

Geological Identification of Seismic Source at Opak Fault Based on Stratigraphic Sections of the Southern Mountains

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Abstract

Earthquake is *one* of the unpredicted *natural disasters* on our earth. Despite of the absence of high-accuracy method to precisely predict the occurrence of earthquake, numerous studies have been carried out by seismologists to find it. One of the efforts to address the vulnerability of a region to earthquakes is by recognizing the type of rock as the source of the earthquake. Opak Fault is an active fault which was thought to be the source of earthquakes in Yogyakarta and adjacent areas. This study aimed to determine the seismic source types of rocks in Yogyakarta and adjacent areas. The methods were by measuring *stratigraphic* sections and the layer thickness in the western part of Southern Mountains. Field study was done in 6 (six) research sites. Results of *stratigraphic* measurement indicated the sedimentary rocks in the Southern Mountains was 3.823 km in thick, while the bedrock was more than 1.042 km in thick. Based on the result, the rock types as the seismic source were thought to originate from the continental crust rocks formed of granite and metamorphic complex.

Keywords: Earthquake, Prediction, Southern Mountains, Yogyakarta, Stratigraphic.

Abstrak

Gempa bumi merupakan salah satu bencana alam yang belum bisa diprediksi waktu kejadiannya sampai saat ini. Sejumlah penelitian telah dilakukan oleh banyak ahli kegempaan untuk bisa menemukan metode prediksi gempa yang akurat. Namun sampai saat ini belum ada yang berhasil. Salah satu hal yang perlu diketahui dalam upaya memprediksi gempa adalah mengetahui jenis batuan yang menjadi sumber gempa. Sesar Opak merupakan sesar aktif yang mengakibatkan sejumlah gempa kuat di wilayah Yogyakarta dan sekitarnya. Penelitian ini ditujukan untuk mengetahui jenis batuan sumber gempa di wilayah Yogyakarta. Metode yang digunakan berupa pengukuran stratigrafi dan tebal batuan di Pegunungan Selatan bagian barat. Penyelidikan lapangan dilakukan di enam lokasi. Hasil pengukuran stratigrafi menunjukkan total ketebalan batuan sedimen pada Pegunungan Selatan adalah 3,823 km, sedangkan tebal batuan dasar diperkirakan lebih dari 1,042 km. Berdasarkan hal tersebut batuan sumber gempa diperkirakan berasal dari batuan kerak kontinen yaitu granit, serta kompleks batuan metamorf.

Kata kunci: Gempa, Prediksi, Pegunungan selatan, Yogyakarta, Stratigrafi.

Introduction

The occurrence of an earthquake as one of natural disasters is hardly predicted, despite the efforts of a number of *plate tectonic expert* and seismologists in carrying out studies to find out how to estimate earthquake precisely. Those studies, in fact, have not yielded any satisfying results. Matsushima (1961) found that there is the relationship between distribution of great earthquakes with strength of the crust and upper mantle.

Yogyakarta is an earthquakes prone area where several powerful *earthquake* measuring 6 in magnitude occurred several times. Newcomb

and McCann (1987), Utsu (2002), Elnashai *et al.* (2006), and USGS (2007), record a number of earthquakes have struck off the region of Yogyakarta and adjacent areas during the period of 1840 to 2006. Several powerful earthquakes took place in adjacent to Opak Fault (Sesar Opak) (Thant, *et al.*, 2008) which were considered as shallow focus earthquakes with epicenter depth of 10 km.

Based on the circumstances, Yogyakarta is a selective and proper area to carry out seismic studies, particularly in disaster prediction and mitigation. Pandita, *et al.* (2012 and 2013) initiated a research on earthquake

