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Application of Seismic Reflection Survey for Aquifer Layers Characterization at the Felda Lepar Utara Area, Pahang, Malaysia

(Pengaplikasian Ukuran Pantulan Seismik untuk Pencirian Lapisan Akuifer di Kawasan Felda Lepar Utara, Pahang, Malaysia)

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ABSTRACT

Precise determination of subsurface structure is crucial in hydrogeological studies to correctly determine the potential of groundwater resources, and the sustainability of those resources. This study used the seismic reflection method to characterize the aquifer layer in Ladang Lepar Utara 8 (Line 1) and Ladang Sungai Rengai (Line 2) in the Felda Lepar Utara area, Pahang, Malaysia, due to its high accuracy, high-resolution and deeper penetration. The field data acquisition survey involved roll-along techniques with shot spacing of 5m along the line using 24-channels ABEM terraloc Mark-6 and CMP (common mid-point) profiling techniques. Seismic interpretation of reflection data and tubewell information from nearby borehole data indicates that the area consists of a single type of rock known as phyllitic meta-sedimentary rocks of the Seri Jaya beds that have been deformed by intense faulting and fracturing (from about 30 to 750 m depth in Line 1 and about 75 m to 500m depth in Line 2). This formation is overlain by recent alluvium that ranges in thickness from 30 to 75 m and is underlain by Lepar Granodiorite. The alluvium is a shallow aquifer system that can be classified as an unconfined aquifer, whereas the phyllitic meta-sedimentary rock of the Seri Jaya Beds is a deep aquifer system that can be classified as a confined aquifer with an alluvium layer (up to 75 m thick) on top as a confining bed. The occurrence of intense faulting and fracturing increases the porosity and permeability of the rock formation and hence increases its potential as a groundwater prospective/promising zone.

Keywords: ABEM terraloc Mark-6; aquifer; groundwater; seismic reflection method

ABSTRAK

Penentuan struktur bawah permukaan sangat penting dalam kajian hidrogeologi untuk menentukan potensi sumber air bawah tanah dengan tepat dan kelestarian sumber tersebut. Kajian ini menggunakan kaedah pantulan seismik untuk mencirikan lapisan akuifer di Ladang Lepar Utara 8 (Jalur 1) dan Ladang Sungai Rengai (Jalur 2) di kawasan Felda Lepar Utara, Pahang, Malaysia kerana ketepatan dan resolusinya yang tinggi serta penembusan yang lebih mendalam kaedah ini. Tinjauan pemerolehan data lapangan melibatkan teknik *roll-along* dengan jarak tembakan 5 m di sepanjang garis menggunakan 24-saluran *ABEM terraloc Mark-6* dan teknik pemprofilan CMP (*common mid-point*). Tafsiran seismik terhadap data pantulan dan maklumat tiub daripada data lubang gerudi yang berdekatan menunjukkan bahawa kawasan ini terdiri daripada satu jenis batu yang dikenali sebagai batuan meta-sedimen filit daripada Lapisan Seri Jaya yang tercangga teruk oleh sesar dan retakan (daripada kedalaman sekitar 30 hingga 750 m di Garis 1 dan kedalaman kira-kira 75 hingga 500 m di Garis 2). Formasi ini dilapisi di bahagian atas oleh aluvium resen dengan ketebalan antara 30 hingga 75 m dan dilapisi di bahagian bawah oleh Granodiorite Lepar. Lapisan aluvium tersebut merupakan sistem akuifer cetek yang dapat dikelaskan sebagai akuifer tak terkekang, manakala batuan meta-sedimen filit Lapisan Seri Jaya merupakan sistem akuifer dalam yang dapat dikelaskan sebagai akuifer terkekang oleh lapisan aluvium (setebal 75 m) di atasnya. Struktur sesar dan retakan yang rencam meningkatkan keliangan dan kebolehtelapan formasi batuan ini dan dengan itu meningkatkan potensinya sebagai zon prospektif air bawah tanah.

