A Poisson's Ratio Distribution From Wadati Diagram as Indicator of Fracturing of Lahendong Geothermal Field, North Sulawesi, Indonesia

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Keywords: Poisson's ratio, Wadati diagram, fracturing, permeability.

ABSTRACT

Poisson's ratio from Wadati Diagram using micro earthquake monitoring is relatively simple and useful for direct indicator of fracture. A short term micro earthquake monitoring in the Lahendong geothermal field shows two distinct shallow and deep hypocenters distributions. This paper describes the Poisson's ratio's distribution from Wadati method in the Lahendong geothermal field. The higher Poisson's ratio associated with shallow hypocenters indicated by the fractured rocks, and the lower Poisson's ratio associated with deeper hypocenters and un-fractured rocks with silicified rocks.

1. INTRODUCTION

The Lahendong geothermal field situated in the North Sulawesi Province which is approximately 30 km from the capital city of Manado.

One of the geophysical method used to detect reservoir permeability is micro earth quake. Each event of micro earthquake can be associated with permeable zone. As a result, this geophysical method is very helpful to develop a geothermal field.

Poisson's ratio is one of the important parameters that can be used as a fracture indicator through simple calculation of Wadati diagram. Whereas, well data like cores, minerals and loss circulation can provide reservoir permeability are very expensive and limited.

This paper describes the calculation and interpretation of Poisson's ratio derived from the short monitoring of micro earthquake at the beginning of production in the Lahendong geothermal field. More over, one layer modeling of earthquake distribution and Poisson's ratio calculation by using Wadati diagram indicate different fracture intensity between shallow and deep reservoir.

2. MICRO-EARTHQUAKE DISTRIBUTION

The Lahendong geothermal field is confined to an area about 12 km^2 as shown Figure 1. Five MEQ's stations with spacing less than 2 km were utilized to cover interest area. Two seismometers L4-C (3-components) and three seismometers SS-1 ranges (1-component) with natural frequency 1 Hz were connected to DATAMARK LS-8000SH. By using sample interval of 10 msec, gains 100 times, pre trigger data 1000, and low pass filter 30 Hz were applied to detect micro-earthquake with magnitude < 3 Richter's scale focal depths < 5 km.

The Lahendong geothermal field was produce steam about 160 tonnes/hr and about 75 tonnes/hr brine were injected back into the earth through an injection well LHD-5 at

WHP 0 up to -0.8 bar. It is believed that local changes in the stress field are obviously caused by production and re-injection; however; the induced seismicity is not confined to the immediate regions of production and re-injection, but also occurs at greater depths (Figure 2).

DATAMARK LS-8000SH is a high precision data logger capable of recording induced or tectonic earthquakes data. Since it is synchronize with UTC by GPS's time calibration function, each logger can record the data independently. It has been claimed by the manufacture that the time accuracy is ± 5 μsec.

In the Lahendong geothermal field, the typical micro earthquakes, see Figure 3, are as follow: duration < 50 second, the depths < 5 km, and the time differences between P and S arrival (S-P) < 3 second. Therefore, a simple assumption that model is a horizontal layered velocity structure, assuming constant, isotropic velocity within one layer, is reasonable enough to get a quick interpretation as preliminary result.

A small error in picking of the arrival time and the inaccuracies of velocity model can produce a large error in determining the hypocenter and epicenter location. Therefore, both factors must be controlled, carefully.

Firstly, as we know, it is easier to pick P wave than S wave, so P wave data from 4 stations is much better than P and S wave data from 3 stations. Using this procedure, which controlled by data from the shortest station usually associated with good event, it is expected to minimize the error.

Secondly, sensitivity analysis was used to obtain the representative velocity of the area. Since there is no direct velocity measurement, and no velocity data from petrophysics, the whole micro-earthquakes data were calculated using a simple linier inversion program (Gede Swantika) with various velocities ranges from 2.5 to 4 km /sec. Most of data converged quickly to provide satisfactory hypocenter locations using a compressional wave velocity of 3.5 km/sec.

Since full production began, as well as during commissioning, four production wells in the Southern block were used to produce 20 MWe. The brine from a production separator were injected into the ground by using one injection well, also in the Eastern block.