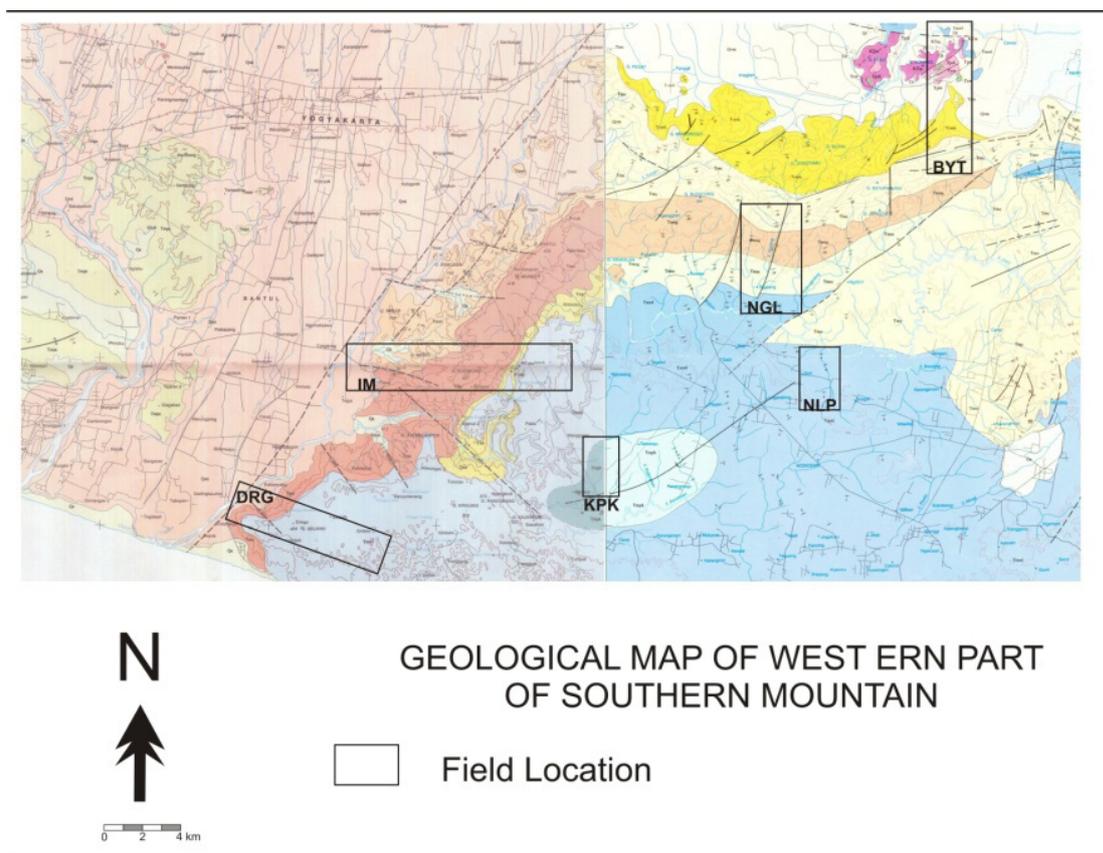
microzonation in Yogyakarta and generated a microzonation map. Meanwhile, Thant *et al.* (2008) carried out a study to estimate the focal depth of the earthquake potentials in Yogyakarta.

As a matter of fact, previous studies have not elaborated the types of rocks as the source of the earthquake. Adequate knowledge on seismic types of rock is required as an initiation to estimate the potential location of the earthquakes in the future. This study aimed to measure the *stratigraphic* section of the western part of Southern Mountains. In addition, the final goal of this study was to provide an initial interpretation of the seismic source types of rock in the area adjacent to Opak fault. This study was a part of research on earthquake prediction in Yogyakarta and adjacent areas.

Research Methods

The method applied in this study consisted of stratigraphic measurements and geological surface mapping of the site. The mapping covered Yogyakarta region and Klaten regency (Figure 1). Those sites were expected to provide ample data with regard to the types of rock as the source of the earthquake. Additionally, four observation sites were determined.

The results of the ground study were subsequently analyzed from stratigraphic perspective as well as calculated to obtain the stratigraphic thickness at the western part of Southern Mountains. The measurement was also performed on the younger rock layer to gain an understanding of the past earthquakes. The rocks samples from the sites are collected and analyzed in the laboratory. The laboratory analysis is petrology description.



Source: Geological Maps (Rahardjo, *et al.*, 1995; Surono, *et al.*, 1992)

Figure 1. Field study was carried out in 6 (six) sites: KPK (Kepek), Ngalang River (NGL), Nglipar (NLP), Bayat (BYT), Imogiri (IM) and Dringo (DRG).

