Stratigraphy and structural pattern of Kebumen Region using Second Vertical Derivative of Gravity Data, Central Java

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ABSTRACT

Gravity forward modeling has been carried out in Kebumen Region, Central Java Province. With its position on the mélange complex, the geological complexity in this area is still a challenge to be modeled. Bougeur anomaly values in the study area ranged from 50 mGal to 130 mGal. The structural morphology of the Luk-Ulo Mélange Complex and Kulon Progo Mountain have higher Bougeur anomaly, ranging from 105 to 125 mGal. The residual positive anomaly zones in the northwest and southeast are situated with residual negative anomaly zones in between. The shallow effect through the Second Vertical Derivative method shows the patterns of fault types separating the two anomalous zones of Karangsambung and Kulon Progo region. The Luk Ulo Mélange Complex and stratigraphy of Karangsambung Formation up to Halang Formation are faulted by thrust-fault and strike-slip structural pattern.

Keyword: Stratigraphy, structural pattern, second vertical derivative.

INTRODUCTION

Since 2006, Karangsambung has become a Geological Nature Reserve based on the Decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number: 2817 K / 40 / MEM / 2006. In Karangsambung, there is a Melange Complex, which is known as the Luk Ulo Group. The Luk Ulo group is chaotic mixture of various kinds of sedimentary, igneous, and metamorphic rocks, and is unconformably overlain by the Eocene Karangsambung Formation (Ansori et al., 2019).

The Kebumen area has always been an object of interest for geologist to study, especially in the Karangsambung area, Central Java Province. The geology of Karangsambung has a historical evolution of the earth's plate movement in the past 60 million years ago (Nur, 2014; Rista et al., 2018). Herein, there are traces of an ancient subduction pathway within a Cretaceous age. However, the island of Java uncovers ancient subduction zone not only in Karangsambung but also in Ciletuh (West Java), Meratus (Kalimantan), and Bantimala (Sulawesi) region. The presence of melange complex and olisostrome deposit of Karangsambung Formation marks evidence of the ancient of subduction pathway.

Historically, research on the reconstruction of ancient subduction paths passed through Ciletuh - Karangsambung - Meratus - Bantimala continued to experience dynamics. The distribution of the petrotectonic age of Java Island by Hamilton (1979) places the boundary of the continental crust and the cretaceous subduction zone of the Ciletuh - Karangsambung - Meratus pathline (Husein & Nukman, 2015). Although Luk Ulo and Bantimala have similar lithologies to their constituents, the ancient subduction of Bantimala was followed by collisions of continental fragments, so it is historically slightly different. Ancient subduction in Karangsambung was relatively simple (Wakita et al., 1997). The Ciletuh, Luk Ulo, and Meratus complexes have the same structural pattern.

The existence of this structural pattern, which is characteristic of the ancient subduction pathway is interesting to observe further its presence, and its effect on the stress regime in Java Island. The study was conducted on 100 data points of Bouguer anomaly data, spread evenly at a regular distance from the Luk Ulo Group in the north to the south of Java Island (Figure 1)

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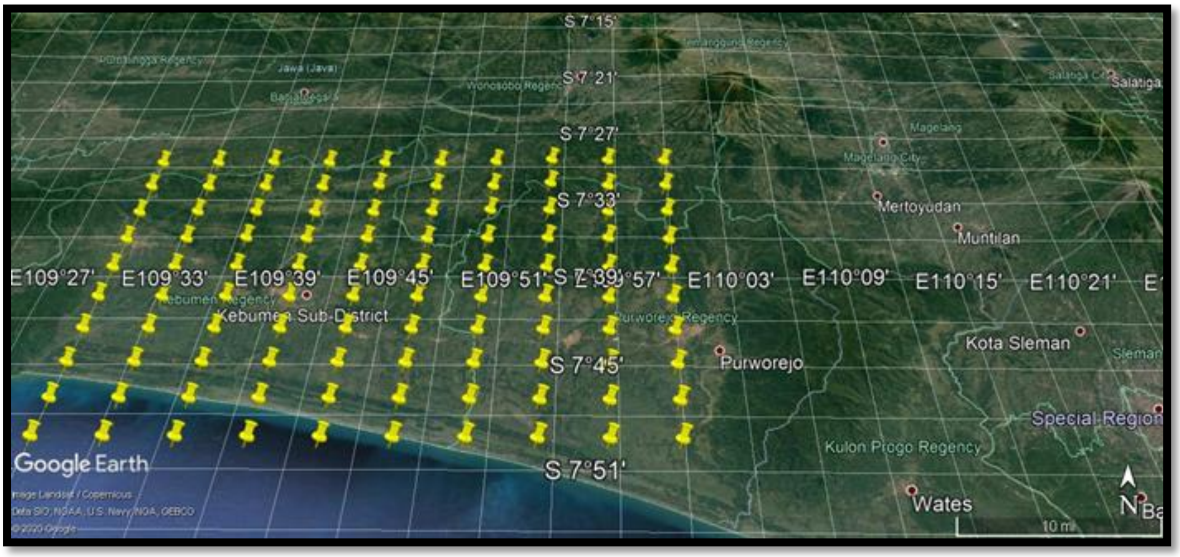

