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The Most Preferable Gravity and Magnetic Survey Design for Medium Enthalpy Geothermal Field. Case Study: X Geothermal Field, Philippines

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ABSTRACT

Geophysical methods such as gravity and magnetic can be used to figure out permeable zone (reservoir) at geothermal field. Several survey designs of gravity and magnetic methods at X geothermal field had been applied to determine the most preferable result at medium enthalpy geothermal field. Two types of gravity design survey are based on the interval of the nearest station points: the first is 250m and the second is 500m. The first magnetic design survey is based on line survey meanwhile the second magnetic design survey is using gravity grid with interval 250m. The interval of 250m design survey at gravity is better for resolution than 500m design survey. The result for line survey at magnetic method is more suitable for mapping local anomaly, while the grid design survey is more suitable for regional mapping.

INTRODUCTION

Geothermal system is an earth natural heat transfer process from heat source into heat sink (Manfred P. Hochstein 2000). This system can be classified into three types based on the temperature at one kilometer depth (**table 1**). According to Hochstein (2000), intermediate temperature geothermal system have medium enthalpy that still can be used as a geothermal power plant with natural output about 30 MW maximum. Surface manifestation that discharge on medium temperature geothermal system are usually neutral hot springs, minor heat transfer warm ground, occasionally neutral hot pools, concealed outflows and seepages. Those surface manifestations are occurs because of the availability of good permeability at subsurface. The permeability is the main cause of rocks at subsurface to transmit fluid that related with two parameters (Patrick Ledru 2010). The first parameter is rock porosity which means the ratio of pore volume to the total volume of rocks. This type of permeability parameter measure of the fluid flow through the pore network of the rocks. The second is the fracture permeability that are present within rocks along which fluid circulation is possible. The potential of reservoir at geothermal system can be determine by both types of permeability. The exploration program objectives should accomplished several things (DiPippo 2007) and one of the most important thing is the permeable of subsurface formation.

Table 1. Geothermal Classification Based On Temperature.

Temperature	Geothermal Sys.	Natural Output
> 225 °C	High Temp.	30 – 300 MW
125 °C - 225 °C	Intermediate	3 – 30 MW
< 125 °C	Low Temp.	0.1 – 3 MW

Geophysical survey has been conducted at the geothermal filed prospects to determined information about condition of the reservoir such as permeability (David Bruhn 2010). Potential methods that can be used for determines permeability are potential methods such as gravity and magnetic method. Gravity method are used to measure differences in density and their lateral extent in the subsurface. Negative anomalies at gravity data results can be interpreted as higher porosities or highly fractured parts of rocks that provide potentially interesting permeability. Faults also can be traced because they usually display a distinct density change with a well-defined linear zone (David Bruhn 2010). On the other hand, magnetic surveys measure changes of earth's magnetic field. For regional exploration, magnetic measurements can be important for interpreting the tectonic setting. Those are two types of potential methods that frequently used at geothermal fields. The most important things is potential method survey design have to be suitable with the need of geothermal prospecting.

MEDIUM ENTHALPY GEOTHERMAL SYSTEM

Medium enthalpy geothermal system refer to geothermal system that have temperature about 125°C - 225°C at about one kilometer depth (Manfred P. Hochstein 2000). For geothermal power plant, the potential of this geothermal system can be estimated from its natural output which is at range about 3 MW – 30 MW. The system itself occur in many geological and hydrological settings. The most intermediate temperature geothermal prospect not directly related by active volcanoes, but derive their energy from deeply penetrating meteoric water that flow like "sweeps" heat from hot upper crust to discharge area. There are a few intermediate temperature that located in active and inactive volcanic arcs. Some of the geothermal prospects are high temperature geothermal system that waning through time into intermediate temperature geothermal system. Some of them just happens because of minor heat transfer from deep heat source (Manfred P. Hochstein 2000).

Characteristic features of intermediate temperature prospects are all prospects have liquid dominated system. Fumaroles and steaming ground that often occur at high temperature prospects are absent here. On the other, boiling springs can be occur in some prospects although their maximum discharge temperature are usually below boiling point. Surface manifestation that usually present at intermediate prospects is neutral hot spring that have major heat transfer (Manfred P. Hochstein 2000). Those surface manifestations are occurs because of the availability of good permeability at subsurface. The permeability is the main cause of rocks at subsurface to transmit fluid that related with reservoir and discharge/recharge zone.

