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EARTHQUAKE DISASTER MITIGATION MAPPING BY MODELING OF LAND LAYER AND SITE EFFECT ZONE IN THE KOTA BARU OF SOUTH LAMPUNG

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Abstract: *Kota Baru is the satellite city of Bandar Lampung. The city is prepared for the expansion of the city of Bandar Lampung. Zonation map of earthquake risk is required for Kota Baru due to its location within the reach of earthquake energy of Semangko subduction fault. In this study, we model the earthquake-prone zone map based on the soil characteristics (site effect) combined with the underground layer model to get a detailed description of the horizontal and vertical soil character. The microtremor method is performed to obtain the zonation effect mapping. Whereas, the ground layer modeling is obtained using the geoelectrical method. The modeling results show that the study area is far from tectonic activity based on the history of past earthquake events. However, this area has a large sediment thickness and has a low dominant frequency value, so it is an area that is vulnerable to earthquakes.*

Keywords: *direct current, disaster mitigation, earthquake, site effect*

INTRODUCTION

Geographically area around Bandar Lampung in Lampung Province is located near two plates subduction. The Indo-Australia plate is moving beneath the Eurasia Plate, which resulting subduction zone and many earthquake sources. Beside the subduction zone, the Sumatra Mega Fault made areas in Sumatra including Bandar Lampung vulnerable to earthquakes. Figure 1 shows some big earthquakes that happened in Sumatera areas (Natawidjaja, 2007).

Other than fault zone, Lampung area also showed ground acceleration value that getting bigger form Bandar Lampung to the west direction (Hidayat & Naryanto, 2007). Since the location is near to the earthquake sources, this made Bandar Lampung City and other areas including Kota Baru have vulnerable potency to earthquakes.

Kota Baru is the satellite city of Bandar Lampung and planned to be government central of Lampung Province, change the former location in Bandar Lampung, while Kota Baru is still the part of South Lampung. In this location is planned to be the new location of Lampung University campus and where the research was held in. Location of Kota Baru can be seen in Figure 2.

Kota Baru is influenced by Sumatera Fault System and plate tectonic subduction of Indo-Australia plate and Eurasia plate. These phenomena make this area cannot be separated from earthquake vulnerability. In its activity as the satellite city of Bandar Lampung, Kota Baru will be developed quickly, such as residence, the population of the inhabitant, and vital infrastructure. The construction process usually disregards the geological aspect of the subsurface. Development of the residence and the other building usually neglect risk zone and technical specification. The usual habit is reacting when the disaster has already occurred. Building damage and fatalities will come when medium to big earthquake happened. The occurrence of an earthquake cannot be prevented or predicted where, when, and how big it will happen. The active effort that can be done is to mitigate the effects that occur such as made ground character zoning (site effect) that can cause building structure damage and civil engineering.

There has not been any research regarding the disaster possibility or ground characterization in Kota Baru yet. Besides that, there has not been any detailed zonation map. Thus, it makes this research become pioneer research in Kota Baru. Currently, only the big scale earthquake-vulnerable zone map on a national scale that has been available. A micro-zonation map of site effect in this area is a novel approach.

Based on that demand, this research purpose is to:

1. Analyze the ground character in term of the natural frequency of the ground/sediment vibration.
2. Analyze and make a ground amplification zonation.
3. Determine the solidity/compaction value of the ground based on the electrical variable.

THEORY

The amplitude from ground vibration is correlated with earthquake energy and ground solidity (compaction). The ductile ground will amplify the earthquake energy so that produce strong vibration to the ground and building on the surface. Vibration characteristic formed is analogous to damped wave with vibration frequency that determined by equation 1.

$$f_0 = \frac{v_s}{4h} \quad (1)$$

where f_0 is vibration natural frequency (Hz), v_s is s wave propagation velocity in the surface layer (km/s) and h is the thickness of the surface layer.

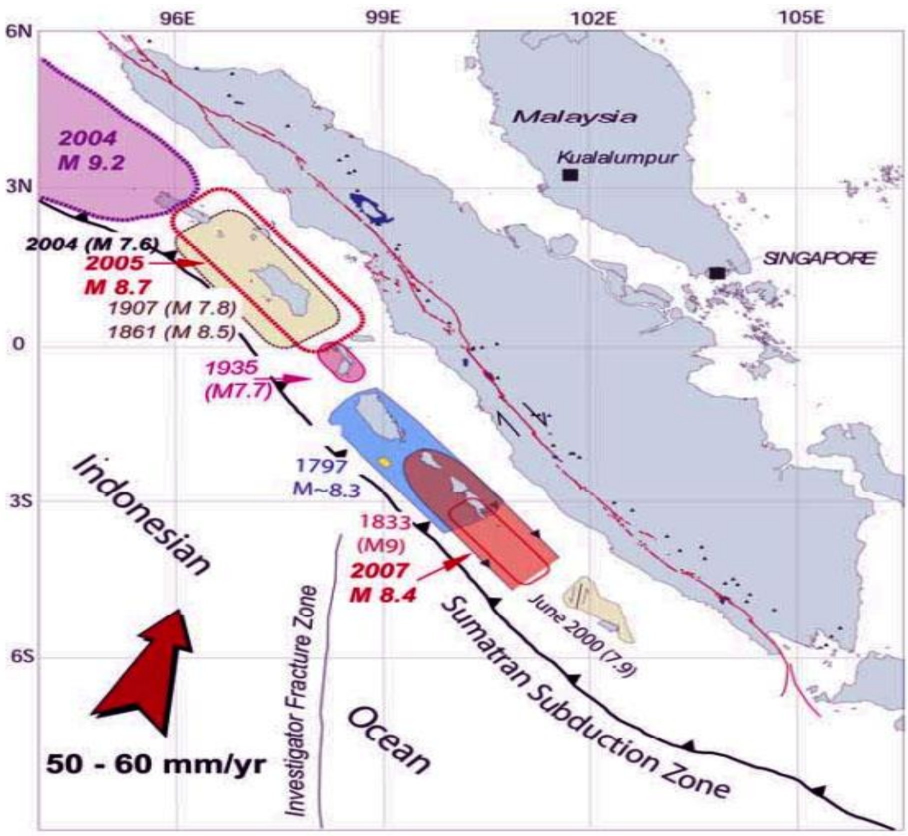

Figure 1. Big earthquake at earthquake zone (subduction zone) in Sumatera (Natawidjaja, 2007)

