Seismic Refraction Tomography (SRT) Study to Characterize Potential Resource of Ie Jue's Geothermal Field of Seulawah Agam Volcano, Aceh Besar-Indonesia

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ABSTRACT

Seismic refraction tomography, a common geophysical method, has been applied to seek geological features and characterize potential resource of geothermal field area of Seulawah Agam's in the Aceh Besar Regency, Indonesia that is close to geothermal manifestations of Van Heuzt (Ie Jue) and Simpago crater. This survey deployed four surveyed lines (L2, L3, L4 and L5) which are oriented to some specific directions whose of each spread length including in line plus offset is 119 meters that is mainly accumulation of 3 meters spacing of a 14 Hz vertical geophones of 24 channels. A 5-kg sledge hammer and iron plate, as a source, were used to generate P–wave by hitting 9 shot points on the iron plate. The seismic data were then processed by using ZondST2D program to produce the seismic tomography profiles for every assessed line. The result shows that the study area is mostly identified as a two layer configuration except the third profile or L4 has three layers. The first layer with the averaged velocity in range of 0.2-0.9 km/s is mainly the top soil of volcanic rocks which are weathered from fairly to completely with rough thickness less than 7 meters. The second layer is suggested to be consists of compacted clay with velocity 1.1-1.8 km/s that has its thickness more less 5 meters. Specially for the third profile, velocity is sharply increased that is controlled by a blended sandstone and even more as a slightly weathered basalt or bedrock having velocity from 2.0 to 3.0 km/s and roughly has 10 m in thickness. A weak zone is founded at surveyed line L3 and it is laterally existed from 35 to 75 m from the SW to NE direction whose P-wave velocity is 1.1-1.8 km/s and strongly characterized by a seemingly trenched neck leading into lower layer concluded as one of the probably hydrothermal systems. All off the resulted seismic profiles also highlight that the layered media are not in planar because of a naturally magmatic activity melting any materials on its and by the end gradually intruding up to upper layers through the fractures or faults and the total depth reached by P-wave is 30 m in average. Therefore, all of the intersected seismic lines show same values of velocity meaning that all of them explain beneath the surveyed lines with the certainly oriented commonly have the homogenous layers. Finally, seismic refraction tomography (SRT) is effectively useful for identifying the shallow subsurface of potential resource of geothermal field.

KEYWORDS: Seulawah Agam, Ie Jue, Seismic Refraction Tomography (SRT), sledge hammer, ZondST2D

INTRODUCTION

Geothermal energy is a valuable source of energy, economic efficiency, environmental benefits, and more reliable of its that are the main factors justifying for an extensive application of geothermal energy in Indonesia. Aceh province is located on the westernmost of Sumatra islands of Indonesia which has 4 active volcanoes, namely Seulawah Agam, Burni Telong, Peuet Sagoe and Jaboi. Seulawah Agam is the most active volcano compared to other volcanoes. Geothermal manifestation of this active volcano is clearly presented by two craters namely Van Heuzt and Simpago crater whose hot springs, mudpots, steam and fumaroles. One of the geothermal manifestations of Seulawah Agam volcano is located at geothermal field of Ie Jue.

The Government of Aceh (GoA), Indonesia, as the relevant authority (the "Contracting Authority") has decided to develop the geothermal resource of Seulawah Agam on Sumatera, located in the province of Aceh. In accordance with the Law 27/2003 on Geothermal Energy, Seulawah Agam will be tendered publicly as an integrated project, i.e. including the exploration, feasibility study and exploitation of the geothermal resource.

The Seulawah Agam Geothermal Working Area is determined by the Indonesian Ministry of Energy and Mineral Resources Decree No. 1786 K/33/MEM/2007 dated May, 23, 2007 with an area of 45,000 ha and a possible power of 160 MWe. The Seulawah Agam prospect is located in Mount Seulawah area and its surroundings and since that time till now it was prepared to explore . (https://www.devex.com/projects/tenders/develop-the-geothermal-resource-of-seulawah-agam-indonesia/66629, cited at August 3th, 2015)

Generally, Indonesian geothermal systems are dominated by high temperatures hydrothermal, 150 -225 °C (Subir, 2005). The main feature of the Sumatran fault systems is the collocation with the volcanic arcs including calderas in direct proximity to the fault and the position of the volcanic arcs are related to the geometry of the subduction zone (Tatsumi, 1989).

