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RESEARCH ARTICLE

A Comparison of Geologic Structure Detection of Sumatera Island Using Goce Satellite Gravity Data and Sgg-Ugm-2 Data

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Abstract

GOCE gravity satellite data can be used for regional fault detection because the observation area is wide and not limited by area. In this study, GOCE satellite data is used to detect geological structures on the island of Sumatra, the results of which are used as the basis for disaster mitigation. GOCE data and SGG-UGM-2 were processed using the GOCE User Toolbox (GUT) software to produce a gravity disturbance map and a complete bouguer anomaly map. The GOCE obtained results were validated using the SGG-UGM-2 high-resolution gravity model data. The calculation results obtained that the gravity disturbance value from the GOCE data was around -140 to 200 mGal, while the value of the gravity disturbance from the SGG-UGM-2 data was around -180-300 mGal. The GOCE gravity disturbance map and the SGG-UGM-2 can detect the Subduction Trench, Mentawai Fault, and West Andaman Fault on Sumatra Island with negative values, while the Sumatran Fault Zone (SFZ) along Sumatra Island with positive values in line with the presence of mountain ranges. The results of the SGG-UGM-2 data processing for the gravity disturbance are more detailed than GOCE because the SGG-UGM-2 data degree is higher than that of GOCE. GOCE complete bouguer anomaly value is around 40-560 mGal, while the value of complete bouguer anomaly SGG-UGM-2 is around 60-560 mGal. The complete bouguer anomaly maps from GOCE and SGG-UGM-2 can detect patterns from the Subduction Trench, Mentawai Fault, and West Andaman Fault but cannot clearly detect SFZ. The complete bouguer anomaly can also detect differences between oceanic and continental crust. The GOCE and the SGG-UGM-2 complete bouguer anomaly map show almost similar patterns and the ability to detect geological structures for sub and regional Sumatra Island. In addition, GOCE data detect geological structures more clearly than GRACE data.

Keywords: GOCE, SGG-UGM-2, Gravity Disturbance, Complete Bouguer Anomaly, Sumatran Fault Zone

1. Introduction

The island of Sumatra is in the subduction zone between the Indian–Australian plate and the Eurasian plate at a speed of 50 to 70mm/year (Prawirodirdjo et al., 2000; Natawidjaja & Triyoso, 2007). The subduction zone stretches from the Sunda Strait to the Andaman Sea. In addition, on the island of Sumatra, there is a mainland fault that stretches for 1900 km called the Sumatran Fault Zone (SFZ). The fault line on the island of Sumatra is characterized by the appearance of hills, shifts in river channels along the fault, and lakes that occur due to the shifting of the earth. This fault line crosses the island of Sumatra along the Bukit Barisan (Putri et al., 2016).

The SFZ has a history of major earthquakes, with more than 19 earthquakes since 1892 of magnitude 6.5 or greater (Hurukawa et al., 2014). Every five years, on average, there is a massive earthquake along the SFZ (Natawidjaja, 2018). Land earthquakes originating from active faults cause severe losses and damage compared to earthquakes originating in the ocean with the same magnitude (Sugiyanto et al., 2011). One aspect of earthquake disaster mitigation efforts is the identification of fault locations through geological structure analysis (Muksin et al., 2019). Analysis of geological structures can be carried out using gravity satellite data, which has a wide observation area and is not limited by area. The gravity method for geological studies is based on measuring variations in Earth's gravity caused by differences in the density of subsurface rocks (Telford et al., 1990). Gravity satellite data is able to provide information related to the redistribution of plates, atmosphere, mantle, hydrosphere, and the earth's centrosphere below the satellite orbit (Saraswati & Anjasmara, 2010).

The principle of gravity satellite is the measurement of satellite orbital perturbation caused by the presence of a gravitational field measured using gravity sensors such as accelerometers, gravity gradiometers, and accurate distance measurements (Zhang et al., 2011). There are two gravity satellites: Gravity Recovery and Climate Experiment (GRACE) and The Gravity field and steady-state Ocean Circulation Explorer (GOCE). GRACE is a gravity satellite developed by the National Aeronautics and Space Administration (NASA) and the German Aerospace Center for scientific information on static and time-variable gravity fields of the Earth (Chen et al., 2018). GRACE's spatial resolution is about a few hundred kilometers because GRACE's altitude is about 400 s.d. 500 km which is insensitive to small-scale gravity signals (Li et al., 2014).