Kata kunci: ABEM terraloc Mark-6; air bawah tanah; akuifer; kaedah pantulan seismik

Introduction

Water is the main source of necessity in daily life. The increase in the population and the rise of the industrial sector have caused an increase in demand for clean water. According to Raghunath (2006), it is estimated that about 97.2% of the world's water resources are salt water and the remaining 2.8% are fresh water. As much as 2.8% of the fresh water on the planet Earth, about 2.2% is available as surface water, while 0.6% is groundwater. According to Carrard et al. (2019), groundwater is an important source of water and is in great demand by people in Southeast Asia and the Pacific as the main source of drinking water. The results of the research conducted showed that 79% of the total population across case study countries used groundwater as the main source of drinking water.

Groundwater is defined as water in subsurface rock formations that enters and moves through pores and cracks in the rock before discharging into drains and rivers (Brassington 2007). This resource, which can transmit water through its pores at a rate sufficient for economic extraction by wells, is called an aquifer (Raghunath 2006; Singhal & Gupta 2010). The two main types of aquifer are the unconfined aquifer and the confined aquifer that can be easily characterized and modelled. According to Kruseman and De Ridder (2000), an unconfined aquifer is an aquifer in which the water table serves as the upper saturated zone which is free to rise and fall, and the below is bounded by an aquiclude. The pressure of the water in this aquifer is at atmospheric pressure which will not rise above the water-table. Meanwhile, a confined aquifer is one type of aquifer in which the top and the bottom of the layer are bounded by impermeable layers such as sandy clay, silty sand, and compacted clay (Mohammad & Roslan 2017).

However, there is one type of aquifer that is difficult to characterize and model, known as the fractured aquifer (Abdelaziz & Bambi 2016). In the subsurface, the key factor for fluid flow and transport is the connectivity of fractures. The fractures may serve as a pathway or barriers for groundwater to move and the movement is related to the geometric and physical properties of fractures (Lin et al. 2014; Margolin et al. 1998). A study on the identification of aquifer types was carried out by Olorunfem and Fasuyi (1993), and it shows that the occurrence of a fractured (unconfined) aquifer is when the weathered zone is underlain by a fractured zone, meanwhile the fractured (confined) aquifer is constructed by an upper weathered layer and an enclosed fractured zone.

Therefore, the determination of a more precise subsurface structure is crucial in hydrogeological studies to correctly determine the types of aquifers, the aquifer thicknesses, the potential of groundwater resources, and the sustainability of those resources. In this study, we aim to characterize the aquifer layer, including determining the thickness of the aquifer and the lithology of the rocks that compose the aquifer layers in the Felda Lepar Utara area, Pahang, Malaysia, particularly Ladang Sungai Rengai and Ladang Lepar Utara 8, using the seismic reflection method. Seismic reflection techniques have been widely utilized to detect and map subsurface features, especially the layered sedimentary sequences in search of oil and gas reservoirs (Burger et al. 1992). The advantages of seismic techniques over other geophysical methods are due to their high accuracy, high-resolution and deeper penetration (Sheriff et al. 1999). Not limited to oil and gas, recently, seismic methods, which include the high resolution seismic reflection method, have been applied to characterize shallow subsurface structures, depth of water tables and identification of engineering related problems (Kearey & Brooks 1984), as well as in groundwater investigation and mapping of aquifer layers (Giustiniani et al. 2009; Whiteley et al. 1998). In this study, where both techniques (reflection and refraction) could be applied, seismic reflection is selected because this method generally has better resolution.

General Geology and Site Description

The regional geology of the Felda Lepar Utara is shown in Figure 1. The oldest rocks identified in the study area are the Seri Jaya beds, a sequence of interbedded argillaceous, calcareous, and volcanic rocks of the Upper Middle to Lower Upper Permian age that crop out at the eastern end of the map. The Mid-Triassic intrusive rocks that are exposed in the eastern half of the study area were mapped as the Lepar Granodiorite by previous investigators, which extends from the Hulu Lepar area (Abdullah 2013). The rock consists mostly of dark grey medium-grained hornblende biotite granodiorite, biotite granodiorite, and quartz monzonite with lesser diorite, granite porphyry, and microgranite.