Geophysical mapping is the most common methods to evaluate a geothermal resource that can lead to utilization (Wanjie, 2012). Geophysical techniques can also used for finding possible geo-hazard risk (e.g. power plant construction sites, surface piping etc.) and conceptualizing sub-surface conditions of an area (conceptual model). Among the geophysical method characterizing of shallow subsurface, seismic refraction is one of the most cost effective methods used from the surface. As velocity is highly dependent on density, seismic methods are very useful in finding and delineating subsurface structures. The purpose of this study is to give an overview of how seismic refraction methods are used in delineating shallow subsurface layers of geothermal field of Ie Jue in the Aceh Besar Regency. This is done by discussing results of seismic tomography refraction surveys near geothermal manifestation area.

SEISMIC REFRACTION METHOD

Seismic refraction is a common geophysical method used for investigating subsurface by utilizing surface-sourced seismic waves. A seismic source is used to generate body wave consists of the compressional (P-wave) and longitudinal wave (S-wave) and also produce surface wave that is composed to Rayleigh and Love wave, which can be measured by using a seismograph and a series of evenly spaced detectors (12, 24, 48 or more geophones).

Seismic refraction method is quantitative as it produces depths of various geo-material layers and the compressional wave velocity *(V_p)* of these layers (Kearey et al., 2002). The seismic velocities can assist in interpreting geo-material layers as well as determining bedrock (I.N. Azwin et al., 2013). Table 1 shows the variation of *(V_p)* value of soils and rocks.

Table 1: Compressional velocities *(V_p)*for soils and rocks (Braja, 2013).

Geomaterial	**V_p (km/s)**
Soils	
Sand and fine grained top soil	0,2 – 1,0
Alluvium	0,5 – 2,0
Compacted clays	1,0 – 2,5
Rocks	
Sandstone	1,5 – 5,0
Slate and Shale	2,5 – 5,5
Granite	4,0 – 6,0

GEOLOGY OF THE AREA

The study was conducted in geothermal field area of Ie Jue which located in Aceh Besar Regency, Aceh Province, Indonesia (Figure 1). The study area is located about 7 km towards north of Seulawah Agam volcano. The study area is lithologically dominated by Lamteuba volcanics which consist of andesitic to dacitic volcanic, pumiceous breccias, tuffs, agglomerate and volcanic ash flow which intrude of the Seulimum formation composed of tuffaceous and calcareous sandstone , conglomerates and minor mudstones (Nordiana, M. M et al., 2014 after Bennett et al., 1981). From our field observations, there was the existence of geothermal surface manifestation such as hot spring, mud pots, warm ground and fumaroles.

