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Possibility of geothermal offshore in Sangihe archipelago, northern part of Sulawesi, Indonesia

To cite this article: F R Widiatmoko *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1010** 012004

Possibility of geothermal offshore in Sangihe archipelago, northern part of Sulawesi, Indonesia

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Abstract. Mostly geothermal power plant placed around volcano on land. Sangihe Archipelago, the northern of Sulawesi Island known as volcano arc that formed by the subduction of Philippines plate beneath Micro-Sunda plate. The geothermal source is located under sea level, this condition needs some approach of remotely applied sciences. The possibility study is conducted by bathymetry, gravity, magnetic, and regional geology. The objective is searching the high value gravity at the high topography as indication of the magmatic product on the seafloor and the low value of magnetic as indication of the active heat resources. A profile section from Philippines oceanic plate to the Celebes Sea by using each data shown a sequence of subduction product, such as trench, outer-arc ridge, and volcano arc. Geological data is used to know the evidence volcano arc and outer-arc ridge. The volcano arc shows that the age is around Quarter which means it is possible for geothermal resources, the outer-arc ridge shows that the rock contents were melange complex and ultramafic rocks. Sangihe area has possibility for further research as geothermal offshores.
Keywords: Geothermal submarine, Gravity, Banua Wuhu, Geomagnetic

1. Introduction

Renewable energy in Indonesia has been developing, since 2010 renewable energy contribution in Indonesia reached 4.42%, meanwhile in 2015 it has increased 6.20% from all of the existing energy contribution coal energy 28.74%, oil energy 43.02%, and gas 22.04% [1]. Indonesian energy production in 2016 was estimated 224.9 kWh, meanwhile 19% of total population without electricity [2], as additional energy demand also occurred from industrial development. The Indonesian government has solution by creating *rencana usaha penyediaan tenaga listrik* (RUPTL) or providing electrical power planning. The last RUPTL period along 2017 to 2026 promote a plan to upgrade electrical power generation about 77.9 GWh, while the upgrading capacity of renewable energy about 21.5 GWh [1]. Geothermal energy contribution for RUPTL is about 6.3 GWh [1], it means the geothermal resources in Indonesia will be used about 36% from a whole geothermal resources in Indonesia.

All of geothermal resources were estimated about 29.5 GWh [1]. But all of them were estimated only on land, meanwhile there are some of geothermal offshore resources. Un-estimated resources are caused by the lack of technology to observe directly. Heretofore, Indonesia has Geomarine ship for marine survey, but the utility purpose did not get in touch to geothermal offshore resources. As another reason geothermal on land resources still as a priority to build geothermal power plant. The lack of technology to observe directly is not the strong obstacle to research about geothermal offshore resources. There are a lot of global geophysical data and geological regional that can be used as an approach for the preliminary observation regarding geothermal offshore resources. The result of preliminary observation will show that the geothermal offshore resource has possibility to be studied further.

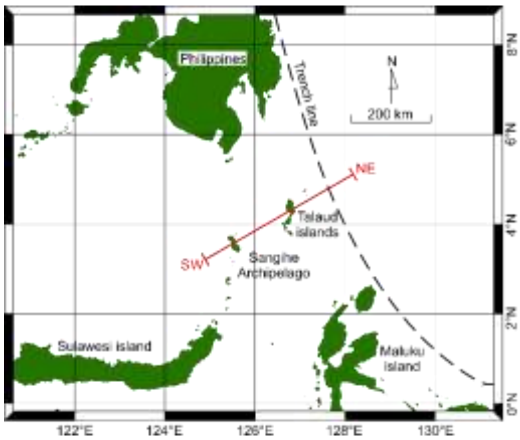

Figure 1. Location of the study area with a trench line as a boundary of each tectonic plates, SW - NE line place as the focus of section study

