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Horizontal Derivative from Gravity Data as a Tool for Drilling Target Guide in Wayang Windu Geothermal Field, Indonesia

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ABSTRACT

The density of the gravity survey points allows "horizontal derivative" filtering to be applied to the complete Bouguer anomaly (CBA) data. The horizontal derivative process produces maximum ridges over the contacts between different density body blocks. The image produced by the horizontal derivative algorithm shows some agreement to the known productive area which lies in the vicinity of the maxima of the horizontal derivative. The horizontal derivative maximum does not correspond well to the known fault pattern. It may possibly indicate the location of the margins of intrusive bodies or major volcanic facies changes.

1. INTRODUCTION

The Wayang Windu (WW) geothermal field is located in West Java Indonesia, at a distance of about 150 km SE of Jakarta, Indonesia (Figure 1). Currently the installed capacity is 220 MWe. The field has been intensively explored, with a total of 39 wells drilled, including production, reinjection and slim hole exploration wells. Several geophysical surveys have been performed including magneto telluric (MT) surveys with 1 km spacing interval, gravity surveys which in places reaches 1 km station density, microearthquake (MEQ) survey and formation imaging well logs.

The Wayang Windu geothermal system, associated with the Malabar, Wayang and Windu volcanic centers, is interpreted to be transitional between vapor-dominated and liquid-dominated. Deep wells encounter liquid reservoir with the top, prior to production, from 0 to 400 m asl (above sea level), which becomes progressively deeper toward the south. It is overlain by three separate vapor-dominated reservoirs, which become progressively shallower to the north, where the top of the reservoir is at 1150 m asl.

The Wayang Windu volcanic setting is identified as an active geothermal system, characterized by the presence of volcanic center and series of intrusion as heat sources. Indications of geophysical features representative of intrusion bodies were derived from the combination of MT and gravity, and then validated by well information. This suggested the occurrence of microdiorite or andesite porphyry dykes. There is also a mineralogy study, reporting the presence of high temperature mineral, identified as amphibole zone in deeper part (Abrenica *et al.*, 2009).

In general, the vicinity of the margin in between the intrusion body and surrounding rock is susceptible to fracturing. They are radial and concentric with high angle in the late stage of fracture development. A hydrothermal system was then developed around intrusive bodies after deep penetrated meteoric water reaction with hot intrusion bodies and stimulated a convective flow circulation through this clustering of permeable zone.

Figure 1: Location of Wayang Windu Geothermal field in West Java, Indonesia.

The horizontal derivative of potential field data is a technique used to enhance data. By taking the derivative along the x and y axis, this enhancement aims to define the anomalous body boundary and to separate with other anomalies through the relevance of analytical calculation. The calculation is achieved by comparing gravity profiles or contours, as the slope or rate of change of gradient with horizontal displacement, since the sharpness of a gravity profile is an indication of the depth of the anomalous mass.

This paper outlines the application of gravity information to understand how the fracture zone is related to intrusion bodies. This study utilizes enhanced horizontal derivative analysis, integrated with fracture information from wellbore data, combined with other geophysical surveys to delineate a prospect area for well targeting.

2. GRAVITY SURVEY AT WW

Gravity surveys have been conducted regularly at WW since exploration stage. The initial survey was carried out by Unocal Geothermal Indonesia in 1982 with 76 stations, and then followed up by Pertamina in 1985-1986 which carried out 256 stations. Low density spacing of stations and coverage area caused low resolution results and difficulties in interpretation. Unocal then carried out a microgravity survey in 2002 which was continued by Star Energy in 2008 which carried out a re-measurement of microgravity survey and systematically gridding gravity survey with high density spacing, for around 250 m - 1 km spacing and larger coverage area. This survey consists of 135 additional stations and extended the area to the unexplored piece in the northern part of the Wayang Windu Geothermal field. The survey was completed in the end of 2008. Data was gained with very good quality and showing higher resolution resulst. All gravity data were analyzed to derive the final structural gravity map.