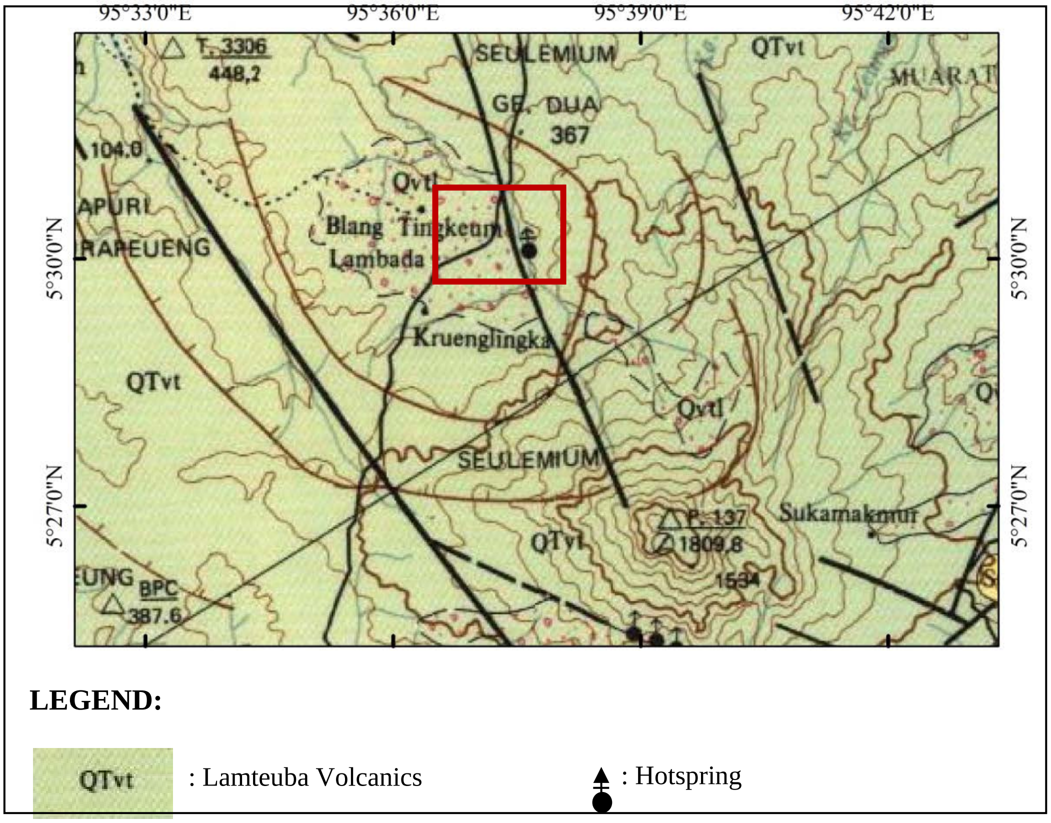


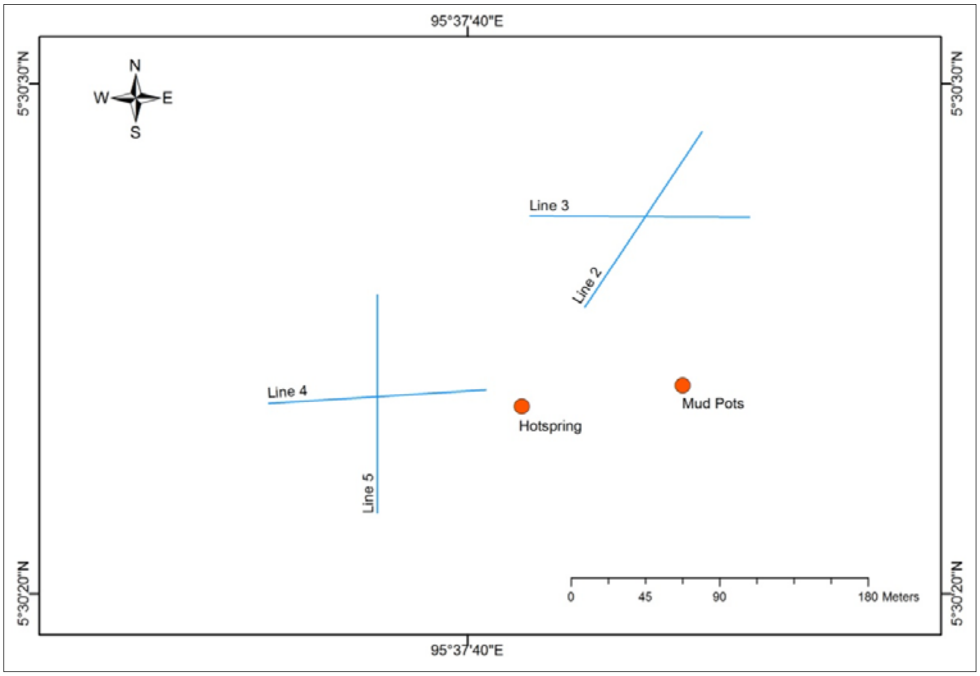
Figure 1: Geological map of study area (Bennett et al., 1981) and the red box is the location of seismic refraction survey.