Although the mechanism which causes induced seismicity is not understood yet, but it has been studied that injection of fluid into the ground already deformed by regional stress can cause "man – made" earthquakes. Another way, detailed study of "the Geyser" reservoir showed that seismicity can also increase due to production (Denlinger et al, 1981)
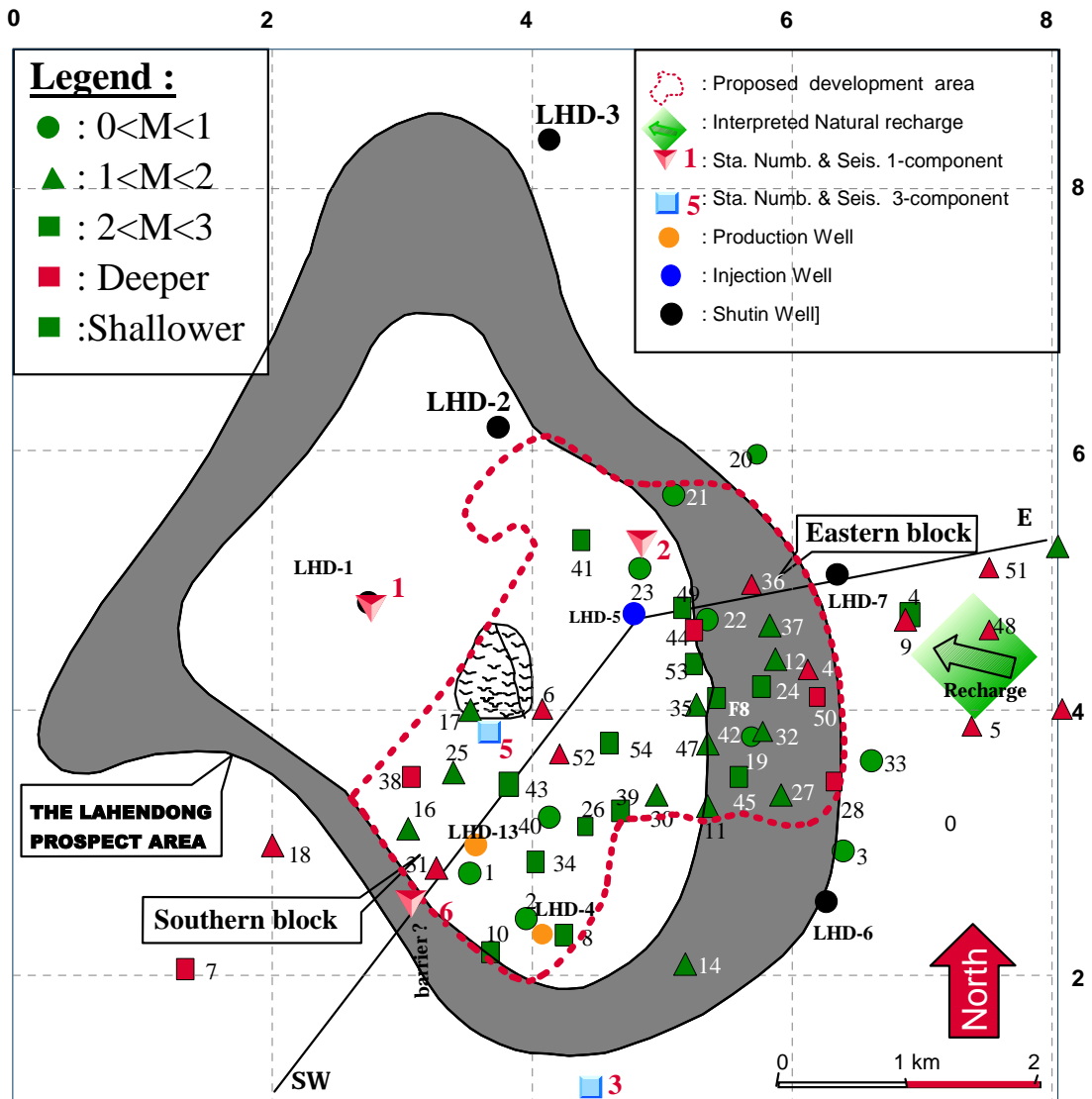
Figure 1 The map of the Lahendong geothermal field showing the prospect area, production and injection wells, micro-earthquakes distributions in the period Desember 2000 - Februari 2001 (Modified from Sudarman S.)
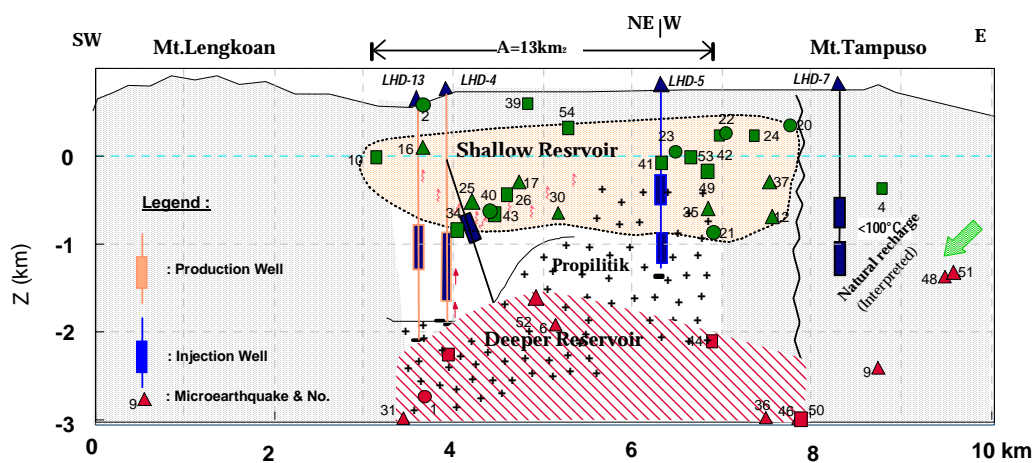