The complete Bouguer anomaly was calculated for all stations, employing:

a. the 1980 formula,

b. terrain corrections to 50km radius,

c. reduction in densities of 2.00, 2.20, 2.40 and 2.60 g/cc.

d. The Bouguer anomaly shows a regional high to the west and southwest, this positive anomaly persists at all reduction densities, and cannot be considered an artifact of the topography vs reduction density alone. The main features are relative gravity high in the south and west with decreasing gravity towards the NE. The gravity then increases again to a cluster of anomalies around the cluster in the middle area which shows SE-NW/NNW trending area prior to significant decrease again in north east and east area. This feature then indicates a significant regional structure which can be interpreted as high density bodies around Gunung Wayang and Windu. These gravity features are interpreted as expression of buried intrusive bodies, while more a attractive anomaly present in the northern area around the Malabar complex (Figure 2).

To assess significant local anomalies, separation of regional from residual geophysical data was performed to enhance localized anomalies (Figure 3). The residual gravity values around the Malabar complex are clearly defined as high anomalies, while in the southern part of Wayang Windu and Bedil regional pattern still show more localized values. Most trends of anomalies are more clearly defined based on residual features. In the northern area, residuals show two peak anomalies, those indicate shallow anomalies.

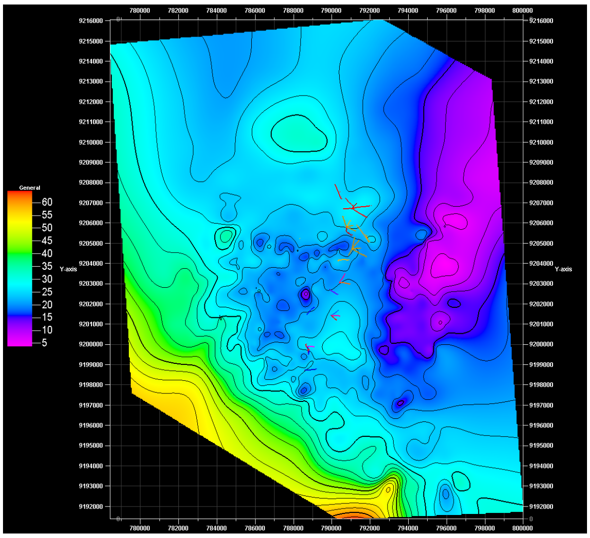


Figure 2: Complete Bouguer anomaly in mgal of Wayang Windu Geothermal field overlie by well trajectory in mgal.

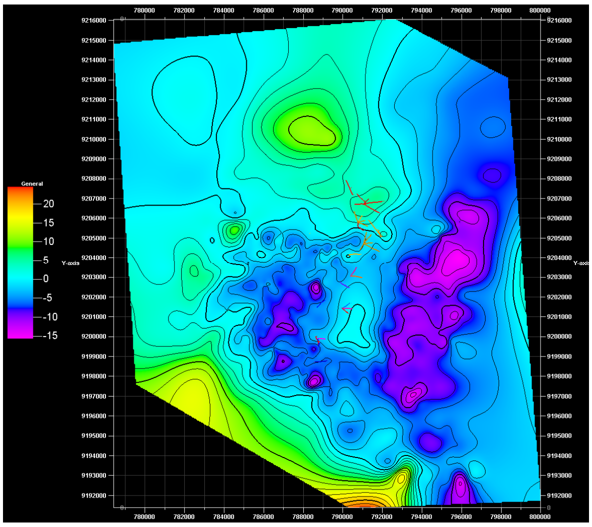


Figure 3: Residual Bouguer anomaly in mgal of Wayang Windu Geothermal field using polynomial 3 overlie by well trajectories.

3. STRUCTURAL MODELING

To examine the gravity models in relation to the 3D, MT modeling carried out by Geosystem in 2009, the residual gravity anomaly is overlain on the 3D MT resistivity. General positive correlation gravity high is modeled straight thorough the high, showing how the required dense body also corresponds to the 3D MT resistivity high. Modeling was carried out using WinGLink's 2.75-D software, allowing the use of up to the limit of body strike length (3 km in the case of the modeled Malabar complex intrusive stockwork) (Figure 4).