RESEARCH METHODOLOGY

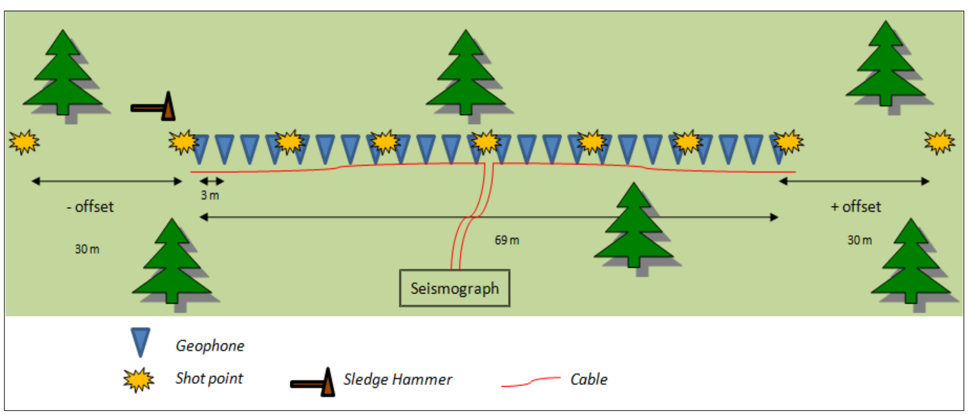
The study involves seismic refraction data acquisition followed by data processing and tomography interpretation. The acquisition was performed using 24 channels PASI seismograph and 14 Hz geophones. Total of four perpendicular seismic refraction survey lines (L2, L3, L4 and L4), whose coordinates at 5°30'27.38" N, 95°37'41.24" E till 5°30'27.36" N, 95°37'45.52" E, 5°30'25.58" N, 95°37'42.30" E till 5°30'29.06" N, 95°37'44.59" E, 5°30'23.73" N, 95°37'36.09" E till 5°30'23.97" N, 95°37'40.38" E, 5°30'21.57" N , 95°37'38.23" E till 5°30'25.86" N, 95°37'38.25" E respectively, were situated to near geothermal manifestation (Figure 2) and as a pair of lines, L2 and L3 are crossed each other then the same pattern is also adjusted for L4 and L5. A 5-kg sledge hammer was used to produce P-wave and 9 shot points were performed symmetrically along for each survey line. 3 m geophone spacing and 30-50 m far offset were applied for each of line. The inversion analysis of the refraction data was modeled by using ZondST2D tomography program.

Tomography is an interpretation technique which requires an initial velocity model to begin with (Mundhra, A et al., 2012 after Zhang and Toksöz, 1998). It has a primary purpose of reducing RMS error between calculated and observed model and to produce a velocity model devoid of small scale artifacts.

Principle behind its working is to divide velocity model into a number of cells of constant velocity followed by iteratively tracing ray through the model further assumptions are made that the seismic pulse will pass through these cells. On the basis of observed travel time through these cells we can assign a region as fast or slow region and their elastic parameters can also be predicted. Inversion is applied over rays to converge to best results. Refraction tomography methods (Hinojosa-Prieto, H.R and Hinzen, K.G, 2015) (ray-tracing and numerical eikonal solvers algorithms) are not interface based and can invert for a discontinuous velocity structure of unlimited number of layers, whose velocity field can vary laterally and vertically.



(a)



(b)

Figure 2: Layout of seismic refraction survey (a) four seismic lines and (b) field setting of recording

RESULTS AND DISCUSSION

Based on the inversion results which are then referred (V_p) values of some of earth materials shown in (Table 1) and also actually correlated to geologic setting of the area, seismic tomography models (Figure 3-6) show that the study area is mostly identified as a two layer configuration except the third profile or L4 (Figure 5) has three layers. The first layer with the averaged velocity in range of 0.2-0.9 km/s is mainly made up of top soil of volcanic rocks which are weathered from fairly to slightly with rough thickness less than 7 meters. The second layer is suggested to be consists of compacted clay with velocity 1.1-1.8 km/s that has its thickness more less 5 meters. Specially for the third profile, velocity is sharply increased when P-wave bumps into different medium which is confidently controlled by a blended sandstone and even more as a slightly weathered basalt or bedrock having velocity of P-wave between 2.0 and 3.0 km/s (Horrent, C et al., 1997) and revealed its thickness 10 meters.