GOCE satellite is a gravity satellite launched by the European Space Agency (ESA) and capable of measuring gravity gradients using a 3-axis gradiometer and has an accuracy of up to 1 mGal and a spatial resolution of less than 100 km (European Space Agency, 2014). Apart from satellite data, there are also high-resolution global geopotential model data such as SGG-UGM-2. Earth gravity model SGG-UGM-2 is a high-resolution earth gravity model combined from GOCE, Gravity Recovery and Climate Experiment (GRACE) data, and EGM2008. This model shows promising performance in GPS validation (Liang et al., 2020).

This study aims to demonstrate the effectiveness of GOCE satellite data for regional fault identification and compare the results with SGG-UGM-2. This research paper focuses on using the gravity disturbance and the complete bouguer anomaly from GOCE and SGG-UGM-2 data in detecting faults. It is hoped that additional geological information can be obtained from the two satellite data and can be an effective method for detecting regional geological structures as a disaster mitigation effort, especially in areas that are difficult to reach by terrestrial methods.

2. Geologi Setting

The map of the geological structure of Sumatra in Figure 1. describes the structure of Sumatra, which is dominated by the subduction of the Indian plate to the northeast under the island of Sumatra. The SFZ is a dextral horizontal fault that stretches along the island through the center of the mountain range from Northwest to Southeast with compression and extension zones, forming uplift and pull-apart basins that form grabens along with the fault system (Barber et al., 2005). The SFZ stretches for 1.900 km in the western part of Sumatra Island, consisting of 19 segments with a length of about 35 to 200 km (Sieh & Natawidjaja, 2000).

The forearc area includes a subduction trench part of the Sunda Trench, an accretion complex composed of seabed material exfoliated from the Indian Plate. The forearc ridges that rise above sea level to form forearc islands and forearc basins located between the ridges and volcanic arcs on the mainland. Sumatra. The Backarc region is a Tertiary sediments basin that extends northeast from the mountain range across the Malacca Strait to the east coast of the Malay Peninsula. Tertiary sediments were formed by Palaeogene rifting and subsidence and were filled by Neogenes up to the present sedimentation (Barber et al., 2005).

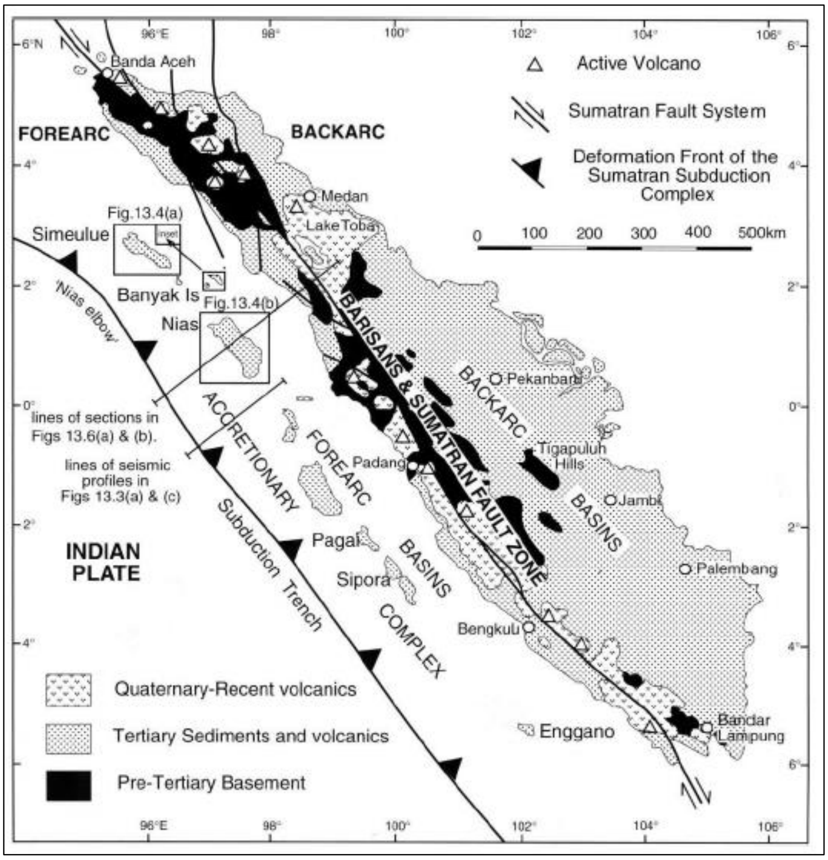

Fig. 1. Map of geological structure of Sumatra (Source : Barber et al., 2005)

