Identifying Subsurface Structures beneath the Sumani and Sianok Segments of the Great Sumatran Fault using Combined Geophysical Methods

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Abstract. The 1900 km long Great Sumatran Fault is a complex active fault system that is divided into segments that include the Sumani and Sianok segments in a rather densely populated area of the West Sumatra Province. Major earthquakes have occurred in these two segments that include the March 2007 Sumatra earthquake. Mitigating future risks requires a better understanding of these complex segments. To identify the subsurface structures beneath the Sumani and Sianok segments, we are conducting combined geophysical study that include gravity and magnetic. Gravity data were obtained from the published regional Bouguer anomaly map of the area around these two segments. The measurements from which the map was derived were rather sparse. Thus, more detailed magnetic measurements were carried out in this study. Magnetic measurements were also expected to be more sensitive as the predominant rocks in the study area are volcanic as well as other type of intrusive rocks. These gravity and magnetic analyses were complemented by seismicity data that will enhance the modelling of subsurface structures. Progress of this study will be reported. Challenges and obstacles will also be presented.

1. Introduction
Located in Indonesia, the Great Sumatran Fault (GSF) is a 1900 km long fault system that is still very active. Studies have shown that this fault system is caused by subduction of Indo-Australian plate beneath the Eurasian plate [1-4]. GSF could be divided into 19 segments [5] and four of these segments (Sumani, Sianok, Siulak and Sumpur) passed through the province of West Sumatera. Two segments, i.e., Sumani and Sianok are particularly intriguing because of their history of damaging earthquakes as well as their proximity to major population centers in the province of West Sumatra [6-8]. Moreover, there were records of damaging doublet earthquakes in the vicinity of Sumani [9-10].
Despite of their geological risks, the structures underneath these two segments are not well understood. 

To resolve these questions, an integrated geophysical study was proposed. The study area is located within these coordinates (99°50' to 100°45' East and 0°05' to 0°50' South) covering an area of about 103 km times 85 km. The main methods are passive or potential methods, i.e., magnetic and gravity [11-12]. These two methods are very suitable for resolving the geometry of underneath structures [13-15]. These two methods are complementary as each of them relying on different physical properties: magnetic susceptibility for magnetic method and density for gravity method [16-17]. Earlier, this area was also subjected to qualitative gravity interpretation [18] based only on Bouguer anomaly map produced by Pusat Survey Geology (PSG or The Center for Geological Survey) of Indonesia. It is expected that the proposed study will produce more comprehensive results but qualitatively as well as quantitatively.

2. Geological Setting

Regionally, the research area are segments of GSF caused by oblique subduction between Indo-Australia and Eurasia plates causing significant lateral force [1]. Based on combined geology and GPS surveys, this lateral force along GSF creates slip rate of about 14-15 mm/year [19] causing seismically active regions that include the Sumani and Sianok segments of the GSF [20]. These two segments are show in Figure 1.

Figure 1. Simplified geological map of Sianok and Sumani segments of the GSF. The active faults are shown in red bold lines (modified from [21-22]).

Based on the regional geological maps [21-22], the research area shown in Figure 1 comprises of various type of rocks ranging from Carboniferous and Permian metamorphic rocks, Tertiary intrusive rocks to quaternary volcanic rocks and sediments. Around Lake Singkarak, Permian metamorphic rocks present along with Cretaceous granite and ultrabasic rocks. Permian rocks also appear in this area as phyllite and shale. Around these two segments, Tertiary rocks appear as andesite to basalt near Lubuk Sikaping, Pasaman while in the foothill of Mt. Singgalang, there are Miocene granitic rocks. Other Tertiary rocks appear as limestone as well as slate and shale.