Figure 2 The cross section of the Lahendong geothermal field showing vertical distribution of micro-earthquake and injection and production wells (Modified from Sudarman S.).
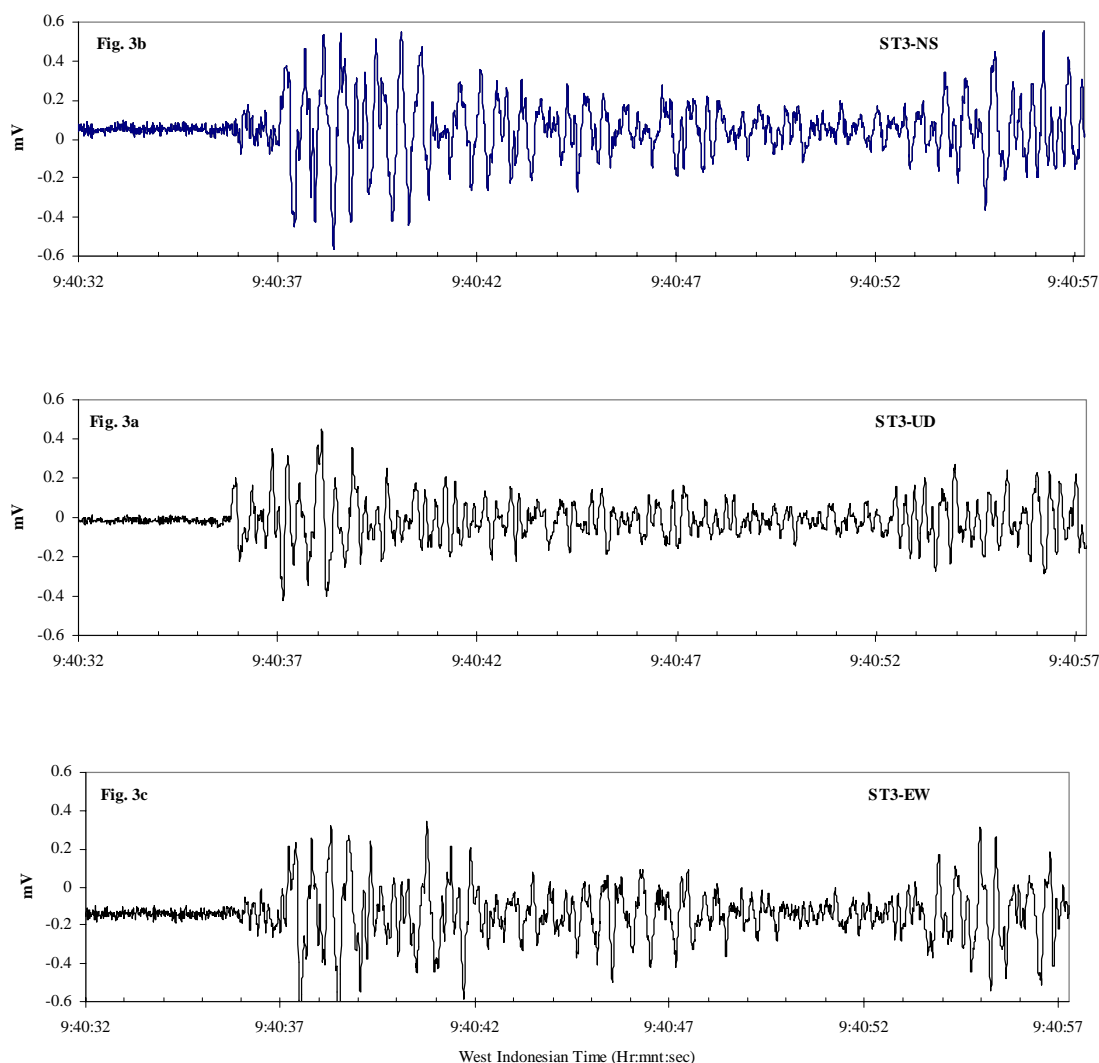
Figure 3 A Typical of micro-earthquake record from a 3-component seismometer in the Lahendong geothermal field, during monitoring (Fig. 3a, record from a vertical component, Fig. 3b and 3c record from horizontal components)

