Second Vertical Derivative Using 3-D Gravity Data for Fault Structure Interpretation

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Abstract. Derivative calculation of potential field for signal enhancement is common to be applied in order to provide geologic interpretation. Second Vertical Derivative (SVD) can be used to estimate fault structure and also tends to emphasize shallower geologic anomalies. In this work, we evaluate SVD results using 2-D and 3-D gravity data from two synthetic models (combination of two faults at different depth). Horizontal grid stations designed in the flat surface with 100 m interval for 2-D synthetic data calculation, while 3-D synthetic data calculation designed with addition of 50 and 100 cm in vertical levels (above each surface grid stations). Comparison SVD calculation using 2-D and 3-D synthetic gravity data conducted to perform the possibility of combined gradient interpretation procedure. SVD from real data application identify 2 normal fault with (NE-SW trend) and 1 reverse fault (with NW-SE trend).

1. Introduction
Gravity method is common to be conducted in early stage of oil and gas exploration to provide regional geology information using Bouguer anomaly map. In order to delineate geology subsurface structure, derivative techniques can be applied to gravity data. The importance of the second derivative for gravity interpretation arises from the fact that the double differentiation with respect to depth tends to emphasize the smaller, shallower geologic anomalies at the expense of larger, regional features [1]. Microgravimetric and gravity gradient surveying techniques are applicable to the detection and delineation of shallow subsurface cavities and tunnels [2].

The second derivative map is also often provide better image to interprete anomalies type which are important in oil, mineral, or geothermal exploration. Some publication ([3] and [4]), described gradient interpretation techniques for gravity data in geothermal field. An example of gradient gravity application to identify fault structure and hydrocarbon prospect in oil field area was also conducted in Indonesia [5].

Based on the study of integrated gradient interpretation techniques for 2D and 3-D gravity data (Saibi et al., 2006) results, the second vertical derivative (SVD) enhances near surface effects at the expense of deeper anomalies. So, in this paper we try to understand the advantage of using 3-D gravity data from simple analysis of SVD using synthetic model. Simple fault structure model will be used to provide synthetic data and then calculated using horizontal and vertical gradient. SVD may amplifies noise and SVD can produce many second derivative anomalies that could be artificial. Using SVD analysis from synthetic study, we will describe the possibility of combined gradient interpretation procedure in real data. More discussion of SVD application will arise in real data application using 3-D gravity data, especially in the interpretation stage.
2. Methodology

In this work, gravity data was analyzed and interpreted using horizontal and vertical derivative methods. Performance of horizontal and vertical derivative were evaluated using synthetic data. SVD calculation using 2-D and 3-D real gravity data were applied to identify fault structure. Horizontal grid stations designed in the flat surface with 100 m interval for 2-D synthetic data calculation. For 3-D synthetic data calculation designed with addition of 50 and 100 cm in vertical levels (above each surface grid stations). The illustration of 2-D and 3-D grid station for synthetic data calculation shown in figure 1.

![Grid data illustration](image)

**Figure 1.** Grid data illustration for: (a) 2-D and (b) 3-D gravity data.

SVD calculation using 2-D gravity data (with example of grid data illustration in figure 1a) can be calculated using Laplace’s equation. The formula for SVD calculation [1] using horizontal gradient as follow:

\[
\frac{\partial^2 \Delta g_0}{\partial x^2} + \frac{\partial^2 \Delta g_0}{\partial y^2} + \frac{\partial^2 \Delta g_0}{\partial z^2} = 0
\]

(1)

\[
\frac{\partial^2 \Delta g_0}{\partial z^2} = -\left(\frac{\partial^2 \Delta g_0}{\partial x^2} + \frac{\partial^2 \Delta g_0}{\partial y^2}\right)
\]

(2)

SVD calculation using 3-D gravity data (with example of grid data illustration in figure 1b, \(\Delta z = 50\) cm) can be calculated using partial differential equation [6] as follow:

\[
\frac{\partial^2 \Delta g_0}{\partial z^2} = \frac{\Delta g_0 - 2\Delta g_1 + \Delta g_2}{\Delta z^2}
\]

(3)

In synthetic data analysis, we show the comparation of SVD maps between equation (2) and (3). The advantage from combination of 2 maps interpretation will be identify before we perform in real data aplication.

3. Synthetic Data Analysis

Three layers density (-0.2 g/cc, 0.0 g/cc, and +0.2 g/cc) used in synthetic model. Synthetic data calculated over (13x13) km² with 100 m horizontal grid interval and 50 cm vertical grid interval. Shallow fault located in 100 – 500 m depth. Deep fault located in 800 – 1500 m depth. Synthetic data calculated using forward calculation of polygon [7].

We used two synthetic models with combination of two faults at different depth (illustration shown in figure 2). Model A as shown in figure 2a has shallow fault in Southern part (normal fault) and deep fault in Northern part (also normal fault). Model B as shown in figure 2b has shallow fault in Southern
part (reverse fault) and deep fault in Northern part (normal fault). Figure 3 and 4 show the illustration of forward calculation for model A and B respectively. After synthetic data calculated as shown in figure 3 and 4, SVD of 2-D and 3-D grid data calculated. SVD maps of model A and B shown in figure 5.

Figure 2. Synthetic model: (a) model A and (b) model B.

Figure 3. Illustration for synthetic data calculation using model A.
Figure 4. Illustration for synthetic data calculation using model B.

