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PROSIDING

Menuju Pengelolaan Energi dan Sumberdaya Mineral Indonesia Yang Lebih Berdaulat : Tantangan, Teknologi, Sistem, dan Solusi

FAKULTAS TEKNOLOGI MINERAL
UNIVERSITAS PEMBANGUNAN NASIONAL "VETERAN"
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Fakultas Teknologi Mineral
Universitas Pembangunan Nasional "Veteran" Yogyakarta
Jl. SWK 104 (Lingkar Utara) Condongcatur Yogyakarta
Gedung Arie F. Lasut, Telp. (0274) 487813, 487814, Fax. (0274) 487813
Email : semnas_ftm@upnyk.ac.id

INTERPRETATION OF CURIE POINT DEPTH AND THERMAL GRADIENT BASED ON MAGNETIC ANOMALY DATA AT SOUTHERN SUMATRA GEOTHERMAL AREA

Syamsurijal RASIMENG[1,2]**, Wawan GUNAWAN A. KADIR**[2]**, Hendra GRANDIS**[2]**,***
***Chalid IDHAM ABDULLAH**[3]*
[1]Jurusan Teknik Geofisika, FT UNILA, Jl. S. Brojonegoro No.1, Bandar Lampung
[2]Program Studi Teknik Geofisika, FTTM ITB, Jl. Ganesha No.10, Bandung
[3]Program Studi Geologi, FITB ITB, Jl. Ganesha No.10 Bandung
*e-mail : syamsurijal.rasimeng@eng.unila.ac.id

Abstract

Curie point depth (CPD) is Curie temperature depth where magnetic mineral lost its magneticity. Curie temperature generally higher on mafic frozen rock than on any other rock. because of its higher titano-magnetic content. The magnetic field induction value depends on rock minerals, so it can be used to determine the depth of the rock. Magnetic field anomaly are series of signals magnitude as the respon of rock composing material under the surface. Power spectrum application for that signals magnitude can be used to determine lower surface rock mass depth including CPD and thermal gradient. Tectonic activity along Sumatra Fault System (SFS) allow the emergence of CPD depth variation and thermal gradient. Southern Sumatera as part of this system become the focus of this research, because it has geothermal potential indicated by numbers of fluid manifest distribution on the surface. Result of thermal gradient analysis obtained from CPD variation informed that value of thermal gradient was 40-75^{0}C/km on shallow CPD area (8-15 km). That area divided Sumatera island and extended to North West – South East direction. Geologically, southern Sumatera also part of magmatic arc area as the SFS product, so it is possibly become geothermal prospect area.

Key Words : Curie point depth, geothermal, spectrum power, thermal gradient, magnetic method

1. Introduction

Curie Point Depth (CPD) defined as Curie temperature depth where magnetic mineral lost its magneticity. Curie temperature generally higher on mafic frozen rock than on any other rock, because of its higher titano-magnetic content. The presence of magnetic mineral such as magnetite (Fe_3O_4), ulvospine (Fe_2TiO_4), hematite (Fe_2O_3) and many others as the earth crust composing minerals will increase Curie temperature up to 580^{o}C (Blakely 1995). CPD depth directly affected by lower surface rocks temperature as consequence of tectonic activity. In consequence, the variation of CPD depth highly depends on the impact caused by the tectonic activity. CPD analysis on Southern Sumatra area with high tectonic activity as the impact of the clash between Indo-Australia and Eurasia plate is very important to performed to get more ideas about the relation between tectonic activity and CPD. Shie and Natawidjaja (2000) divided three Sumatra areas according to their tectonic activities on Sumatera fault, they are northern Sumatera, central Sumatera and southern Sumatera.

Magnetic methods based on magnetic field induction observation as the respon of magnetized rocks below the surface. The value of magnetic field induction depends on the composition of the rock magnetic mineral content. This makes the presence of magnetic minerals as earth crust rocks composer can be used as an indicator of magnetic measurement. Magnetic method ability to detect lower surface rock mass, including CPT by applying spectrum analysis has been performed by many researchers. Nevertheless, this technique still considered as interesting matter, proved from researches performed by Bansal *et al*. (2010), Büyüksaraç and Bektas (2007), Dolmaz *et al*. (2005), El Nabi (2011), Karastathis *et al.* (2010), Maden (2010), Minea and Vlad (2010) and many others.

