A Preliminary Study For Initial 1-D Velocity Model in The Banggai’s Tectonic System

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Abstract. After Palu Earthquake that occurred on September 2018, another moderate earthquake on April 2019 with 6.8 Moment Magnitude (Mw) at a depth of 17 km occurred in Banggai Islands. The earthquake occurred on the shallow depth that generated by an active fault with horizontal mechanism on the Banggai’s tectonic system. To explain the tectonic system in the Banggai Islands, we present a well-calculated 1-D velocity model by solving the coupled hypocentre-velocity inversion for 385 local earthquakes that recorded by BMKG regional network. The earthquakes was selected based on azimuthal gap, minimum number of stations and root mean square of travel-time residuals. Technically, the fit solution are simultaneously inverted for total 81 initial models and will give an unique final model. The model is constructed by using Velest program that analyse the fit velocity model from body wave traveltimes (P and S wave), together with station corrections. The final 1-D velocity model will be very useful to conduct another high precision relative relocation and make a focal mechanism inversion.

1. Introduction
On April 12\textsuperscript{th} 2019 after 2018 Palu Earthquake, The Meteorology, Climatology and Geophysics Agency of Indonesia (BMKG) reported an earthquake hit the central part of Sulawesi near Banggai Islands with 6.8 Moment Magnitude (Mw) at a depth 17 km. This earthquake trembled a number of areas in Central Sulawesi Province, such as Morowali Regency, North Morowali and Banggai Islands. Initial reports suggested that it would trigger a possible tsunami, with height less than 50 m.

Based on hipocenter distribution with focal mechanism, there is a suspicion about the fault structure which generated this earthquake. The fault structure is Peleng Fault which traces Southwest-Northeast on Peleng Island and Tolo Bay. Peleng fault is one of the active fault in which has a slip rate of 1.0 mm/yr and its maximum strength reaches 6.9 magnitude.

The results of the analysis of the source mechanism indicate that this earthquake was generated by rock deformation with a mechanism of horizontal movement (strike slip). This assumption is based
on the reason that the epicenter's location lies in the continuity of the Peleng Fault which continues to the sea and the source of this earthquake has a dextral mechanism.

![Figure 1](image.png)

**Figure 1.** Historical Earthquake in Banggai Islands show a dominance mechanism is horizontal movement (strike-slip). On April 2019, the main earthquake was followed by an earthquake with Mw 5.4, the mechanism from GCMT and faults lineation from [1].

To know better about the characteristics Banggai’s Tectonic System, we investigated the seismic activity that derived from local and regional earthquake data from 2008 to 2019. The data is compiled from BMKG network with more than 380 events occurring in almost part of Banggai Island.

In this research, we used the local event that has coverage gap of azimuthal angles more than 200° were not included to avoid a biased earthquake locations. The precision of relocation result is depended by an initial hypocenter. The selected event will be processed simultaneously by inversion analysis to conduct a precision location which is suitable with 1-D velocity model obtained.

The velocity model in the Banggai tectonic system with highly seismic activity is very important because the earthquake will not trapped on the specific depth. In addition, the velocity model is recommended as the one of the first step before continue to another relative relocation method. Therefore, the velocity model in the Banggai tectonic system can give a complementary studies for tectonic process. Furthermore, we present a well-calculated 1-D velocity model that previously, no one study about that.

1.1 Geological and tectonic setting

Banggai Island is one of the highly populated islands and has economic developing activity in Central Sulawesi Province, Indonesia. It is very important to highlight the seismic activity for disaster mitigation reason and newly understanding about tectonic process. The island is located in the south of Peleng island in the north of the Great Salue and northeast of Labobo island. Banggai Island is known for its natural gas potential. To the southeast of Banggai Island, there is the Sula Platform which forms together with Banggai Island.

The uniqueness of this island is the similarity of rock formations in its region with the area of East Kalimantan, but different from the rock formations in Sulawesi in general, separated by a rising fault that stretches across the eastern arm of Sulawesi. In general, Sulawesi is composed of volcanic rock lithology such as pyroclastic or igneous rock due to its location close to the Sangihe volcano series [2].
However, eastern Sulawesi and Banggai Island have metamorphic rock lithology. The age of lithology from the two regions on the two sides of the fault is also different. As explained in the previous section, this happened because East Sulawesi and Banggai Island were previously far apart from other parts of Sulawesi. Where the two regions are microcontinent from the territory of Australia [2].

Australia, which crashed into the Sunda Cratons and the Philippine Plate, then moved in rotation and joined the island of Sulawesi. The reconstruction of the movement of East Sulawesi and Banggai Island can be done through several studies, one of which is observing the multibeam bathymetry map. Through this map, we will get the appearance of lineaments that can represent the movement of geological structures in the region.

2. Data and Method

We use the earthquake data from BMKG seismic network in Central Sulawesi that consisting of 34 actively recording seismometers. BMKG is operating many various seismometers to record the earthquake waveform and routinely pick the P and S phase arrivals to determine and disseminate the hypocenters [5].

