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Title	Identification of Seismic Types of Rock Adjacent to Opak Fault Based on Stratigraphic Sections of the Southern Mountains
Author	<i>Hita Pandita</i>
Co-author(s)	<i>Sukartono Sukartono, Agustinus Isjudarto</i>

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## Identification of Seismic Types of Rock Adjacent to Opak Fault Based on Stratigraphic Sections of the Southern Mountains

### 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. The last earthquake took place in 2006 at an epicenter depth of 10 km. 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.

Key words: 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. Gempa yang terakhir terjadi pada tahun 2006 dengan kedalaman episentrum 10 km. 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,

**Commented [AC1]:** Did you mean that Opak Fault was responsible to 2006 Yogya Eq.? Please be careful, mention it in introduction completed by reference. See Tsuji et al, 2009

despite the efforts of a number of tectonicologists and seismologists in carrying out studies to find out how to estimate earthquake precisely. Those studies, in fact, have not yielded any satisfying results. Based on those studies, sufficient knowledge for the constituent of the seismic rock types, is significantly required (Matsushima, 1961).

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

## RESEARCH METHODS

The method applied in this study consisted of stratigraphic measurements and surface mapping of the site. The mapping covered Yogyakarta region and Klaten regency (Figure 1). Those sites were

regarding with disaster prediction and mitigation. Pandita, et al. (2012 and 2013) initiated a research on earthquake microzonation in Yogyakarta and generated a microzonation map. 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 earthquakes in the future.

## PURPOSES AND OBJECTIVES

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.

expected to provide ample data regarding with the types of rock as the source of the earthquake. Additionally, four observation sites were determined.

**Commented [AC4]:** with regard to or regarding, not regarding with

**Commented [DD5]:** 2008?

**Commented [AC2]:** 1.It seems you wanted to say that earthquake (when, where, magnitude) is unpredictable yet, to predict earthquake precisely, we need to have to understand the type of seismic rock type. However, Matsushima found the relationship between distribution of great earthquakes with strength of the crust and upper mantle, not to predict when and in which geographical coordinate will the earthquake occur. 2.Tectonicologist is not common term, I think plate tectonic expert is better.

**Commented [AC6]:** What are you going to estimate? Location, time, magnitude or all of them?

**Commented [DD3]:** 2008?

**Commented [AC8]:** Regarding or with regard to

**Commented [AC7]:** Geological surface mapping

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 about the past earthquakes. The rocks derived from the sites became the samples and furthermore analyzed in the laboratory.

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**Commented [AC10]:** The rocks samples would be analyzed in the laboratory. You can sample the rock but you can derive the rock, I think.

**Commented [AC11]:** Specify the laboratory tests did you apply, explain the result in Data and Analysis section

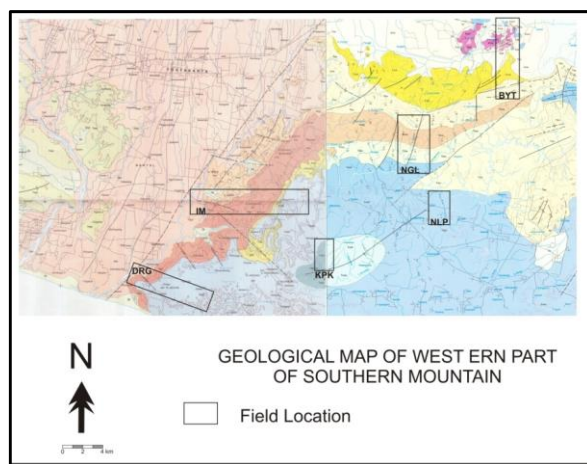


Figure 1. Field study was carried out in 6 (six) sites: KPK (Kepek), Ngalang River (NGL), Nglipar (NLP), Bayat (BYT), Imogiri (IM) and Dringo (DRG). Source: Geological Maps (Rahardjo, *et al.*, 1995; Surono, *et al.*, 1992)

### 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 2).

**Commented [AC12]:** Did you create all of these or someone else did? As you mentioned, Figure 2 was made by Surono, 2008 while you might be created stratigraphic profile in 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 to 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 Nglanggran 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 is approximately 1405.3 m.