Figure 1. Location of gravity measurement, Map data; Google Earth

GEOLOGICAL SETTINGS

Karangsambung is geologically coincided on the border of Bogor Trough and Kendeng Trough. Sediments from the Bogor Trough, such as the Halang Formation, are also exposed and spread widely to the Kebumen area, and the two basins are in the zone of the anticlinorium structure as well as the tectonic compression regime (Alam et al., 2019; Genevraye & Samuel, 1972; Sujanto & Sumantri, 1977). Physiographically, this area belongs to the South Serayu Mountains Zone. The well-known of amphitheater geomorphology, shaped like a circular hill, consists of an anticline fold structure that has undergone erosion. This morphology occupies the Melange Complex. The Luk Ulo River, which flows from north to south, cross cuts the structural fold's morphology. Another geomorphological unit is the alluvial plain in the south.

Regional stratigraphy of Karangsambung, according to Asikin et al. (1992), from old to young is Cretaceous Complex Melange Luk Ulo to Pliocene-Pleistocene in the Halang Formation Formation (Figure 2). The Melange Luk Ulo complex is composed of various kinds of chaotic rock fragments, including graywacke, mica schist, phyllite, serpentinite, gabbro, pillow lava, chert. The Eocene Karangsambung Formation is composed of scaly clay with boulders of sedimentary rock, including the Nummulites limestone and methamorphic fragments. The next formation is the Totogan Formation, which deposited conformably with the overlying Waturanda Formation. The Early Miocene to the Pliocene period was composed of Penosogan Formation and. The interbedded limestone sandstone, mudstone, marl, and calcarenite forms Penosogan Formation. In contrast to Penosogan Formation, the Halang Formation composed of mostly interbedded sandstones and mudstone, as well as the presence of breccias in the Halang Formation Members.

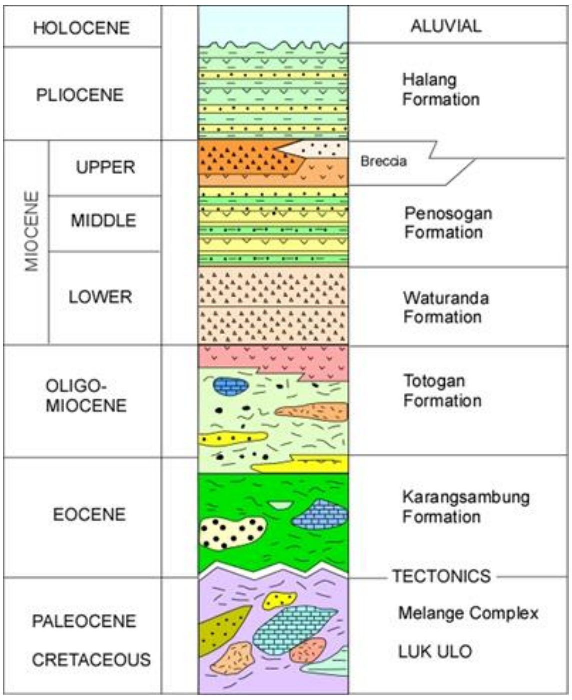

Figure 2. Regional stratigraphy of Karangsambung area (modified from Asikin et al., 1992)

The geological structures commonly found in the study area are folds and faults.