3. Methods

The research location for detecting regional geological structures was carried out, covering the entire island of Sumatra in a geographical position of -7⁰ to 6.5⁰ N and 94.5⁰ to 108⁰ E. The data used include GO_CONS_GCF_2_TIM_R6e with degree 300, SGG-UGM-2 with degree 2190, and Topographic Gravity Field Models data. The data is obtained from http://icgem.gfz-potsdam.de/. The spatial resolution of GOCE and SGG-UGM-2 be determined using,

$$\frac{\pi R}{N_{max}} \qquad (1)$$

Where R is the earth's radius (6,371 km) and N_{max} degree. The spatial resolution of GO_CONS_GCF_2_TIM_R6e data is 67 km. While the spatial resolution of SGG-UGM-2 is 9.1 km.

In addition, the default DEM (GUT ACE2 BATHY 5M) data from the GUT (GOCE User Toolbox) software is used. Supporting data are faults shapefile data (SFZ, Subduction Trench, Mentawai Fault, West Andaman Fault), geological structure maps, and Sumatra Administration.

Figure 2 explains GOCE and SGG-UGM-2 data processing to get the value of gravity disturbance and complete bouguer anomaly using GUT software with a grid of 0.05^0. Processing gravity disturbance using GUT ACE 2 BATCH 5 M data while processing complete bouguer anomaly requires Topographic Gravity Field Models data for terrain correction.

Gravity disturbance is a kind of free air anomaly that is reduced to the normal earth ellipsoid surface as the reference surface, usually used for estimating the geoid height. The equation for gravity disturbance δg is as follows (Bauer Marschallinger et al., 2015):

$$\delta g = g_P - \gamma_P \text{......}(2)$$

with g_P the difference between the observation gravity g and the normal gravity γ at the same point P on the geoid.

The complete bouguer anomaly map is an anomaly distribution that describes the general subsurface geological conditions, a combination of regional anomalies and residual anomalies. The complete Bouguer anomaly equation Δg_{CB} is as (Bauer Marschallinger et al., 2015):

$$\Delta g_{CB} = \Delta g_{FA} - g_{SB} - g_T \text{......}(3)$$

with Δg_{FA} free air anomaly, g_{SB} simple bouguer anomaly, and g_T terrain correction. The Bouguer anomaly was compiled with a reduced density of 2670 kg/m³ for the density of crust and 1020 kg/m³ for the density of water (Rio & Dinardo, 2011).

Visualization of gravity disturbance map and the complete bouguer anomaly map using Surfer software. Furthermore, the gravity disturbance map and the complete bouguer anomaly map are overlaid with supporting data in QGIS software for interpretation and analysis purposes.