Data and Analysis

As many as 6 (six) stratigraphic or geologic sections of the 6 (six) sites had been examined in this study. The results and analysis can be explained as follows. Field study in Bayat was done from the north to the south of the northern part of Joko Tuo the southern part of Trembono, which consisted of 9 (nine) sites along the route. Based on the field data compiled with the regional geological map, a geological map and its section was constructed (Figure 3).

Stratigraphic sequence of the site is constituted from the metamorphic complex rocks allegedly formed in the Pre-Tertiary period. Erratically, the top of the metamorphic complex is overlain by *Oligocene to early Miocene limestone* of the Gunung *Wungkal Formation* (Surono, *et al.*, 1992). Limestone-Wungkal Formation is unconformably overlain by Kebo-Butak Formation of basaltic sills at the bottom allegedly formed in the Oligocene to early Miocene (Atmaja, *et al.*, 1995 and Surono, 2008). Subsequently, Kebo-Butak Formation

are overlain by the early Miocene Semilir Formation. The total *layer thickness* of Bayat site in accordance with the measurement of the cross-section indicated the thickness (t) *measured perpendicularly* to bedding plane (Figure 3). The results showed the thickness of sedimentary rocks (t_1) of 2.37 km, whereas the metamorphic complex (t_2) was 1.04 km.

Field study in Ngalang River (Kali Ngalang) site was carried out by measuring north-south stratigraphic section across Ngalang River to Oyo River. Samplings were conducted at 11 observation points. A measured stratigraphic section was attained from the field investigation that contained 4 (four) formations at Ngalang River (Figure 4). The bottom is the early Middle Miocene that is unconformably overlain by the Middle Miocene Ngalanggran Formation. The late Middle Miocene Sambipitu Formation is conformably overlain by the youngest formation in Ngalang River, which is Oyo Formation (Pandita and Sukartono, 2014). The total layer thickness of Ngalang River measured section is approximately 1405.3 m.

