3D modeling of subsurface jiwo fault around gantiwarno sub-district, klaten district, central java using the magnetic method

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Abstract. The Yogyakarta and Klaten earthquake on May 27, 2006, which caused around 5700 people to become victims (from the district of Klaten in 2000 and around 5000 from the Special Region of Yogyakarta). Some earth experts believe that the earthquake was caused by the activities of the Opak Fault in Yogyakarta and the Jiwo Fault in Klaten. That is because the biggest victims are indeed located around the two fault lines. This study aims to map the existence of the Jiwo Fault in Gantiwarno District and surrounding Klaten Regency by magnetic methods. The study area was conducted at an estimated location as the Jiwo Fault with an area of about 20 km x 20 km. Data collecting of total earth magnetic field data in this study using the Proton Precession Magnetometer, while the coordinates of the data collection point are measured with GPS Garmin III Plus. In this study, 150 points were successfully measured. Total magnetic field data is then corrected daily variations and IGRF corrections. The corrected magnetic field data was an inversion of 3D modeling using oasis montaj software. Based on the modeling of the total magnetic field data and the results of the geological survey it was concluded that the dominant geological structure is the fault trending southwest-northeast to west-east, which is interpreted as the Jiwo Fault. Based on the results of 3D modeling using oasis montaj software that began to be seen at a depth of 500 m, it began to be seen clearly at a depth of 1000 m to a depth of 3400 m below sea level is still clearly visible.

1. Introduction
The Jiwo fault is a fault that is estimated to be in the lowlands between the Jiwo Hills and the Southern Mountains. Based on the geological map of the Surakarta-Giritontrro Sheet [1], there was no fault under the lowlands. However, from the shape of the landscape in the form of the escarpment in the southern part of the lowlands, it can be estimated that there is a hypothetical fault under the lowlands [2]. The results of mapping the level of damage to buildings during the earthquake on May 27, 2006, showed that around the low-lying area has a high level of damage. This is more indicative of the existence of a weak zone along the escarpment as intended above. It is most likely related to the continuity of the Opak Fault line which turns eastward into the Jiwo Fault which is widely thought to be the source of earthquake events.

The Opak Fault itself is trending northeast-southwest approximately N 235°E/80°, where the east block is relatively shifted north and west-south block with a width of this fault zone estimated at around 2.5 km [3]. This Opak Fault became popular after the Yogyakarta earthquake on May 27, 2006, because
some earth experts argued that severe damage caused by the earthquake was indeed in the vicinity of the Opak fault line, which was associated with correlating with the Opak Fault activity. The Opak Fault stretches from the coast of Depok towards the northeast to Prambanan. From Prambanan the fault turns eastward to Gantiwarno and Bayat, the fault that turns eastward is known as the Jiwo Fault [4]. According to the USGS, the Yogyakarta earthquake occurred at shallow depth on the Sunda plate overriding, so it was concluded that it was not directly associated with the subduction regime, but rather caused by local faults which were suppressed by the subduction mechanism below [5].

Considering the condition of the area around the Jiwo fault line is densely populated, the existence of the fault needs to be investigated to prevent the number of victims if the fault is dislocated or shifted again. After the May 27, 2006 earthquake, many researchers have conducted research to determine the epicenter position of the earthquake, but not to examine the fault itself. Previous research showed that there was the reactivation of faults around the Jiwo Hills, namely at the location where the Jiwo Fault was thought to be located [2]. However, the fault line as a whole is still not known with certainty. This study examines the existence of the Jiwo Fault with a geophysical approach that is by applying a magnetic method to map the position of the fault in the lateral or vertical direction so that physical parameters can be known from the Jiwo Fault. From these physical parameters, it can predict areas that are predicted to be disaster-prone, so that it can provide information for people who live around fault areas and related agencies.