3. WADATI DIAGRAM

Wadati diagram is important in processing micro-earthquake data for two reasons. The first is that we can control the correct picks of travel time of P wave and S wave (ts and tp) from record data. The second reason is that we can compare the origin time of earth-quake (To, if the time of S and P are equal, it means the rock are fractured) with To from a computer program e.g. linier inversion.

In many cases, it is hard to pick S wave accurately even though we use 3-component seismometers. Particularly, in the Lahendong geothermal field we only use 2 seismometers 3-components. Therefore, the use of Wadati diagram is very important to control the correct picks.

After picking all of the ts and tp from all micro-earthquake stations as shown in Tabel-1, we can construct a Wadati diagram by plotting all Ts – Tp vs Tp for all the receiver stations, as shown in Figure 4.

Table 1 The corrects picks of micro-earthquacke data on 1st January 2001

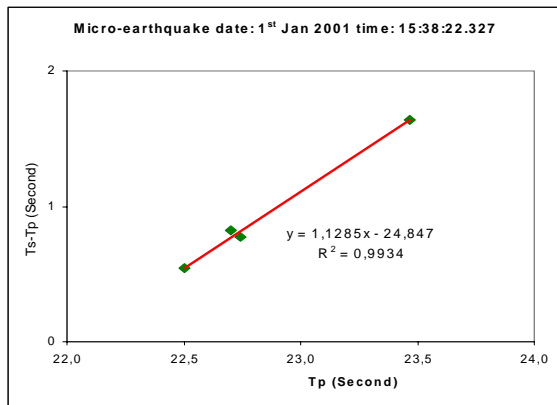| Sta.	Tp (second)	Ts (second)	Ts – Tp (second)
2	22.501	23.041	0.540
5	22.700	23.520	0.820
1	22.740	23.510	0.770
3	23.470	25.110	1.640
To (Wadati)	22.327		
To (Inversion)	22.197		
Error	0.006		
Poisson's ratio	0.36		

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Figure-4: Wadati diagram of micro-earthquakes on 1st January 2001

4. POISSON'S RATIO CONCEPT

Basically Poisson's ratio is defined by the ratio of the strain perpendicular to either type of deforming force to that in the direction of the force itself. In other way, by using compressional velocity and transversal velocity or the comparison of both velocity from Wadati diagram the Poisson's ratio is defined as follow :

$$\sigma = \frac{(Vp^2 - 2Vs)}{2(Vp^2 - Vs^2)}$$

where σ, Vp dan Vs are Poisson's ratio, the compressional wave velocity (longitudinal) and the shear wave velocity (transversal) respectively.

If we assume that the ray-paths are confined to homogeneous geology, experimental and theoretical results indicate that additional fracturing of a fluid-filled rock will cause an increase in the Poisson's ratio. The P-wave velocity decreases slightly and the S-wave velocityis significantly reduced. This phenomena is observed in a survey on Hawaii near the successful HGO well (Butler David).

The study of refraction survey indicates the anomaly of the velocity structure in the high temperature; the velocity of the compression wave (Vp) reduced by the fluid composition and temperature; velocity of transversal wave also influenced by temperature but not affected by fluid composition. (Ito vide Soengkono 1999). In the steam dominated system, Vp decreases faster than Vs. The two parameters provide poisson ratio lower than 0.25. In the water dominated system at the higher porosity pressure, the Poisson's ratio is bigger than 0.25. The Vs decreases faster than Vp.