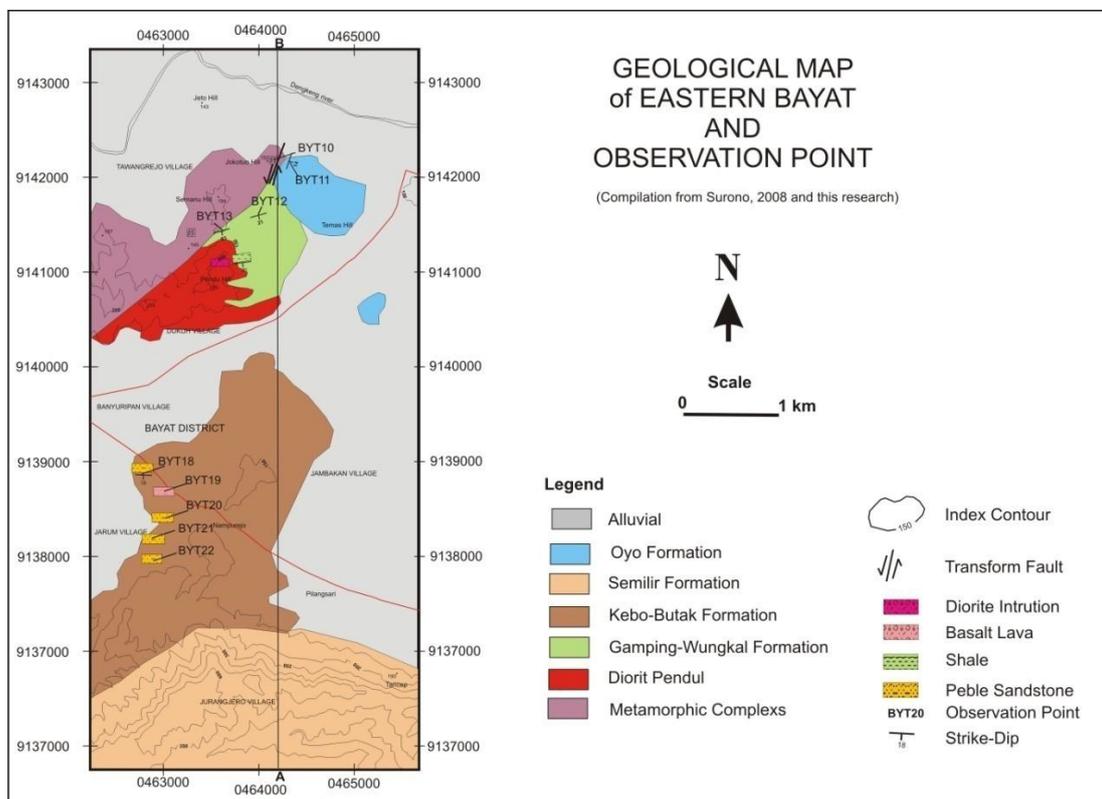


Figure 2. Geological Map of Eastern Bayat and Observation points (compiled by Surono, 2008 and data analysis).

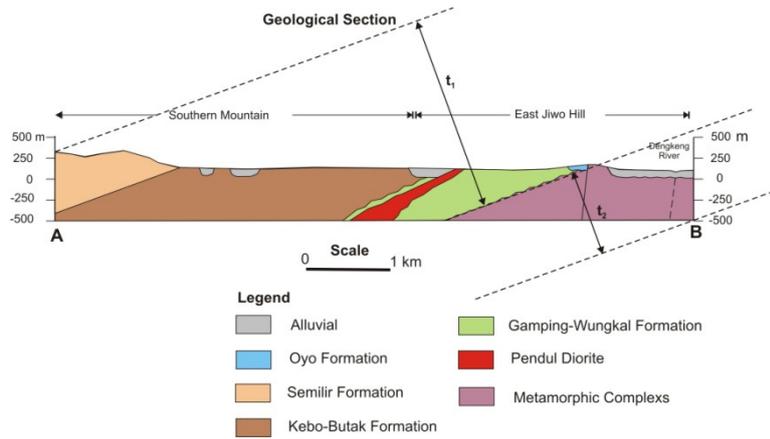


Figure 3. Stratigraphic section of Bayat and adjacent areas, t_1 : sedimentary rocks thickness, t_2 : metamorphic rocks thickness.