GEOPHYSICS SURVEY DESIGN

Five things a geothermal exploration should accomplish (DiPippo 2007):

- Locate areas underlain by hot rock.
- Estimate the volume of the reservoir, the temperature of the fluid in it, and the permeability of formation.
- Predict whether the produced fluid will be dry steam, liquid or a two-phase mixture.
- Define the chemical nature of the geo-fluid.
- Forecast the electric power potential for minimum 20 years.

Permeability as the second thing that should be accomplish by exploration strategies can be defined by porosities and fault structure. Fault structure itself can be determined by geology (surface) and geophysics (subsurface). Geophysics method that can be used to mapping the permeability of a geothermal fields is potential method such as gravity and magnetic. Those methods usually conducted as the preliminary method to reconnaissance geothermal prospect. To make the reconnaissance process more effective and efficient, survey design for potential methods should be prescribe.

Gravity measurements are used to determine differences in density and their lateral extent. Positive anomalies of gravity data results are associated with young intrusions (< ~1Ma) and also deposition of silicates from hydrothermal activities. Meanwhile, negative anomalies are associated higher porosities or by highly fractured parts of rocks and also faults that usually display a distinct change in density across a well-defined linear zone (David Bruhn 2010). This mean the exploration of permeability can be determine by negative anomalies of gravity. The most gravity design survey that always be used is grid design which distinguished just by its resolution. The resolution mean its spacing from one observed gravity station to another station. Regional gravity surveys usually have about 500m – 1km observed station interval, but for more detailed surveys the intervals are less than 500m.

Magnetic surveys measure changes of the earth's magnetic field at the observed area. The magnitude of a magnetic anomaly depends on orientation/position of the magnetic structure in subsurface and the latitude location. The latitude location can cause bipolarity of data that become more complex to interpret (David Bruhn 2010). Processing bipolarity onto monopole can be a better step to make it simpler. For regional exploration, magnetic measurements can be important for understanding the tectonic setting. There are two design surveys that often used for magnetic method, line survey and grid survey. Line survey usually used for exploring faults and another geometric shape with more detail resolution. Grid survey usually used to mapping regional magnetic anomalies.

CASE STUDY: X GEOTHERMAL FIELD

There is a medium enthalpy geothermal system at X geothermal field that located in Philippines. Reconnaissance steps was conducted at this geothermal area to accomplish five exploration objectives by DiPippo (2007). Permeability was observed by geology study (**figure 1**) and geophysics using potential methods.

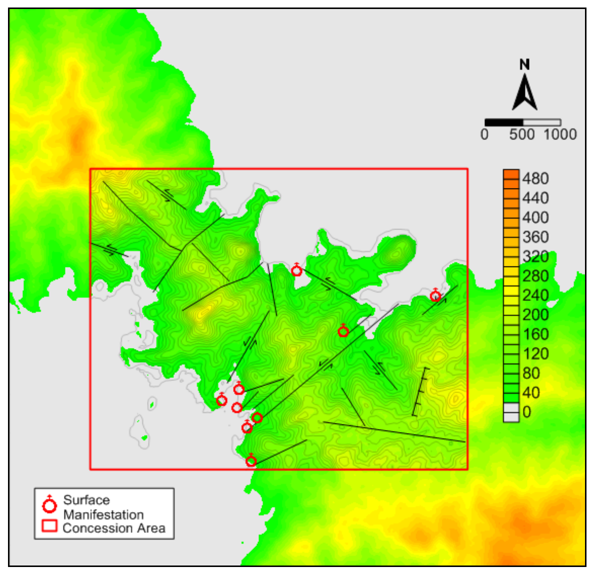

Figure 1. Geothermal Concession Area with Surface Manifestation and Fault Structures.

Geophysics exploration conducted at X geothermal field to confirmed surface structure that prescribe by geology study. Gravity survey was design by two station intervals. The first one is interval of 500m (**figure 2**) and the second one is interval of 250m (**figure 3**). Those intervals were conducted to study the preferable design at medium enthalpy geothermal system to determine permeability zone by fault structure. Magnetic survey was conducted by two survey designs, line survey (**figure 8**) and grid survey (**figure 9**). The objective of magnetic survey is similar with gravity method.