2. Geological research area
The area that was damaged by the Yogyakarta earthquake on Saturday, May 27, 2006, is included in the Bantul-Klaten plain which extends from the mouth of the Opak River on the coast of Depok to Prambanan to the west of Klaten. The oldest rocks exposed around the Bantul-Klaten plain include the Oligo-Miocene, Kebo-Butak Formation composed by volcanic breccia, andesite, and agglomerates. Above it, the Semilir Formation was deposited consisting of the repetition of tuffs breccias and tuff clusters of Oligo-Miocene age. Unconformity above it deposited the Nglanggran Formation in the form of volcanic breccias, tuffs of Early-Middle Miocene age. Furthermore, the Sambipitu Formation was deposited consisting of tuffs, shales, siltstone. Furthermore, the Wonosari Formation was deposited in the form of coral limestone and calcarenite-coated limestone. Above, the Kepek Formation was deposited consisting of napal and limestone. Subsequently in the west, the Sentolo Formation was composed of layered limestone. On top of it deposited the Sentolo Formation consisting of limestone, marbled sandstone. Furthermore, it is unconformably deposited by the volcanic material of Merapi Volcano and colluvial and alluvial deposits which are all quarterly deposits [6].

The Jiwo Fault area is mostly in the Klaten Regency area and a little in the Gunung Kidul Regency. Geomorphologically, it consists of alluvial landforms of volcanoes (young volcanoes), isolated structural hills consisting of rock, deposits (eolin and Marin), and denudational mountains consisting of breccia rocks (tuffs). The plains between the Jiwo Hills and the Southern Mountains are thought to be plains that occur due to further erosion in the fault zone. The existence of the fault was supported by the abundance of evidence in the form of a line scratch structure on the escarpment south of the lowlands. Considering the morphology, lithology and claw pattern appearance similar to claw in the Opak Fault pathway, it is assumed that the Jiwo Fault occurred simultaneously or almost simultaneously with the Opak Fault [9]. The Opak Fault is located along the Opak River which is found in lithology between the Miocene Wonosari limestone and the Merapi Quaternary volcanic deposit that closes in Sleman, Yogya, and Bantul. The type of soil which is the Opak River sediment is in the form of loose sand and thick Opak Fault cutting Yogya Low and Wonosari High with old andesite rocks (OAF) as a compiler of the fault cutting structure, while in the east of Opak there are still Semilir and Nglanggran Formations. also involved in enlargement [10].

3. Method
The study was conducted on an area suspected as the Jiwo Fault, which is the area around the escarpment between the Jiwo hills and the Southern mountains. The area of research is around 20 km x 20 km. The
research location and location of data collection in the UTM coordinates are shown in Figure 1. Measurement of the earth's magnetic field is carried out at measurement points on a predetermined path. The selection of points measuring the earth's magnetic field considers the location of the point free of magnetic field disturbances such as the PLN power transmission network, HP transmission tower, radio transmitter.

![Figure 1](image)

**Figure 1.** Location of total magnetic field measurements in Klaten area (bullet Location of data collecting)

Measuring the total earth magnetic field in this study uses the main equipment: Two PPM (Proton Precession Magnetometer) types of Geometrics model G-586, equipped with sensors, sticks and dry batteries. One PPM records or measures the price of the magnetic field at the base station point automatically, while the other PPM measures the total magnetic field price at each measurement point. Supporting equipment includes a Garmin GPS unit for measuring the coordinates of measurement points. While other supporting tools used in this study include the Geological Compass to determine the north direction as the orientation of the PPM sensor direction, the topographic map of the study area to determine the measurement points, the geological map to see the distribution of rock types and the location of the opaque fault. Daily notes to record measurement results. The parameters recorded on this measurement are the location of the coordinates of the measurement point by GPS, the time of measurement with a watch and the value of the total magnetic field with PPM and the weather conditions at the time of measurement and the time of measurement. PC computer equipped with Microsoft Excel software, and Oasis Montaj for data processing and modeling.

When measuring the earth's magnetic field with the measured PPM is the total field at that point caused by the earth’s main magnetic field, daily variations, and the field due to the induction of rocks below the measurement point. While the target of the magnetic method is the latter, so the two influences that previously needed to be eliminated. To eliminate this effect IGRF corrections and daily corrections were carried out. IGRF correction removes the value of the main magnetic field of the earth under normal conditions at a certain point\[7\]. The IGRF value at that point changes at any time, for the purposes of magnetic surveying this value is corrected every 5 years\[8\]. In Indonesia, one of the agencies authorized to make IGRF corrections is LIPI. If not, then the IGRF correction can use a map of the earth's magnetic field issued by the IGRF. Daily correction aims to eliminate the influence of magnetic fields originating
from outside the earth, for example, those caused by cosmic rays from or lightning atmospheres. After the magnetic data has been corrected, the total magnetic field anomaly is obtained in the topography, then the low-frequency component (regional effect) and the high-frequency component (local effect) are separated, then the magnetic data is ready to be interpreted.

