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Opak Fault Strand Delineation Using Merapi Slope Shifted Indicator

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ABSTRACT. After the Yogya earthquake occurred on May 27, 2006, two groups of opinion regarding the location of the responsible fault for the earthquake: (1) First group argues that Opak Fault displacement caused the earthquake. The fault line is commonly known as running along the Opak River, striking NE-SW from Parangtritis in the SW to Prambanan in the NE; (2) Second group of experts stated a different opinion than another fault is located about 10 km to the E of Opak River, triggered the earthquake. The present study is purposed to unravel the Opak Fault position by recognizing the main active fault movement underlying the Bantul region influenced by the mechanical continuum process of Merapi Sediments surface and indicated by morphotectonic feature as an en echelon slope shifted alignment, and to define the attribute of the principal displacement zone (PDZ) using its en echelon indicator of shifting slope alignment. This study also presents the results of determining the Opak fault line location using the Digital Elevation Model (DEMNAS) to generate custom shading in approaching landform features. Independent field morphotectonic data sets such as scarp, terraces, water springs alignment, and cracks are encountered in the vicinity of shifted Merapi sediments slope, particularly in Tirtomartani Jetis village, Kalasan area. Identifying such structures from the morphotectonic analysis is a reliable indicator of fault in the field.

Keywords: Opak fault · Morphotectonic · Slope shifted · Delineation.

1 INTRODUCTION

After the Yogyakarta Earthquake occurred on May 2, 2006, the name Opak Fault became very well known. This happened because the damaged area around Opak River is quite severed. The sinistral Opak Fault was originally known from the Geological Map of Yogyakarta with a scale of 1:100000 (Rahardjo et al., 1995). Then some studies with various approaches have been carried out. However, the description, position, and kinematics of the Opak Fault vary. Rahardjo *et al.* (1995), Supartoyo *et al.* (2016), and Natawidjaja (2016) described Opak Fault strand position traces along Opak River. On the other hand, Abidin *et al.* (2009) and Tsuji *et al.* (2009) mentioned that Opak Fault has located in the Gunung Kidul area about 10 Km to the East of the Opak River. Figure 1 shows the geological map of Yogyakarta, showing the different traces of the Opak Fault. The white line is from Rahardjo et al.(1995). Supartoyo *et al.* (2016) placed the Opak Fault along the red line. Natawidjaya (2016) drew the Opak Fault along the brown line. Meanwhile, the dashed black and yellow lines were drawn by Abidin *et al.* (2009) and Tsuji *et al.* (2009) (Figure 1).

Observation of the Opak Fault is not easy because it is covered by younger sediment from the eruption of Mount Merapi, one of the most active in Java, located on the border between Central Java Province and Yogyakarta Special

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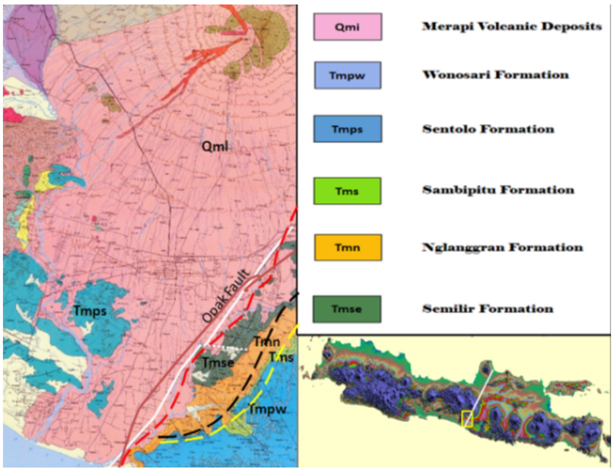

FIGURE 1. The geological map of Yogyakarta (Rahardjo *et al.*, 1995) shows different traces of the Opak Fault. The white line is from Rahardjo *et al.* (1995). Supartoyo *et al.* (2016) placed the Opak Fault along the red line. Natawidjaya (2016) drew the Opak Fault along the brown line. Meanwhile, Abidin *et al.* (2009) and Tsuji *et al.* (2009) drew the dashed black and yellow lines.