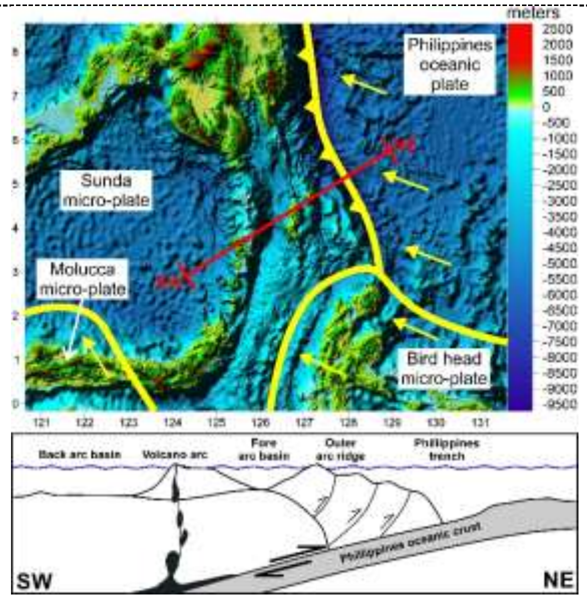

Figure 2. Tectonic settings of the study area by using GEBCO data that is modified from [3] (top), arrows are the direction of plate movement, thick lines are the trench line and boundaries of the tectonic plate, SW-NE line is the profile section line. The SW – NE profile is adopted from Rangin section model [7], [8], and the surface elevation from bathymetry data.

As an example, Sangihe Archipelago, Indonesia (Figure 1) has offshore volcano activity which related to magma activity as well as geothermal resources. Sangare Archipelago is a product of subduction between Micro Sunda continental plate with Philippines oceanic plate [3]. This area becomes interesting to be studied further because of having offshore hot springs complex which is known as Gunung Kawo Barat complex. Hot spring is one of indicator for preliminary geothermal survey due to hot spring represents that heat source is active.

1.1. Geological Settings

Sangihe Archipelago has been formed by Philippines oceanic plate under the subducting Sunda continental micro-plate since the late Miocene [4]. The occurrence is caused by separation plate between Sunda microplate with Philippines plate from the same basin in the late of Oligocene, the movement plate firstly strike-slip followed to be convergent boundaries plate [5]. Sangihe Archipelago has been formed on the Sunda continental micro-plate. The plate thickness was estimated about 6-7 km [6]. The Sangihe Archipelago has been formed by subduction that product magmatic and volcanoes (Figure 2). The basement of Sangihe archipelago is Basaltic [7]. The basement was buried by Quarternary magmatic product (Figure 2) [4]. The SW-NE section (Figure 2) has similarity with the Rangin section model in the outline geology of Nusa Tenggara Timur [8]. The profile section show that Sangihe Archipelago is the subduction product which is included to the volcano arc and Talaud Islands are included to the outer arc ridge [7], [8].

2. Methodology

To determine the possibility of geothermal offshore energy required to do an integrated approach. In this paper, we use bathymetry data, global gravity data, global magnetic data, and regional geological regional maps.

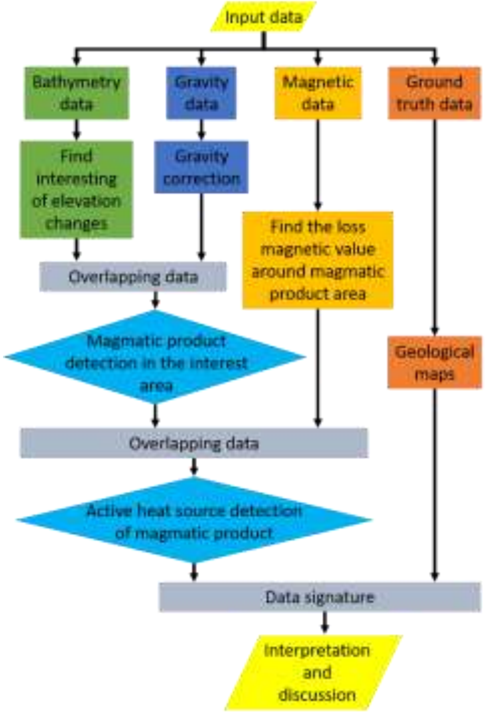

Figure 3. The flow chart of the study, the parallelogram as the first-end, the rectangle as data representative, the diamond shape represent the both of the result.