The study area is generally dominated by the Mesozoic sedimentary rocks that are widespread in the study area and were mapped as the Mangkin Sandstone and the Kerum Formation (Khoo 1977) which were described by Burton (1973) and Khoo (1983) as part of the Tembeling Group. This group consists of four formations, namely (in ascending order); the Kerum Formation, Lanis Conglomerate Formation, Mangkin Sandstone Formation, and Termus Shale Formation. Mangkin Sandstone Formation is a rock formation which is arranged from a sequence of whitish gray to light gray sandstone interbedded with shale, mudstone and siltstone in gray to reddish gray (Abdullah 2013; Ab. Talib 2012). The rock succession is predominantly red and grey in colour, as is often related to the oxidation process in the continental deposits.

The Kerum Formation, however, shows no typical characteristics of continental deposits as it consists of interbedded tuffaceous sandstone, shale, and siltstone which were deposited in a marine environment. Therefore, the Kerum Formation is removed from the Jurassic-Cretaceous Tembeling Group because it more closely resembles the Middle Triassic rocks of the Semantan Formation (Harbury et al. 1990). Quaternary alluvium consists of unconsolidated fluviatile clay, silt, sand, gravel, and residual soil. The clasts, which consist of sandstone, metabstone, reddish brown conglomerates, grey shale, and grey mudstone, are interpreted to be formed by rocks from the Mangkin Formation, Lanis Formation, and Serentang Formation (Muhammad Pauzi 2013).