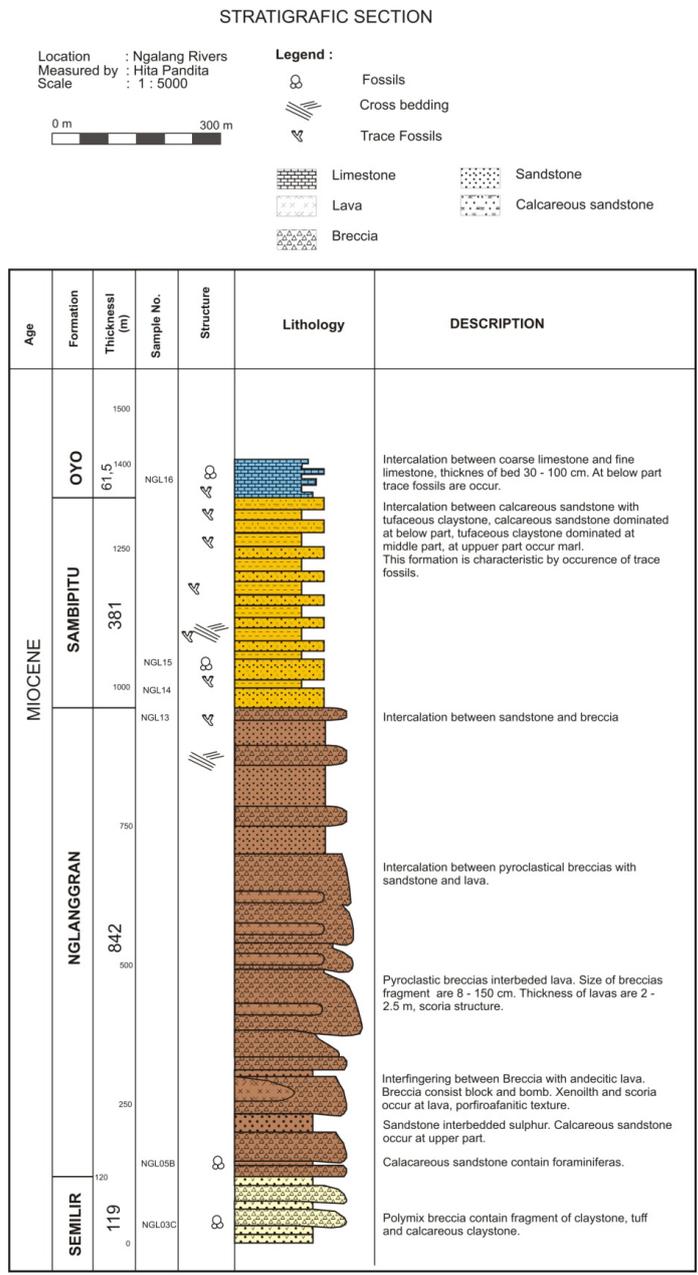


Figure 4. Measured stratigraphic section of Ngalang River.

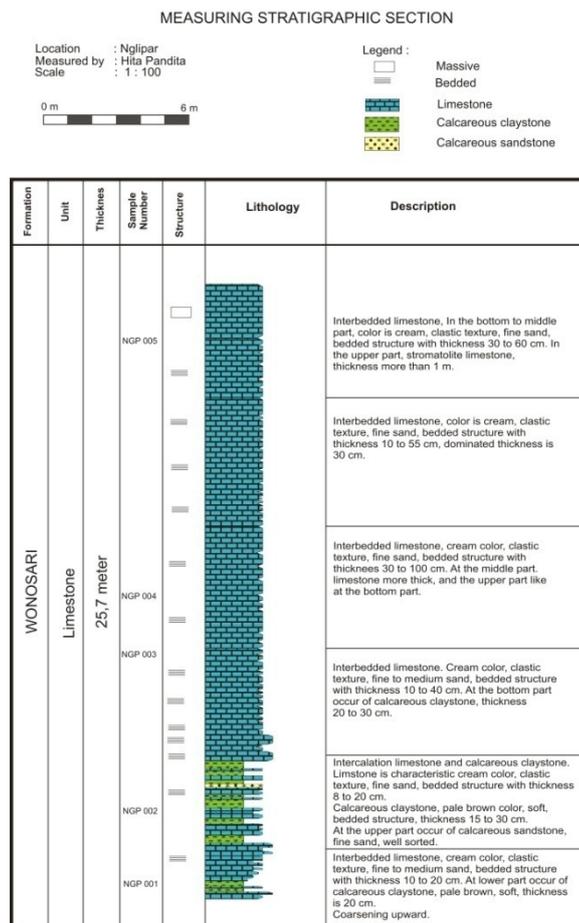


Figure 5. Measured Stratigraphic section of Nglipar.

The research site was in Oyo River precisely in Nglipar started from the bridge in Nglipar-Wonosari road to the upstream of Oyo River. Based on the geographical position, it lies at 9125466 S and 49 M 0456939 E. In general, Wonosari Formation in Karangmojo and adjacent areas primarily consists of limestone. However, *limestone* comprises a *fine fraction* of limestone particles and a *coarser fraction* of limestone (Figure 5). Overall, limestones in this area have endured *karstification* process identified from the layered rocks. It reaches

25.7 m in thick. The research site was in Kepek Sub-village in the southwest Wonosari. A trajectory was established in one of the hills. Its geographical position is at 9119262 S and 49 M 0444248 E. It is a thick tuffaceous marls with limestone on top of them. These rock units are part of Kepek Formation. At the bottom of the formation is tuffaceous marls with abundant *planktonic foraminifera* (Figure 6). It is overlain by coarse limestone with high *foraminifera* content. Total thickness of Kepek Formation is 32.4 m (Figure 6).