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The northeast-southwest strike-slip fault intersects the east-west structural fold trend, indicating a Meratus pattern existed in the Karangsambung area. The west-east structural pattern developed in Tertiary rocks (Harsolumakso et al., 2006)The Second Vertical Derivative approach can prove those strike-slip and thrust faults.

METHODS

The gravity method determines variations in density contrasts on the surface of the earth due to changes in the mass distribution below the earth's surface. Gravity data used in this study is obtained from the report of the Map of Bouguer Anomaly of Kebumen Region Sheet published by the Directorate of Geology, Bandung (Dibyantoro & Sutisna, 1977). This density variation will produce a difference in gravity, which is called Bouguer anomaly. Therefore, the deep structure (regional anomaly) influences the Bouguer anomaly frequency, which has a low frequency. The anomaly with the high frequency associated with shallow structures in the earth's crust conducts as a response to residual anomalies.

The separation of Bouguer anomaly into regional and residual anomaly uses Polynomial Surface Fitting and Frequency Filtering methods. Frequency filtering uses a high pass filter, which one of the methods is the Second Vertical Derivative (SVD) analysis. SVD analysis is useful for displaying anomalies associated with shallow structures (Alam & Saputra, 2017). The use of SVD in geology is a basis for interpreting fault types (thrust faults, strike-slip faults, or normal faults). The modeling of subsurface geological conditions carried out the modeling by intuitive process. Forward modeling theoretically, that the model will be observed on the earth's surface if the value of particular subsurface model parameters is known.

In his book, Reynold (1997) states that the criteria for determining the type of fault structure are as follows:

$$|SVD|_{min} < |SVD|_{max} = Normal\, fault$$

$$|SVD|_{min} > |SVD|_{max} = Thrust\, fault$$

$$|SVD|_{min} = |SVD|_{max} = Strike - slip\, fault$$

Interpretation through gravity data uses the absolute value of SVD and can be used as an indication of the fault structure. Meanwhile, anomalies caused by intrusion bodies act the opposite way. The rock density contrast is a parameter measured by the gravity method. Sedimentary rocks usually have lower density values than igneous and metamorphic rocks, resulting in a negative Bouguer anomaly compared to their surrounding location which can be either a basin boundary or a paleohigh.

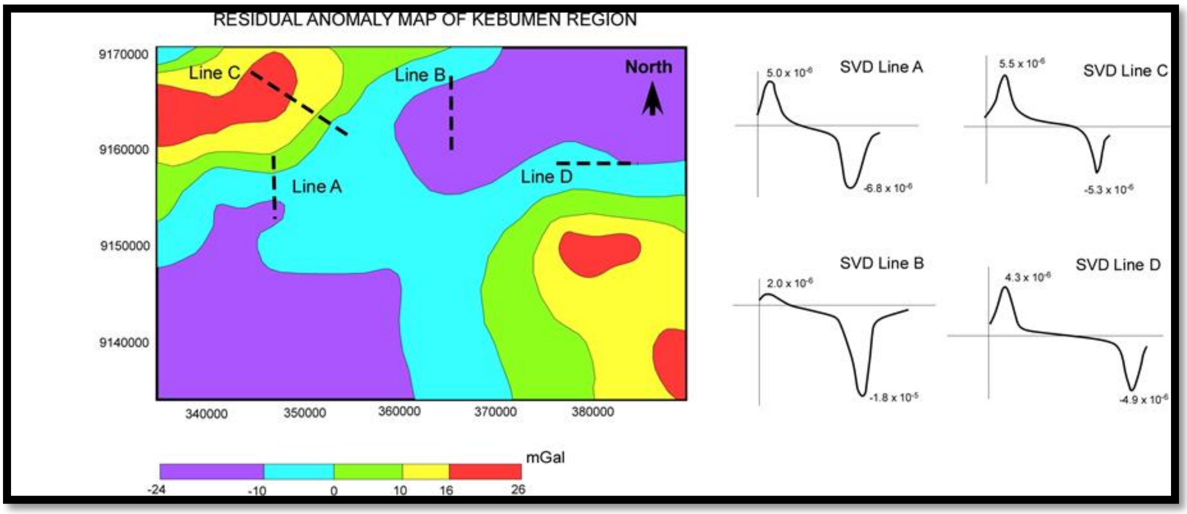

Figure 3. SVD Analysis on Residual Anomaly of Kebumen Region

RESULT AND DISCUSSION

Complete Bouguer Anomaly is a superposition of the gravity field caused by

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shallow (local) energy sources with high frequencies and deeper sources (regional) with low frequencies. Regional anomalies are still influenced by the mass centre of gravity at the earth's core. Meanwhile, anomalies with high frequency are anomalies that interact only in the earth's crust. Therefore, trend surface analysis was performed to separate local anomalies from regional ones.