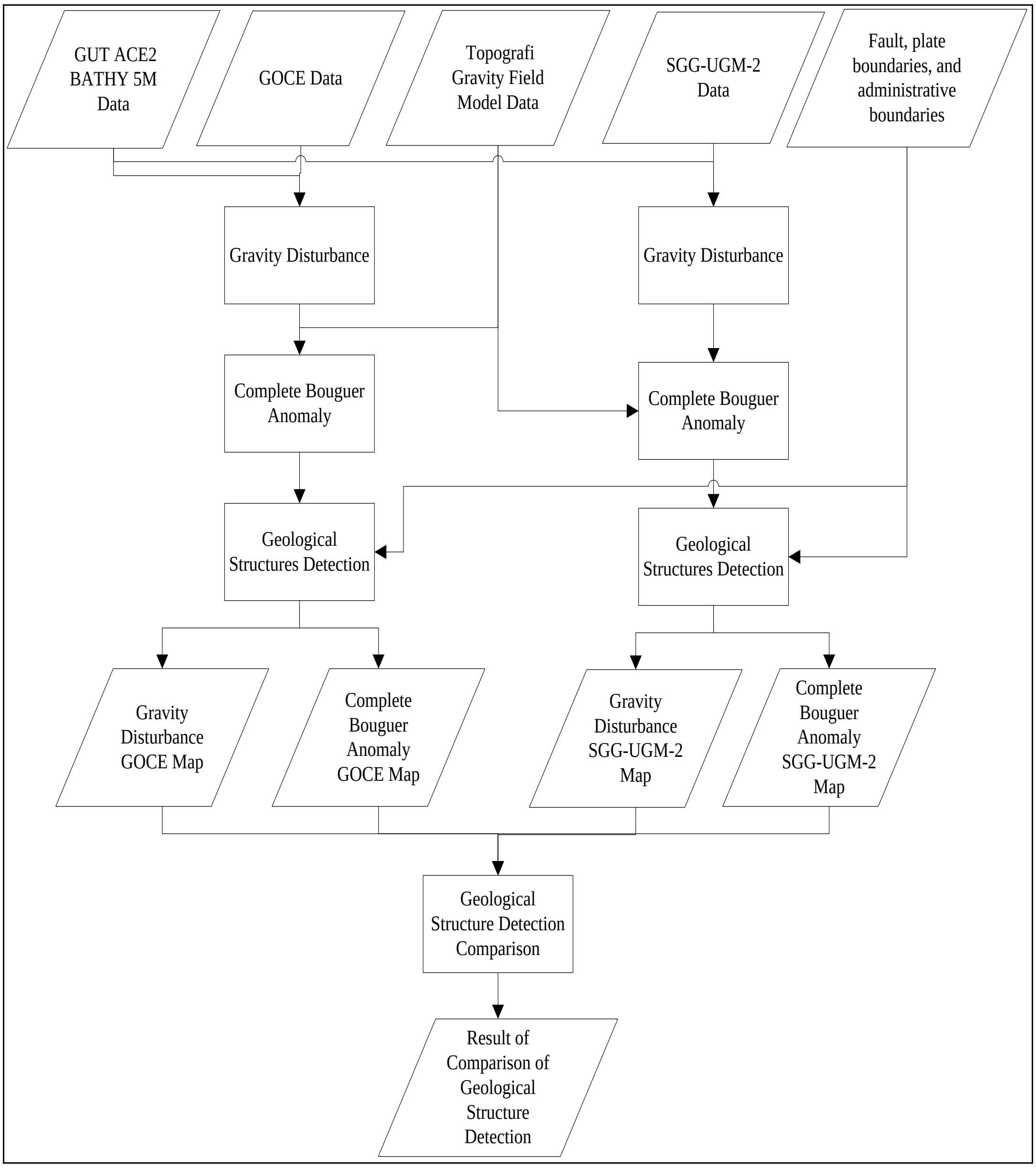

Fig 2. Research diagram

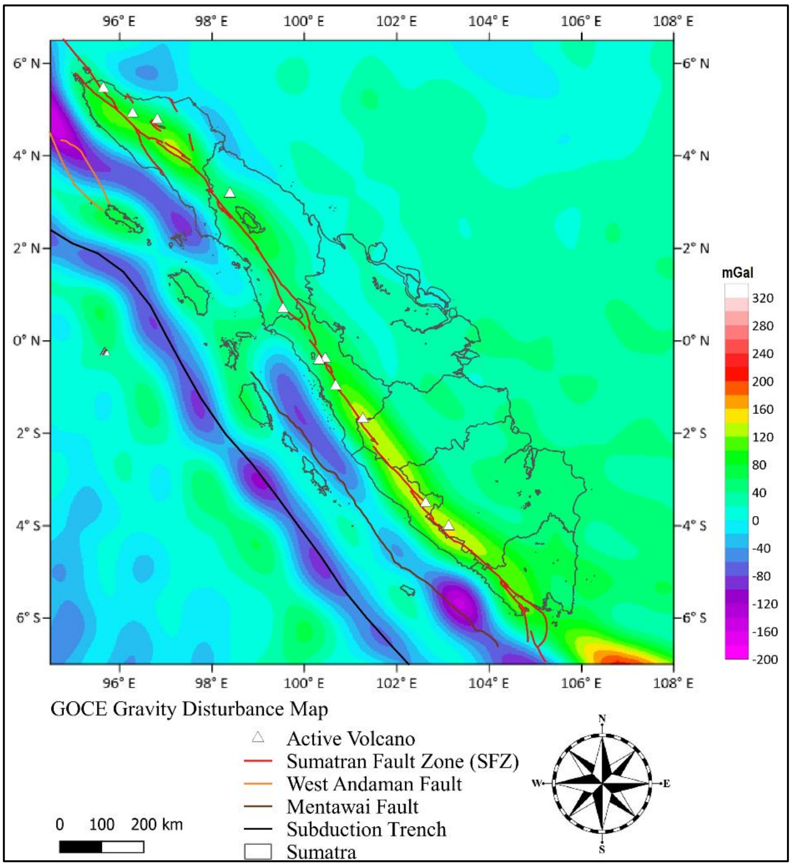

Fig 3. Gravity disturbance GOCE Map

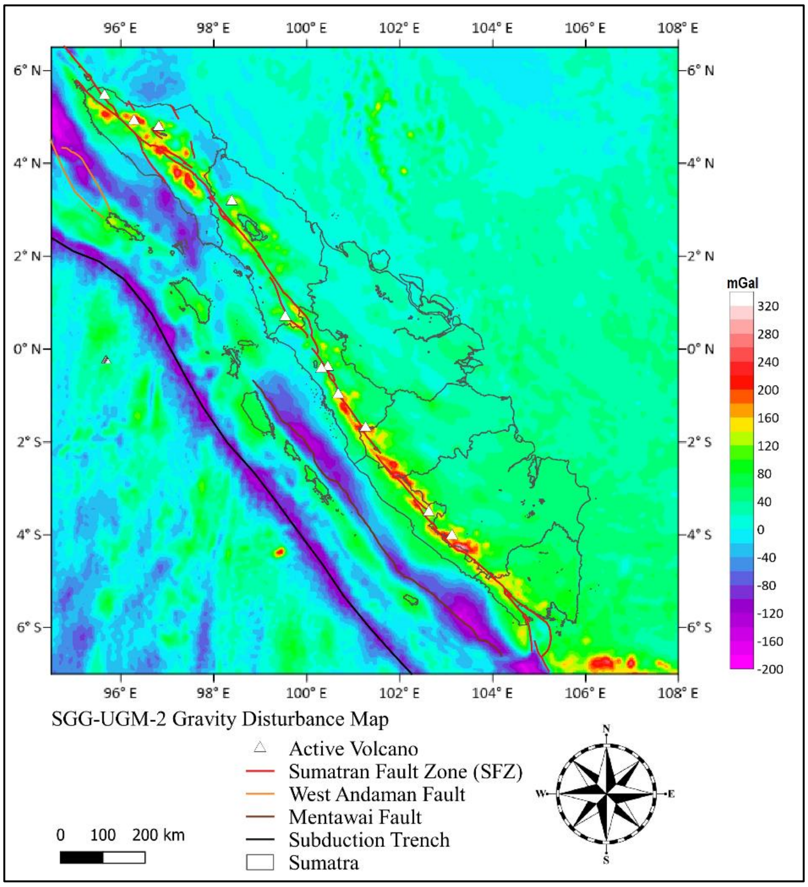

Fig 4. Gravity disturbance SGG-UGM-2 Map

4. Result and Discussion

4.1 Gravity Disturbance

The results of processing the gravity disturbance from the GOCE data are shown in Figure 3 with values around -140 to 200 mGal and from the SGG-UGM-2 data shown in Figure 4 around -180 to 300 mGal. The value of the color bar range of Figure 3 and Figure 4 is made the same, around -200 to 320 mGal with an interval of 20. This aims to see the differences and similarities in the results of the gravity disturbance GOCE and SGG-UGM-2.