![Figure 2. The seismic station distribution on Sulawesi that used to relocate the earthquake in banggai island.](image)

For this research, we analyzed the body seismic (P and S-wave) with arrival times from each station along 11 years months period (2008-2019) and the total events around 380 events. To conduct a uniquely solution, we need to filtered the good initial data with depth less than 50 km, that means all earthquakes location was occurred in the crust. Furthermore, all earthquake for this research have more than 4 phase (P or S), azimuthal gap < 180° and distance between earthquakes and stations less than 5.5 deg (> ~600km).

Statistically, time series analysis is needed to present the explanation physics properties as shown in the Figure 3. We can see, if the distribution significantly change in the 2019 after big earthquake
occurred. Total release energy is quietly low before 2019 in the active fault that give a stress accumulation. Some big earthquakes from subduction in the northern and southern part and active faults could trigger the seismic activity in the study area.

![Figure 3](image.png)

**Figure 3.** The historical earthquake in Banggai, and total moment and energy seismic in there. Also, the quality of earthquake, which has more event in M 3-5.

### 2.1 Method

Hypocenters of earthquakes are nonlinearly parameter that fully influenced with the suitable velocity model and how the distribution of seismic stations [2]. A seminonlinear approach is one of many techniques to relocate the hypocenters that still in the fixed depth and to determine the appropriate velocity model. Recently, a seminonlinier approach is very useful to relocate a fixed initial regional or local earthquake which trapped on an spesific depth. In this paper, we applied the method to relocate the initial hypocenters from BMKG which shown a fixed depth solution because using a global velocity model [3].

To improve the precision of the hypocentre locations, we need to obtain an appropriate 1-D seismic velocity model by using a simultaneously inversion. In this researh, we use the VELES program [4] to conduct a newly velocity model which suitable with the hypocenter distribution and tectonic system in the study area. We used total of 81 different initial velocity models and initial locations of earthquake that derived from prelimi

3. Preliminary Results and Discussion
The locations of the earthquakes need to be relocated by using a simultaneous earthquake relocation and velocity determination. In other hand, the relocation result has a purpose to give an structure imaging by earthquake position. We gained 81 initial velocity models and then the 1D inversion was applied for each initial model with 100 iterations as shown in the figure 4. Each model will be inverted in the 100 iteration and produce the final solution. All initial will give specific model, hypocenter relocation, and root mean square value.

Figure 4. The total of 81 initial 1D velocity models was imposed as an first model to make simultaneously inversion (a) Vp model, (b) Vs model and (c) Vp/Vs ratio. We can see on the histogram in the right side, the earthquake was trapped on the fix depth (10 km). The fixed depth is caused by using global velocity model to determine the earthquake hypocenter.

After simultaneously inversion, 81 initial model will generate a new model that relevant and suitable with hypocenter distribution. The total of 81 initial models were chosen arbitrarily to be within the boundary corridor that indicated by dashed line in Figure 5. All imposed models was converged to produce the one best velocity model with low rms that indicated by red lines in Figure 5. The 1D velocity model will be used for imaging the structure beneath the study area. The best velocity model has an unique solution with convergence rms value. The average rms for all initial model has rms < 1.0, we need to choose the best rms which has lowest value. On figure 5, we can see the best model is red line which has lowest rms and convergence solution.

Figure 5. The 1D velocity model after 100 iterations (a) Vp model and (b) Vs model. The red lines can be assumed as the best models with the smallest RMS values. The dash lines represent the
minimum and the maximum of all initial models. We can see from the figure if the red line is highly precision which is located in the center of all model. That is caused by a convergence comparison for all results which generate an unique model. The model is suitable with hypocenter distribution, as we can see the depth significantly changing in the right part.

The depth variation of the earthquakes in figure 5 significantly changing from fixing depth to the various depth. From this research, we get the best velocity model in the Banggai tectonic system and can be used as the reference to make an advance relative relocation with well-known model. The velocity model will change by following the depth, because in the earth crust, the layer is almost has a solid material. The model need to be fixing again by 3-D model to get a better difference value.

The 1-D model is also can used as the velocity reference to conduct the source physics of earthquake analysis, such as mechanism inversion [6]. The shallow depth is categorized as the active cluster because mostly hypocenters located in there. In addition, the earthquake with shallow depth is very vulnerable to the area that has a soil structure with highly risk potential [7]. Study of microtremor to learn the soil properties to explain the amplification effect is needed in the study area for disaster mitigation plan. Furthermore, the 1-D velocity model also can be a useful parameter to calculate the NDSHA [8] and conduct a realistic shakemap for important subsurface information [9].

4. Conclusion
The Banggai Island and its surrounding can be included as the active region after the occurrence of big earthquake with M 6.8. This area is actively produce the aftershocks after the mainshock. In this research, we successfully generate the suitable 1-D seismic velocity model that is very important to explain the tectonic system. The 1D velocity model by using simultaneously inversion is one of the important analysis for earthquake relocation and the result give a good depth variation and suitable with tectonic condition.

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