After the total magnetic field anomaly data is separated from the local and regional components, an iso contour map is created with the Surfer program package. The contour map can be analyzed qualitatively and quantitatively. Quality interpretation is done by analyzing regional and local maps. Usually, anomalies are indicated by magnetic dipole pairs on local and regional maps. The local magnetic field component is then modeled in inversion with the Oasis Montaj software.

4. Results and discussion
Anomaly map of the total magnetic field of the study area is shown in Figure 2, from the map it can be seen that the existence of a magnetic field dipole pair or a magnetic field pair of high and low value. From the total magnetic field anomaly, a reduction to the pole (RTP) is then carried out as if it consisted of one pole to estimate the location of the anomaly. The purpose of the polar reduction is to estimate the cause zone of the anomaly so as to facilitate the qualitative interpretation. The reduction to the poles is a magnetic data-processing filter to remove the effect of inclination angle and declination. The results of the reduction to the poles of the total magnetic field anomaly are shown in Figure 3. The location of the anomaly is in the middle to the east of the south side of the study area, which is estimated to be a fault.

![Figure 2](image1.png)

Figure 2. Map of total magnetic field contour and distribution point of magnetic field measurement.

![Figure 3](image2.png)

Figure 3. Contour map of results of reduction to the pole of the study area.
The total magnetic field anomaly is then modeled in 3D with the inversion method with Oasis Montaj Software. Modeling results of the top view at a depth of 0 m are shown in Figure 4. At this depth, there is a fault which appears but is not very clear. The Locations estimated as Faults are indicated by black dush lines.

**Figure 4.** Distribution of Susceptibility Contrast at a depth of 0 m, the red dashed line represents the area estimated as a fault.

The contrast value of the susceptibility at a depth of 500 m below sea level is shown in Figure 5. At the depth of 500 m, the fault appears more clearly. The location of the fault is indicated by a black line. At this depth, the fault on the western part of the study area begins to disappear, while the right side is still clearly visible.

**Figure 5.** 3D Model contrast susceptibles at a depth of 500 m below sea level, the black line is estimated as the fault location

The contrast value of the susceptibility at a depth of 1500 m below sea level is shown in Figure 6. At the depth of 1500 m, the fault appears more clearly. The location of the fault is indicated by a black line. At this depth, the fault on the western part of the study area more clearly depends on 500 m depth, while the right side is still clearly visible.
The contrast value of the susceptibility at a depth of 2500 m below sea level is shown in Figure 7, and at a depth of 3400 m below sea level is shown in Figure 8. At the depth of 2500 m and 3400 m, the fault appears more clearly. The location of the fault is indicated by a black line. At this depth, the fault on the western part of the study area begins to disappear, while the right side is still clearly visible.
The results of this study are in accordance with the study of co-seismic deformation by Abidin, et al. 2007, that in the area around Gantiwarno Sub-district a horizontal fault was found called the Jiwo Fault with the South Fault block moving relatively eastward and the block in the ultra fault is relatively moving towards the westward direction. The results of the co-seismic study are shown in Figure 9. The direction of the arrow is the direction of relative ground movement on the surface while the length represents the magnitude of the movement.

![Figure 9](image)

**Figure 9.** Coseismic deformation of the 2006 Yogyakarta earthquake, the main epicenter is marked with yellow stars [11].

5. Conclusions
From the results of 3D inversion modeling, it can be concluded that the geological structure in the form of fault trending is relatively southwest-northeast not continuous, but there is a shift in the middle that is at easting between 447000–450000. The Fault location is more to the west while the east is more to the south. Fault began to be seen clearly at a depth of 500 m below sea level increasingly down increasingly clear until the depth of 3500 m below sea level is still visible. The location around the Jiwo Fault is an area of many buildings damaged and fatalities during the 2006 earthquake.

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