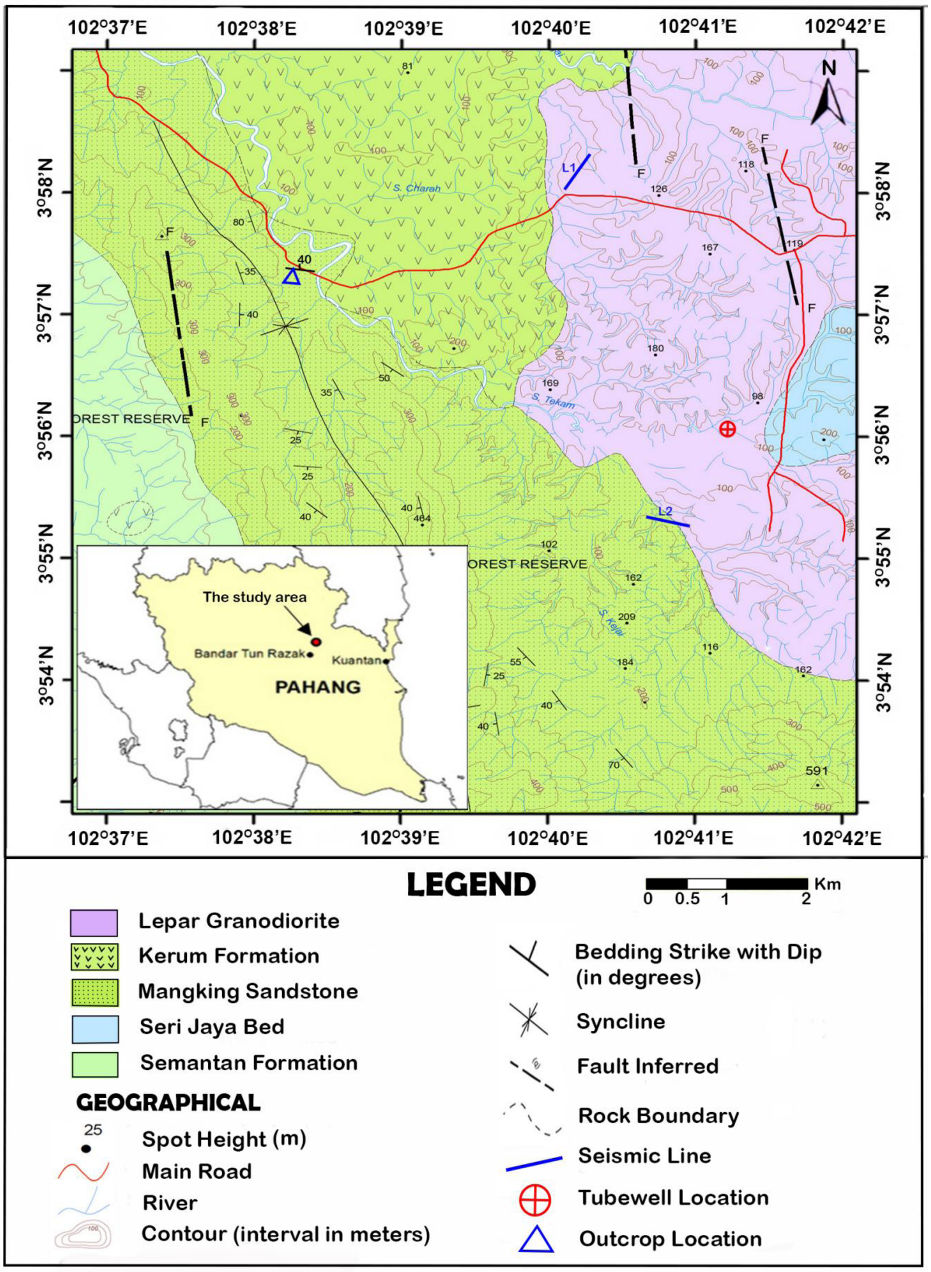

FIGURE 1. Geology map of the study area
(Modified from Minerals and Geoscience Department Malaysia)

Materials and Methods

In this study, two seismic reflection surveys have been carried out in Ladang Sungai Rengai and Ladang Lepar Utara 8 (3°57'59.9" N, 102°40'05.6" E, and 3°55'15.8" N, 102°40'58.7" E) (Figure 1). The field data acquisition survey involved the roll-along techniques with shot spacing of 5 m along the line by hitting a 5 kg sledgehammer on top of a rubber plate in order to reduce the pinging effect of coherence air-wave noise. All types of waves penetrating into the earth plus those travelling along the surface of the earth were recorded by a total of 24 low-frequency 14 Hz sensors (*ABEM terraloc Mark-6* seismograph) arranged equidistantly along the survey line with a shot-sensor offset of 50 m. By using this technique, which is also known as CMP (common mid-point) profiling, a total of 24 channel wave trains from each station will be recorded. Therefore, about 2400 channels of wave trains were collected from a total of 100 shots accomplished for one seismic survey line. The CMP technique helps increase the amplitude of seismic waves because each wave reflection will be collected and combined to form one seismic wave that has a large amplitude. These collected wave reflections are reflections from different sources and geophones but originate from points above the reflector at the same depth. Random interference and coherent interference can also be reduced by applying this profiling technique in reflected seismic surveys.

The wave trains were conventionally processed following several routine stages, including noise filtering, CMP gathering, normal move out correction, velocity analysis, stacking, and migration. With quite a small aperture of 24 sensors, the velocity analysis and migration are of negligible effect. The end product of each processing is the production of a seismic section, considered as a photographic image of the earth section underneath the survey line along the vertical z-axis, representing the depth of the geological section in waveforms. Interpretation begins with understanding the geological and hydrogeological background of the study area. This information is then used to determine the lithology, aquifer layers, and corresponding stratigraphy and structures in the study area. Seismic images are interpreted by identifying the seismic packages by analysing their seismic facies. The analysis can be done by understanding the seismic reflection termination, internal reflection configuration, continuity, amplitude, and frequency (Silalahi et al. 2019).

Results and Discussion

Seismic Interpretation

The study area is an oil palm plantation area where fresh rock outcrop is relatively limited. The closest outcrop of road cut, however, has been identified at 3 ° 57'16.82 "N, 102 ° 38'16.31" E 3-5km from the study area (Figure 1). Based on the lithology, the rock succession closely resembles the Mangkin Sandstone Formation of the Tembeling Group. The rock succession predominantly consists of quartz sandstone interbedded with red and grey siltstone with strike and dips readings U100 ° E/40 ° (Figure 2). However, there is a tubewell which

FIGURE 2. Outcrop found at the study area

was constructed by Geo Strata Sdn. Bhd in 2018 at Felda Lepar Utara 7 area which is approximately 3 km from the study area (seismic lines proposed in this study) as shown in Figure 3. The depth of the tubewell is 150 m below the surface; with 13 m thick quaternary alluvial layer from on top of diorite (at 96-108 m depth) and phyllite of Seri Jaya Formation. Considering limited outcrop information to help justify the geological information within the study area, seismic interpretation is based on the lithological information (types and thickness of strata) from the drilling activities (Geo Strata 2018) and seismic refection pattern (amplitude contuinity, strength, and internal geometry).