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Commented [AC14]: Ngarang River measured section

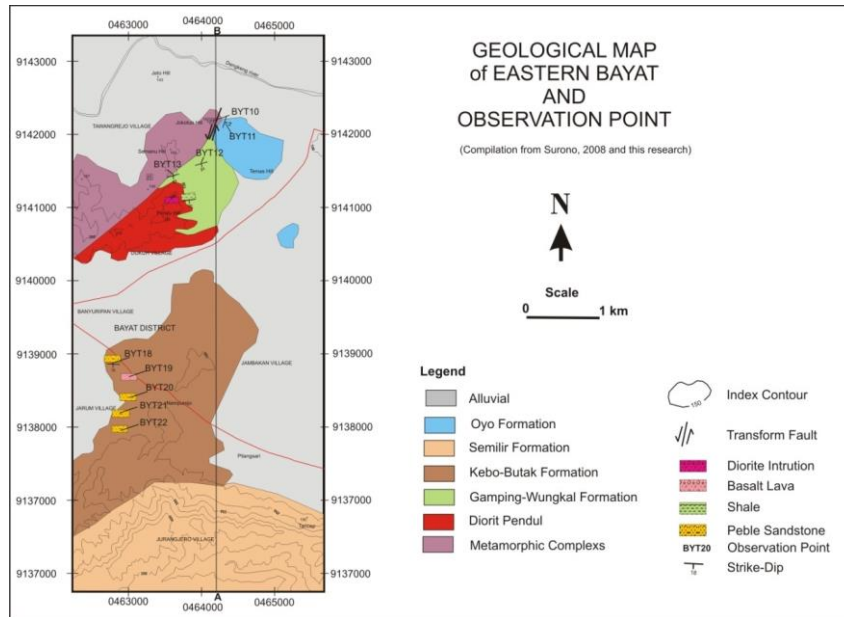


Figure 2. Geological Map of Eastern Bayat and Observation points (compiled by Surono, 2008 and data analysis).

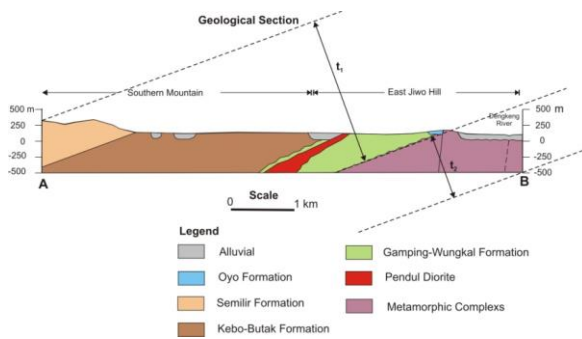
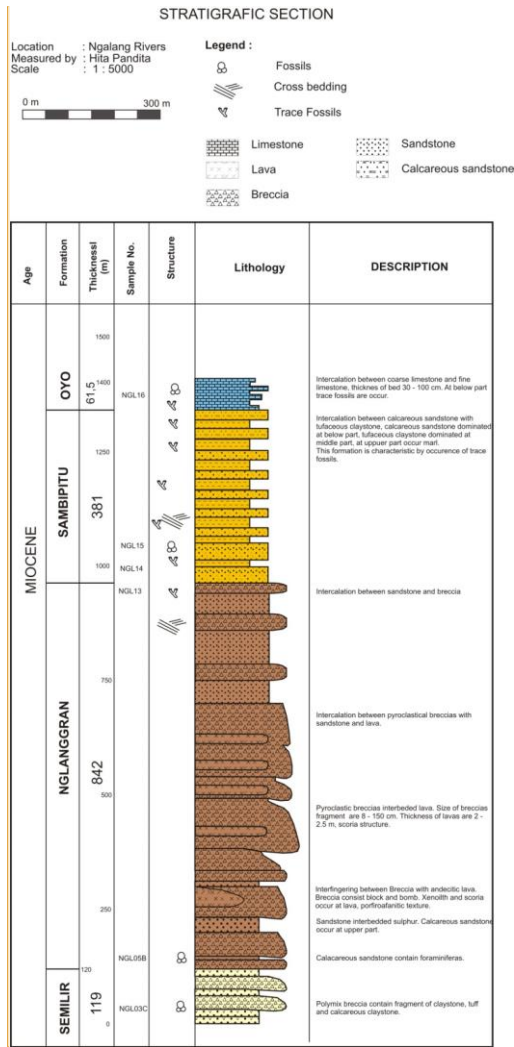