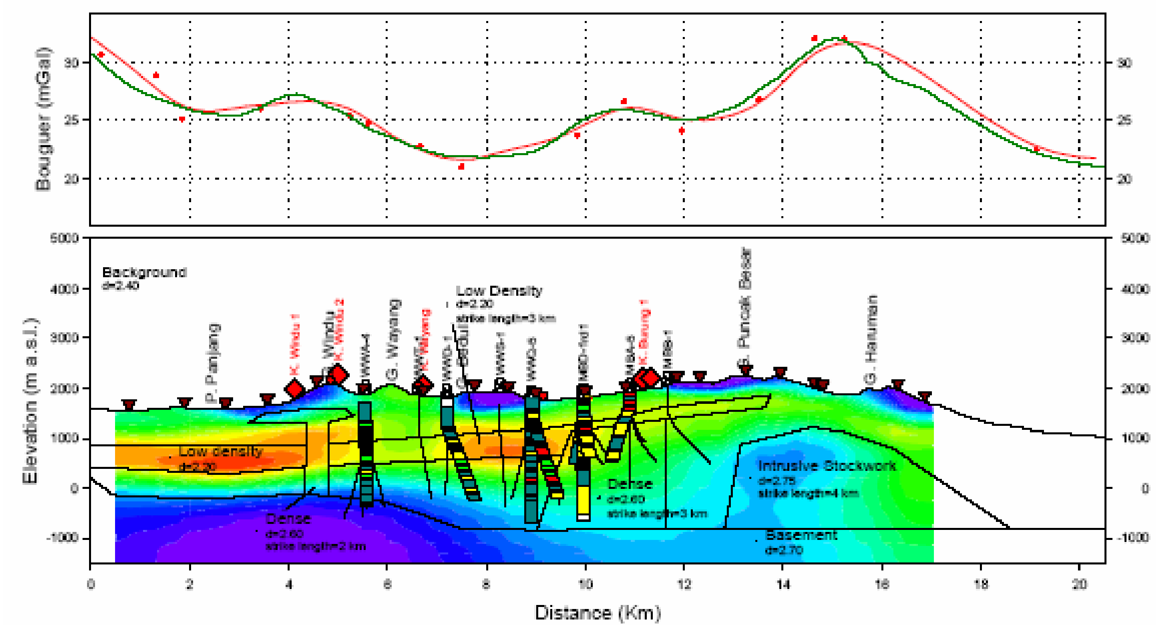


Figure 4: Gravity modeling of Bouguer anomaly combined with resistivity MT.

3. HORIZONTAL GRADIENT

Blakely (1995) stated that the horizontal gradient of gravity anomaly caused by a tabular body tends to overlie the edges of the body, if the edges are vertical and well separated from each other. The biggest advantage of the horizontal gradient method was its low susceptibility to the noise in the data, because it only requires the calculation of the two first-order horizontal derivatives of the field (Phillips, 1998). The method also has robust delineation, either shallow or deep, in comparison with the vertical gradient, which is useful only for the shallower structures. The amplitude of the horizontal gradient (Cordell and Grauch, 1985) is expressed as:

$$HG = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \qquad (1)$$

Where ($\frac{\partial g}{\partial x}$ and $\frac{\partial g}{\partial y}$) are the horizontal derivatives of the gravity field in the x and y directions. The horizontal gradient amplitude of the complete Bouguer anomaly data of the Wayang Windu area was computed and illustrated in Figure 5.

Contrast in between high gradient values and low gradient values were observed as scattered, and the pattern of high gradient anomalies is broad, but overall localized middle values are defined. Referring to Grauch and Cordell (1985), the limitation of the horizontal gradient methods for gravity data is that the horizontal gradient magnitude maxima can be offset from a position directly over the boundaries, if the boundaries are not near-vertical and close to each other.

For selecting gradient values, the data have to be integrated with other information as guidance, to define gradient magnitude maxima correlated to area which are interpreted as intrusion boundaries data. MT information and well performance can be used as assistive tools as well as formation evaluation, based on other geoscientific assessment, for better interpretation.

Interesting results were found when medium high – high (0,03-0,05 mgal/m) gradient contrast values coincide with major productive area between the intrusive and the local reservoir rocks. These were interpreted from structural modeling of gravity and MT. Based on this agreement; it indicates that the geothermal areas in Wayang Windu are mostly located around intrusion boundaries especially for the deep sources.