GRAVITY

The first design for gravity method is 500m station's intervals. 65 stations placed prevalent at concession area. Some of the gravity station located outside of the land as seen on the figure 2. Actually, none of gravity station that placed outside the land, this is just because the resolution of SRTM map that used at this figure

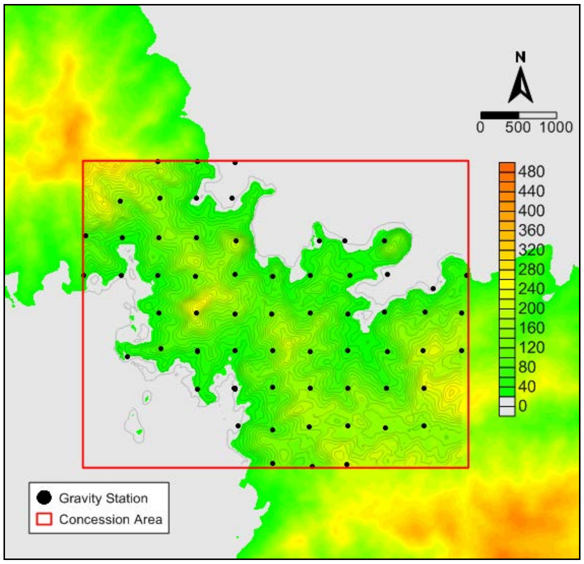

Figure 2. Gravity Station with 500m Interval.

The second gravity design is 250m station's intervals with 260 observed stations.

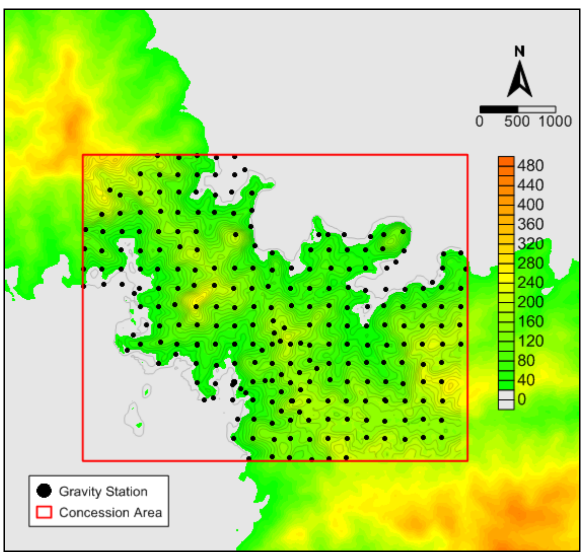

Figure 3. Gravity Station with 250m Interval.

GRAVITY PROCESSING

The first step of gravity processing is to get Complete Bouguer Anomaly (CBA) with all factor correction until terrain correction. CBA map of 250m (**figure 4**) and 500m (**figure 5**) were displayed along fault structure that studied by geology.

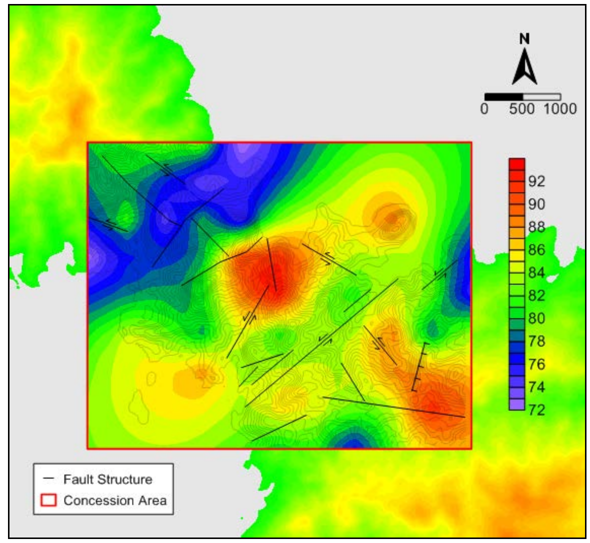

Figure 4. CBA of Gravity with 500m Interval.