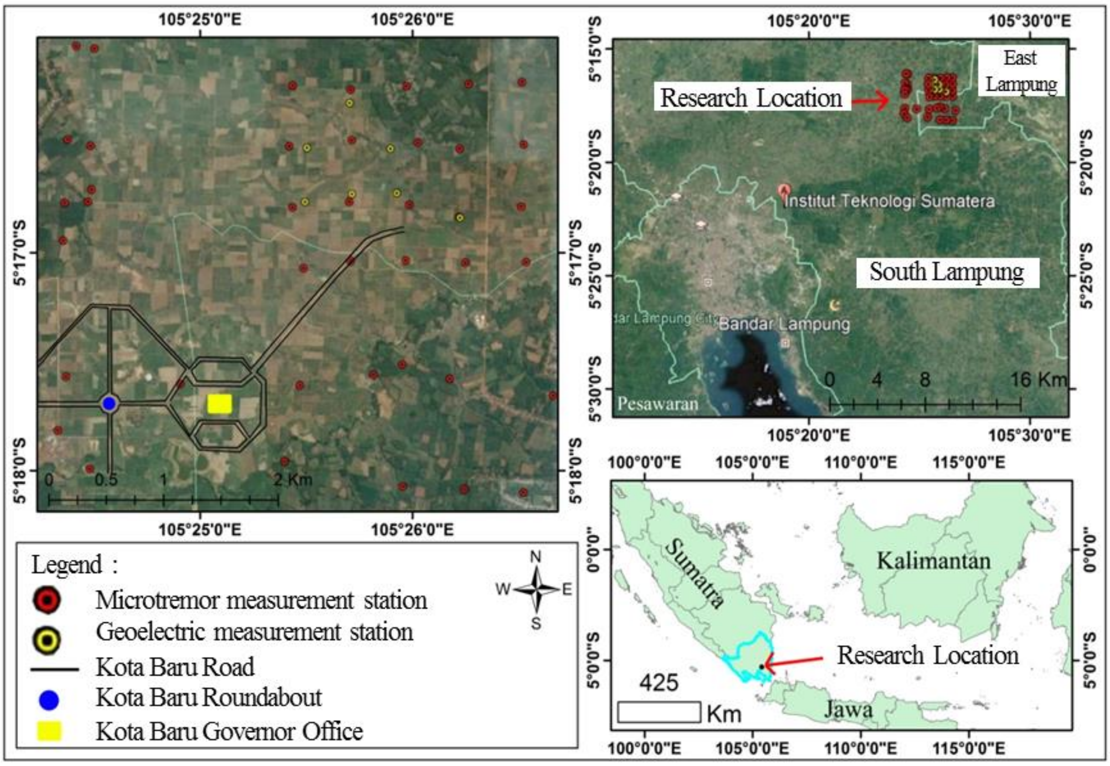

Figure 2. Research area map

Nakamura, Sato, and Nishinaga investigated ground characteristic three months after the Kobe earthquake, 1995 (Nakamura, Sato, & Nishinaga, 2000). Based on microtremor, it was found that high damage area correlated to a natural frequency of less than 3 Hz, which formed strong vibration. This ground response was produced by ductile and thick ground layer. There was a linear relationship between the peak of ground velocity and intensity. The greater peak ground velocity increases the earthquake intensity (Sunarti, Arsyad, & Sulistiawati, 2014).

Ground response site effect map from Nakamura, 2000 became an important reference for making a similar map in the high earthquake risk area. Many similar types of research were placed in various places as a mitigation purpose, such as (Bararpour, Janalizade, & Tavakoli, 2016; Bo, Yuanqing, Zhihua, Yang, & Yongjiu, 2016; Tavakoli, Talebzade Amiri, Abdollahzade, & Janalizade, 2016). The site effect map could help the civil engineer in making building and important facility design (Javanmardi et al., 2015; Kim, 2014; Kotrasova & Kormaníková, 2014).

Site effect analysis approach was done by measuring the seismic response of ground layer that was formed by human activity, industrial activity and the other sources that could produce vibration (Nakamura et al., 2000). The vibration of the ground was recorded by three component accelerograph.

HVSR (Horizontal to Vertical Spectral Ratio) method is an effective, cheap, and environmentally friendly method that can be applied in the urban area. Nakamura stated that natural frequency vibration of sediment can be extracted by analyzing the microtremor response from HVSR method (Mufida, Santosa, & Warnana, 2013). This method was proven to be better than Site Specific Analysis (SSA) (Partono, Irsyam, Prabandiyani, & Maarif, 2013).

Soil and lithology that composed subsurface layer contains various minerals, pores, the fluid inside the pore and various deposition time (Johnson, Versteeg, Ward, Day-Lewis, & Revil, 2010). Variety factor of those variables made soil and lithology has difference specific electrical properties. From this condition, electrical properties such as resistivity can be analyzed in depth function.

The superiority of the subsurface study based on electrical properties has been proven in many locations. Johnson et al, did pioneering work to study fault zones in underground mining that had landslide risk (Johnson et al., 2010). The geoelectrical method has been applied for determining the structure of the geothermal area (Basid, Andrini, & Arfiyaningsih, 2014; Putriutami, Harmoko, & Widada, 2014). Furthermore, this method was also reliable for determining geological structure and water aquiver (E.C et al., 2015; Saranga, As'ari, & Tongkukut, 2016; Sedana, As'ari, & Tanauma, 2015; Supper et al., 2014; Wijaya, 2015). In determining waste contained in the subsurface, this method gave sufficient results (Pujiastuti, Arman, & Putra, 2014; Santoso, Arman, & Ihwan, 2015). In natural resource exploration, this method could identify lithology layer that contained coal (B State, Marere, & Ojo, 2014; N. U Ugwu, Ranganai, Simon, & Ogubazghi, 2016).

In hazard mitigation study, research form (Bayelsa State, Marere, & Ojo, 2014; Nicholas U Ugwu, Ranganai, Simon, & Ogubazghi, 2016), could predict shallow water existence that caused liquefaction. Robert Supper et al., did landslide monitoring by using this method (Supper et al., 2014).

The important part for hazard mitigation is understanding the capability of ground soil/lithology near the surface with a depth of 0 – 30 meters to support its burden. Some important variables that influence material resistance to the earthquake are lithology type and thickness, water level, and the existence of cavities under the ground, which will be studied by using geoelectrical direct current.

The measurement will apply the vertical electrical sounding technique, which studied the lithology resistivity change to the depth.

METHOD

Microtremor measurement was distributed evenly with the measurement points forming a grid with 500 meters separation for each point. For making earthquake risk zone, the measured data was processed to become a contour map with the isopotential method (connecting same value parameters).

Measurement in each point was completed in 15 to 20 minutes. After that raw data was processed with the Command Prompt program and converted to sac format. After the conversion, the data were processed by using Geospy software version 2.9.1. Furthermore, the HVSR method was used which comparing horizontal and vertical component of the wave spectrum. In the data processing, window width was 10 seconds following the existence noise. Konno & Omachi method was applied for smoothing the data with smoothing constant was 40. The results of HVSR was HVSR curve which contained amplitude and frequency. Information that could be obtained from curve was dominant frequency (f_0) of the measurement points. The curve that was shown was FFT result of H/V amplitude spectrum.