5. POISSON'S RATIO OF THE LAHENDONG GEOTHERMAL FIELD.

The Poisson's ratio of the Lahendong geothermal field indicate a significant differences between shallower and deeper zone. In the shallower zone, the Poisson's ratio varies between 0.35 up to 0.43. In the deeper zone, the Poisson's ratio varies from 0.27 to 0.35.
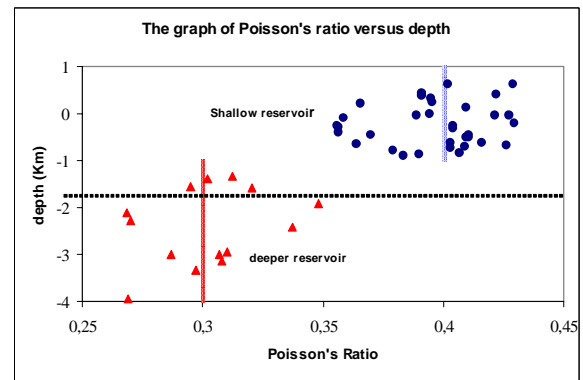

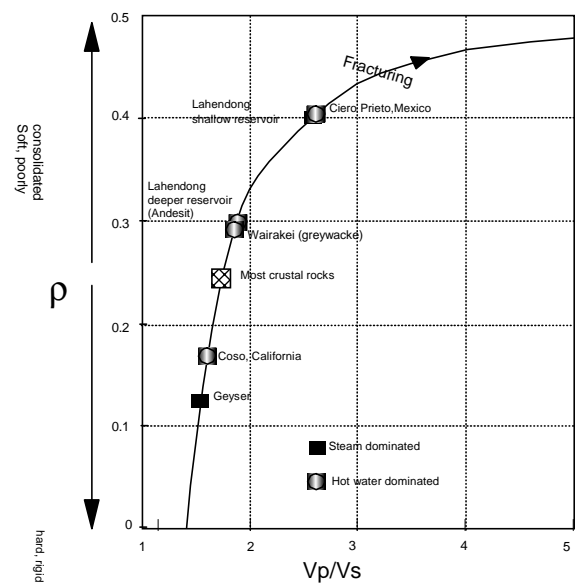**Figure 5: The graph of Poisson's ratio value of Lahendong geothermal field versus depth relative to sea level.**

Figure 6 Poisson's ratio of some geothermal fields (from Soengkono, S.; Dobrin) over the world wide versus Vp/Vs.

Figure 6 shows the significant differences between Poisson's ratio in the shallower zone and deeper zone. The best explanation of the Poisson's ratio anomaly is where the rocks type is different from in the anomalous area.

6. CORRELATION OF POISSON RATIO WITH WELL BORE DATA

The value of Poisson's ratio with depth in the Lahendong geothermal field can be divided into two zones which correspond to shallower and deeper zone. The shallower zone with interval of Poisson's ratio varies from 0.35 to 0.43 has depth from surface to 2000 meter depth and the deeper zone with interval of Poisson's ratio varies from 0.27 to 0.35 has depth is deeper than 2000 meter. The correlation between cores and Poisson's ratio data provide the two reservoir zones.

The shallower zone is distinguished by the intensively fractured rock, the loss circulation, partial loss circulation and drilling break. All the steam in Lahendong field derived from this zone which is the main target to develop another 2X20 MWe. In the deeper zone, the rock is silicified without loss circulation zones, see Figure 7.
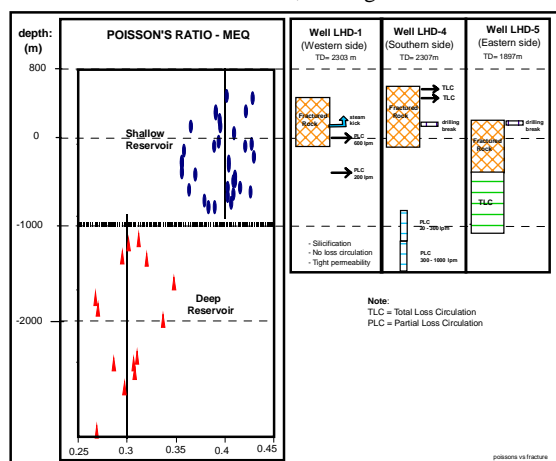

Figure 7 Poisson's ratio versus fracturing system (Total Loss Circulation) and lithology (Modified from Siahaan, E. E.)

7. CONCLUSIONS

1. Lower Poisson's ratio is associated with shallower hypocenters, indicative of fractured rock's.

2. Higher Poisson's ratio is associated with deeper hypocenters characterized by un-fractured rocks and the silicified alteration.

ACKNOWLEDGMENTS

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