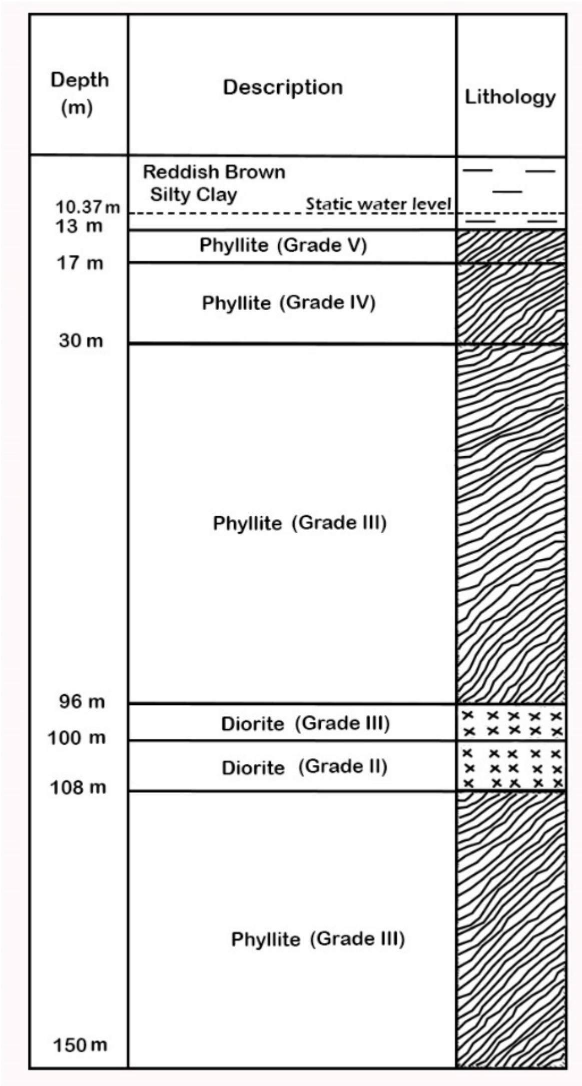

FIGURE 3. Tubewell at the area of Felda Lepar Utara 7

LADANG LEPAR UTARA 8

The seismic section of line 1 is shown in Figure 4 covering an X-Z dimension of about 625 m in length and approximately 1000 m in depth, respectively. Based on the geological borehole log drilled close to the survey area, the top layer from surface to about 30 m depth is interpreted as recent alluvium consisting of reddish brown silt and clay. Basically, the silty alluvial clay is thinner towards the right side of the survey line and thickens towards the left side of the survey line (up to 75 m). Based on the reflection pattern, the formation underlying the top soft alluvial can be considered to consist of a single type of rock, namely from 30 to about 750 m in depth. In the nearby well, this rock formation is characterized as phyllitic meta-sedimentary rocks of the Seri Jaya beds with different weathering grades, which are higher at the top of about IV to V and lower, approaching grade II to fresh at the bottom. The meta-sedimentary rock formation seems to consist of interlayering between thin layers of sandstone, siltstone, and mudstone that are about 10 to 50 m thick. The free-reflection zone underlying this metamorphic rock can be inferred as granitic igneous rock widely known as Lepar Granodiorite. The rock formations along the whole seismic line indicate the presence of intense faulting and fracturing experienced by the formation, presumably during the Triassic-Jurrasic igneous intrusion that uplifted the main range granite. A few major faults are found cutting through the formation from depths of 50 to 900 m at about 150 to 300 m along the seismic line. Most of the faults are interpreted as reverse faults based on the geometry of the fault and the down-thrown nature of the layers surrounding the faults. The area with a width of approximately 100 m may presumably be considered as part of the Lepar fault zones. Numerous other minor faults with normal sense of movement can easily be traced throughout the seismic section, presumably due to post orogenic extension(?).