The product of HVSR was the natural frequency and amplification parameter which able to identify the vulnerable or safe area to the earthquake. The outcome was maps of frequency, amplification, thickness and seismic vulnerability which later were analyzed. Then, the analyzed result was converted to earthquake risk zone map in Kota Baru Bandar Lampung.

Afterward, the geoelectrical direct current was applied for determining ground layers, cavity existence and water level in the purpose of completing the ground characteristic. This combination of two methods gave ground characteristic illustration horizontally and vertically. The combination of HVSR microtremor and the direct current was new method inspired by Nakamura et al, which stated there was a different characteristic of ductile ground and cavity existence in the same type of ground (Nakamura et al., 2000).

RESULTS AND DISCUSSION

Results

Data acquisition was held in 25 days for 40 microtremor stations and 7 VES point stations. Station locations were shown in the geological map in Figure 3. The location was located in 549262.01 - 544937.24 latitudes and 9417737.23 - 9413954.25 longitude with the area about 16.5 km^2. There is only one geological formation in this area which is Lampung Formation (QTi). Lampung formation is aged from Pleistocene quarter. Based on the geology of the region, Lampung Formation consists of pumiceous tuff, rhyolitic tuff, welded tuff tuffit, tuffaceous claystones and tuffaceous sandstone (Appendix).

The results of HVSR is HVSR curve which contained amplitude and frequency. Information that can be obtained from the curve is the dominant frequency (f_0) of the measurement points. The curve that is shown was FFT result of H/V amplitude spectrum.

Based on microtremor measurement with Reftek, dominant frequency, amplification, and VS30 map were made (Figure 4, 5, and 6). The dominant frequency was 0.63-1.18 Hz in Kota Baru, Jati Agung, and South Lampung. The dominant frequency in the western part of UNILA campus was greater than the east area.

VES (Vertical Electrical Sounding) measurement at Kota Baru, South Lampung was applied by using Schlumberger configuration with AB/2 of 250 meters. IP2Win was used to process the data and the majority of the results were 5 layers (Figure 7).

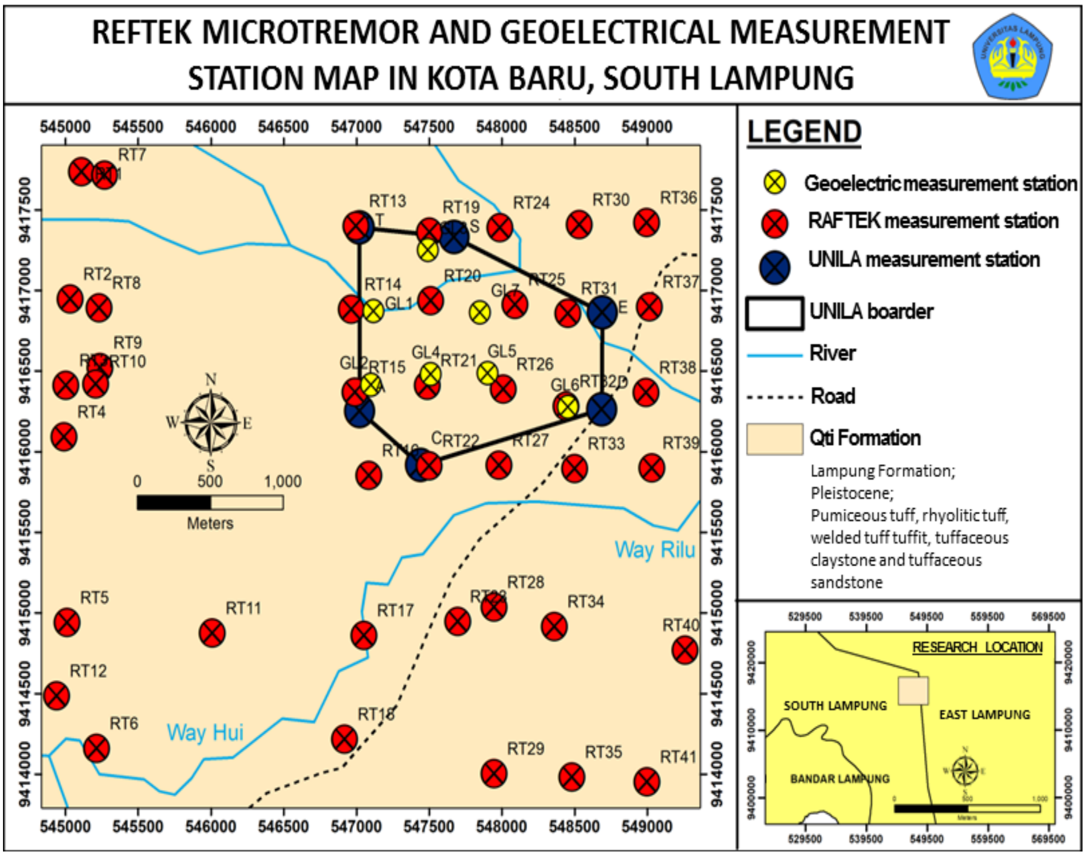

Figure 3. Reftek microtremor and geoelectrical measurement station map

Discussion

Microtremor Analysis

1. Dominant Frequency Value Analysis

Based on microtremor dominant frequency classification, the research area shows less than 1.33 Hz. This is indicated as alluvium that formed from deltaic sedimentation. Top ground soil with 30 meters depth has a ductile characteristic, with very thick sediment. Knowing one area dominant frequency is important because the dominant frequency is usually believed as the natural value of that medium. The dominant frequency is strongly related to sediment thickness. While the greater sediment thickness, the smaller dominant frequency.