Region. It is located approximately 28 Km north of Yogyakarta city. The last significant eruption of the Merapi volcano was in 2010. The product of Merapi eruptions is widespread in the surrounding areas as young volcanic deposits consisting of pyroclastic flow such as lava, volcanic breccia, and pyroclastic falls such as lapilli and tuff. In the southern part, the volcanic deposits form various morphology from steep to gentle slopes. The steep slopes consist mainly of lava, volcanic breccia, and gravel (cobble and boulder). The intermediate slopes are less lava, volcanic breccia, and gravel of smaller size. The Opak Fault is located in the gentle slope areas dominated by materials consisting of tuff and lapilli.

Due to the thick cover of younger Merapi deposits, it is difficult to detect structural features such as fractures and faults at the surface of the study area. The young Merapi deposits may fill the basin created by the Opak Fault system. The young, unconsolidated sediments of Merapi are distinct compressible materials that cover a basement faulting. Hardy and Allmendinger (2011) suggested that their basement model involved a fault propagation fold (Figure 2).

The purpose of this study is to unravel the Opak Fault position by recognizing the main active fault movement underlying the Bantul region influenced by the mechanical continuum process of Merapi Sediments surface and indicated by morphotectonic feature as an en echelon slope shifted alignment; to define the attribute of the principal displacement zone (PDZ) using its en echelon indicator of shifting slope alignment. This paper also presents the results of determining the Opak fault line location using the Digital Elevation Model (DEMNAS) to generate custom shading in approaching landform features.

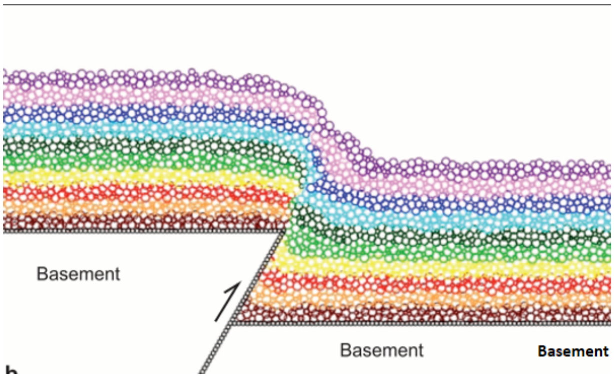

FIGURE 2. The distinct element model of a basement involved a fault propagation fold (Hardy and Allmendinger, 2011).

2 METHODS

The methods used in this study include landform and morphotectonic analyses, field observation, and resistivity measurements.

Landform analysis was performed using Satellite Imagery Data utilizing the DEMNAS Digital Elevation Model 8m-resolution, including volcanic contour shifting. The contours of volcanic slopes are circular and can be traced to the top of the volcano. These characters can be used to reconstruct slope changes. We do this by drawing the ideal contour above the actual contour that has the perfect curve. Furthermore, we can sort out the actual contours that indicate "shift up" and "shift down" (Figure 3).

This study also applies morphotectonic analysis based on the relationship between geological structures and landforms (Stewart and Hanock, 1994). Field observations include the identification of terraces, springs, ground cracks, liquefaction, and minor scarp.

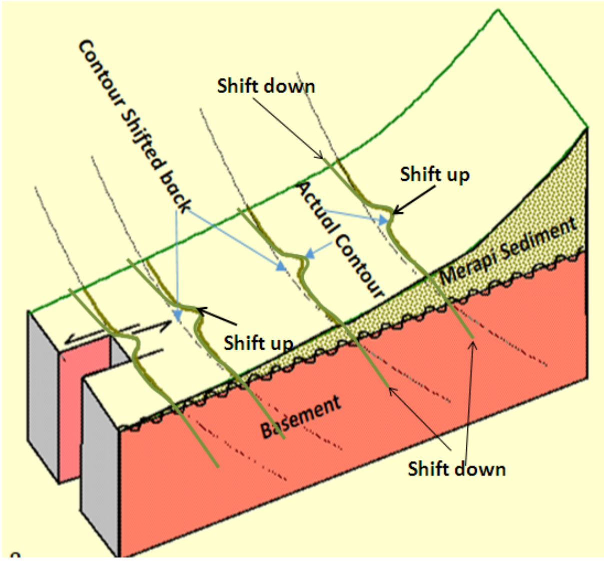

FIGURE 3. The proposed model shows distinct slope shifting elements associated with basement-involved strike-slip fault propagation over periods.