Bathymetry data is used to determine the elevation in offshore and on land. The elevation changes indicate of different rock content, structural geology, and other geological processes [9]. One of the interest elevation change is used to find the area that has magmatic product (Figure 3). The bathymetry has resolution data 30 arc second that is provided by General Bathymetric Chart of the Oceans (GEBCO) [10].

Gravity data is used to determine the difference of weight force in some areas. The elevation changes on bathymetry data do not have rock content information. One approach for knowing the rock information is using gravity data. The weight force information represents that the area has typical weight of rock (Figure 3). The Gravity data has resolution 60 arc second that is measured by Geosat and ERS 1 satellite altimetry which provided by University of California San Diego [11]. To detect the magma product, the gravity data is required to has complete anomaly bouguer, then we filter the complete anomaly bouguer by using SVD filtering to divide data between regional bouguer and residual bouguer. The residual bouguer map has function to know the shallow gravity value, it is used to know the area has high gravity value [12].

Geomagnetic data is used to determine the susceptibility value on some areas. The high susceptibility value represents that the area containing magnetic elements and some metal elements

IOP Conf. Series: Materials Science and Engineering 1010 (2021) 012004 doi:10.1088/1757-899X/1010/1/012004

(Figure 3). Geomagnetic data has resolution 2 arc minutes that is provided by World Digital Magnetic Anomaly Map (WDMAM) [13].

The integrated approach use bathymetry data, gravity data, and geomagnetic data. The area that has magmatic product is shown by the high elevation changes and having high gravity value (Figure 3). The active magmatic activity is shown by the dropping magnetic value (Figure 3). As our assumption when a magnet is given heat, the magnet will lost the susceptibility force. Magmatic product has high magnetic value, but the active magmatic activity will have the lower magnetic value than the others magmatic product area. As signature, those data is necessary to have ground truth data. Data synchronization is using regional geological maps that were mapped [14] (Figure 3).

3. Results

The processed gravity data are conducted to get the residual anomaly map. The residual anomaly is obtained by separation data from regional anomaly, so the residual anomaly has function to know locally gravity influences [12]. The local gravity was used for interpretation of rock content inside the high elevation.

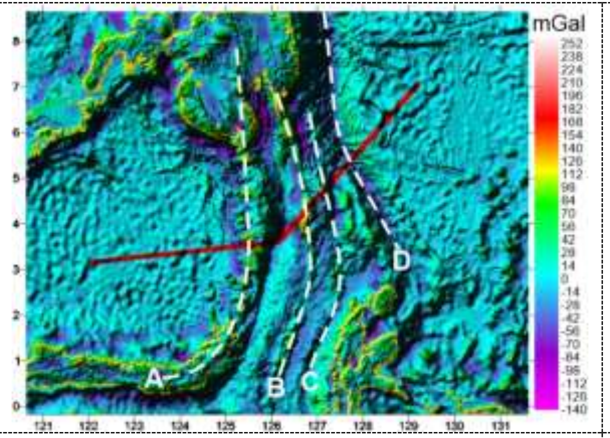

Figure 4. Overlapping residual gravity data in milliGal unit on the bathymetry elevation model from GEBCO, solid lines are the section profile, and dotted lines are the interest line areas.