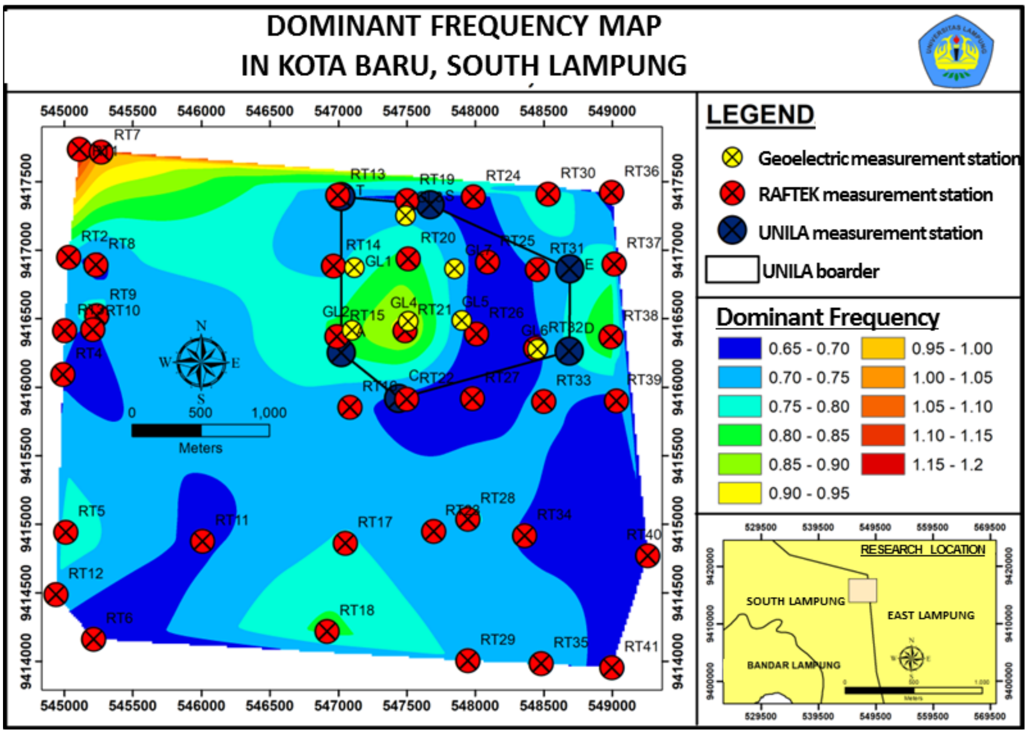

Figure 4. Dominant frequency map of Kota Baru

This condition makes the research area is vulnerable to an earthquake. In spite of that, the research area is inactive tectonically. Referring to USGS data, there has not been an earthquake happened in this area (Figure 8). This tectonic earthquake data showed that the area is far from the tectonic earthquake.

2. Amplification Value Analysis

Amplification is an intensification of seismic wave that happened when there is a significant difference between layers. The seismic wave will be amplified when it propagates in the more ductile medium than the previous medium. The greater that difference, the greater the amplification that happened to the wave. Amplification factor value of a soil is related to the impedance ratio contrast of the surface layer with the layer beneath it. Figure 5 shows the amplification value is 3.4-5.7 times amplification. Hence, it could be indicated that this area has high-risk damage when an earthquake happened because it is formed from the ductile ground that has large sediment thickness layer. This made the propagated wave will be highly amplified when an earthquake happened and causing serious damage.