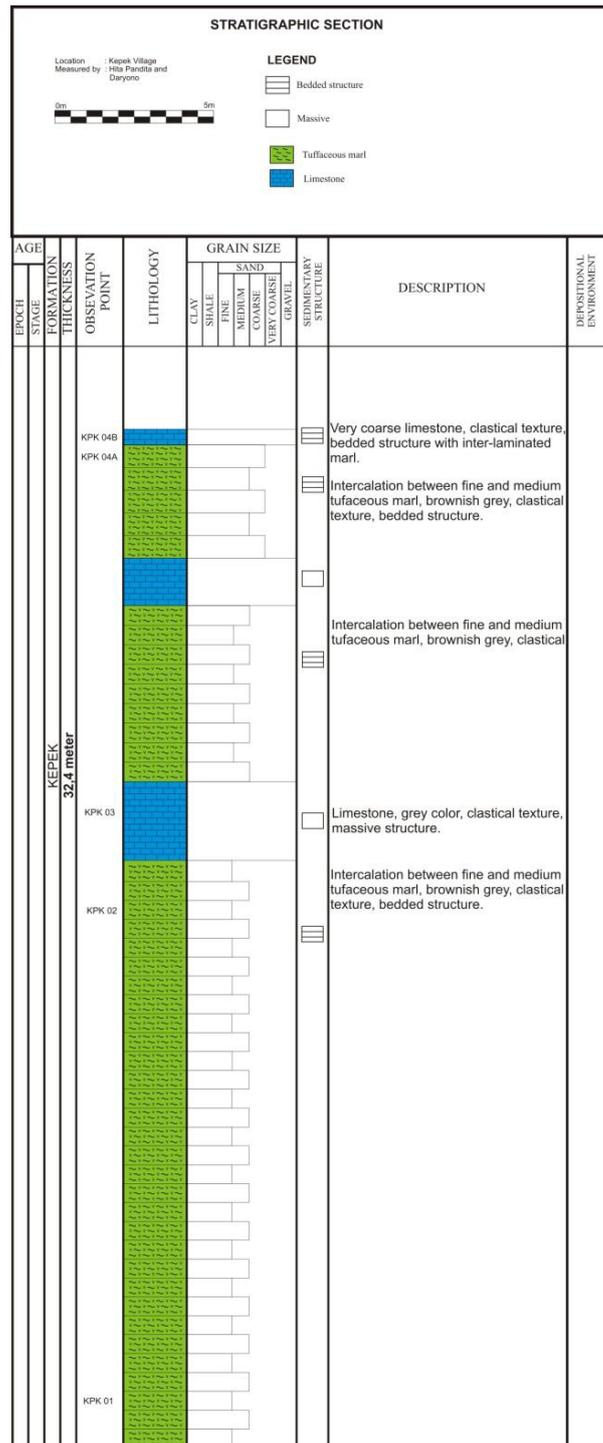


Figure 6. Stratigraphic section of Kepek Formation as measured in Kepek Sub-village.

Total Layer Thickness of Southern Mountains

Measurement of the layer thickness was carried out by two methods, namely the stratigraphic measurements in the sites and the reconstruction of the geological section.

Reconstruction of geologic section was performed in Bayat and adjacent areas, while the stratigraphic measurements were carried out in three sites including Nglipar (NLP), Kepek (KPK) and Ngalang River (NGL).

The results of the geological section of Bayat indicated the stratigraphic sequence from the oldest to the youngest, respectively is as follows: Metamorphic Complex, Limestone-Wungkal Formation, Kebo-Butak Formation, and Semilir Formation (Figure 3). Based on the analysis on the section, the layer thickness (t) measured perpendicularly to bedding plane (Figure 3) was determined. The sedimentary rocks (t_1) was 2.37 km in thick while metamorphic complex (t_2) was approximately 1.04 km in thick.

Direct measurement methods in the field were done in three sites, namely, Nglipar (NLP), Kepek (KPK) and Ngalang River (NGL). The Formasi Oyo-Wonosari Formation in Nglipar (NLP) was measured and the result was 25.7

m in thick. In the area Kepek (KPK), Kepek Formation was calculated with the result of 24 m in thick. In Ngalang River (NGL), there are four formations, namely Semilir Formation, Nglanggran Formation, Sambipitu Formation and Oyo Formation, with a thickness of 1405.3 m. Thus the total layer thickness of threes sites was 1.455 km.

Based on these two methods, the total thickness of sedimentary rocks in the Southern Mountains was obtained of 3.823 km. Furthermore, the bedrock thickness of Southern Mountains in the form of metamorphic rocks was estimated approximately 1.042 km. Compilation of regional data indicated the possibility of higher thickness of the bedrock as identified by the seismic data (Figure 7) (Prasetyadi, 2007).