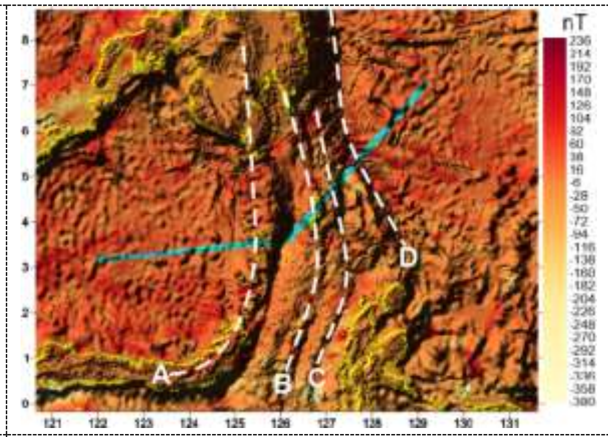

Figure 5. Overlapping geomagnetic data in microteslas or nT unit on the bathymetry elevation model from GEBCO, solid lines are the profile section, and dotted lines are the interest line areas.

In Figure 4 show that sea floor has the same gravity value, it is estimated that both of the sea floor is the same type rock by using gravity approach. Some areas in the middle of map (Figure 4) shows the high gravity values, those areas are estimated have magmatic product, different type rock, structural geology, and deformed formation rocks. Four lines are detected in the middle of residual anomaly map (Figure 4), each of these lines has orientation line to different direction.

In geomagnetic map (Figure 5) show some areas contain high magnetic values, those are estimated containing magnetic and metal sources, it has possibility the rock content is basaltic rock, ultramafic metamorphic rock, and metallic mineral deposits. The low magnetic values are estimated containing the low amount of magnetic and metal sources, it has possibility the rock content are granitic rock, sedimentary rock, non-metallic metamorphic rock, and non-metallic mineral deposits.

4. Discussion

We created profile sections (Figure 6) on both of map (Figure 4 and 5) that across four of those lines. We created those line sections by following the availability of ground truth data and for compare with the section from [7], [8]. The available ground truth data are on the Sangihe Island regional map [4] and Talaud Islands regional map [14].

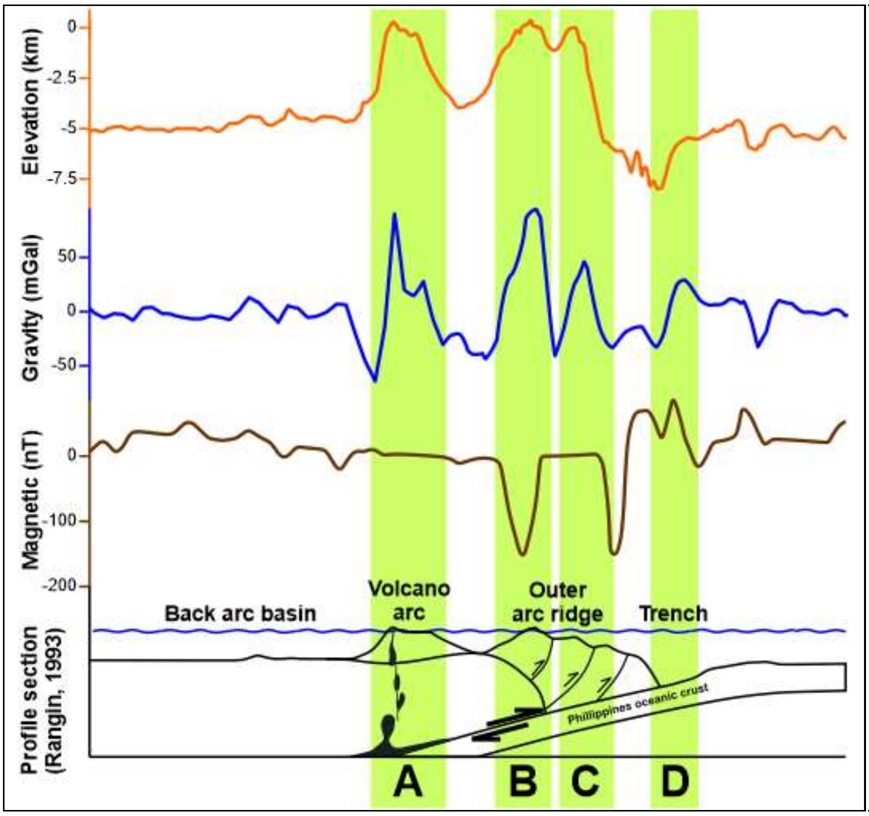

Figure 6. Profile section of Figure 4 and 5. First top curve represents of bathymetry data, second curve represents residual gravity data, third line represent of geomagnetic value, and the rectangles represents each line area in Figure 4 and 5.