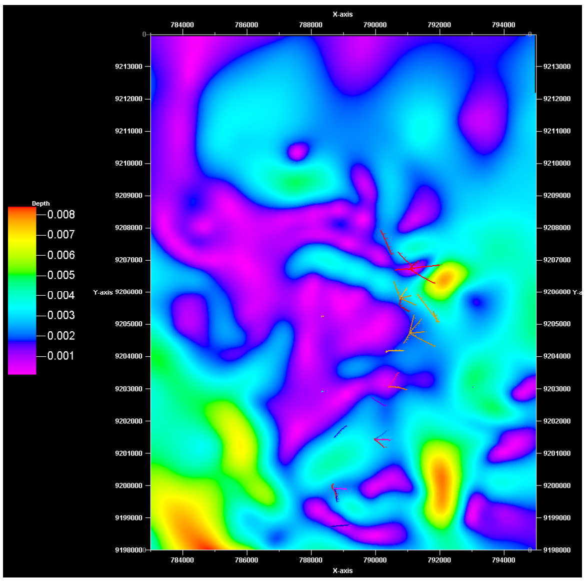


Figure 5: Horizontal derivative in mgal/m of the regional gravity data overlied with well trajectories. Mostly northern part wells as major productive well lying on 0.03-0.05 gradient values.

Integration of data with resistivity, MEQ events, and high temperature minerals show correlation between maximum gradient, which have values of 0,03 and 0,05, with the existence of MEQ cluster, and existence of high temperature minerals showing correlation with each other. (Figure 6).

This combination indicates that maximum gradient can be utilized to define fracture zones which are possibly favorable for production within the geothermal system.

Integrated horizontal gradient as a derivative analysis with other information can lead to better understanding of the geothermal system itself and especially identification of a permeable fracture area.

Permeable zones in the Wayang Windu reservoir have been identified primarily from field structural mapping including remote sensing interpretation. The fractures were then assessed based on wireline log analyses. Away from well bores, the recognition and characterization of fluid paths have been investigated using microearthquake (MEQ) analysis. The events observed during the survey time were mostly induced events triggered by injection water into injector wells through hydro-fracturing, where in 2007 the survey used MBB-1 as injector well.

The integrated information of permeable zones based on all available data combined with specific values of contrast gradient horizontal derivative profile enhances the understanding area of interest, which is interpreted as contacts between the intrusive bodies and the local reservoir rock.