A weak zone strongly presumed as fracture or fault is unveiled at survey line L3 and horizontally, it is existed from 35 to 75 m from the SW to NE direction. This feature is clearly pointed out by P-wave velocity that is 1.1-1.8 km/s. Furthermore, it is also strongly marked by the characteristic shape of the weak zone whose a seemingly trenched neck that is downward to lower layer which is finally concluded as one of the hydrothermal systems . The lower velocity in certain range reflects zones with fracture porosity and associated small faults (Ackermann, H. D, 1979). This result also has been supported by the previous research done by (Marwan et al., 2014) at Seulawah Agam by applying Gravity measurement whose survey area is closed to the seismic refraction of surveyed lines. The result show that around Heutsz and Ie Jue’s field, there exists the fracture zones or fault because some points have high anomaly of density influenced by hydrothermal mineralization in the fractures, so that the gravity survey moderately corresponds to the result obtained by seismic refraction tomography (SRT).

Moreover of related to the survey area in the Seulawah agam’s geothermal field, all off the resulted seismic refraction profiles also highlight that layered media are not in planar or regular shape. This is naturally because of magmatic activity melting any materials on its and by the end gradually intruding up to upper layers and the total depth reached by P-wave is 30 meters in average. Another information than can be derived from all of the profiles that intersection of each pair shows same values of velocity meaning that all of them explain beneath the surveyed lines with the certain orientation commonly have the homogenous layers.

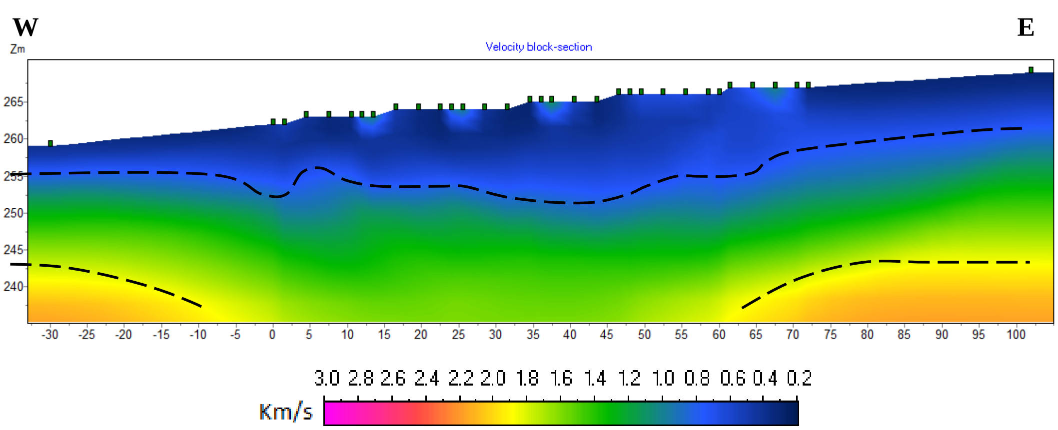


Figure 3: Seismic tomography model for survey line L2.

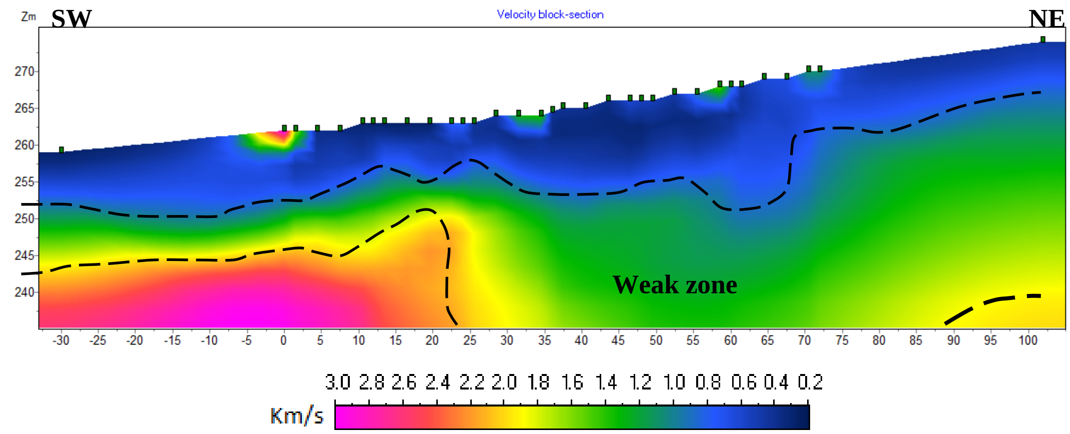


Figure 4: Seismic tomography model for survey line L3.

