks in the peatlands of Kubu Raya Regency.

# Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

# Acknowledgment

The authors would like to thank the head of the Center for Mineral, Coal, and Geothermal Resources, Bandung for providing the data for this research and the head of the Geophysical Laboratory and Geographic Information System of Universitas Tanjungpura for facilitating this research.

# References

[1] Osaki, M., Nursyamsi, D., Noor, M., Wahyunto, & Segah, H. (2016). Tropical peatland ecosystems. *Peatland in Indonesia*, 49–58.
[2] Masganti, Anwar, K., & Susanti, M. A. (2017). Potential and utilization of shallow peatland for agriculture. *Jurnal Sumberdaya Lahan*, 11(1), 43–52.
[3] Jawad, A., Nurdjali, B., & Widiastuti, T. (2015). Zoning area of forest fire in Kubu Raya District of West Kalimantan. *Jurnal Hutan Lestari*, 3(1), 88–97.
[4] Yuwati, T. W., Rachmanadi, D., Pratiwi, Turjaman, M., Indrajaya, Y., Nugroho, H. Y. S. H., Qirom, M. A., Narendra, B. H., & Winarno, B. (2021). Restoration of degraded tropical peatland in Indonesia: A review. *Land*, 10(11), 1–31.
[5] Koyan, P., Tronicke, J., Klose, T., & Guillemoteau, J. (2023). 3D GPR to explore peat deposits: Strategies for data acquisition, processing, and interpretation. *12th International Workshop on Advanced Ground Penetrating Radar (IWAGPR)*, 1–4.
[6] Dewi, I. K., & Adriansyah, R. (2023). Pemodelan 2D data ground penetrating radar (GPR) pada lahan gambut di Desa Jati Mulyo. *Journal Online Physics*, 9(1), 15–22.
[7] Ryazantsev, P. A., & Ignashov, P. A. (2022). Integrating TDR and GPR methods to study the structure of peatland. *Limnology and Freshwater Biology*, 5(4), 1556–1558.
[8] Beres, M., & Haeni, F. P. (1991). Application of ground penetrating radar methods in hydrogeologic studies. *Ground Water*, 29(3), 375–386.
[9] Luo, G., Cao, Y., Xu, H., Yang, G., Wang, S., Huang, Y., & Bai, Z. (2021). Research on typical soil physical properties in a mining area: Feasibility of three-dimensional ground penetrating radar detection. *Environmental Earth Sciences*, 80(3), 1–11.
[10] Reynolds, J. M. (2011). *An introduction to applied and environmental geophysics* (2nd ed.). John Wiley & Sons.
[11] Annan, A. P. (2009). *Electromagnetic principles of ground penetrating radar*. Elsevier.
[12] Sinyutkina, A. (2021). Investigating peat deposits with ground penetrating radar: A case study of drained bogs in Western Siberia, Russia. *E3S Web of Conferences*, 258, 1–7.
[13] Sumargana, L., Frederik, M., Sumirah, & Nugroho, D. (2019). Ground penetrating radar mapping of peat depth at Burnai-Sibumbung rivers peatland hydrological unit Ogan Komering Ilir Regency. *IEEE*, 1–10.
[14] Jol, H. M. (2008). *Ground penetrating radar: Theory and applications*. Elsevier.
[15] Kaufmann, M. S., Klotzsche, A., Vereecken, H., & Kruk, J. (2020). Simultaneous multichannel multi-offset ground penetrating radar measurements for soil characterization. *Vadose Zone Journal*, 19(1), 1–18.
[16] Ceru, T., Pezdir, V., & Gosar, M. (2021). Using GPR on an ombrotrophic bog in Slovenia to delineate peat morphology. *11th International Workshop on Advanced Ground Penetrating Radar (IWAGPR)*, 1–6.
[17] Rais, R., Muhardi, & Siregar, H. E. A. (2024). Analisis tingkat kematangan gambut berdasarkan refleksi radargram di Kecamatan Rasau Jaya Kabupaten Kubu Raya. *Prisma Fisika*, 12(1), 25–29.
[18] Marpaung, F., Sumirah, Sumargana, L., & Nugroho, D. (2020). Profile of dielectric constant of peat in Ogan Komering Ilir Regency, Indonesia using SAR Sentinel-1 and ground penetrating radar. *IOP Conference Series: Earth and Environmental Science*, 500(012041), 1–6.
[19] Lu, Q., Liu, K., Zeng, Z., Liu, S., Li, R., Xia, L., Guo, S., & Li, Z. (2023). Estimation of the soil water content using the early time signal of ground-penetrating radar in heterogeneous soil. *Remote Sensing*, 15(12), 1–18.

[20] Akinsunmade, A., Tomecka, S., Kiełbasa, P., Juliszewski, T., Pysz, P., Karczewski, J., & Zagórda, M. (2021). GPR geophysical method as a remediation tool to determine zones of high penetration resistance of soil. *Journal of Physics: Conference Series*, 1782(012001), 1–8.
[21] Li, S., Xiong, Z., Fan, P., & Xie, K. (2022). Experimental study on the influence of moisture and clay content on stress wave attenuation characteristics of filled joints. *Applied Sciences*, 12(9140), 1–15.