Based on the Residual Anomaly Map in Figure 3, the residual gravity anomaly is positive in the northwest and southeast. The Karangsambung occupies the northwest Luk Ulo Complex, and the Kulon Progo High occupies the southeast. Negative anomalies occupy the area between the positive anomalies. The stratigraphy of surrounding sedimentary rock is in association with the negative anomaly ranging value from -24 mGal up to -10 mGal. The Totogan, Waturanda, Penosogan and Halang Formations have negative residual anomalies and show a structural pattern trending northeast-southwest.

SVD analysis was carried out on Line A, Line B, Line C, and Line D with the following results:

1. Section SVD Line A shows $|-6.8\,x\,10^{-6}| > |5.0\,x\,10^{-6}|$
2. Section SVD Line B shows $|-1.8\,x\,10^{-5}| > |2.0\,x\,10^{-6}|$
3. Section SVD Line C shows $|-5.3\,x\,10^{-6}| \approx |5.5\,x\,10^{-6}|$
4. Section SVD Line D shows $|-4.9\,x\,10^{-6}| \approx |4.3\,x\,10^{-6}|$

On the SVD Line A Graph, the maximum value is $5.0\,x\,10^{-6}$ and the minimum value is $-6.8\,x\,10^{-6}$. The minimum value of the SVD Line B Graph is $-1.8\,x\,10^{-5}$ and the maximum value is $2.0\,x\,10^{-6}$. Based on the comparison of the SVD value, Line A dan Line B conclude that there is thrust fault in the study area.

In contrast to Line A and Line B, the results of the SVD analysis on Line C and Line D show the strike-slip fault that cuts over the thrust fault. The conclusion regarding the strike-slip fault is due to the SVD value, which is congruent or equivalent between the maximum and minimum values. The maximum values on the SVD Line C and D Graphs are $5.5\,x\,10^{-6}$ and $4.3\,x10^{-6}$, and the minimum values are $-5.3\,x10^{-6}$ and $-4.9\,x10^{-6}$.