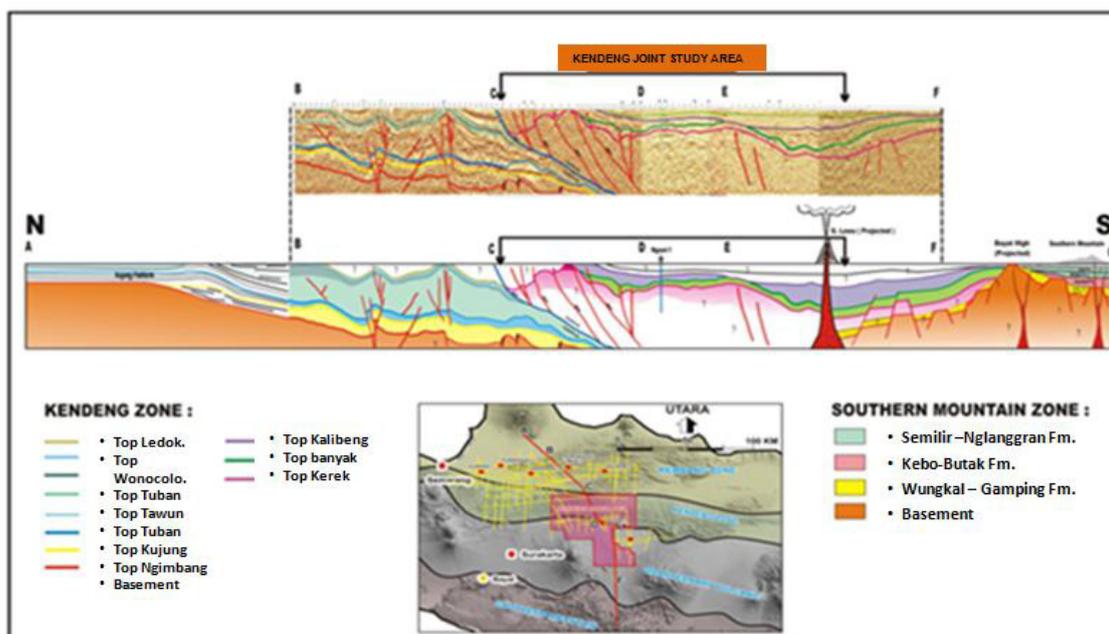


Figure 7. Seismic-based Interpretation of East Java Subsurface from Rembang Zone to Southern Mountains demonstrates the bedrock thickness (Prasetyadi, 2007).

The result of field study supported by several literatures (Prasetyadi, 2007; Suroño, *et al.*, 1992; and Rahardjo, *et al.*, 1995) indicated the bedrock of Southern Mountains basin is formed by metamorphic complex. To determine whether the bedrock was the seismic source, several approaches were carried out as follows.

In accordance with the several literature studies, the earthquake occurred in adjacent to Opak Fault was at a depth of +10 km (Pandita, *et al.*, 2013, and Thant, *et al.*, 2008). The total layer thickness as the finding of the field study was 5 km in thick, with more than 1 km was formed by metamorphic complex. From these two conditions, it can be predicted that there

are two possible types of rock as the seismic source in the adjacent areas of Opak Fault, namely, the metamorphic complex and older rocks of the metamorphic complex. In fact, there is an absence of study regarding with the existence of older rocks of metamorphic complex in the Southern Mountains, thus, the alleged seismic source type of rock was metamorphic complex.

Conclusion

The total layer thickness of Southern Mountains can be calculated based on the thickness of sedimentary rocks that reach 3.823 km in thick. Nevertheless, the thickness of bedrock of Southern Mountains in the form of metamorphic rocks was estimated reaching approximately 1.042 km. In accordance with the compilation of seismic data, the thickness of sedimentary rocks and bedrock was more than 5 km.

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Based on epicenter data, the earthquake occurred in adjacent to Opak River was at 10 km in depth. Subsequently, the data was compiled with the total layer thickness of Southern Mountains. The seismic source type of rock was allegedly came from the bedrock of Southern Mountains basin. The bedrock is formed by metamorphic complex.

Acknowledgement

This research was a part of the *Competitive Grant (Hibah Bersaing)* funded by the Directorate of *Higher Education (DIKTI)* for the fiscal year 2014-2015. The researchers would like to express gratitude for the student assistants who support the process of data collection, both in the field and the laboratory.

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