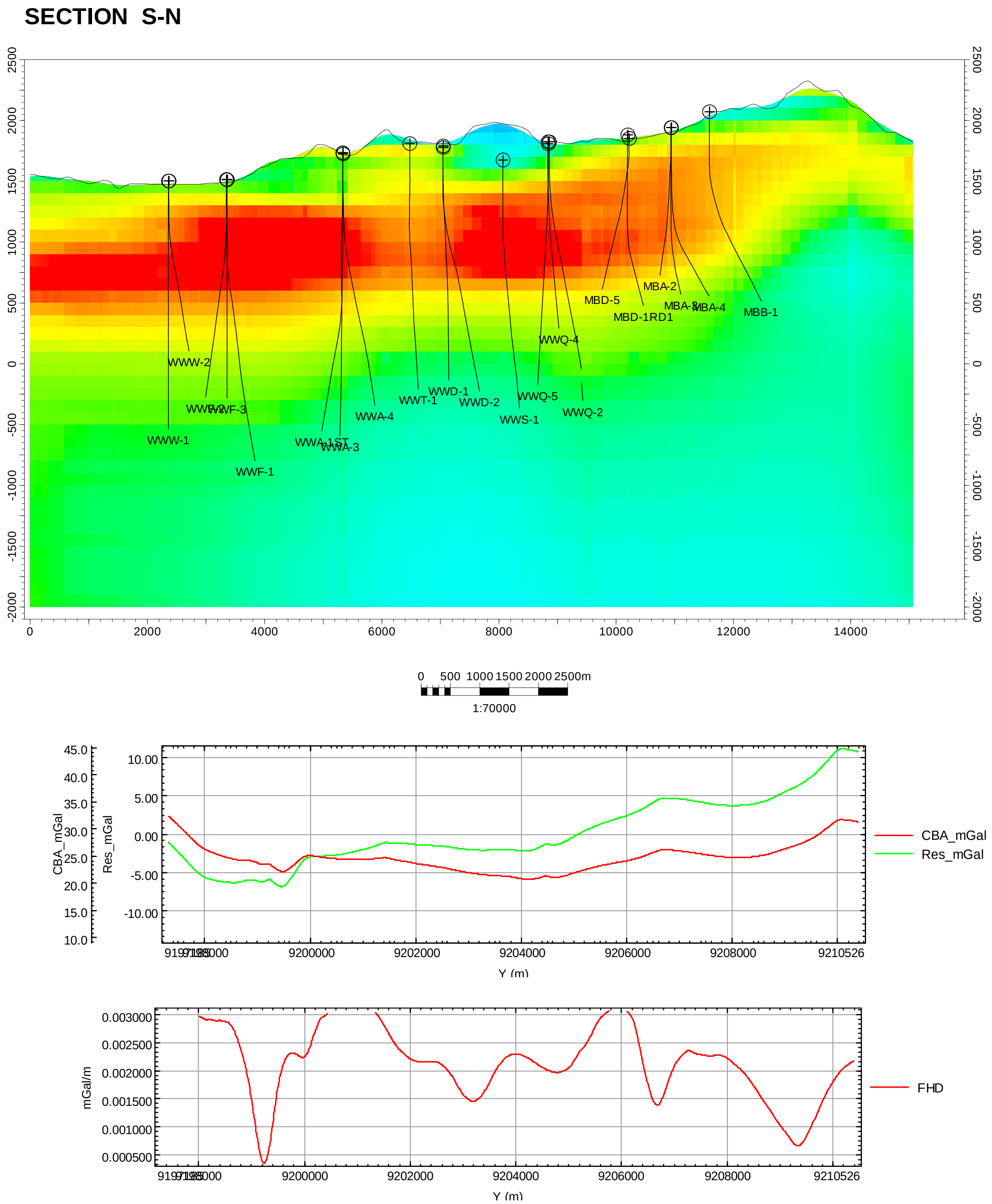
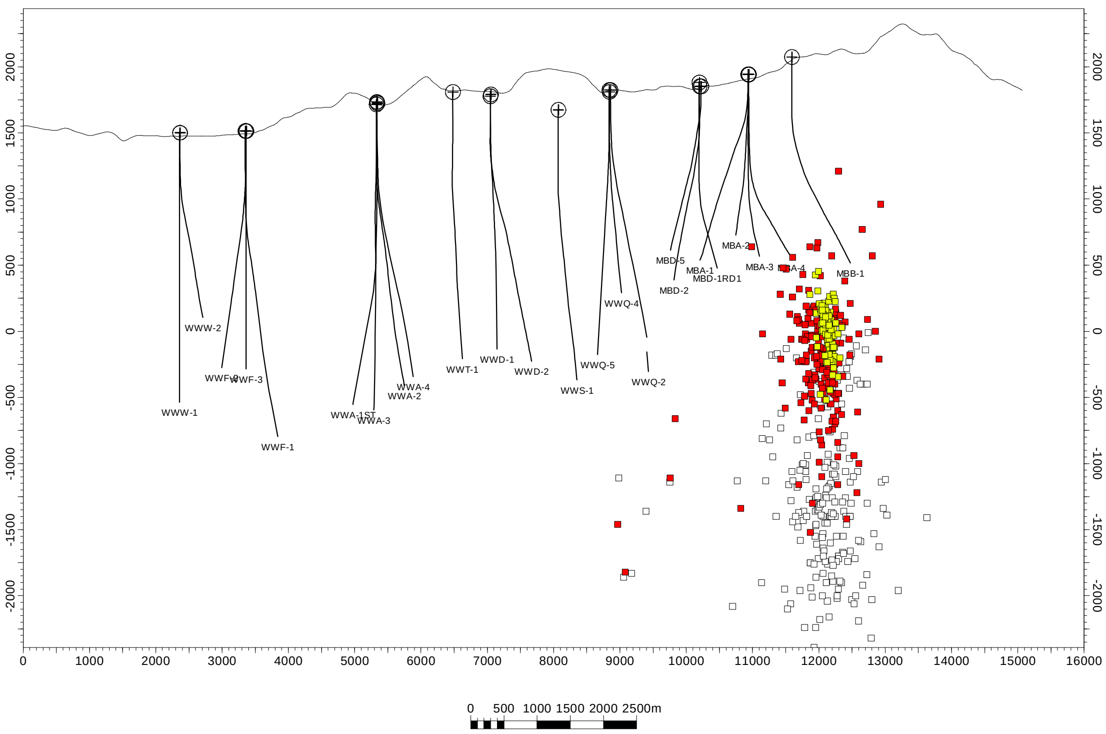


Figure 6: Integrated interpretation of resistivity, Bouguer, and residual gravity compared to MeQ event and high temperature mineral (red for amphibole, green for biotite and yellow for pyrophyllite).