The A-line area (Figure 6) has high elevation (-5km to 0.2km), high gravity value (-65mGal to 90mGal), and medium magnetic value (0nT to -20nT). It means the rock content of the A-line area is high density rock that has possibility containing igneous rocks, high density sedimentary rocks, and high density metamorphic rocks. But according to geological settings, this area is included to the volcano arc [7], [8], so it has high possibility containing igneous rock. Meanwhile the magnetic value is about 0nT to -20nT, normally the magnetic value on the magmatic area will be increased, but in this case the gravity curve was flat. We have assumption if magnet was given heat, it will lost the susceptibility force. The A-line area also, if the magmatic inside the A-line area still has active heat source, geomagnetic only detect magnetic value similar with the sea floor magnetic value.

The B-line area (Figure 6) has high elevation (-3.5km to 0.1km), high gravity value (-45mGal to 100mGal), and low magnetic value (-10nT to -150nT). It means the rock content of B-line area is high density rock that has possibility containing igneous rocks, high density sedimentary rocks, and high density metamorphic rocks. But according to the geological settings, is included to the outer arc ridge [7], [8], so it has high possibility containing high density sedimentary rocks and metamorphic rocks. Meanwhile, the magnetic value is about -10nT to -15nT, we estimated the B-line area contains material non-magnetic, such as limestone formation, and high density metamorphic rocks.

The C-line area (Figure 6) has high elevation (-3.5km to 0km), medium gravity value (-40mGal to 50mGal), and flat magmatic value (-5nT to 2nT). According to the geological settings, the C-line area is included to the outer arc ridge, but it has different character with the B line area. Especially the magnetic value is medium (-5nT to 2nT). The rock content in this area has lower density with magnetic similar with sea floor magnetic. We interpreted the C line area was uplifted part of the sea floor that caused of the friction while convergent movement.

The D-line area (Figure 6) has the lowest elevation (-8km to -5.5km), low-medium density (-35mGal to 30mGal), and high magnetic value (-10nT to 100nT). According to the geological settings, the D-line area is included in the trench area. We estimated the D-line area contain basalt sea floor

(Hall et al., 1988), mono-mineral sedimentary rock and some deposit on the base of trench from slump processes.

On the gravity map (Figure 4) show that both of the sea floors have similar gravity value, that means those sea floors are formed from the similar component, according to literature both of those sea floors are basaltic [7]. Previously both of those sea floors were the unity sea floor, then those sea floors got separated by strike slip movement then followed to be convergent boundaries [5]. The convergent movement caused some of basement rocks were uplifted to be land and friction. The friction of those sea floors caused magma generation and produced volcanoes.

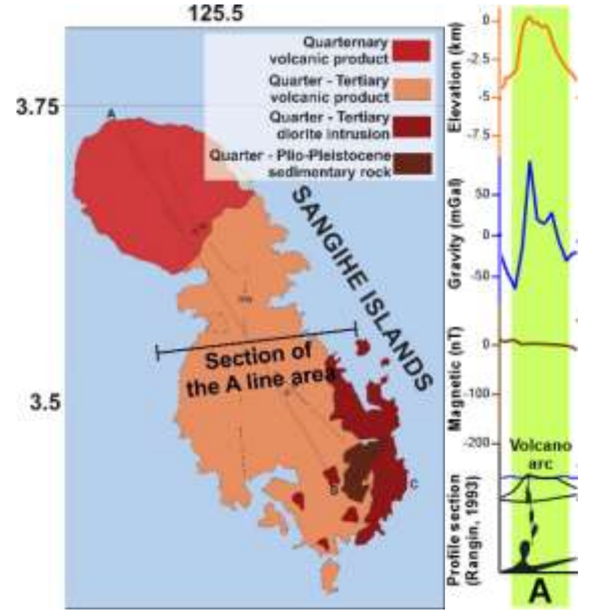

Figure 7. Geological map of Sangihe Islands (left) (Modified from [4]). Profile section of elevation, gravity, magnetic, and geological settings of [7], [8] around the A-line area.