Younger Quaternary rocks (Holocene to Pleistocene in age) appear in several places that include the Marapi andesite (near Mt. Marapi) and the Singgalang Tandikat andesite (around Mt. Singgalang-Tandikat. Around Lake Maninjau, there are Maninjau andesite as well as pumiceous tuff and andesite. Around Lake Singkarak, there are lahar, conglomerate, and undifferentiated flows. As shown in Figure
1, the predominant rocks around Sianok and Sumani segments are relatively Quaternary volcanic rocks followed by Tertiary and Permian rocks.

3. Methods
The main method in this study is geomagnetic survey carried out using GEM Proton Precision Magnetometer GSM-19T (GEM system, Markham, Canada) in the following cities and districts in the province of West Sumatra (Tanah Datar, Solok, Padang Pariaman, Agam, Pasaman Timur, Padang, Padang Panjang, Batusangkar and Bukittinggi). The measurements were carried out along highways, streets and dirt roads that are accessible either by car or motorcycle. The density of survey points varies between 500 m to 1000 m depending on their distance to the suspected fault lines (based on geological maps). The density is higher in the vicinity of fault lines. The coordinates of survey points were determined using Garmin GPS system.

Field magnetic data were then subjected to various corrections that include diurnal correction and IGRF (International Geomagnetic Reference Field) correction to obtain the magnetic intensity values. To complement magnetic data, gravity data in the form of Bouguer anomaly were used based on the anomaly maps for Solok and Padang regions derived from ground measurements with station spacing of about 5 km [23-24]. The gravity data were digitized so that they could be integrated seamlessly with magnetic data. The magnetic and gravity data were then processed further using GM-SYS Oasis Montaj (Geosoft Inc., Toronto, Canada). The processing includes gridding (with a minimum curvature approach) due to the relatively equal distance of the measurement stations and that is followed by extrapolation processing through adjustment of blanking distance. The values of the emptying distance were set at 5000 because of these values the magnetic anomaly is easier to be interpreted. The data were then filtered using Gaussian Regional/Residual filter. This type of filter was chosen as it produces better magnetic anomaly pattern compared to that of other filters such as Bandpass filter.

This filtering process was carried out using the inclination and declination values of respectively -18° and -0.5° representing that of this area.

4. Progress Report
So far, 798 survey points have been measured in Solok, Tanah Datar, Padang Panjang, Agam and Padang Pariaman (see Figure 2). The points are in the area around Sumani which constitute the first phase of this research. Interim results from the measurements of the Sumani segment have been submitted to the journal Tectonophysics. The surveys were carried out in 23 days using multiple magnetometers. The geomagnetic surveys in Sianok segments were initially planned in 2020. However, due to COVID-19 pandemic, the surveys would be postponed to 2021. The survey lines in Sianok segments are 437 km long with about 637 survey points (shown in Figure 3). Like that in Sumani segment the distance between each survey point is about 500-1000 m.

The condition in the research area is not always easy as the survey lines often must follow undulated terrain along the mountainous Bukit Barisan Range. Some of the survey points are located around 850 m above sea level. The roads are also often impassable to car so that often motorcycle must be used to access the survey points. Some points are also located in Lake Singkarak requiring a special modification on sampan (small boats) that are available on the lake shores.

5. Conclusions
Identification of the subsurface structures beneath the Sumani and Sianok Segments of the GSF is currently underway employing magnetic and gravity data. The magnetic surveys have been completed in the Sumani segment but were delayed in the Sianok segment due to COVID-19 pandemic. In total 798 survey points have been measured and 637 points are to be measured as soon as the pandemic is over. Interpretation of the magnetic anomaly maps of Sumani segments is underway.
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Figure 2. Locations of geomagnetic survey points (shown as red dots) in the Sumani and Sianok segments of GSF. The SRTM satellite image for Sumatra was obtained from the following site: https://www.earthdata.nasa.gov (downloaded on March 5, 2019).
Figure 3. Locations of the proposed geomagnetic survey points (shown as red dots) in Sianok segment of GSF. In total there are about 637 survey points that will be measured.

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