MEQ Events (S-N)



High Temperature Minerals

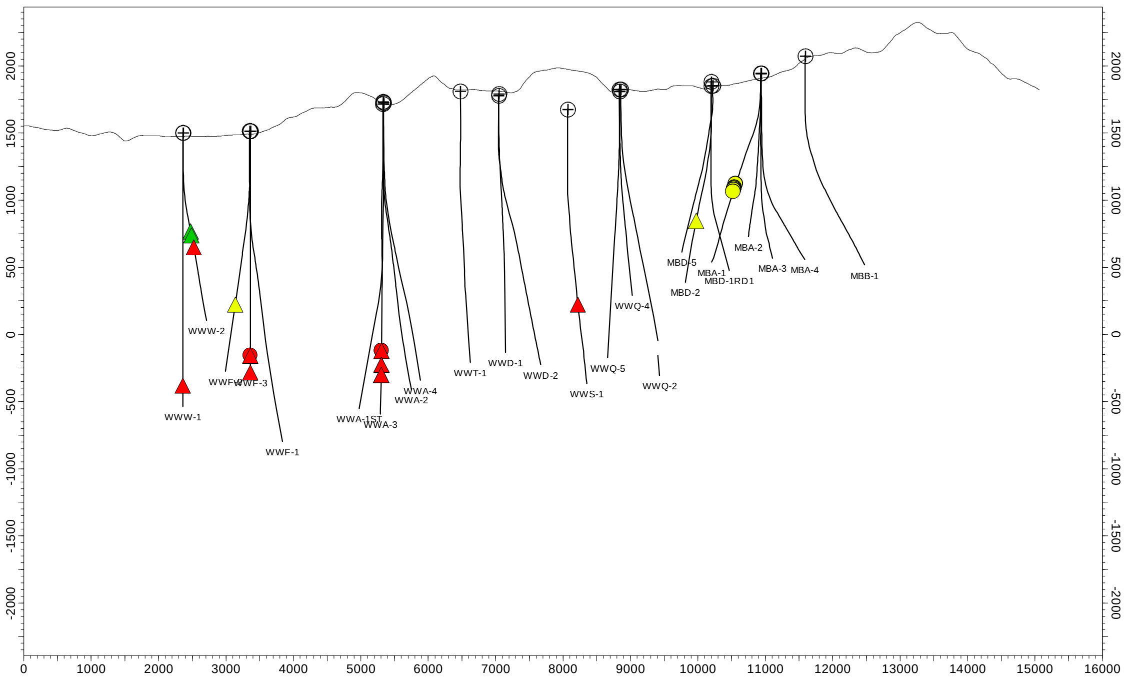


Figure 7 (continued): Integrated interpretation of resistivity, Bouguer, and residual gravity compared to MeQ event and high temperature mineral (red for amphibole, green for biotite and yellow for pyrophyllite).

4. APPLICATION FOR WELL TARGETING

The margin between intrusion bodies and surrounding rock is favorable development as fractured area. They are radial and concentric and high angle in the late stage of fracture development. Intrusion bodies themselves are less permeable areas. Therefore the delineated margin zone is essential to identify the geothermal system which developed around intrusive bodies after deep penetrated meteoric water reacts with hot intrusion bodies and stimulated a circulation convective flow through this clustering of permeable zones.

Correspondence between horizontal derivatives, MEQ events and intrusion indications from high temperature mineral can help locate narrow bodies that can be delineated as an attractive zone, i.e. a fracture zone within the geothermal system for drilling targeting.

5. CONCLUSION

- Gravity and MT results identified possible high density bodies that were interpreted as intrusion bodies

- Enhancement with horizontal gradient analysis shows correspondence between specific values of horizontal gradient and productive fractures within the geothermal system.

- Based on this assessment, the next drilling target should take into consideration the result of horizontal derivative analysis for well targeting.

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