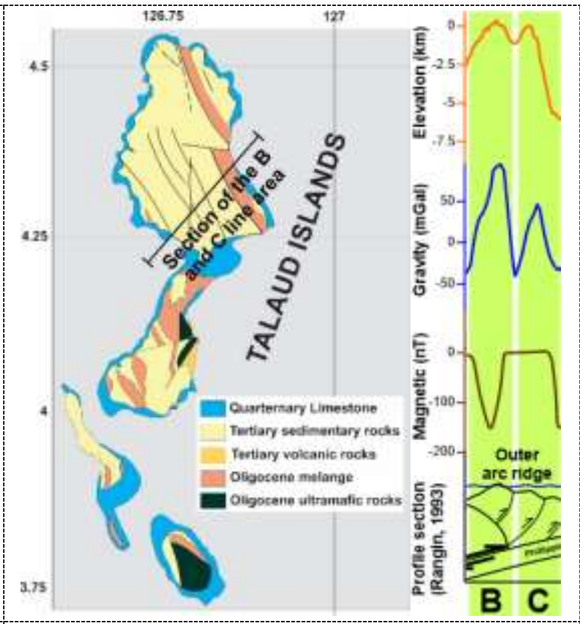

Figure 8. Geological map of Sangihe Islands (left) (Modified from [14]). Profile section of elevation, gravity, magnetic, and geological settings of [7], [8] around the B and C line area..

According to Figure 7. Elevation, gravity, and geomagnetic data show that the active heat source is detected on the A line area. As data signature, we also compare to the ground truth data that was made by [4], [14]. The A-line area is included to Sangihe Island, that area was mapped by [4]. As ground truth data, the A-line area is Quarter – Tertiary volcano product that across the Sahendaruman volcano [4]. We compared with elevation, gravity, and geomagnetic data showing the character of igneous rock, then the lower magnetic than normal value of igneous rock is the active heat source character. 50,000–200,000 year of the volcano formation has high possibility to get geothermal development, that age is about early Pleistocene [15]. Sahendaruman volcano is included to the high possibility of geothermal development. Meanwhile, the younger Awu volcano is on the north of the Sahendaruman volcano, that volcano formed at Quarter [4]. On the south of Sangihe Island there is Karangetang Island and also Ruang Island on the north of Sangihe Island, both of these islands is the young volcano on the Sangihe Archipelago complex.

According to figure 8. Elevation, gravity, and geomagnetic data show that there has two different of rock characters. As data signature, we also compare to the ground truth data that was made by [4], [14]. The B-line and C-line area are included to Sangihe Island, that area was mapped by [14]. As ground truth data, the B-line area is Tertiary sedimentary rocks and on the top has deposited Quarternary limestone [4]. We compared with the elevation, gravity, and geomagnetic data showing the sedimentary rock character that related with the ground truth data. The C-line area is Oligocene melange, Quarternary limestone [14], and interpreted at the Northeastern shoreline there has possibility outcrop of Oligocene ultramafic rocks under the sea level. We compared with these data showing the similarities with the metamorphic rocks.

