3D inversion modelling of gravity data to identify gold mineralization zones in region “X”, Pongkor

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Abstract. Gold originates from hydrothermal liquids and is deposited in the form of epithermal deposits. Structures such as faults play an important role in the process of gold deposition because they form hydrothermal flow paths to the surface. One method that can be used for gold exploration is the gravity method. This method can identify gold mineralization zones in the faults of a research area. Three-dimensional (3D) inversion modeling can be used to obtain further information on a target. Such modeling allows the process to be more realistic because the geometry model can be fitted to the actual conditions in the field, which allows the measurements to be more accurate. The gravity data acquisition for this study was performed by PT. Antam Tbk gold mining company in Pongkor. The hydrothermal deposit area is categorized as containing low sulfidation epithermal deposits. Analysis and interpretation of the gravity data were performed using derivative analyses, a spectrum analysis, and 3D gravity inversion modeling. The results show gold mineralization zones in the middle of the study area that have high gravity anomalies at the faults. There are eight faults detected in the potential gold mineralization zone. From the inversion result, the density of the rocks in the gold mineralization zone was determined to be in the range of 2.80–3.34 g/cm³.

Keywords: Gravity data, 3D inversion modeling, gold mining, Pongkor

1. Introduction
Gold is one of the most popular metals with economic benefits and is considered to be a precious metal because of its characteristics. In nature, gold is generally deposited in hydrothermal systems in the form of epithermal deposits. The gold deposits in this study are located in the area of Pongkor, which is characterized by low sulfidation epithermal deposits. In this environment, gold minerals are present in veins associated with fault structures. Faults are used as pathways to the surface by hydrothermal fluids containing the gold mineral. These hydrothermal fluids mix with meteoric water and then cool down, forming gold veins. The shape of the veins depends on the cavity produced by the structure. The existing structures in the potential gold mineralization zone have a density contrast anomaly and can therefore be best explored using the gravity method.

The gravity method is a geophysical method that is sensitive to measuring variations in the gravitational field on the earth’s surface because of the existence of subsurface density contrasts. The observed heterogeneous density distributions are due to geological structures beneath the earth’s surface. In mineral exploration, especially gold exploration, the gravity method is used to identify fault structures...
in gold mineralization zones. Gold mineralization zones are revealed via three-dimensional (3D) gravity modeling because this method provides clear information concerning the surveyed target. This type of modeling is better than two-dimensional (2D) modeling because it is considered more realistic. The shape of the geometry model can be adjusted to the actual shape of the object in nature, making the calculation more accurate. The density, depth, and volume of anomalous objects can then be identified via 3D inversion modeling.

In this study, we identified the faults and gold mineralization zones in Region “X” in a study area in Pongkor on the basis of the results of derivative analyses, a spectrum analysis, and 3D inversion modeling. This analysis was also supported by geological data to identify the subsoil structure of the gold potential zone.

2. Geology and Pongkor gold mineralization

Epithermal deposits located near the surface form in hydrothermal environments via thermal fluids and are associated with igneous rocks. This type of deposit has a relatively low temperature and pressure. Based on their fluid conditions, alteration, texture, and mineralogy, epithermal deposits can be classified into low and high sulfidation epithermal deposits [1]. In low sulfidation epithermal deposits, quartz veins form from filling minerals. This type of deposit is commonly found in volcanic subaerial zones. One example of low sulfidation epithermal deposits is the epithermal deposits in the area of Pongkor in West Java.

The stratigraphy of Pongkor is composed of young quaternary volcanic rocks and old volcanic rocks synchronized with the Miocene Cimapag Formation. Young volcanic rocks composed of andesite lava and intrusive andesitic units cover old nonaligned volcanic rocks consisting of an intermingling of tuff, lapilli tuff, and breccia tuff.