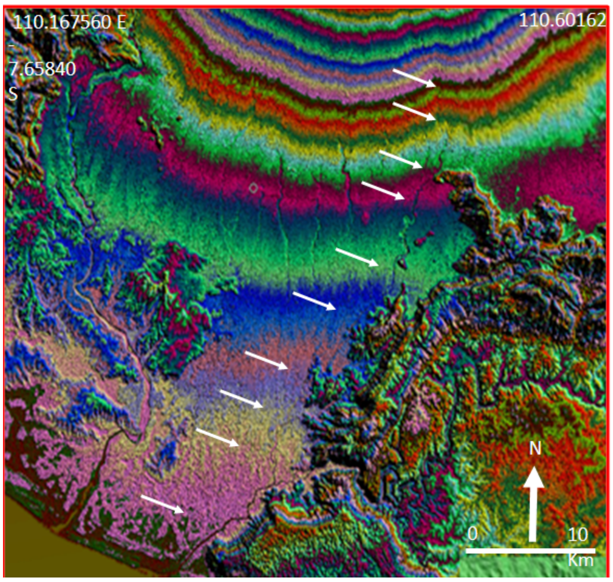

FIGURE 4. Merapi Slope shows a specific pattern of land movements as indicated by an en-echelon alignment slope shifted (smaller white arrows).

A field resistivity measurement using 48 multi-channels with a dipole-dipole configuration was performed to control the surface data.

3 RESULTS

3.1 Opak fault and slope shifting

An analysis of the DEM-NAS elevation model was performed to create the shaded relief indicating aspects of topography that may relate to the specific pattern of land movements. Based on a 25-m contour interval and custom shading contrast, the slope topography of Merapi shows indications of shifting of the en-echelon alignment slope (Figure 4).

Locations of landform changes have been evaluated and marked using circle line contour interpolations. Based on the reference line of the slope, the slopes shifted towards the direction N196°E (to the S), which is an ideal slope from the crest of Merapi. For slopes facing relative to the SE, there is no disturbance. The following are results of slope shifting analyses: (1) Western threshold points shifting is indicated by upward slope contour facing to the E; (2) Eastern threshold points shifting are indicated by upward slope shifting contour facing to the W; (3) Truncating points of West young Merapi sediments (Figure 5). In Figure 5, Truncating line of West Merapi sediment is indicated by the blue line, the black line is the shift up contour interpolation line, yellow arrows are shift down contour points facing the E, and the red line is the shift down contour points facing to the W (Figure 5).

The unconsolidated materials of Merapi Sediments are influenced by underlying Opak Fault displacement, which affects the mechanical continuum process shown by specific landscapes linked to the fault. The area of these specific landscapes can also be attributed to the fault's movement over the S flank slope of Merapi from Kepurun village at about 400 m toward the Parangtritis area at 25 m of elevation. Indicator slope shifting analysis proves that Opak Fault is located in this area (Figure 5).

3.2 Bounding structures

Determination of lineament is very fundamental to classifying landscapes into suitable structural clusters. Faults are often revealed as linear or curvilinear traces on satellite images, commonly referred to as lineaments. Observation of several lineaments has been carried out during this study. At least three kinds of important bounding structures lineaments related to Opak Fault delineation can be reconstructed (Figure 6).

Opak Fault lies along the Bantul basin, confined by sidewall faults at both sides. The

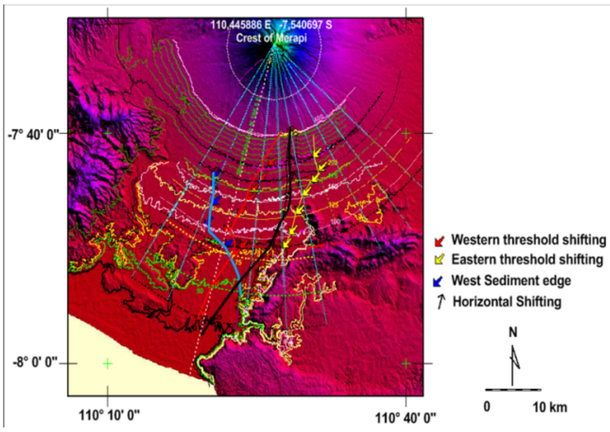

FIGURE 5. The slope-shifting analysis results show West Merapi sediments' truncating line, shifting up a contour, and shifting down interpolation lines. Red and yellow arrows indicate western and eastern threshold shifting, respectively, blue arrows are W sediment edge, and black arrows are horizontal shifting.