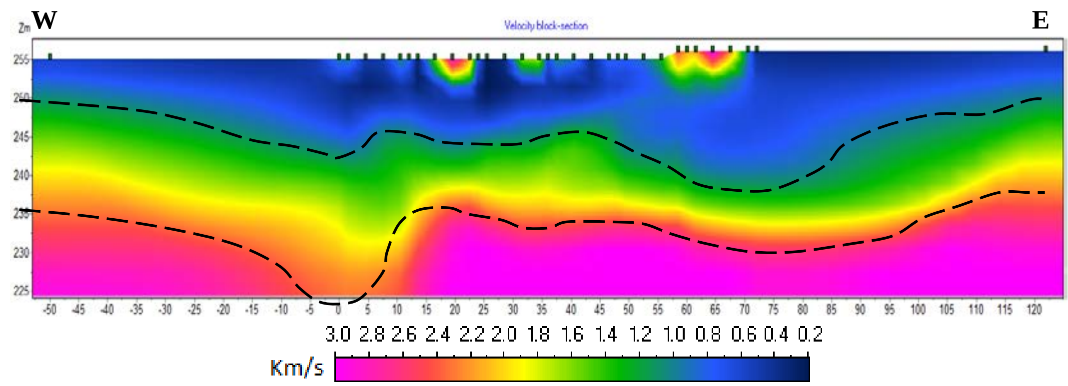


Figure 5: Seismic tomography model for survey line L4.

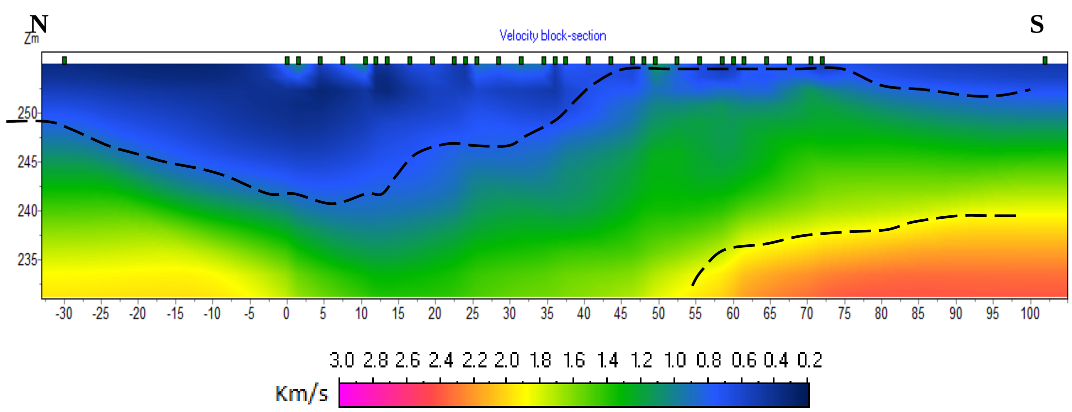


Figure 6: Seismic tomography model for survey line L5.

CONCLUSION

Seismic refraction tomography study in Seulawah Agam's geothermal field effectively revealed that all of the surveyed lines resulted mainly two layers except the the third profile whose three layered configurations. The averaged P-wave velocities for every layer of the L2, L3, L4 (except the third layer) and L5 are successively 0.2-0.9 km/s is mainly made up of top soil of volcanic rocks which are weathered from fairly to slightly with rough thickness less than 7 meters. The second layer is suggested to be consists of compacted clay with velocity 1.1-1.8 km/s that has its thickness more less 5 meters and specially for the third profile of last layer, velocity is sharply increased when P-wave encounters different medium which is largely controlled by a mixed sandstone and even more as a slightly weathered basalt or bedrock having P-wave velocity between 2.0 and 3.0 km/s.

Furthermore, there is interestingly presumable founded a fracture zone or fault unveiled from line L3 and underlain by first layer then laterally, it is existed from 35 to 75 m from the SW to NE direction. This feature is clearly pointed out by P-wave velocity that is 1.1-1.8 km/s. It is also strongly marked by the characteristic shape of its whose a seemingly trenched neck that is downward to lower layer which is finally estimated as one of the hydrothermal systems. The total depth traveled by P-wave is roughly 30 m and all of the intersected points of two pair surveyed lines certified the concordant results.

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