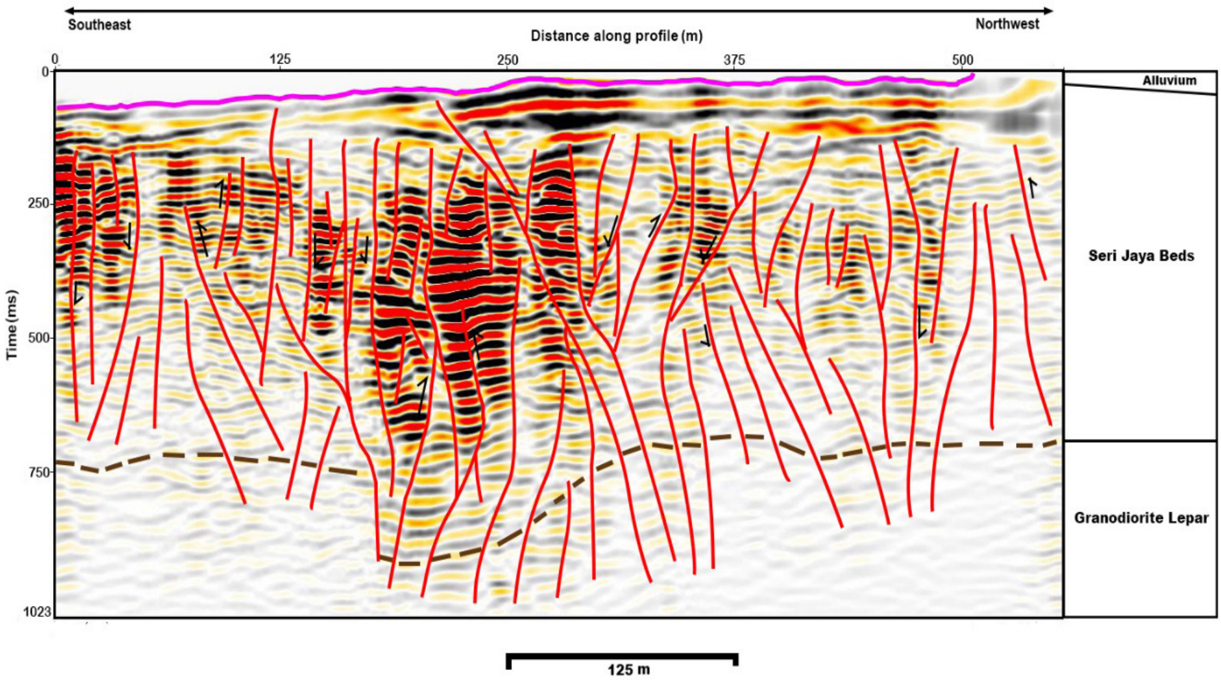

FIGURE 4. Seismic section image for Ladang Lepar Utara 8 area after interpretation

LADANG SUNGAI RENGAI

The seismic section of line 2 is shown in Figure 5 covering an X-Z dimension of about 600 meters in length and 1000 m in depth, respectively. The top layer from surface to about 70 m depth is interpreted as recent alluvium consisting of reddish brown silty clay. Based on the reflection pattern, the formation underlying the top soft alluvial can be considered to consist of a single type of rock, namely the phyllitic meta-sedimentary rocks of the Seri Jaya beds, from about 75 to about 500 m in depth. The rock formation has been intensely deformed by numerous faults and fractures, with a few major faults found cutting through the formation from depths of 100 to 500 m. Most of the faults are interpreted as normal faults based on the geometry of the fault and the down-thrown nature of the layers surrounding the faults. Within these major faults, there are many antithetic and synthetic minor faults of comparable dipping angles at depths greater than 200 m. The free-reflection zone underlying this rock formation can be inferred as granitic igneous rock at a depth of 500 to 650 m.