This research covered magnetic anomaly data spectrum analysis to analyze CPD depth variation and thermal gradient caused by tectonic activity on southern Sumatera area. Thermal circulation that came from earth mantle (astenosphere) and pass through fault planes on earth crust causing a thermal convection current. The thermal convection current then will cause variation of CPD distribution pattern under the surface.

2. Methods

Blakely (1995) and Maden (2010) described total magnetic field power spectrum anomaly $\Phi_{\Delta T}$ as,

$$\Phi_{\Delta T}(k_x,k_y) = \Phi_M(k_x,k_y)F(k_x,k_y) \qquad (1)$$

with,

$$F(k_x,k_y) = 4\pi^2 C_m^2 |\Theta_m|^2 |\Theta_f|^2 e^{-2|k|Z_t}\left(1-e^{-2|k|Z_b-Z_t}\right)^2 \qquad (2)$$

where $\Phi_{\Delta T}$ is power spectrum as caused of magnetization Φ_M, C_m is a constant, Θ_m and Θ_f are magnetization direction factor and magnetic field direction factor, k_x and k_y are wavenumber on x and y direction. Z_t and Z_b are the upper and lower limit depth of magnetic anomaly. $|\Theta_m|^2$ and $|\Theta_f|^2$ are radial simetrical form where the average radial value from factor Θ_m and Θ_f are constant. If magnetization on anomaly M(x,y) is random and not depend on each other then power spectrum as caused of magnetization $\Phi_M(k_x,k_y)$ become constant, and so the total magnetic field anomaly power spectrum $\Phi_{\Delta T}$ became,

$$\Phi_{\Delta T}(|k|) = Ae^{-2|k|Z_t}\left(1-e^{-2|k|Z_b-Z_t}\right)^2 \qquad (3)$$

with A is a constant. If the wave length much smaller than twice of magnetization source anomaly thickness, then equation (3) can be described as,

$$\ln\left[\Phi_{\Delta T}(|k|)^{1/2}\right] = \ln B - |k|Z_t \qquad (4)$$

B is a constant and $Z_b = 2Z_o - Z_t$. Power spectrum curve slope of magnetic field anomaly total on equation (4) is upper limit depth Z_t of magnetic anomaly source (Figure 1).

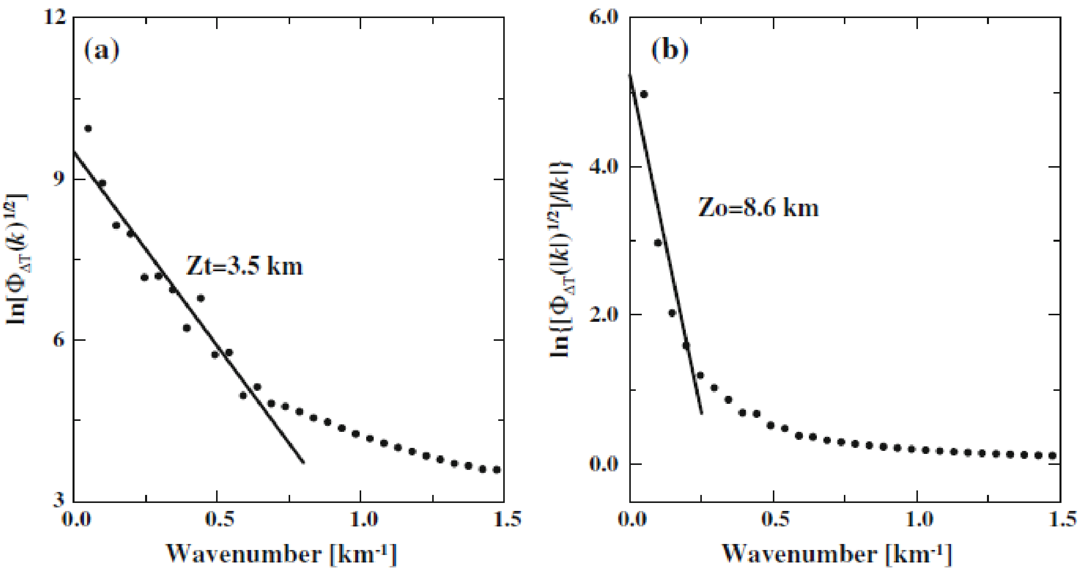

Figure 1. Power spectrum curve of magnetic anomaly data, (a). Determination of upper limit anomaly Z_t, (b). Determination of anomaly central depth Z_o (Maden 2010).