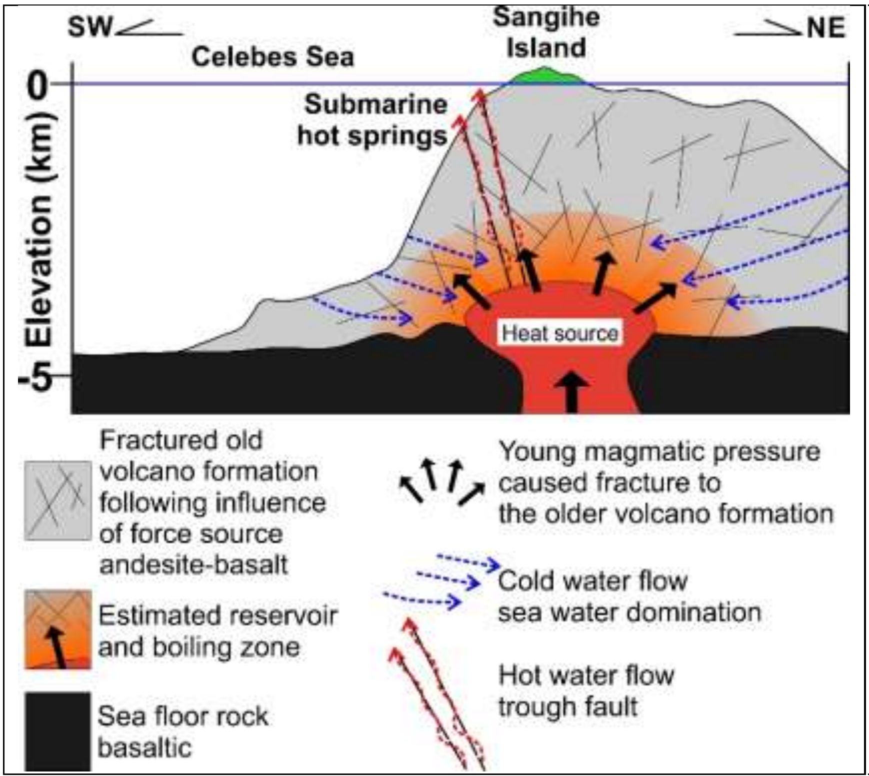

Figure 9. Unscaled conceptual model of geothermal system in the study area, adopted from [16].

We created an unscaled geothermal conceptual model of study area (Figure 9). Basically, this model is adopted from offshore geothermal model that is introduced by Armani and [16]. We modified by adding the estimated reservoir and boiling zone. For the magma positioning followed gravity curve. For the basaltic sea floor rock is used from [5]. We added some fracture that has probability formed that is caused by young magmatic force [17], the fracture direction following influence of the force source by pure shear model [18]. The hot water flow as well flowing through estimated fault [19], and as evidence supports the occurrences of the offshore hot springs [20]. The cold water flow is pushed by hydrostatic pressure of sea level depth, also supported by the circulation water inside the reservoir.

5. Conclusions

As our conclusion, The A-line area especially Sangihe Archipelago as the Tertiary-Quarter volcano belt, Active heat source can be detected by high elevation, high gravity, and low geomagnetic data. The further research about offshore geothermal resources shall be detailed around The A-line area or Sangihe Archipelago volcano belt. For future research about this area is detailed gravity, detailed geomagnetic, and offshore geochemistry survey is necessary.

As possibility study, we suppose this result is enough to be studied further and detail. This method also can reveal a sequence of subduction product, fortunately, we can compare with the available ground truth data as evidence.

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Acknowledgement
Our thanks presented to Mr. Eko Bayu Purwasatriya who inspired us to bring this topic out. Special thanks to all of colleagues from National Dong Hwa University (NDHU), University of Jenderal Soedirman (UNSOED), Adhi Tama Institute of Technology (ITATS), and Bandung Institute of Technology (ITB). Geological Engineering Department of Jenderal Soedirman University and dr.Bumi Research Group (dBRG) are thanked for supporting this work. Gebco.net are thanked for providing General Bathymetric Chart of the Oceans (GEBCO), to TOPEX University California San Diego for providing gravity data, and also to Geomag.org for providing World digital magnetic anomaly map (WDMAM).