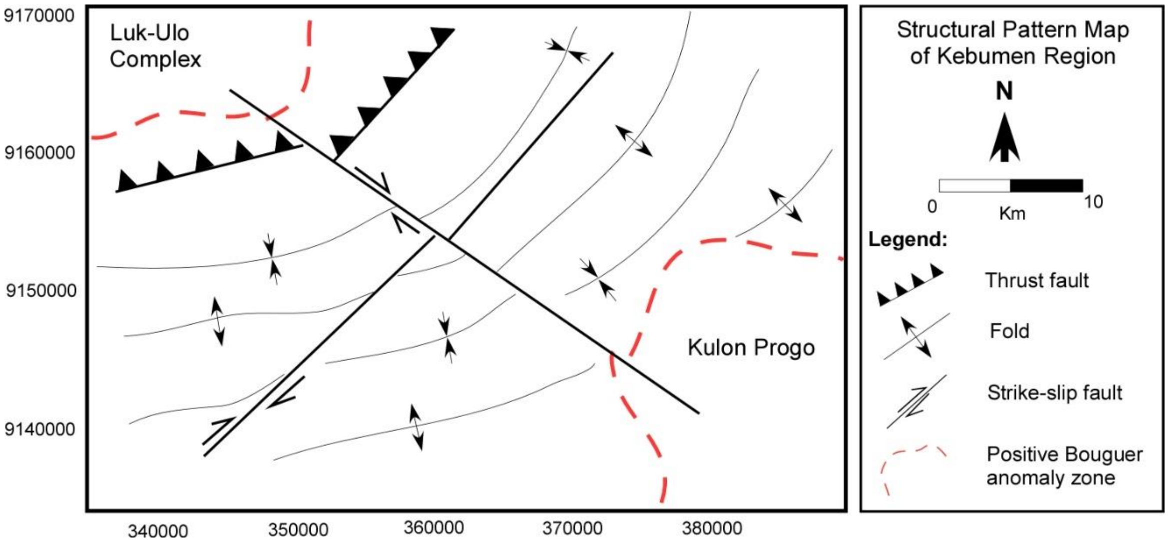

Figure 4. Structural pattern and configuration inferred from SVD analysis

The structural pattern in Figure 4 shows similarities to the Meratus pattern. The structural pattern of the Luk Ulo Complex is northeast-southwest with Tertiary sedimentary rock formations following the same pattern as the Meratus Pattern. Deep and shallow anomalies also indicate a Meratus suture pattern in the Kebumen area, namely by using polynomial trend surface analysis in the second and third orders. In other words, the Cretaceous structural pattern is also reflected in the Tertiary structural pattern.

Not only in Karangsambung, but another prominent morphology that resulted from gravity modelling is the Kulon Progo morphology. Kulon Progo morphology is composed of Oligocene volcanic rocks. The volcanic rock is dominated by clastic material, and there are basaltic-andesite intrusions. These clastic rocks are composed mainly of breccias and lapilli, and tuff. The Kulon Progo morphological area is also known as the "Oblong Dome". Three regional tectonic patterns have controlled the morphological formation of the Kulon Progo

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Mountains, those are Meratus, Sunda, Java trends, operating in SW-NE, NNW-SSE, and E-W directions respectively (Syafri et al., 2013). In this paper, the Bouguer anomaly pattern in the Kulon Progo High section indicates a northwest-southeast direction which is related to the Sumatra Pattern. The northwest-southeast structure pattern occurs during the compression phase in the Late Jurassic-Late Cretaceous epoch (Pulunggono, 1992). The difference in this structural pattern is suggested as a boundary condition for the paleo-subduction pathway in the southeastern Sundaland.

The description of the stratigraphic configuration and structure can be modelled through the forward gravity modelling, which will be correlated with the Regional Geological Map of the Kebumen Sheet. Forward modelling uses input in the form of a body source that still considers geological intuition and expected to fit with the gravity data. In this paper, the cross-section lines that selected to be modelled was north-south and northwest-southeast trending. The north-south line was chosen to determine the geological relationship between the Cretaceous subduction pathway and the Tertiary-recent subduction, as well as to Kulon Progo High in the northwest-southeast relation.