The GOCE and SGG-UGM-2 gravity disturbance maps show the same pattern for the Subduction Trench, Mentawai Fault, and West Andaman Fault, which is dominated by negative gravity disturbance values around -200 to -10 mGal. This interpretation is also validated by the shapefile data of the Subduction Trench, Mentawai Fault, and West Andaman Fault, which are overlaid on the two maps. The GOCE and SGG-UGM-2 gravity disturbance maps show the SFZ zone pattern on land, which is dominated by high positive gravity disturbance values. On the GOCE gravity disturbance map, the high value is around 40 to 200 mGal. Meanwhile, on the gravity disturbance map SGG-UGM-2, the high value is around 40 to 300 mGal. The high gravity disturbance value in the SFZ zone may be influenced by the mass of the Bukit Barisan, including an active volcano on the mainland of Sumatra Island. These results were also validated with secondary data from SFZ shapefiles and active volcanoes. The SFZ pattern from the SGG-UGM-2 gravity disturbance map (Figure 4) is more detailed for SFZ detection than the GOCE gravity disturbance map (Figure 3).

4.2 Complete Bouguer Anomaly

The complete bouguer anomaly displays the anomaly that the terrain has corrected in the study area (Asniar et al., 2020). Figure 5 shows a complete bouguer anomaly map from GOCE, whose values are around 40 to 560 mGal. Figure 6 shows a complete bouguer anomaly map of SGG-UGM-2 with values ranging from 60 to 560 mGal. Figures 5 and 6 also have the same color bar range, so you can see the similarities and differences between the two results. The value of the complete bouguer anomaly on the mainland of Sumatra Island is dominated by low values of around 40 to 240 mGal. It is different from the gravity disturbance value, which is dominated by high values on the mainland of Sumatra Island. The difference is because the complete bouguer anomaly takes into account rock mass and topography, while the gravity disturbance is not taken into account. Terrain correction in the GUT software is done globally, there is no distance limit so that the results of the complete bouguer anomaly are smoother.

The complete bouguer anomaly maps from GOCE and SGG-UGM-2 show the SFZ clearly in certain areas such as Aceh, North Sumatra, West Sumatra, and Jambi. Meanwhile, the complete bouguer anomaly map from SGG-UGM-2 shows the SFZ from Aceh to Lampung. In the suspected pattern of SFZ, the value of complete bouguer anomaly is very low, around 40 to 160 mGal. In the Mentawai zone the Fault and West Andaman Fault can also be detected. Other information obtained from the complete bouguer anomaly maps of GOCE and SGG-UGM-2 clearly shows the Subduction Trench and a clear distinction between oceanic crust and continental crust.

The effect of high and low anomaly is due to differences in subsurface density. The high anomaly in the Southwest Figure 5 and Figure 6 show that the density of the oceanic crust (Indo-Australian plate) is higher than that of the Continental crust (Eurasia plate). The complete bouguer anomaly map of SGG-UGM-2 and GOCE did not have a significant difference. It is necessary to measure gravity in the field to validate this research.