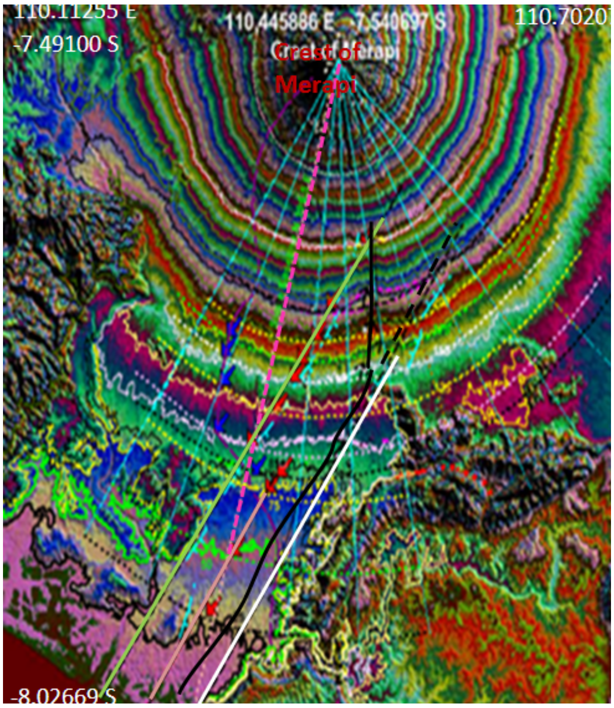

FIGURE 6. Structural lineaments (green and white lines) are determined as bounding structures.

structural lineaments were determined based on analyses that include: (1) sidewall faults, (2) outer boundary, and (3) slope shifted. The resulted four lineaments are described below (Figure 6):

a. The southeastern sidewall fault occupies the Parangtritis-Prambanan lineament (white line), striking NE-SW at approximately N35°E. It traces from Parangtritis through Kembangsongo Hill until reaching Prambanan at Boko Harjo foothill. This lineament is commonly known as the Opak Fault rather than the sidewall fault.
b. Northwestern sidewall fault is reflected by Gadingsari – Gowasari – Triharjo lineament, stretching along western threshold shifting (pink line) ranging from 25 m to 75 m in elevation.
c. Poncosari-Bangunjiwo-Kepurun lineament may act as an outer sidewall fault on the NW side (green line).
d. The main Opak Fault occupies an area of the fault-filled basin between NW and SE side-wall faults. This coincides with the slope-shifting area that also indicates the fault lineament in this location (black line).

3.3 Resistivity

The resistivity measurement line is determined according to the findings from morphotectonic observation in the field. Independent data from the resistivity profile of the Tirtomartani-Jetis-Kalasan line shows the following results (Figure 7):

a. Fault 1(red line) separating the west and middle terraces can be encountered at 53 m. Historically, this fault was a conduit of liquefaction (red circle) overflowing to the surface when the Yogya earthquake occurred on May 27, 2006.
b. Scarp (fault 2, blue line) is indicated by the resistivity profile traced at 70 m. This fault separates the middle and East terraces.
c. Active fault (fault 3, yellow line) was encountered as cracks of floor house. The resistivity profile can be traced to the depth of 110 m.
d. The main fault (fault 4) is found along with the resistivity profile at a depth of 97 m. This fault constraints subsurface water of the dug well.
e. Resistivity Profile traced at 223 m indicates a fault (fault 5) may cross a water well that had experienced liquefaction resulting from the Yogyakarta earthquake on May 27, 2006.