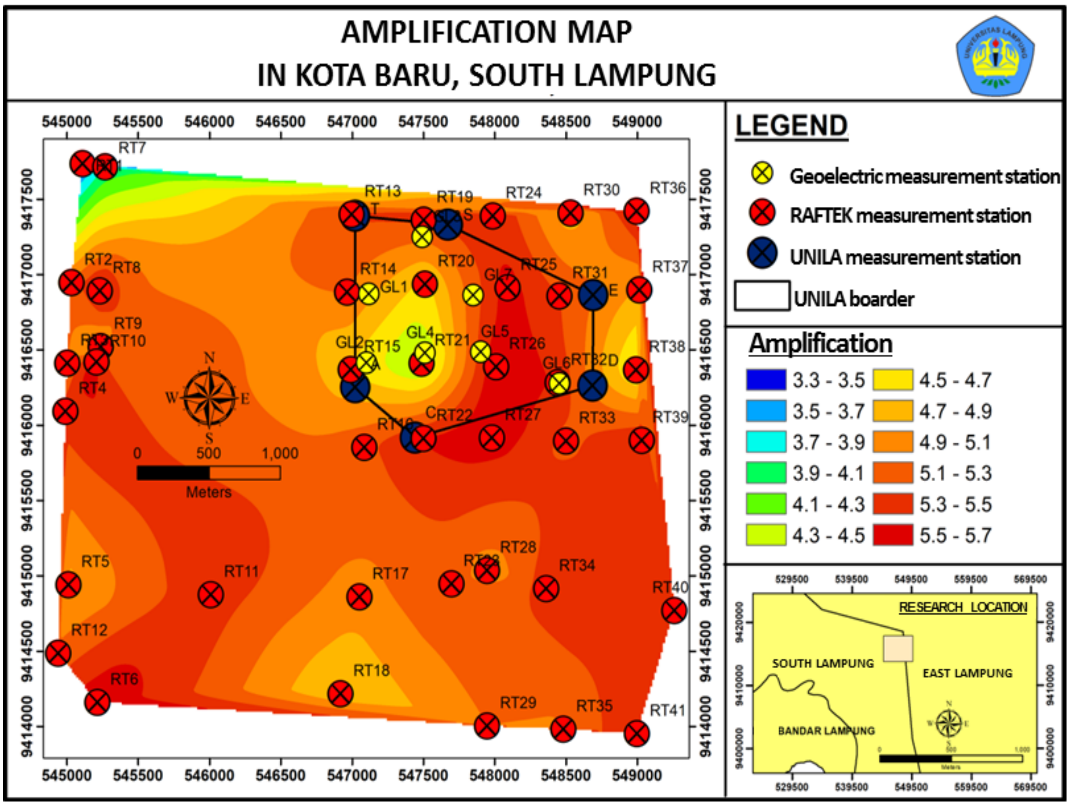

Figure 5. Amplification map of Kota Baru

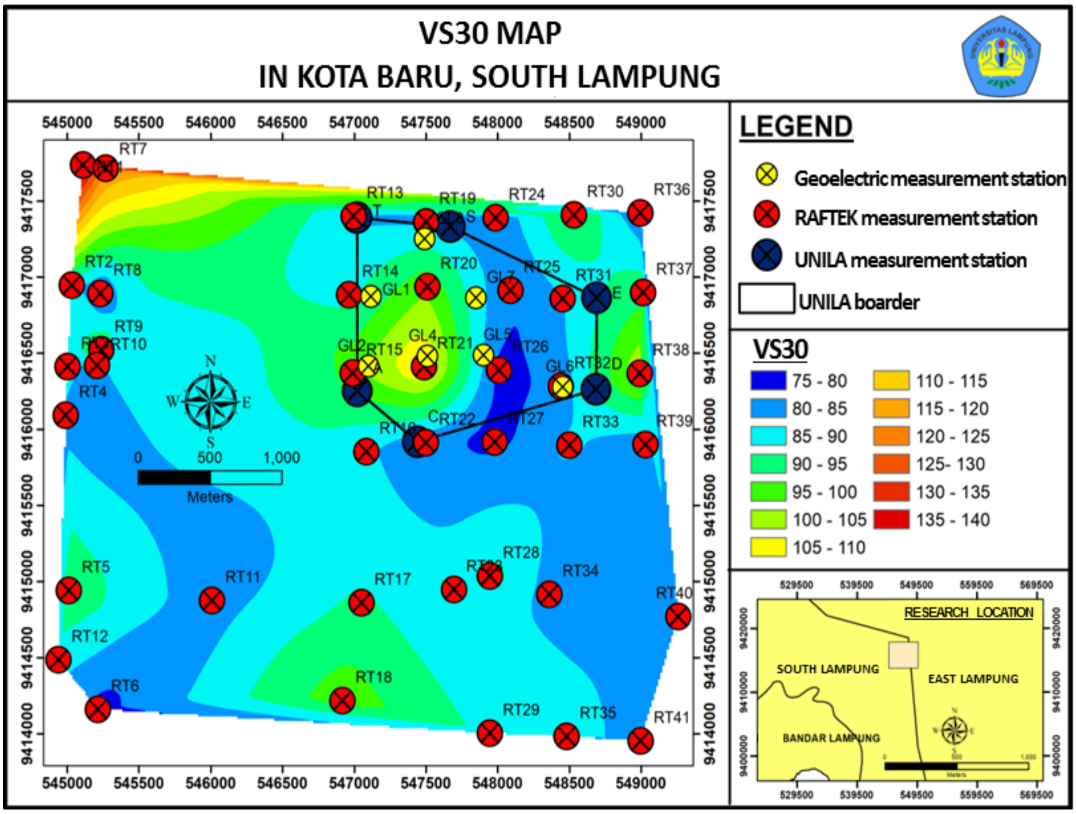

Figure 6. VS_{30} map of Kota Baru

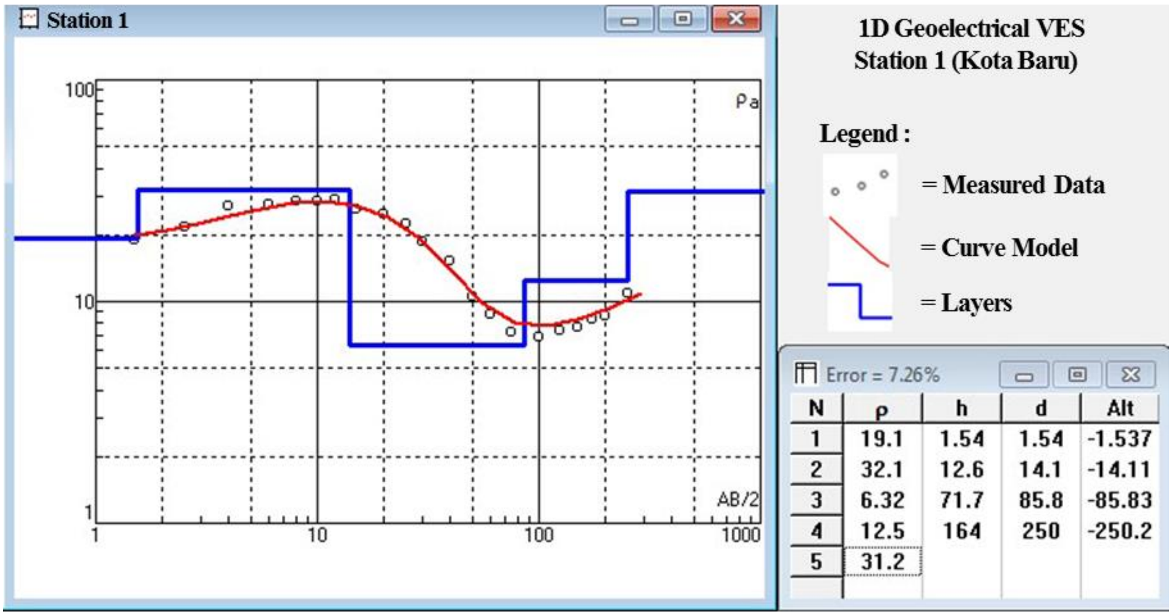

Figure 7. 1D geoelectrical modeling result at station 1

A region in Lampung Province that has been known vulnerable to the earthquake is Liwa. Referring to (Arifin, Mulyatno, Marjiyono, & Setianegara, 2017), Liwa has amplification factor value 5-6 times, even landslide that has happened in Olak Alen village, Blitar with amplification value 4.1-5.7 times and sediment thickness about 52-87 meters (Sitorus, Purwanto, & Utama, 2017).

3. VS_{30} Map Analysis

VS_{30} is shear wave velocity average in 30 meters depth. This VS_{30} value can be used in lithology classification based on earthquake vibration strength because of local effect, also for earthquake-proof building design. According to Nakamura et al, estimated that only layers up to 30 meters of depth will determine the wave amplification (Nakamura et al., 2000). Lithology type classification based on National Earthquake Hazard Reduction Program (NEHRP) shown that this area has a layer with 75-145 m/s shear wave velocity and indicated as a ductile layer (Figure 6). It causes wave amplification so this zone has a high vulnerability to an earthquake. Fortunately, this area is far from an active fault zone. In comparison, VS_{30} of Opak fault area that amplified the earthquake damage in Yogyakarta and Bantul is 200-750 m/s (Marsyelina, Wibowo, & Darmawan, 2014).

3. VES (*Vertical Electrical Sounding*) Analysis

VES correlation with lithology for GL.1 and GL.2 is shown in Figure 9. By the same treatment, the correlation between other lines was made. At VES station GL.1, it is interpreted that it had lithology or layer of alluvial with a depth of 0.00 – 1.54 meters, then at the depth of 1.54 – 14.1 meters is sandy claystone, at the depth of 14.1 – 85.8 meters is clayey sandstones, and at the depth of 85.8 until >250 meters is sandy claystone. At VES GL.2, it is interpreted that it has lithology or layer of alluvial with a depth of 0.00 – 1.08 meters, then at the depth of 1.08 – 21 meters is sandy claystones, at the depth of 21 – 77.3 meters is clayey sandstones, and at the depth of 77.3 until >266 meters is sandy claystone.

At VES GL.3, it is interpreted that it had lithology or layer of alluvial with a depth of 0.00 – 2.36 meters, then at the depth of 2.36 – 6.8 meters is sandy claystones, at the depth of 6.8 – 30.3 meters is claystones, and at the depth of 30.3 until >248 meters is clayey sandstones. At VES GL.4, it is interpreted that it has lithology or layer of alluvial with a depth of 0.00 – 4.54 meters, then at the depth of 4.54 – 72.7 meters is sandy claystone, and at the depth of 72.7 until 248 meters is sandy claystone.