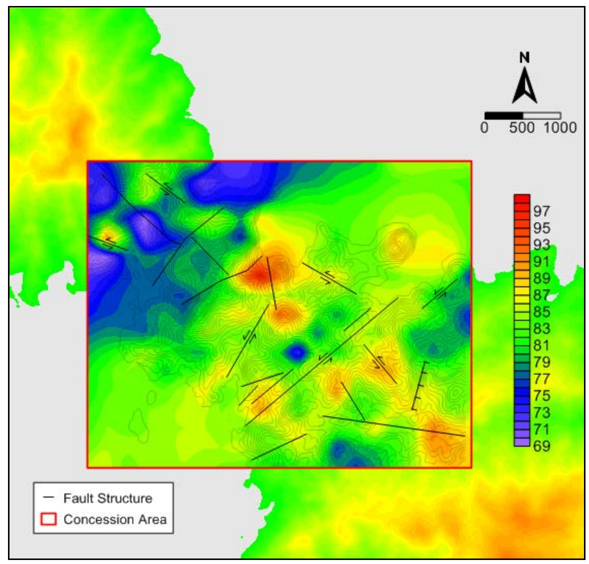

Figure 5. CBA of Gravity with 250m Interval.

Fault structure mostly confirmed by 250m station's interval. The next step is to get residual map of CBA gravity. This residual map calculated using Butterworth filter.

$$L(k) = \frac{1}{[1 + (\frac{k}{k_o})^n]}$$

The Butterworth filter function (n) that used at 500m and 250m station's intervals was 8, and the wavenumber (k) that used at 500m and 250m station's intervals was 0.6.

Residual map of 500m (**figure 6**) did not shown significant anomalies that can confirmed fault structure at subsurface. But for regional mapping, interval 500m can be used to delineating high densities and low densities that can be interpreted as anomalies in geothermal.

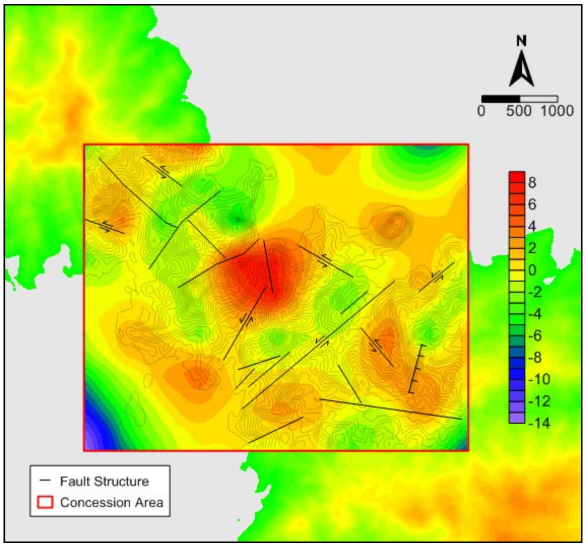

Figure 6. Residual of Gravity with 500m Interval.

On the other hand, residual map of 250m (**figure 7**) can be used already to mapping fault structure because of the resolution. Some of surface structure can be confirmed by residual map of 250m. If we decrease station interval, it will increase the data resolution and can be used to mapping local structures.

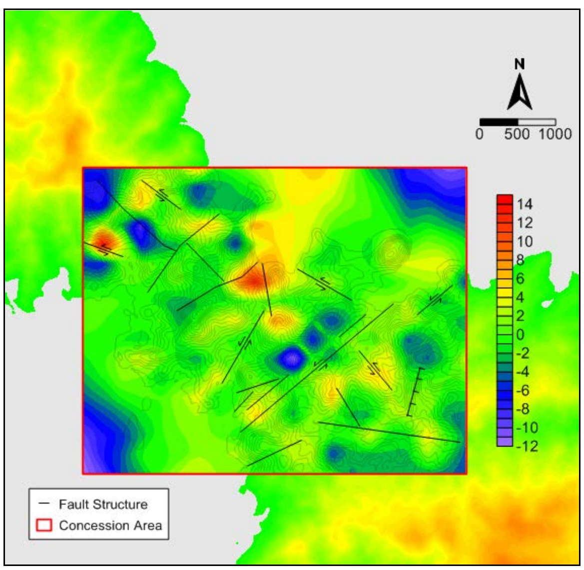

Figure 7. Residual of Gravity with 250m Interval.

Efficiently, interval of 250m can be used to mapping local structure already, but it will be better if the interval of the station smaller to gain more resolution.

MAGNETIC

Magnetic survey was conducted by two survey designs, line survey and grid survey. The line survey using 11 lines NW-SE and 1 line NE-SW with 5m interval from one reading to another reading (**figure 8**). Grid survey using 244 point observations with 250m station's interval (**figure 9**).

