Tracing Baribis active fault continuity in the Subang region using gravity edge detection analysis

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Abstract. Elucidating the Baribis active fault in the central part of West Java is challenging due to the lack of physiography appearance. A gravity survey was conducted on 838 stations around the North of Bandung to Subang region to identify its buried spatial fault continuity. Regular processing routine reduced the observed gravity acceleration to generate the refined Bouguer anomaly map. Additionally, edge detection techniques (e.g., tilt derivative and analytic signal) were analyzed to delineate the proven fault emergence from the published active fault database and surface geological map. The results depict that the Baribis fault was continued to the Subang region and enhanced clearly by applying analytic signal attributes. Thereby, the Baribis fault continuity is better interpreted on the analytic signal anomaly map, whereas the tilt derivative technique explains the factor of unclear surficial discontinuity of Baribis fault on the zone.

1. Introduction
The Baribis Thrust Fault Zone (BFZ) is located on a potentially damaging earthquake area with a relatively high peak ground acceleration of 0.4-0.5g [1]. It is considered to be an active geological structure based upon the shallow earthquake activities [2], historical earthquake simulations [3], geodetic observations [4,5], and integrated active fault study [6]. The fault is presumably crossing the Java island to the Kendeng Thrust in the Eastern Java [4,7] and tectonically back-arc inverted in the Pleistocene [8].

The studied region extended from north of Bandung to the Pamanukan bay in the Subang region (107.43283,-6.88465 to 108.03434,-6.1938) is surrounded by intensive shallow earthquakes occurrence related to its geological condition (figure 1). Geologically, the north part of the zone is situated in Pamanukan High of North West Java platform, the central part in the Bogor basin, and the southern part in the Quarternary Tangkuban Parahu volcanic area [9]. The geomorphology of the Baribis fault zone (BFZ) in the Subang to Purwakarta region is unclear based on remote sensing and field mapping studies [10]. However, investigating the active fault structure is critical in measuring the potential earthquake hazard zone. Moreover, the detailed spatial continuity of the Baribis fault has not been extensively studied, especially by considering the subsurface properties.

The gravity method is powerful in investigating the subsurface rock density contrast and has been extensively applied to delineate subsurface geometry such as fault structure, rock discontinuity, mineral occurrence [11–13]. In order to trace the Baribis active fault spatial spreading, the potential gravity method was conducted in 838 stations to generate the Bouguer anomaly map. It was then
analyzed by edge detection tilt derivative and analytic signal techniques to accurately delineate the spatial continuity of the Baribis active fault in the Subang region to the northern Bandung extent.

Figure 1. (a) The study area (red rectangle) and the Baribis fault zone (black rectangle), (b) The complete Bouguer anomaly map and the 838 stations (black dot symbol). The relocated shallow (<30km) earthquake [2] and the Indonesian active fault (red line) [6] are overlined on the digital elevation map.

2. Data and Method
The gravity survey was conducted on 16 to 25 October 2019 using Lacoste-Romberg gravimeter on the 247 measurement points with roughly 50 to 100-m spacing and tied to the BS-Geoteknologi LIPI station. The data acquisition was closely looped for 3-5 hours to tolerate the instrument drift carefully. GNSS (Global Navigation Satellite System) survey was carried out on each measurement point. The 8-m resolution of DEM released by Indonesian Geospatial Agency (BIG) were used to obtain accurate topographical correction. Measurement points were mostly following the road access with 50-meter station spacing inside the probable fault continuity area and 100-500 m outside the area. Besides the acquired data, the gravity points from Bureau Gravimétrique International (BGI) and BIG were also used to increase the resolution in the empty data areas. The entire gravity observation around the area was over 838 data. Additionally, a published Indonesian active fault database [6] and systematic surface Bandung quadrangle geological map [14] were used to analyze the result.