Pongkor is located in a volcanic and tectonic system controlled by subduction, resulting in paired structures that open the magmatic path. The encountered geological structures are in the form of faults, fractures, and rock layers, where the fault structures are filled with hydrothermal fluids. The fault structures that exist in the study area of Pongkor have northwest–southeast, north–south, west–east, and northeast–southwest directions. Most of the fault structures are in the middle of the study area, and some are associated with the presence of veins. The Au–Ag Pongkor precipitate consists of nine substantial quartz-adularia-carbonate substallic moons rich in manganese and limonite oxides, containing only a small amount of sulfide [2]. These veins are between 700 m and 2500 m in length, are several meters thick, and have depths of more than 200 m, bypassing volcanic rock units. This gold mineralization zone can be identified using only one geophysical method, the gravity method. Geological structures such as faults and weathered zones correlated with the mineralized zones can be detected via the gravity method because they result in density contrasts.

3. Methodology

The first step was to prepare the complete Bouguer anomaly (CBA) data of the research area and supporting data in the form of geological data. First horizontal derivative (FHD) and second vertical derivative (SVD) analyses and a spectrum analysis were implemented on the CBA data. The derivative analyses were performed in order to determine the existence and type of the faults, whereas the spectrum analysis was performed in order to determine the window width to be used in the moving average filtering process. The next step was to create a 3D gravity inversion model from the CBA contour map to obtain the depth and density of the anomalies. Then, potential zones of gold mineralization in region “X” were identified on the basis of the results of the spectrum and derivative analyses and the 3D gravity inversion modeling with the geological data as supporting data.
4. Results and discussion

CBA maps were obtained from the corrected observed gravity data. The values of the obtained CBAs ranged from 49 mGal to 74 mGal. The center of the study area has mostly high CBA values, whereas the surrounding area has lower CBA values. High CBA values indicate high subsurface density and/or the presence of anomalous objects on the surface. This can be due to the intrusion of igneous rocks in the area. Conversely, low CBA values followed by dense contours (high frequency) indicate low subsurface density due to subsurface geological structures such as fractures. However, this is not yet certain because the generated CBA value is a combination of regional and residual anomalies; therefore, it is necessary to separate the regional and residual anomalies. One method to separate the regional and residual anomalies is the moving average method. The width of the window used in the moving average is obtained by the spectrum analysis.

The spectrum analysis was performed by digitizing and slicing seven lines across the CBA contour map covering the entire study area, as shown in figure 1. From the seven lines, we obtained an average window width of 33.5. Rounding up, the window width to be used in the moving average filtering to separate the regional and residual anomalies was 35. The result of the moving average method is the regional anomaly. Residual anomalies can be obtained by subtracting the regional anomalies from the CBA.

From the contours of the regional anomaly map in figure 2a, it appears that most of the research area has large regional anomaly values (63.8–65 mGal) aligned in the northeast–southwest direction. This anomaly value may be due to the existence of high-density regional rocks or deep andesite breccia basement rocks. In the residual anomaly map in figure 2b, a large residual anomaly value of approximately 7 mGal is seen at the center of the study area. This anomaly may be caused by a geological structure such as a fault filled with gold mineralization. As seen from the geological map, there are many faults and veins in the high residual area; therefore, this area is interesting and requires further analyses, such as FHD and SVD analyses.

From the FHD map, the existence and boundary of fault structures characterized by the maximum values of the anomalous objects can be identified. FHD values in the study area vary from 0 mGal/m to 0.075 mGal/m (see figure 3a). The maximum FHD value (green–red color) is mostly located at the center of the study area, indicating the existence of a fracture. In addition, if viewed relative to the geological map, the area has a vein; therefore, the middle of the study area is considered to be an interesting area (indicated by the dark blue box in figure 3).

![Figure 1. Spectrum analysis lines covering the CBA map of the study area.](image)
Figure 2. (a) Regional and (b) residual anomaly contour maps of the study area obtained by separating the anomalies using moving average method.

Figure 3. (a) FHD and (b) SVD maps with an interesting area denoted by a dark blue box and the fault locations based on a geological map.