Figure 3. Stratigraphic section of Bayat and adjacent areas,  $t_1$ : sedimentary rocks thickness,  $t_2$ : metamorphic rocks thickness.



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Figure 4. Measured stratigraphic section of Ngalang River.



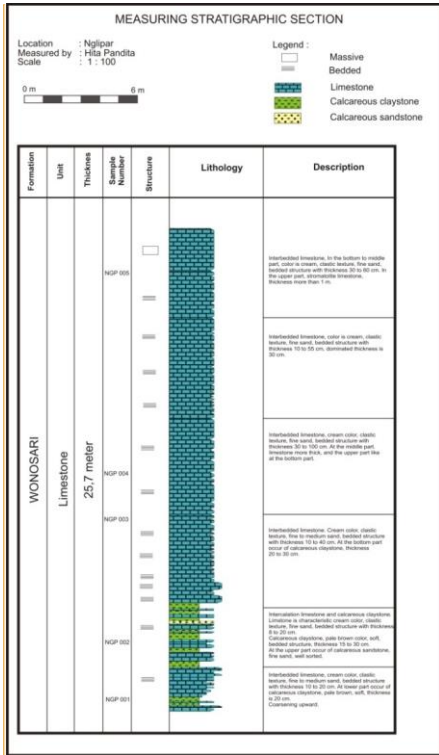


Figure 5. Measured Stratigraphic section of Nglipar.

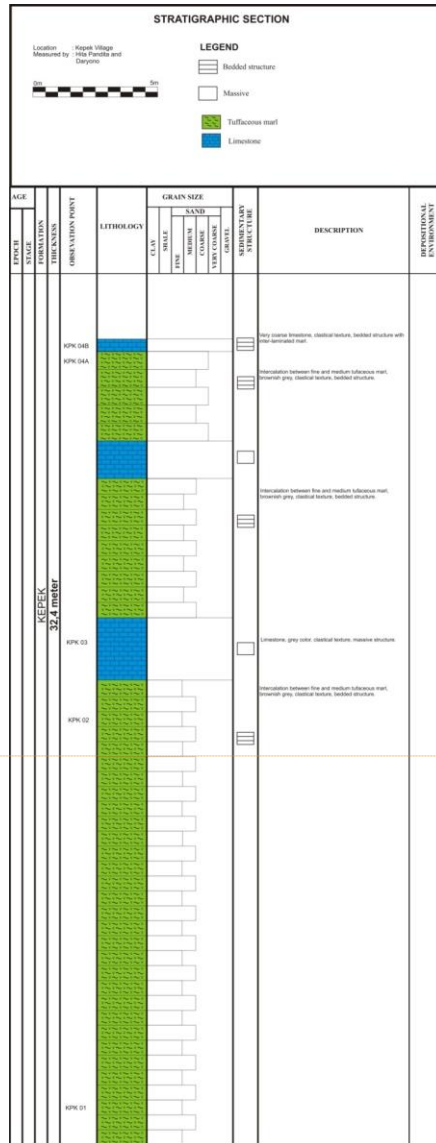


Figure 6. Stratigraphic section of Kepek Formation as measured in Kepek Sub-village.