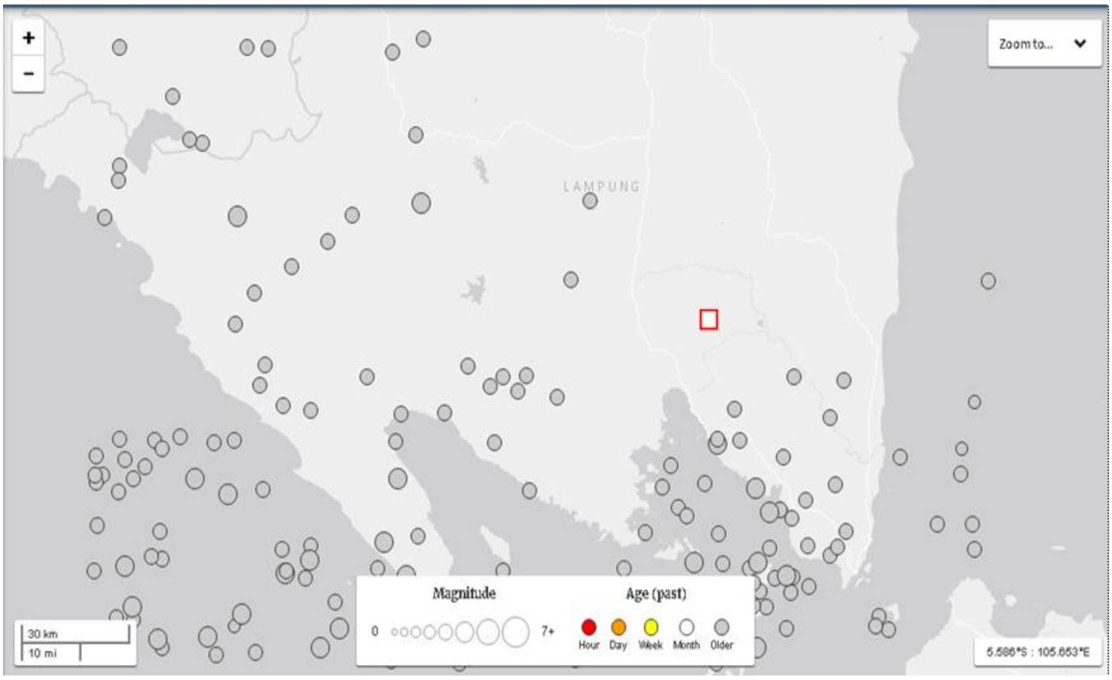

Figure 8. Lampung tectonic earthquake data 2000-2018 (USGS)

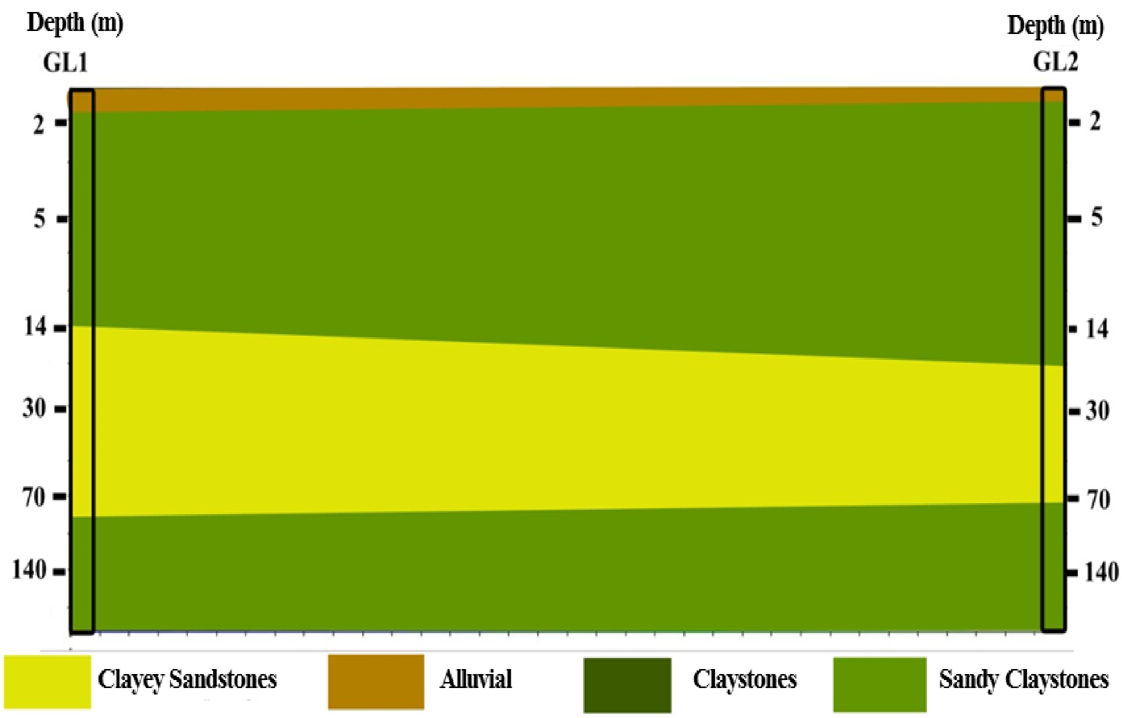

Figure 9. VES (*Vertical electrical sounding*) lithology correlation at GL.1 dan GL.2

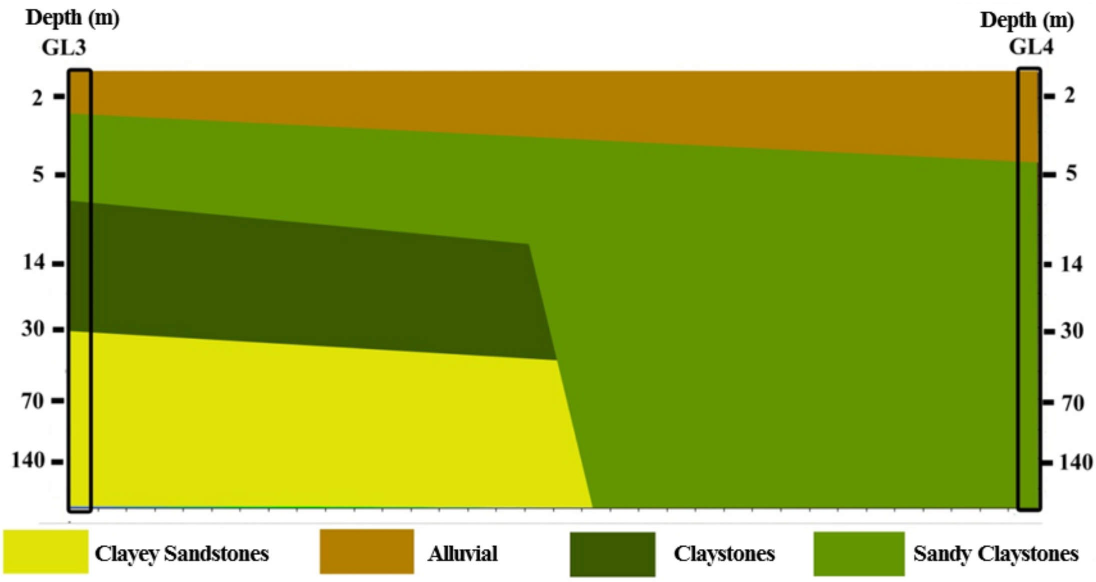

Figure 10. VES (*Vertical electrical sounding*) lithology correlation at GL.3 and GL.4