2.1. Correction and filtering
The Bouguer anomaly was calculated on the 838 acquired data using regular reduction methods such as drift, tide, free-air, and Bouguer corrections. The Parasnis approach was used to estimate the Bouguer slab density of 2670 kg/m3. The terrain correction added to the anomaly generated the refined (complete) Bouguer anomaly (CBA). Residual CBA calculated by minimum curvature and first-order trend removal were transformed to the wave-number domain and decomposed into 3D derivation to extract the tilt derivative [15] and analytic signal attribute [16] by Eq.1 and Eq. 2, respectively.
\[ TDR = \tan^{-1} \left( \frac{\partial P}{\partial x} \left( \left( \frac{\partial P}{\partial x} \right)^2 + \left( \frac{\partial P}{\partial y} \right)^2 \right)^{-1/2} \right) \]  

(1)

\[ |\Delta S(x, y)| = \left( \left( \frac{\partial P}{\partial x} \right)^2 + \left( \frac{\partial P}{\partial y} \right)^2 + \left( \frac{\partial P}{\partial z} \right)^2 \right)^{1/2} \]  

(2)

P is the observed gravity acceleration in a station with x, y, z coordinate. Both methods using a derivation technique to illuminate the contact between the different densities of rocks on the discontinuity zone, such as faults and fractures. The Geosoft Oasis Montaj software was used to apply these filters.

3. Result and Discussion
The complete Bouguer anomaly (CBA) indicates the anomaly superposition of shallow and deep sources (figure 1b). The resulting high and low CBA anomalies mimic the basement rock geometry. Higher anomalies on a wide range area indicate the shallower basement layer from the earth geoid than the lower anomalies. The CBA was matched significantly with the region's regional geological background, such as the West Java platform on the northern part, Bogor basin zone in the center, and the Quaternary volcanic Tangkuban Parahu area in the southward. The drastic change (~80 mGal) from the north to the center part depicted the change of environmental deposition zone from the Sunda shelf to the Java deepwater play. In contrast, the gradual decrease gradient to the westward of the area expressed the thickening sediment layer. The lowest anomaly (12.5 mGal) was probably associated with the zone's depocenter and agreed with previous research based on well-log data [17].

Figure 2. The resulting fault detection filter: (a) tilt derivative (TDR) and (b) analytic signal method. The thick black solid line indicates the Indonesian active fault [6] and the thick black arrow symbol indicates the missing continuity of the anomaly.
The tilt derivative (TDR) on figure 2a and the analytic signal result (figure 2b) depict a clearer subsurface discontinuity delineation. Interpretation of those two attributes depends on the target and should be supported by other methods or data. In comparison with the tilt derivative, the result of the analytic signal is more accurate (figure 3) in referring to the Indonesian active fault lineaments [6] and the systematic Bandung quadrangle geological structure map [14]. Moreover, the filter also significantly improved the left-lateral strike-slip Lembang fault feature (figure 3). The tilt derivative anomaly is sometimes best in delineating fault in other areas [11,13], specifically in this study, the analytic signal has better performance.

The missing fault continuity in TDR (figure 2a) could reveal the reason behind the hidden surficial trace of the fault reported by the researcher [10]. The TDR was probably associated with the shallower source, while the segment's fault was considered deep-seated. Moreover, the attribute was well delineating the eastward proven structures (figure 2a), a surficial feature. The first scenario to answer this hidden structure was the segment has never been uplifted to the surface since the fault reactivation due to a deep basin deposition. Another scenario was some intensive geological processes have removed the trace. Significant elevation difference, tectonic regime, erosion, and weathering process in this segment might lead to the surficial extinction of the fault feature. The shallower source of anomaly illuminated by the TDR also revealed significant N-S and E-W structures related to Meratus and Java pattern, respectively (figure 2a).

Figure 3. The interpreted analytic signal anomaly performed a spatial match to the proven Baribis structures. The black dashed line indicates the inferred Baribis fault continuity from this study, the thick-black solid line indicates the Indonesian active fault [6], the thin-black solid line indicates the Bandung quadrangle surface structures [14]. The filter also verified the Lembang sinistral strike-slip fault.
4. Conclusion
The rock density contrast detection of the gravity method, dense measurement data, and edge detection analytic signal technique in this study have accurately indicated the existence of the Baribis fault continuity on the Subang region. The TDR technique matched the shallower subsurface structure related to the extinction of the surficial trace of the Baribis fault on the segment. The published research based on subsurface data and surface geological structure has supported the interpreted trace of the Baribis fault continuity. The vertical inversion of the anomaly and detail near-surface coupled method (e.g., seismic, resistivity tomography, GPR) would help confirm the vicinity of the interpreted fault and its geometry.

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