To predict the depth of Z_o central magnetic anomaly source, equation (3) can be rewritten as,

$$\Phi_{\Delta T}(|k|)^{1/2} = Ce^{-|k|Z_o}\left(e^{-|k|(Z_t-Z_o)} - e^{-|k|(Z_b-Z_o)}\right) \qquad (5)$$

where C is a constant. For large wave length, equation (5) can be differentiated to,

$$\Phi_{\Delta T}(|k|)^{\frac{1}{2}} = Ce^{-|k|Z_o}\left(e^{|k|(-d)} - e^{-|k|(d)}\right)$$
$$\approx Ce^{-|k|Z_o}2|k|d \quad (6)$$

with 2d is magnetic anomaly source thickness. Next, by taken a logarithmic form on equation (6), obtained

$$\ln\left\{\left[\Phi_{\Delta T}(|k|)^{\frac{1}{2}}\right]/|k|\right\} = \ln D - |k|Z_o \quad (7)$$

D is a constant. Based on magnetic anomaly power spectrum curve slope on equation (7), central depth (centroid) of magnetic anomaly Z_o can be predicted. Meanwhile, lower limit depth of Z_b magnetic anomaly can be calculated from the relation of,

$$Z_b = 2Z_o - Z_t. \quad (8)$$

Next, determination of thermal flow can be calculated based on Maden (2010) description as,

$$q = \lambda\frac{dT}{dZ} \quad (9)$$

q is thermal flow and λ is thermal conduction coefficient

If assuming that temperature gradient $\frac{dT}{dZ}$ is constant. Curie temperature (θ) can be determined based on value (Z_b) and geothermal gradient $\frac{dT}{dZ}$ such as,

$$\theta = \left[\frac{dT}{dZ}\right]z_b \quad (10)$$

Equation (10) usage were based on assumption that surface temperature was 0°C and there was no heat releasing from the source (CPD) to surface. In consequence, equation (9) and (10) resulting a relation between CPD and thermal flow (q) in form of,

$$q = \lambda\left[\frac{\theta}{z_b}\right] \quad (11)$$

Equation (11) showed the inverse relation of CPD with thermal flow (Stampolidis et.al., 2005)

3. Result and Discussion

Sumatera fault occurred because of the clash between Indo-Australia plate and Eurasia plate along more than 1600 km, started from southern Sunda strait until northern Andaman Sea (Genrich 2000). Bukit Barisan mountains as product of Sumatera fault created geothermal prospect areas (Hermawan and Rezky 2010). The uplift along Bukit Barisan mountains on Middle Miocene resulting volcanic mountains product, which also followed with granite and diorite intrusion. On Pliocen-Plistosen period, magma activities on this area resulting basaltic, andesitic, and dalsit rocks, and also geothermal system (Mulyadi 1995).

Generally, Sumatra tectonic areas formed by Indo-Australia and Eurasia plate subduction that emerged large magmatic arc on Bukit Barisan mountains that started since Early Permian (Cameron, 1980 dalam Amin dkk., 1994) or Mid-Late Permian (Katili 1969, 1972, 1981; Gafoer 1990 dalam Amin dkk., 1994).

Research area that lies on magmatic arc composed of pre-Mesozoikum metamorf, Mesozoikum and Kenozoikum frozen rocks, the crumbling of Tersier – Quartener volcano, and also sediment above it. The movement along Sumatera fault varies from 45-60 mm/year on northern Sumatera to only 1 mm/year on Sunda Strait (Sieh and Natawijaya 2000). 2D power spectrum analysis applied on real data which is the compilation data of satelite magnetic, airborne, and marine magnetic (Maus *et al.* 2009). The next step was data extraction from that magnetic anomaly contour on southern Sumatera described on Figure (4), which covered 6⁰00’ - 0⁰00’ south latitude and 102⁰00’ - 108⁰00’ east longitude.