In addition to the FHD analysis, we performed an SVD analysis. The SVD analysis provides information to determine the type of fault (normal or reverse). If the maximum SVD value is greater than its minimum absolute value, then the fault includes a normal/down fault, whereas if the maximum SVD is smaller than its minimum absolute value, then the fault includes an up/reverse fault. The SVD values in the study area varied from -0.00065 mGal/m² to 0.0007 mGal/m² (see figure 3b). On the SVD map, the existence of the fracture can be determined from the contrast in the SVD values (i.e., the area flanked by the maximum (red) and minimum (blue) values). The SVD contrast is mostly located at the center of the study area, again indicating the presence of a fracture.

To obtain a more accurate fault location and to determine the type of fault, we performed digitizing and slicing for five lines on the residual anomaly, FHD, and SVD maps. These lines were made perpendicular to the fault. Furthermore, the residual anomaly, FHD, and SVD results are plotted...
overlaying each other. Maximum or minimum points on the FHD plots that are parallel to zero on the SVD and residual anomaly plots indicate the presence of anomalies (faults). From the results of the FHD, SVD, and residual anomaly analyses, the fault locations were identified on the residual map (see figure 4). Based on our results, it appears that the detected faults are shifted by several meters with respect to the faults on the geological map. In addition, there are several undetected faults in the plot result. The undetected faults are thought to be shear faults.

Inverse modeling is a type of modeling in which the model parameters are obtained directly from the data. From the 3D inversion modeling results of the CBA region with the data that are considered interesting, it appears that the contrast of the subsurface density varies between -2.98 g/cm³ and 3 g/cm³. Deksissa and Koeberl [3] stated that gold mineralized zones are estimated to have density contrasts between 0.36 g/cm³ and 0.90 g/cm³. Accordingly, the estimated gold mineralization zone in this study area has a density of 2.8–3.34 g/cm³ and is shown in the green–yellow areas in figure 5.

![Image 4](image4.png)

**Figure 4.** Fault locations based on the residual anomaly curve, FHD, and SVD are indicated by black dots. The letter U denotes an up fault, and the letter D denotes a down fault.

![Image 5](image5.png)

**Figure 5.** 3D modeling of the gold mineralization potential zone in region “X” with a density range of 2.8–3.34 g/cm³.
Figure 6. Cross-section of (a) line 1, (b) line 2 and (c) line 3 of the residual anomalies and the fault indication points as seen from south of region “X.”

Figure 7. Cross-section of (a) line 4 and (b) line 5 of the residual anomalies and the fault indication points as seen from the south of region “X”.

Based on the cross sections of lines 1, 2, and 3 of the residual anomaly in region “X” in figure 4, it appears that there is a range of very-low- to high-density rock (dark blue–red), as seen in figure 6. Based on the geological map, in this area, there are tuff rock (low density, blue), breccia tuff and tuff lapilli (medium density, green), and andesite breccia (high density, yellow). Gold mineralization is predicted to be in the medium- to high-density areas in the red–yellow areas. Veins containing gold are thought to be in this area. Based on the FHD and SVD plots, there is a fault, and based on the geological map, there is low-density rock; however, the area has a high gravity anomaly value and high density (yellow–red color); therefore, the area is likely the location of a gold vein. Similar conclusions can be drawn for lines 4 and 5 in figure 7.

5. Conclusion

The potential gold zone in Region “X” is composed of tuff, lapilli tuff, and andesitic as well as contains eight faults. The gold mineralization zone is identified via high residual anomaly values (3–8 mGal) and by the presence of fault structures. The subsurface density of Region “X” has a density contrast between -2.98 g/cm³ and 3 g/cm³. The gold mineralization zone in Region “X” has a density contrast of 0.3–0.9 g/cm³ (with a rock density of 2.8–3.34 g/cm³) and is at a depth of 30–1,735 m below the surface.
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