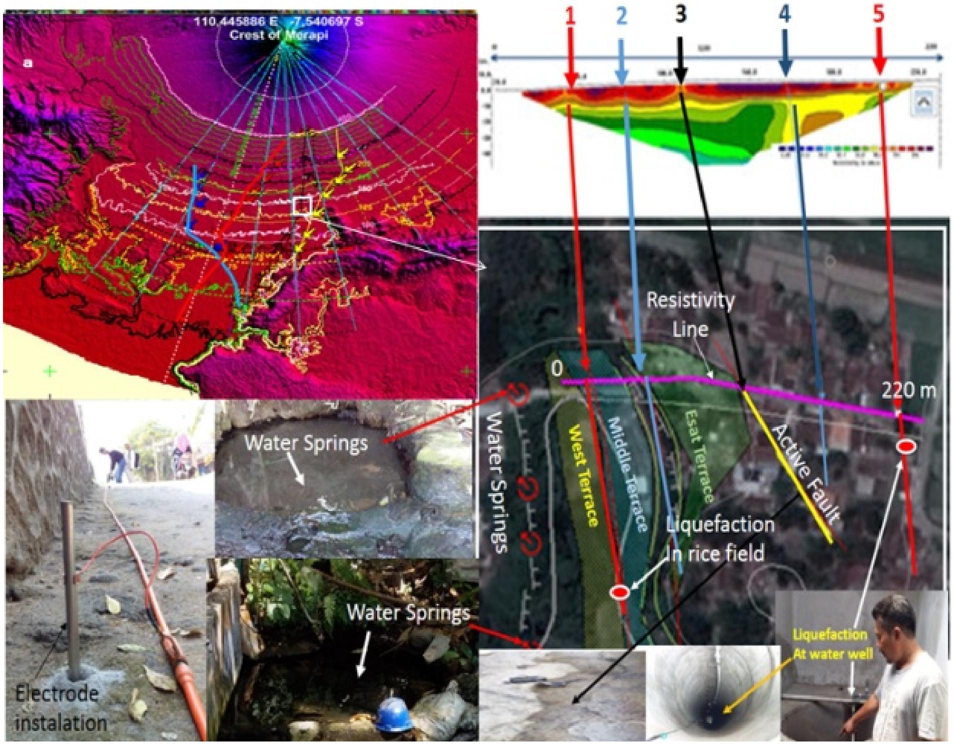

FIGURE 7. The representative resistivity profile measured in the Tirtomartani-Jetis-Kalasan area shows the resulting anomalies agree with the nature of morphotectonic features. The right-hand photo indicates the occurrence of three terraces (W, middle, and E terraces).

4 DISCUSSION

The continuing sedimentation of Merapi volcanic materials has caused difficulties in distinguishing prominent Opak Faults and their cluster faults along with their attributes. The young sediments of Merapi made diffuse boundaries of the faults that occupy the Bantul basin. However, this study indicates that the results of analyses can recognize the existing Opak Fault.

To delineate the main fault position, the first step is to identify sidewall faults to reconstruct the confinement boundaries, followed by defining the important specific nature of their structural elements.

The first analysis dealt with a fundamental aspect: creating fault maps obtained from imagery morphotectonic mapping. This map effectively leads to selecting important areas of field observations (field mapping) and establishing suitable resistivity profiles that cross fault traces.

It seems that the Opak Fault in Prambanan is breached to the N towards the crest area of Merapi, although this directional orientation is only a structural trace. It may form during the first faulting generation representing extension fracture which is relatively parallel to the regional stress orientation (σ_1).

5 CONCLUSION

The Opak Fault zone is a sinistral strike-slip fault in which its deformation includes properties that can be delineated by recognizing slope shifting and bounding faults. Shifted slope landform is a morphotectonic aspect based on the criteria of the relationship between geological structures and landforms. . Morphotectonic features mapped on satellite imagery generally agree with the results from field observation and mapping. Satellite imagery mapping conducted over the entire area was seen vaguely, but the morphotectonic features can still be identified, even with diffuse landscape shapes. It is shown that identifying faults obtained from the morphotectonic analysis is regarded as reliable because some of them can be observed and encountered in the field.

The current Opak Fault line shown in the Yogyakarta Geological Map (Rahardjo *et al.*, 1995) is not the main fault (or PDZ, principal displacement zone). This structure is the SE side wall fault which occupies the Parangtritis-Prambanan lineament. The Main Fault Zone of Opak Fault is approximately 2.5 to 3 Km to the west of the Opak Fault, as drawn on a Geological map (Rahardjo *et al.*, 1995).

The Bantul Basin Fault Zone occupies an area relatively lower than the surrounding, indicating that this nature is characterized by subsidence zones that may associate with the transtensional regime of the main Opak Fault.

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