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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).

**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, 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

Commented [AC17]: Is as ...

1405.3 m. Thus, the total layer thickness of the three 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).

## DISCUSSION

The result of field study supported by several literatures (Prasetyadi, 2007; Surono, *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 to 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 to the compilation of seismic data, the thickness of sedimentary rocks and bedrock was more than 5 km.

Referring to the 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 derived from the bedrock of Southern

**Commented [AC18]:** The phrase should not be here. It is supposed to be like this: Thus the total layer thickness of threes sites was 1.455 km. Is it three sites or 3 formations?

**Commented [AC22]:** Your findings are:  
1.Total layer thickness was 5km  
2.The metamorphic rock composed the bottom of the layer.  
3.Lower than 5km of depth, the rock type is still unknown  
From the reference, the epicenter was at the depth of 10 km. Was that what do you want to say in this paragraph?  
  
If yes, how could you say that at the depth of 10 km, the rock is older metamorphic rock? Only assumption?

**Commented [AC23]:** The title of this paper is **Identification of Seismic Types of Rock Adjacent to Opak Fault Based on Stratigraphic Sections of the Southern Mountains**, however in Discussion and Conclusion sections seismic type was not mentioned at all. What you have done is geological identification of the rock expected as the epicenter of Yogyakarta Earthquake. I tend to rewrite the title as Identification of Rock type of seismic source ...  
Or Geological Identification of Seismic Source ...

**Commented [AC19]:** The supporting facts should be written after you write down your findings.

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**Commented [AC25]:** Reference?

**Commented [AC26]:** How about rock type of seismic source?

**Commented [AC21]:** I couldn't see geomorphic rock in your stratigraphic log. Metamorphic rock should appear in Bayat, but you don't show any of stratigraphic log in Bayat.

**Commented [AC27]:** I don't understand this phrase, rock derived from bedrock

Mountains basin. The bedrock is formed by metamorphic complex.

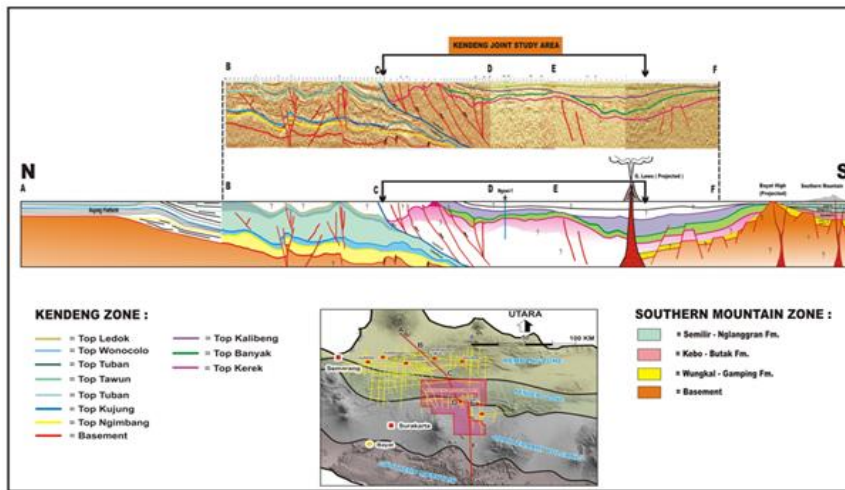


Figure 7. Seismic-based Interpretation of East Java Subsurface from Rembang Zone to Southern Mountains demonstrates the bedrock thickness (Prasetyadi, 2007).

#### ACKNOWLEDGEMENT

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## Identification Of Seismic Types Of Rock Adjacent To Opak Fault Based On Stratigraphic Sections Of The Southern Mountains

*Hita Pandita, Sukartono Sukartono, Agustinus Isjudarto*

### Abstract

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### Keywords

Stratigraphy, Earthquake, Southern Mountain

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