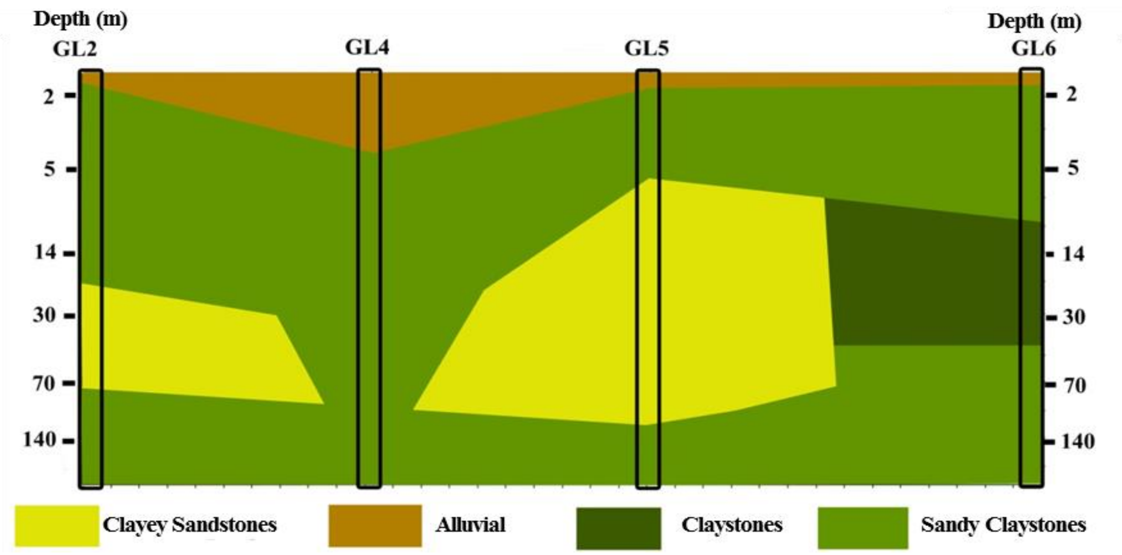

Figure 11. VES (*Vertical electrical sounding*) lithology correlation at GL.2, GL.4, GL.5 and GL.6

VES measurement at point GL.5 produces an interpretation at depth of 0.0 – 1.24 meters is alluvial, a lithology with a resistivity of 47.7 Ohm.m. At depth of 1.24 – 5.28 meters is sandy claystone with a resistivity of 138 Ohm.m. At depth of 5.28 – 122 meters is clayey sandstones with a resistivity of 7.64 Ohm.m, and also predicted that there is groundwater existence. At depth of 122 – 248 meters is sandy claystone with a resistivity of 72.7 Ohm.m. At depth of > 248 meters is sandy claystone with a resistivity of 33.3 Ohm.m.

VES measurement at point GL.6 produces an interpretation at depth of 0.0 – 1.14 meters is alluvial, a lithology with a resistivity of 37.1 Ohm.m. At depth of 1.14 – 3.41 meters is sandy claystone with a resistivity of 335 Ohm.m. At depth of 3.41 – 9.51 meters is sandy claystone with a resistivity of 16.3 Ohm.m. At depth of 9.51 – 44.6 meters is claystone with a resistivity of 6.14 Ohm.m. At depth of 44.6 – 250 meters is sandy claystone with a resistivity of 105 Ohm.m. At depth of >250 meters is sandy claystone with a resistivity of 18.6 Ohm.m (Figure 11).

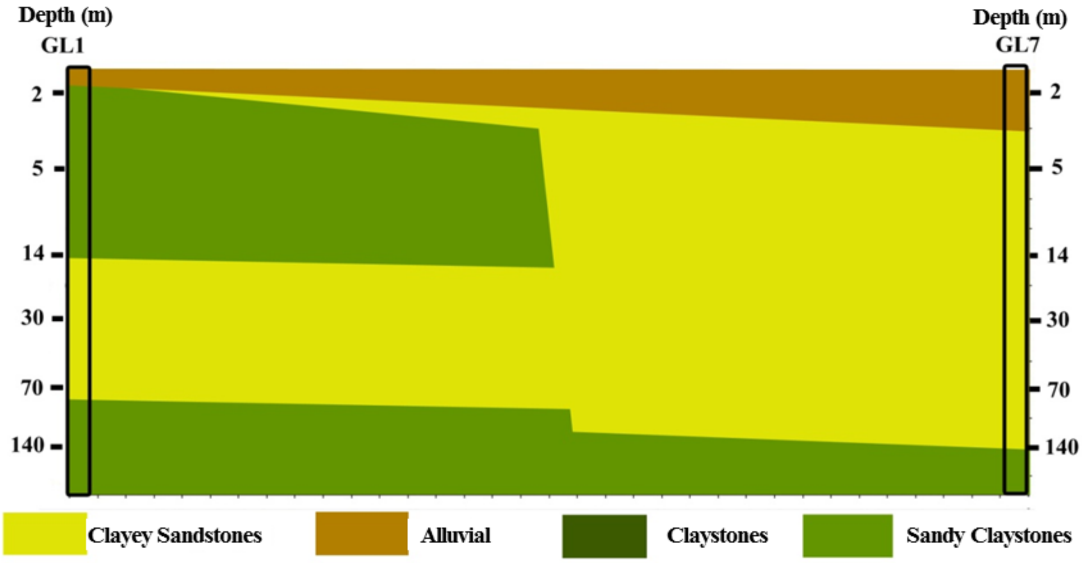

Figure 12. VES (*Vertical electrical sounding*) lithology correlation at GL.1 and GL.7