Figure 5. SVD maps calculated using 2-D grid data of: (a) model A and (b) model B with black dashed lines are interpretation of fault location. SVD maps calculated using 3-D grid data of: (c) model A and (d) model D.
Based on SVD maps calculated using 2-D grid data able to detect shallow fault and deep fault location. Fault structure location interpreted in zero SVD value that separate pairs of positive and negative SVD value. The location of fault structure drew with black dashed lines in figure 5a and 5b. From the colour bar, we can see that normal fault has \(|+\text{SVD}| > |-\text{SVD}|\), while the reverse fault has \(|+\text{SVD}| < |-\text{SVD}|\). We can more easy to see the difference between \(|+\text{SVD}|\) and \(|-\text{SVD}|\) in shallow structure, while in deep structure the difference between\(+\text{SVD}|\) and \(|-\text{SVD}|\) become smaller (and still we can observe zero value of SVD that separate pairs of positive and negative SVD value). We also observe there are zero value that artificially constructed in the Eastern and Western part of the SVD maps figure 5a and 5b. It gives us some consideration in the interpretation stage that zero SVD value not always fault structure.

Based on SVD maps calculated using 3-D grid data, we observe more chaotic pattern and smaller value in colour bar of SVD maps figure 5c and 5d. In Southern part of SVD maps figure 5c and 5d, we see maksimum and minimum global respectively and align very close to the shallow fault location. Maksimum global of SVD maps in figure 5c indicate normal fault structure, and minimum global of SVD maps in figure 5d indicate reverse fault structure. Deep faults in SVD maps (figure 5c and 5d) are not visible to identify, so we understand that SVD calculation using 3-D grid data has depth limitation to detect fault structure.

Illustration in figure 6 provide us closer look of the minimum global of SVD value. Figure 6a is illustration of slicing in SVD map (figure 5d as this example) with AB section. SVD value in AB section then shown in figure 6d, and we notice minimum global high-lighted to help our optimization of fault response. Figure 6c shows the illustration if we mute several colour scale to emphasize fault structure location.

**Figure 6.** Illustration of step-by-step to emphasize shallow fault structure location of SVD map (from 3-D grid data): (a) slice SVD map, (b) identify range of minimum SVD value, and then (c) we mute other SVD value.
4. Real Data Application

Study area located in East Java Province, Indonesia (figure 7a). Gravity data collected during 2014 using Scintrex CG5 with average interval grid in x-, y-, and z-axis respectively are 326, 330, and 0.476 meter. A density of 2.2 g/cm³ (derived from Nethleton’s density estimation methods) was used to produce the Bouguer anomaly map of the study area (figure 7b). Bouguer anomaly map calculated with ground surface data has range value from 77 – 105 mGal. Spectral analysis (figure 7c) provide the information of estimated shallow source ranged in the depth of 39 - 207 meters. Residual anomaly (figure 7d) map derived using moving average filtering to separate regional anomaly from Bouguer anomaly.

![Figure 7](image_url)

**Figure 7.** Study area shown in: (a) the map with red star and (b) is residual anomaly map.

The residual anomaly map, that has range value from -5 to 8 mGal, then become an input for 2-D grid data SVD calculation. From synthetic data analysis we can identify deep and shallow structure from SVD map using 2-D grid data. SVD map shown in figure 8a interpreted with six trends (drew with black lines). Three NW-SE trends are: N34°W, N37°W, and N44°W. Three NE-SW trends are: N32°E, N32°E, and N57°E.

SVD map resulted with 3-D grid data also calculated as shown in figure 8b. After we mute certain colour bar, we can observe similar trend considering maksimum and minimum global SVD value. The fault trends are easier to be conducted (as shown in figure 8b). SVD map shown in figure 8b interpreted with six trends (drew with black lines). Three NW-SE trends: N29°W, N36°W, and N38°W. Three NE-SW trends are: N35°E, N48°E, and N49°E. Integrated interpretation from figure 8a and figure 8b shown in figure 9.
Figure 8. SVD map: (a) calculated using 2-D grid data, (b) calculated using 3-D grid data. Each SVD map interpreted with six trends.

Figure 9. Integrated results from SVD calculation using 2-D grid 3-D grid data: (a) trends comparison between figure 8a and figure 8b overlaid with residual anomaly map, (b) combine interpretation overlaid with residual anomaly map, (c) schematic model section SW-NE, and (d) schematic model section NW-SE.
Figure 9a shows trends comparison derived from SVD map figure 8a (black lines) and figure 8b (gray dashed lines). As we can see, six of the trends relatively close to each other and we confirm the fault structure with contour pattern of residual anomaly map. We optimize the interpretation for shallow structure as shown in figure 9b. We identify two normal faults with NE-SW trend in the Western part and Eastern part of study area. We also identify weaker SVD signature in the Northern part of study area as reverse fault. In center part of study area, three trends seems like circling significance low anomaly. Considering geology information in the study area, three trends in center part study area seems like to show syncline or small bowl shape. Subsurface model based on residual anomaly shown in the schematic model in SW-NE section (figure 9c) and in NW-SE section.

5. Conclusion
SVD from synthetic data calculation using 2D gravity data can be used to detect shallow fault and deep fault. SVD from synthetic data calculation using 3D gravity data can be used to optimize shallow fault location. SVD from real data application identify 2 normal fault with (NE-SW trend) and 1 reverse fault (with NW-SE trend).

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