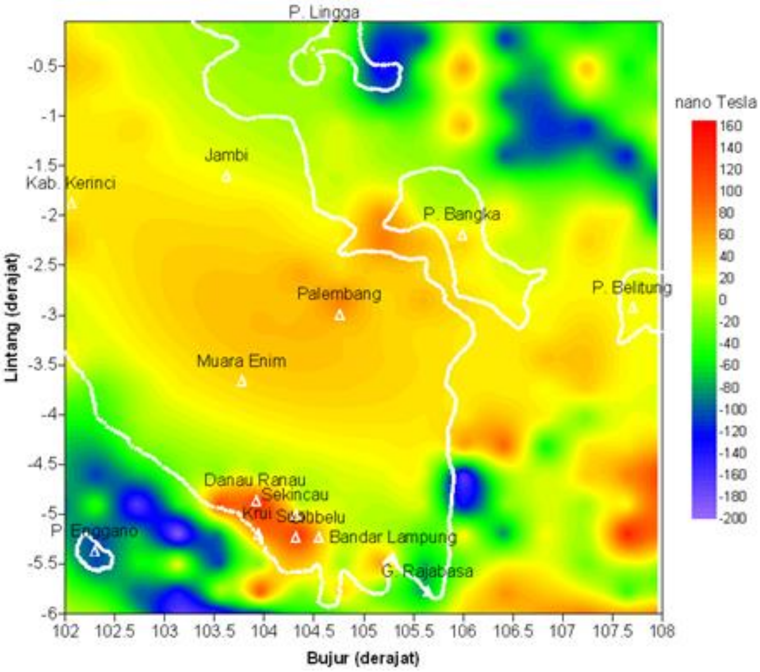

Figure 2. Southern Sumatera Dipole Magnetic Anomaly contour, contour grid 0.05^0, contour interval 25 nT, contour plane 5 km above sea level

The earth magnetic field came from the earth core through magnetohydrodynamic process. That main magnetic field inducted the rocks under the surface. Some researches concluded that magnetic rock depth lied on the meeting border of crust-mantle which is CPD (Minea and Vlad 2010). 2^0x2^0 coverage area windowing then performed from southern Sumatera dipole magnetic anomaly map (Figure 4). The windowing real data consists of 81 areas.

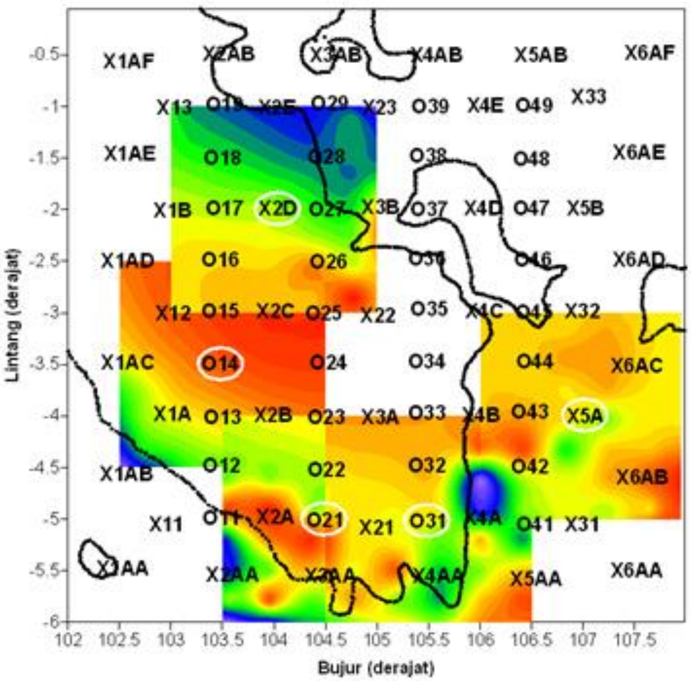

Figure 3. Window area power spectrum 2D as sample for area O14, O21, O31, X2D and X5A.