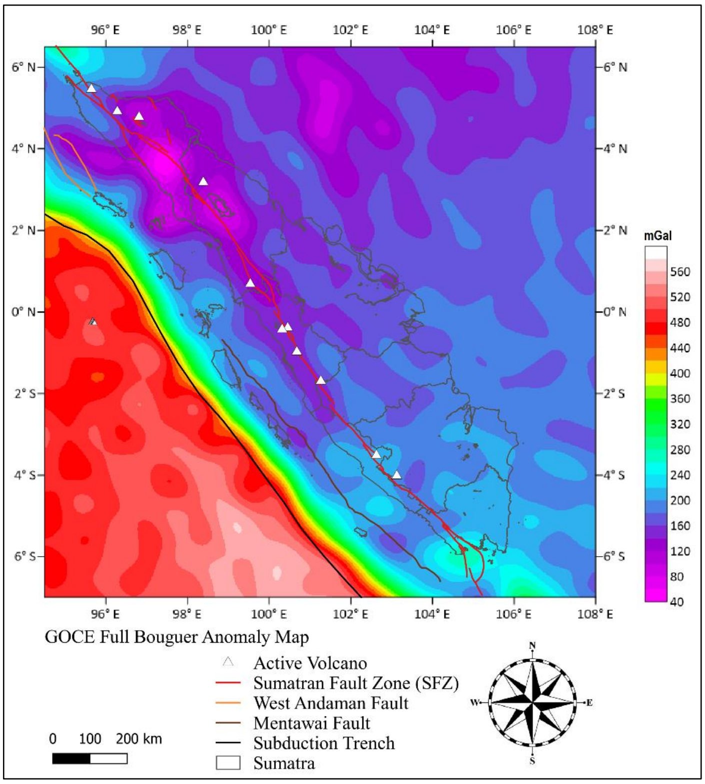

Fig 5. Complete bouguer anomaly GOCE Map

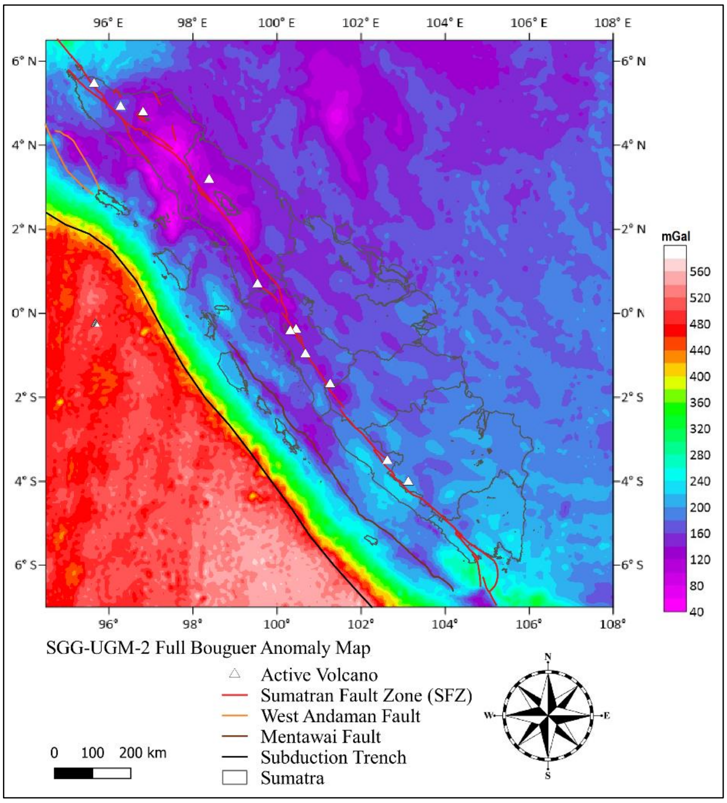

Fig 6. Complete bouguer anomaly SGG-UGM-2 Map

4.3 Comparison

The gravity disturbance map (from GOCE and SGG-UGM-2) detects the SFZ, Mentawai Fault, West Andaman Fault, and Subduction Trench better than the complete bouguer anomaly map (from GOCE and SGG-UGM-2). The SGG-UGM-2 gravity disturbance map is clearer and more detailed in detecting geological structures of SFZ compare to GOCE gravity disturbance. Meanwhile, GOCE and SGG-UGM-2 complete bouguer anomaly maps are better at detecting Subduction Trench and differences between Ocean crust and the Continental crust. The GOCE and SGG-UGM complete bouguer anomaly maps are similar but SGG-UGM complete bouguer anomaly maps more clearly detect geological structures. The results of fault detection, subduction trench, and differences between the Ocean crust and the Continental crust can be used for disaster mitigation and other geodynamic studies.

The GOCE interpretation results are similar to the study conducted by Julzarika et al., (2020) using GRACE data in the Sunda Strait. The results of the gravity disturbance and bouguer anomaly from GRACE can detect faults and plate boundaries. Geological structure detection research using GOCE is wider in area than the research study using GRACE. In addition, GOCE has better spatial resolution and spatial coverage than GRACE, in solid earth studies, GOCE regional focus shows different anomalies in certain areas (Van der Meijde et al., 2015). Therefore, GOCE more clearly detects geological structures such as faults and plate boundaries than GRACE.

7. Conclusion

Based on the research that has been done, the gravity disturbances and the complete bouguer anomaly from GOCE and SGG-UGM-2 data can detect regional geological structures of the island of Sumatra. The results of the GOCE and SGG UGM gravity disturbances shows clearly the Subduction Trench, Mentawai Fault, West Andaman Fault, and SFZ. The results of the complete bouguer anomaly can better detect the Subduction Trench and the difference between the Oceanic crust and Continental crust. The results of this research can be used for disaster mitigation and other geodynamic studies. The novelty of this study is related to the comparison of GOCE and SGG-UGM-2 data that can be used for the detection of regional geological structures whose results can be used for disaster mitigation and other geodynamic studies.

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