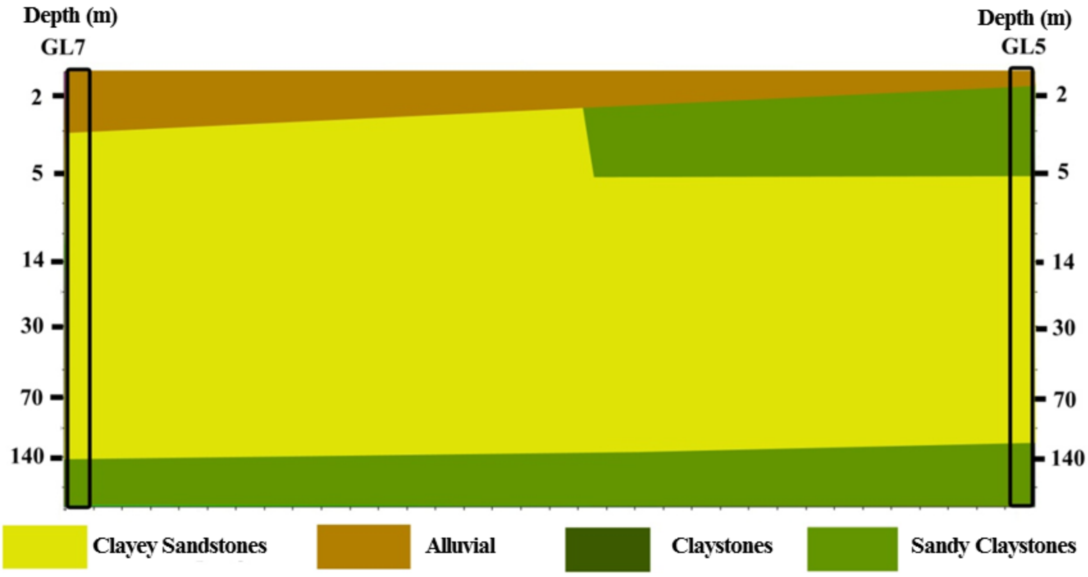

Figure 13. VES (*Vertical electrical sounding*) lithology correlation at GL.7 dan GL.5

At point GL.7 produced an interpretation at depth of 0.0 – 3.03 meters is a lithology of alluvial. At depth of 3.03 – 142 meters is clayey sandstones. At a depth of 142 until >250 meters is sandy claystone (Figure 12).

The implication of this research is requiring the development in this area to pay attention to the shape of the building, depth of the foundation and the building material so it will be the earthquake proof. From this interpretation, it is suggested that a story building is placed around points GL.1, GL.2, GL.3, GL.4, and GL.6 because from the VES data it is predicted that the ground layer is not water saturated up to a depth of 12 meters. In other hands, the construction of well for water source should be placed around points GL.5 and GL.7, which from VES data is a basin for the surrounding area and a water trap with the depth of the well >80 meters (Figure 13).

CONCLUSION

Bandar Lampung and area around it including Kota Baru is far from tectonic activity based on the past earthquake history. However, this area has large sediment thickness and low dominant frequency, so it is a vulnerable area to the earthquake.

Kota Baru area that is planned to be the new campus of Lampung University was parted to be two segments, which are a segment that was suited for building and a segment that is suited for a water source. Building segment is located in the west area (GL 1, GL 2, GL 3, and GL 4), where the water source segment is located in the east area (GL 5 and GL 7). The far east area at GL 6 is still suited for building construction.

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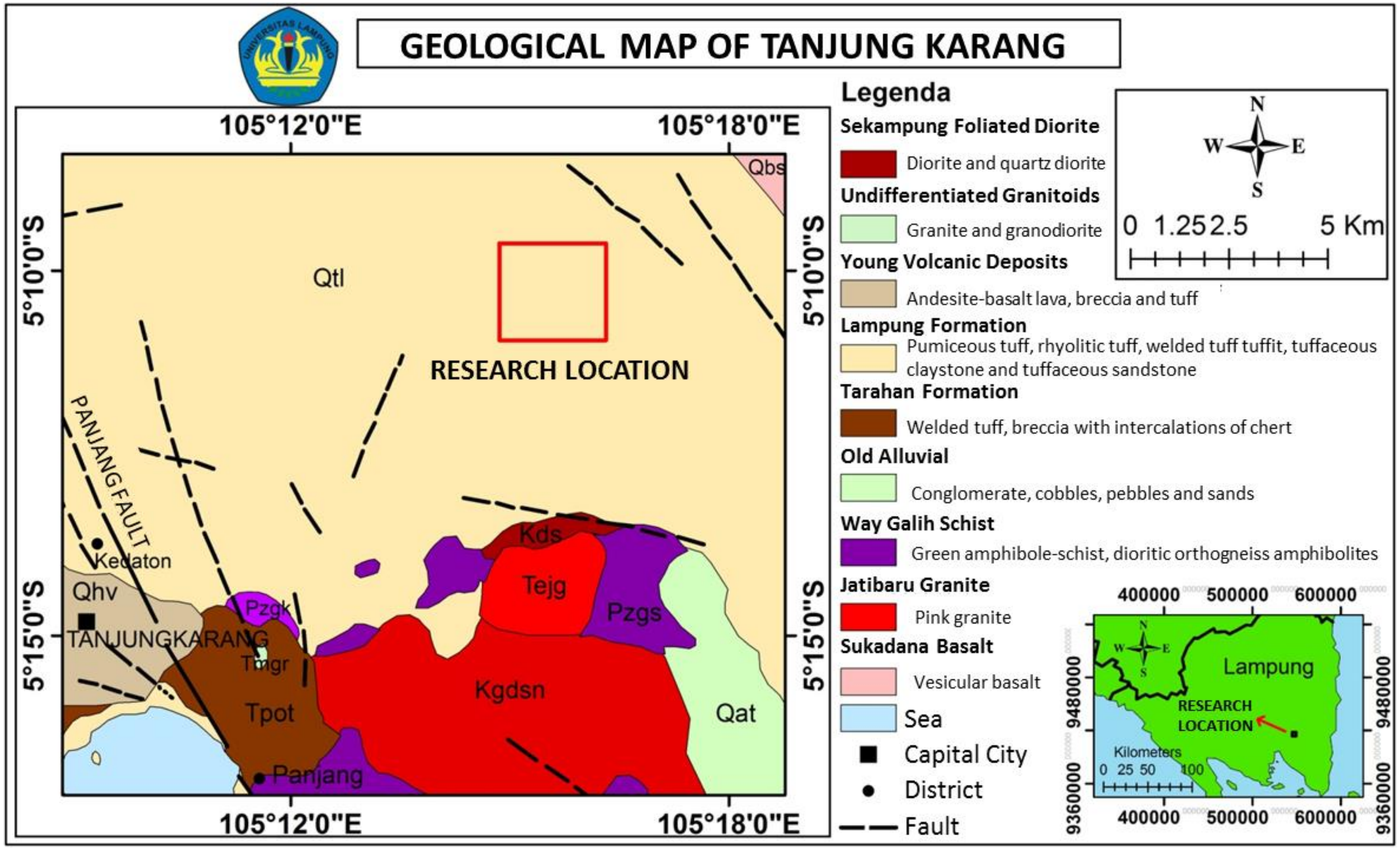
Appendix



The figure for Research of the Geological Area Map.