Based on windowing result, 2D radially average power spectrum calculated to get Z_t depth, Z_o depth and Z_b depth or CPD value. CPD depth obtained from radially average power spectrum logarithmic curve calculation using least-square fitting method that described by Dolmaz (2005). This method performed in three steps; (1). Square windowing with area overlapping for 2D power spectrum, (2). Radially average power spectrum logarithmic calculation on each area, (3). Z_b CPD depth estimation of each area according to Z_o centroid depth and Z_1 upper limit depth on each area. By modifying equation (4), magnet anomaly Z_t upper limit depth can be calculated from 2D radially average power spectrum logarithmic curve.

$$\ln[power] = lnB - |f|Zt \tag{12}$$

while Z_o magnet anomaly centroid depth obtained from,

$$\ln[(Power)/|f|] = lnD - |f|Zt \tag{13}$$

f is wavenumber (km^{-1}). For Z_b CPD depth calculated using equation (8)

Radially average power spectrum was radially shifting logarithmic power spectrum 2D averaged curve . The curve slope of radially average power spectrum 2D related with magnetic anomaly source depth under the surface. These are depth calculation result of *radially average* power spektrum logarithmic curve from couples of window area.

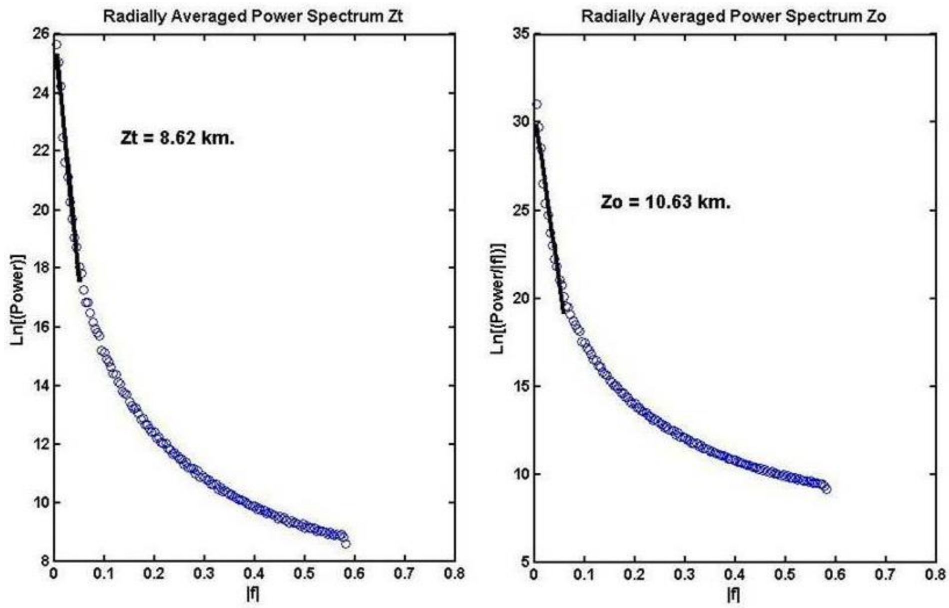

Figure 4. *Radially average* power spectrum window area O21. Z_t=8.62km., Z_o=10.63km and Z_b=12.64km

Z_b depth calculation result obtained from logarithmic curve slope then plotted in form of contour map. These Figures showed contour depth or CPR and thermal gradient value on southern Sumatera area.