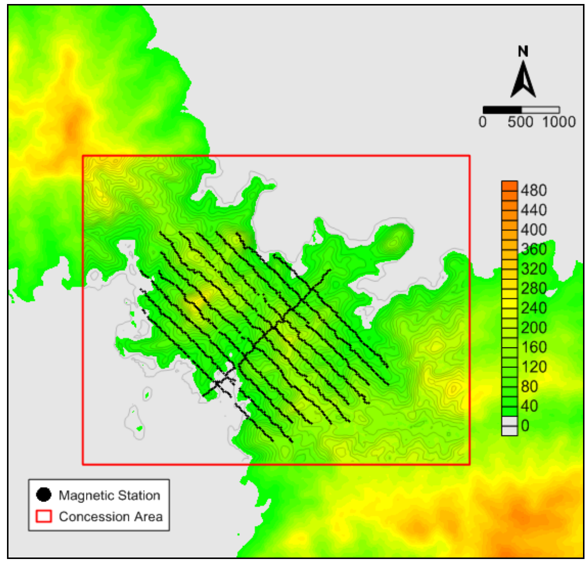

Figure 8. Magnetic Line Survey.

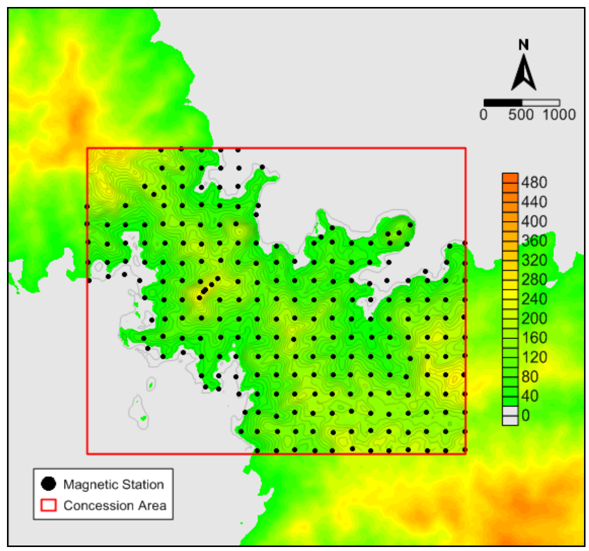

Figure 9. Magnetic Grid Survey.

MAGNETIC PROCESSING

All of magnetic data that conducted at X geothermal field then processed with corrected by base data. Line survey (**figure 10**) showing good resolution better than grid survey (**figure 11**).

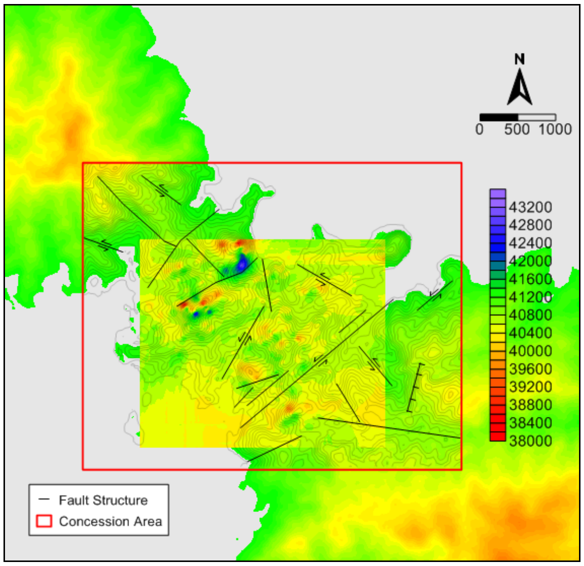

Figure 10. Total Magnetic (Line Survey)

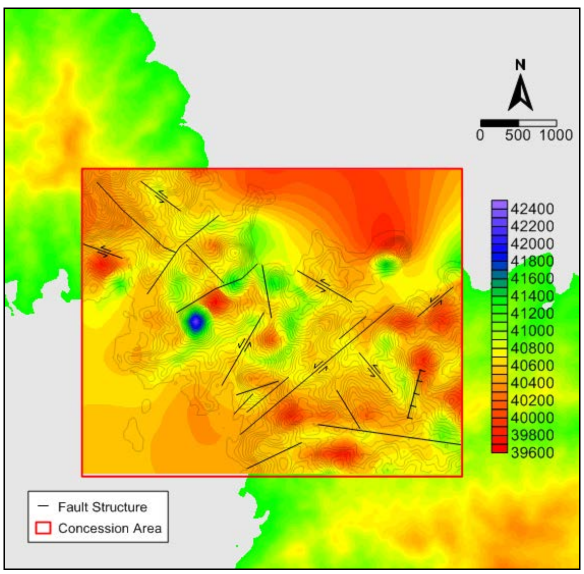

Figure 11. Total Magnetic (Grid Survey)