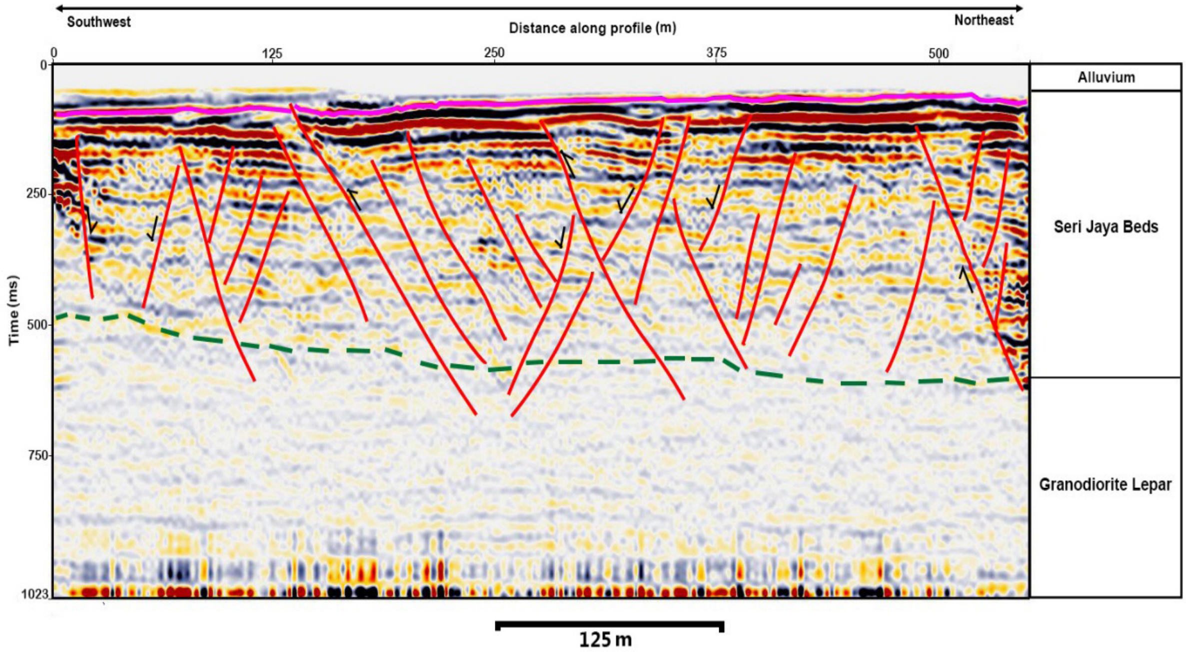

FIGURE 5. Seismic section image for Ladang Sungai Rengai area after interpretation

CHARACTERIZATION OF AQUIFER LAYERS

From seismic interpretation of reflection data and tubewell information from nearby borehole data (including the static water level information at 10.37 m below the surface), there are two types of aquifer in the study area (Figures 6 & 7). The alluvium layer is a shallow aquifer system, and the deep aquifer system is in fractured rock layers. The alluvium aquifer is classified as an unconfined aquifer which can store and transmit water. The phyllitic meta-sedimentary rock of the Seri Jaya Beds can be classified as a confined aquifer with an alluvium layer (up to 75 m thick) on top as a confining bed.

Even though there is no information regarding the fractures in the borehole log, the faults and fractures set can be observed clearly from the seismic profiles obtained. Geological structures play a major role in the groundwater flow that is capable of transmitting and storing significant quantities of groundwater. The occurrence of intense faulting and fracturing as well as basin-bounding structures in the rock formation may serve as channels for groundwater movement, which may result in an increase in secondary porosity and permeability, and therefore, can result in a groundwater prospective or promising zone.