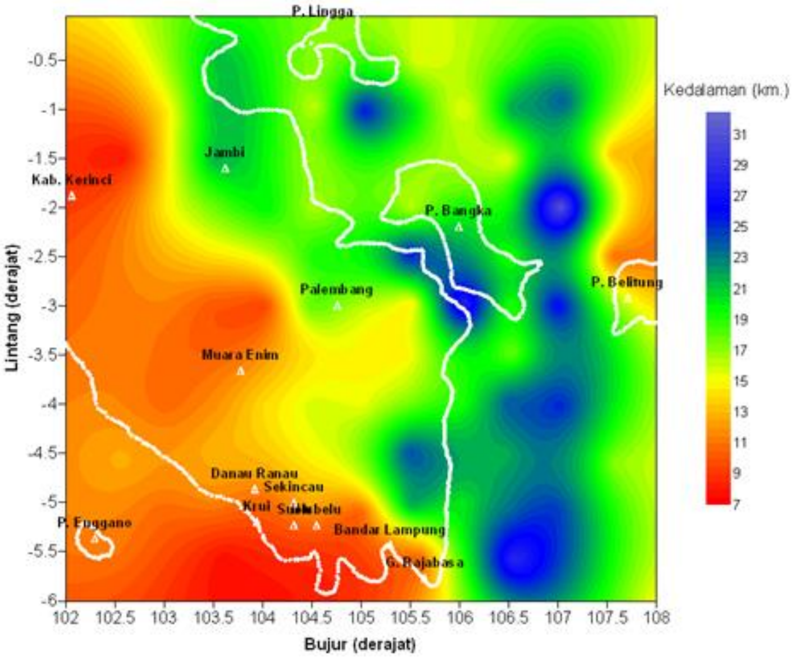

Figure 5. Southern Sumatera CPD depth contour. Contour Grid 0.05^0, contour interval 0.5 km, contour plane elevation zero km on mean sea level.

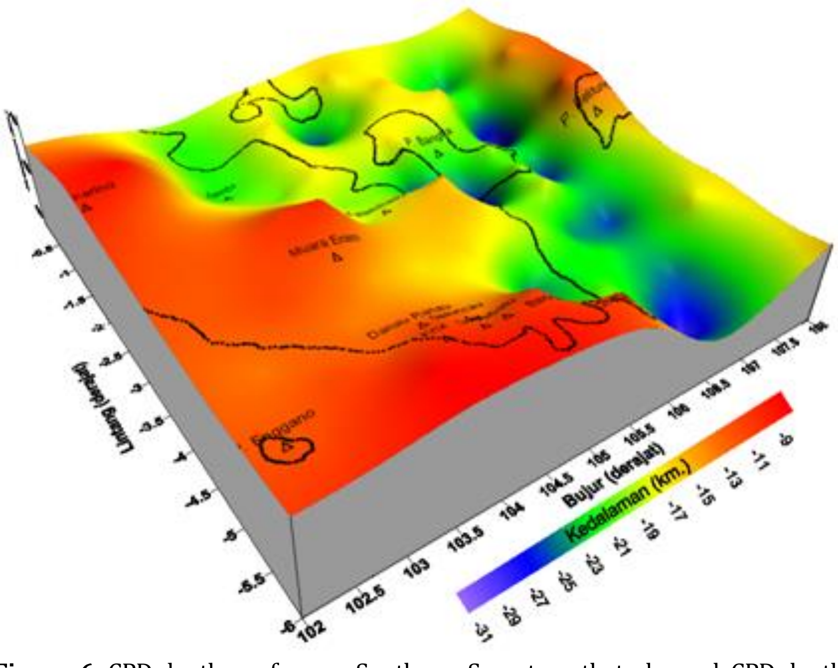

Figure 6. CPD depth surface on Southern Sumatera that showed CPD depth increasing on to East direction

Based on the calculation of radially averaged power spectrum logarithmic curve on research areas, magnetic anomaly CPD depth divided into three depth categories, shallow (8–15km), moderate (15–25 km) and deep (25–32 km).

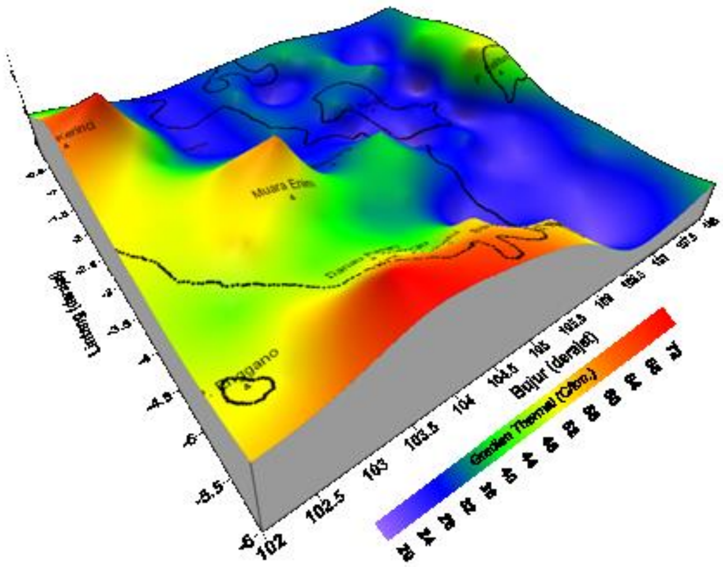

Figure 7. Southern Sumatera thermal gradient anomaly surface that showed thermal gradient decreasing on to East direction.