The next step is processing bipolarity onto monopole using analytic signal. The analytic signal or total gradient is formed through the combination of the horizontal and vertical gradients of the magnetic anomaly. Analytic signal can be used as reduce to pole processing to simplify interpretation.

Line survey at magnetic (**figure 12**) showing better resolution than grid survey (**figure 13**). Some of surface structure can be confirmed using line survey map. Grid survey did not shown significant anomalies that can confirmed fault structure at subsurface. But for regional mapping, magnetic grid survey can be used to delineating low magnetic that can be interpreted as alteration process by hydrothermal activities that can decrease magnetic susceptibility of rocks.

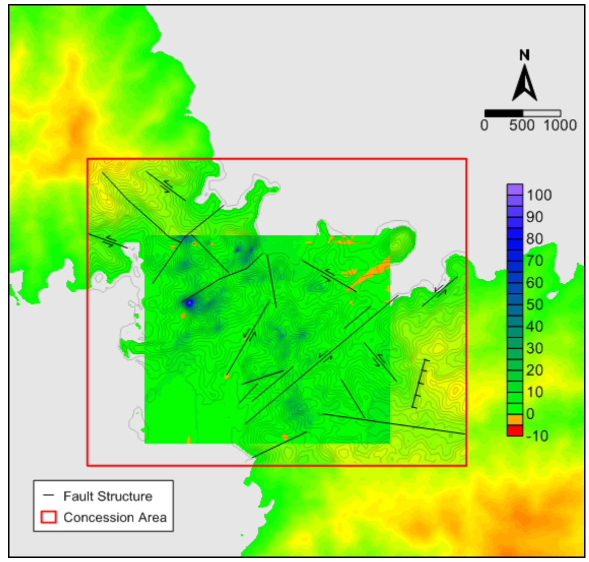

Figure 12. Analytic Signal (Line Survey)

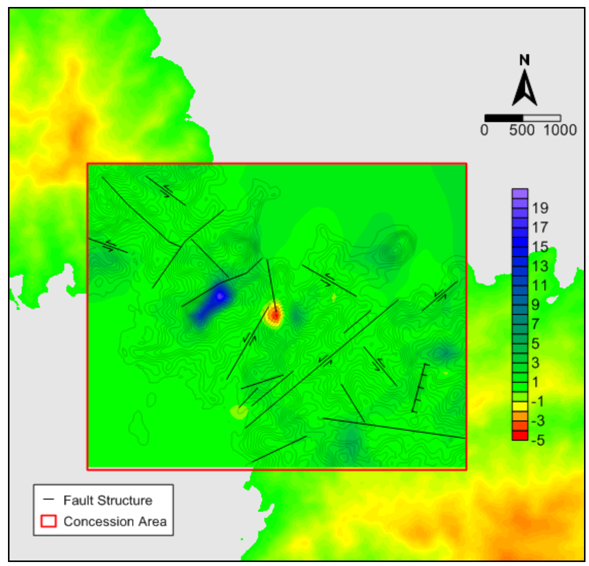

Figure 13. Analytic Signal (Grid Survey)

CONCLUSIONS

Several survey designs of gravity and magnetic methods at X geothermal field had been applied to determine the most preferable result at medium enthalpy geothermal field. Two types of gravity design survey are based on the interval of the nearest station points: the first is 250m and the second is 500m. The interval of 250m design survey at gravity is better for resolution than 500m design survey, if exploring the fault structure is the objective. Regional reconnaissance is not necessary for using 250m interval, interval of 500m is already good enough. The first magnetic design survey is based on line survey meanwhile the second magnetic design survey is using gravity grid with interval 250m. The result for line survey at magnetic method is more suitable for mapping local anomaly because produce better data resolution, while the grid design survey is more suitable for regional mapping.

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