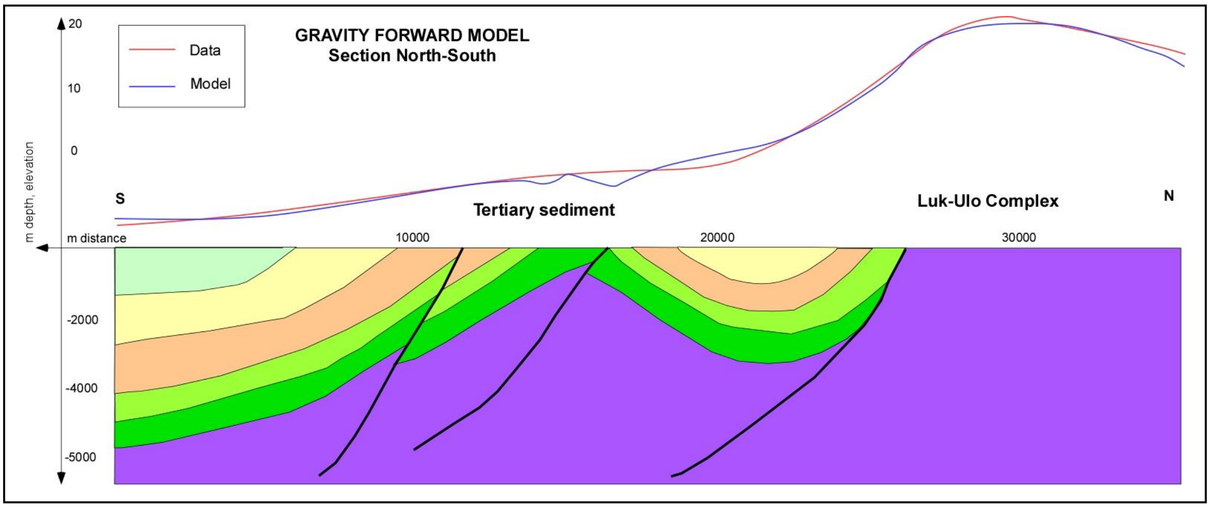

Figure 5. Gravity forward model on the north-south section

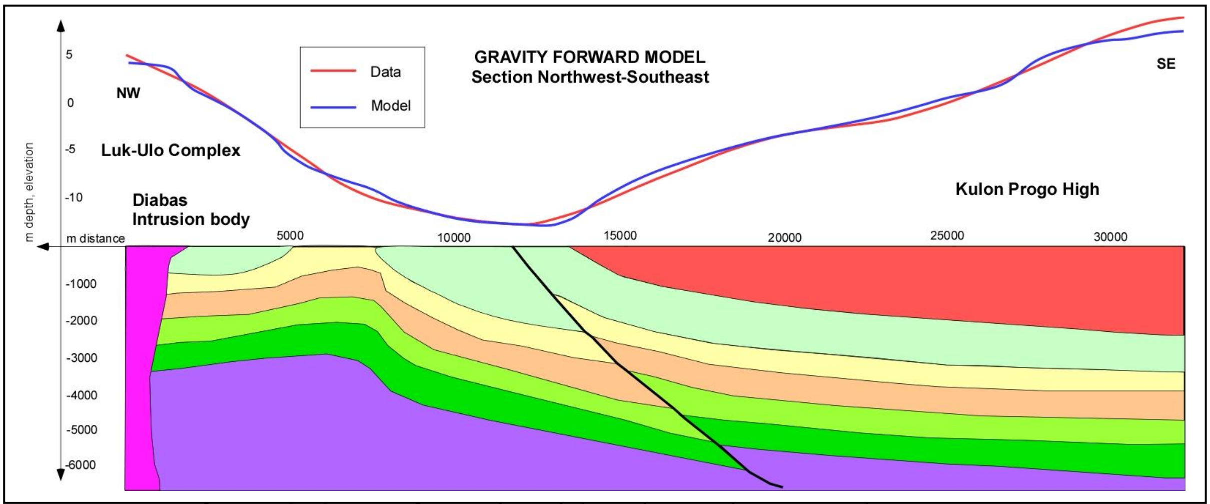

Figure 6. Gravity forward model on the northwest-southeast section

Figures 6 and 7 are geological models based on gravity forward modeling. A good model is a model that has the smallest error with data. The model created shows that the

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curve of the model and the data have a small error difference, and it looks almost fit. Thrust faults and fold belt appear in the model deformed sediment in Tertiary sediment units, in this case the Karangsambung Formation to the Halang Formation from Eocene to Pliocene sediment. Not only deforming sedimentary rocks, but these faults also attached to the Luk-Ulo basement complex, which is the Melange Zone.

Bouguer anomaly on gravity data shows a curve that resembles the shape of a valley and hill. Positive anomaly is associated with hill curve shape, and the negative anomaly is associated with valley curve shape. The Melange Luk-Ulo and Kulon Progo High complexes in the gravity data have a positive Bouguer anomaly. The negative anomalies are in the sedimentary rocks of the Karangsambung, Totogan, Waturanda, Penosogan, and Halang Formations with several fault factoring mechanisms attached to them. A positive anomaly also characterizes diabase intrusion in Figure 6.

CONCLUSION

Gravity forward modeling can be an alternative way to understand subsurface geological conditions. As proven by SVD analysis, the trust fault mechanism has made Luk-Ulo Melange Complex exposed to the surface. Besides, SVD analysis can also reveal a strike-slip fault trending northeast-southwest that cross cut by another strike-slip fault on the northwest-southeast pattern. The stratigraphic setting in this area has also undergone folding and faulting, as evidenced by the thrust fault belt. The northeast-southwest structural pattern shows the Meratus pattern in the Karangsambung area, Kebumen. In contrast to Karangsambung, Kulon Progo High shows a northwest-southeast structure pattern similar to the Sumatra pattern.

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