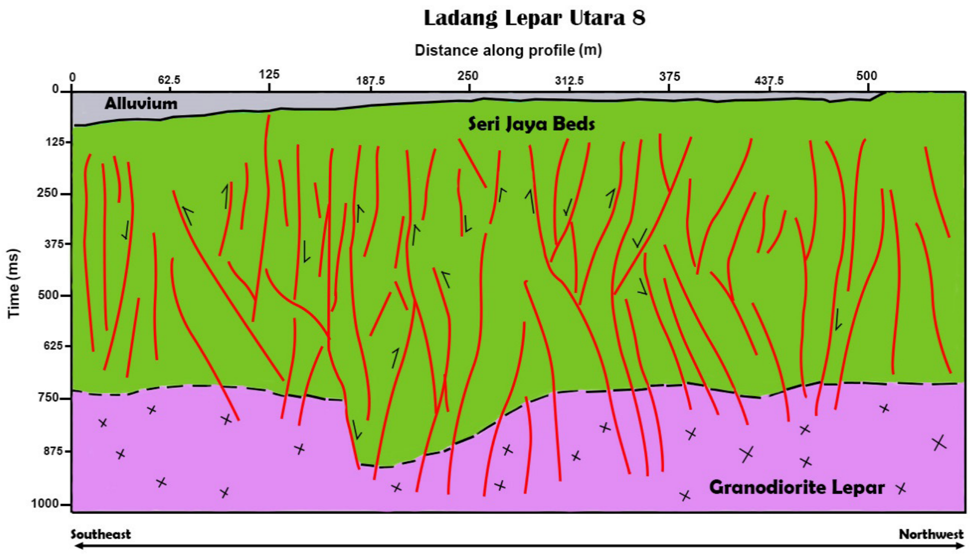

FIGURE 6. Schematic representation of subsurface for Ladang Lepar Utara 8 area

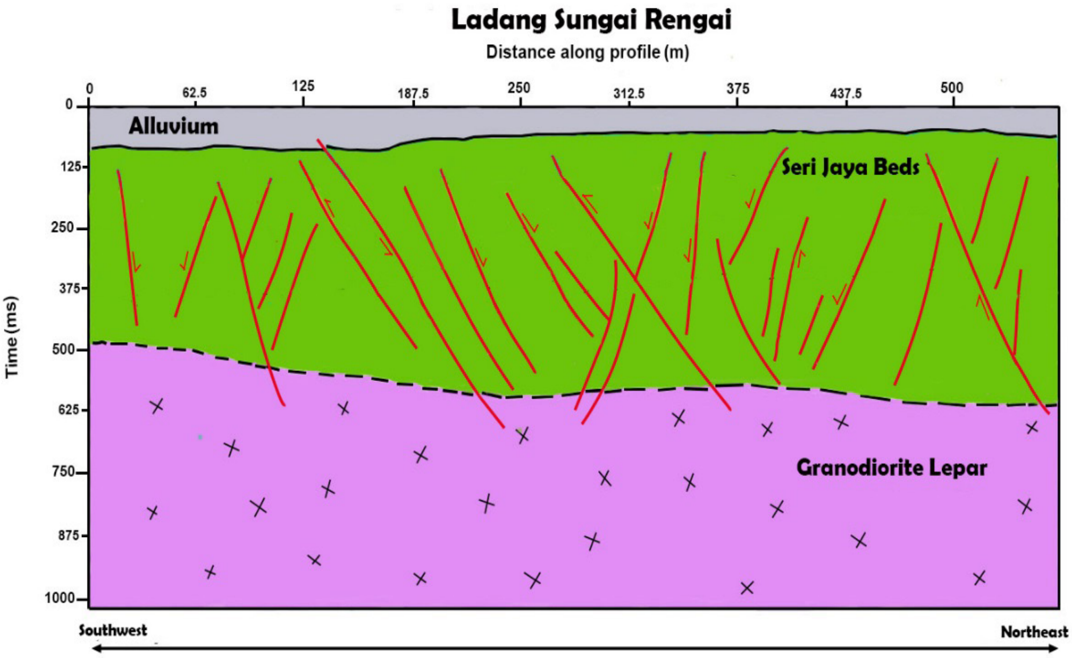

FIGURE 7. Schematic representation of subsurface for Ladang Sungai Rengai area

CONCLUSION

Seismic reflection surveys were conducted in two places, namely at the Ladang Lepar Utara 8 (Line 1) and Ladang Sungai Rengai (Line 2) areas. Based on the seismic section, alluvium in these two areas has a thickness of approximately 30-75 m from the subsurface. This alluvium is a shallow aquifer system that can be classified as an unconfined aquifer which can store and transmit water. The rock formation underlying the top soft alluvial is interpreted as phyllitic meta-sedimentary rocks of the Seri Jaya beds. This rock formation can be found from about 30 to 750 m depth in Line 1 and about 75 to 500 m depth in Line 2. The rock formation has been intensely deformed by numerous faults and fractures, with a few main faults found cutting through the formation from a shallower to a deeper section. Most of the main faults are associated with many minor faults (antithetic and synthetic) that can easily be traced throughout the seismic section. The free-reflection zone underlying this metamorphic rock can be inferred to be a granitic igneous rock widely known as Lepar Granodiorite. The phyllitic meta-sedimentary rock of the Seri Jaya Beds is a deeper aquifer system that can be classified as a confined aquifer with an alluvium layer (up to 75 m thick) on top as a confining bed. Intense faulting and fracturing increases the porosity and permeability of this rock formation and hence increases its potential as a good aquifer.

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