Thermal gradient anomaly surface showed similar pattern to CPD depth. The thermal gradient on research area has high value on shallow CPD area (40-75 ^{0}C/km). Tendency of thermal gradient value relatively decreasing on to east direction of research area.

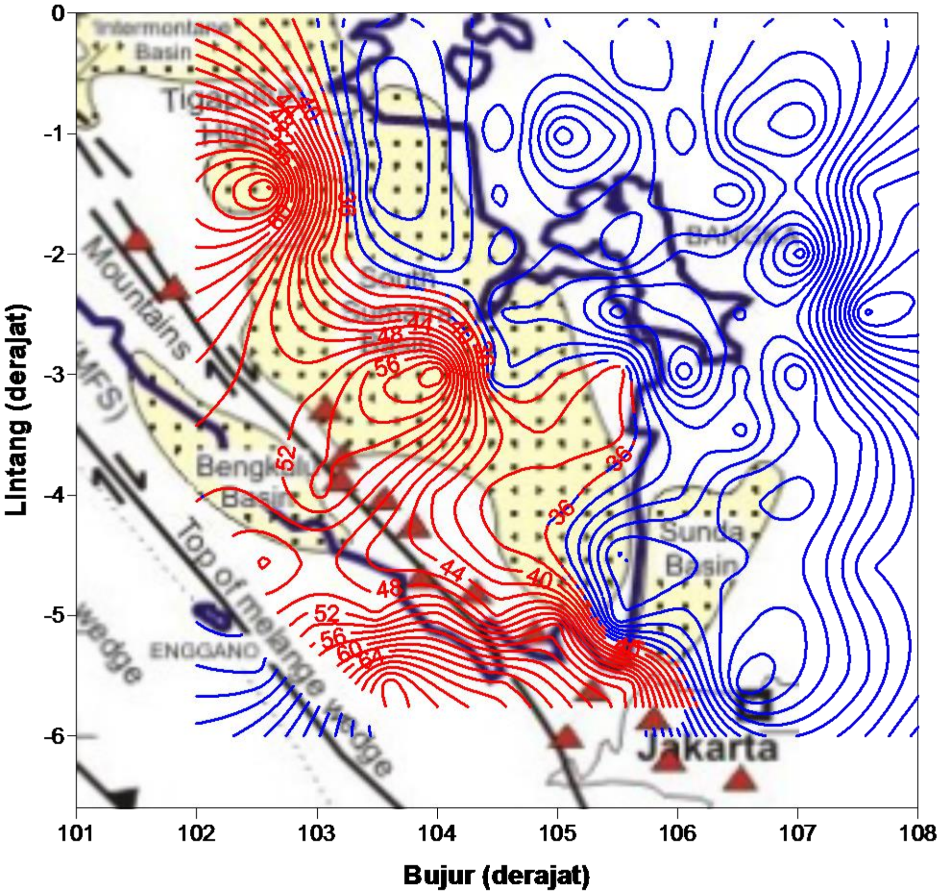

Figure 8. Thermal gradient anomaly overlay and southern Sumatera geology map. Red contour line represent 40-75^{0}C/km thermal gradient while blue line represent less than 40^{0}C/km thermal gradient.

Thermal gradient anomaly overlay result of Southern Sumatera geology map showed tendency of high thermal gradient value along the magmatic arc area.

4. Conclusion

Thermal gradient analysis result obtained from CPD variation informed that high thermal gradient value (40-75^{0}C/km) has shallow CPD depth (8-15 km). Geologically, the area along Sumatra island magmatic arc, which is a product of Sumatera fault system, has a high thermal gradient anomaly. Based on these informations, this area considered as an potential geothermal prospect area.

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