Neogene Tectonics And Paleomagnetism Of The Western And Eastern Of Palu Bay, Central Sulawesi, Indonesia

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Abstract. Geologic observations and paleomagnetic studies of the western and eastern Palu Bay was undertaken, in order to study the extent of rotated areas and to develop constraints on tectonic models concerning the formation of this bay. Characteristic of remanent magnetization (ChRM) results from Palu bay, the western show that; yield a pole at -39.116°N, 119.895°E with R=13.99, \( \alpha_{95} =0.42, D_{m}/I_{m}=61.76/-26.7 \) and the Eastern Palu bay show that; yield a pole at -81.855°N, 52.913°E, R=8.99, \( \alpha_{95} =0.29, D_{m}/I_{m}=67.1/-5.42 \). The granitic rocks in these areas are dominated by granite and Monzonit-Quartz in composition, with high-K calc-alkaline photosisk (KAP) and show metaluminous-peraluminous affinity. This suggests that the rotational motion on both sides of the bay are similar during the Neogen.

1. Introduction
Sulawesi Island, central part of the Indonesian Archipelago, is located at the junction between the converging Pacific-Philippine, Indo-Australian Plates and the Sundaland, i.e. the south-eastern part of the Eurasian Plate. Sulawesi tectonic evolution results from successive collisions of continental slivers, island arcs, and oceanic domains with the Sundaland [1]. The Palu Koro Fault System (PKFS), one of the major structures in SE Asia, cuts across Sulawesi Island from NW to SE, connecting the North Sulawesi subduction zone to the Banda Sea deformation zones [1].

The multi-armed shape of the island, with different lithologic sequences suggests that it is a complex assemblage of tectonic terranes, leading to the wide range of interpretation for the evolution of the island [2]. One of the most problematic features in Sulawesi island is the occurrence of various contrasting igneous rocks in space and time. For example, whereas HK (high-K or shoshonitic series) and CAK (high-K calc-alkaline series) igneous rocks are only restricted in the younger (less than 14 Ma) rocks from the southern part of the Western Sulawesi Province, the CA (calc-alkaline) to low-K series igneous rocks are widely distributed in the central and northwestern part of the province which yielded a relatively older magmatic series (more than 16 Ma). Despite intensive scientific research, there is an ongoing controversy about the source of these magmatisms and the processes responsible for their petrogenesis as well as the geodynamic setting [2]. One of main components of the magmatic products in this island is the Neogen granitoids which extend from the Western to the Northern part of the island. Granitic rocks are the most abundant plutonic rocks in the upper crust and plate tectonic
processes including crustal evolution. Many granitic rocks are associated with mineralization [3]. Another important consideration in studying granitic rocks is Paleomagnetism.

The paleomagnetism of the Sulawesi Islands are important for the study of tectonic evolution. Paleomagnetism is the study of the record of the Earth’s magnetic field in rocks. The Earth’s magnetic field has its origin in the convection of the iron rich material of the outer core of the Earth. At any point of the earth surface, the magnetic field (F) can be defined by two angles [4]. Declination (Dec) is the angle between the horizontal component of F and the geographic north, ranging from 0 to 360 ° and defined as positive clockwise; inclination (Inc) is the vertical angle or the angle between F and the earth’s surface.

In this paper, the paleomagnetic data were analysed Characteristik Of Remanent Magnetization (ChRM) of the Granitic rocks to assess the relationships between Granitism and tectonic evolution in the Palu Koro Fault Zone (PKFZ). The work focused to measurements rock magnetism on hand and core sampling in the granitic rocks.

2. Regional Geology and Tectonic Setting Tectonic evolution Sulawesi Island
Sulawesi can be divided into four tectonic provinces namely (1) the Western and North Sulawesi Pluton-Volcanic Arc, (2) the Central Sulawesi Metamorphic Belt, (3) the East Sulawesi Ophiolite Belt and (4) the Banggai-Sula and Tukang Besi continental fragments [2]. The tectonic history of Sulawesi began in the Cretaceous when several Gondwana fragments accreted to the eastern Sundaland margin, now forming the present day basement of a large part of Western Sulawesi. Western Sulawesi subsequently separated from east Borneo by rifting that began around the Middle Eocene and led to the formation of the Makassar Strait. Calc-alkaline volcanism took place along the length of Western Sulawesi, but appears to have been localized in both space and time. It ceased by the end of the Eocene in SW Sulawesi but continued into the Oligocene further north [5].

In Neogen, convergence between the Australian plate and the Eurasian plate was absorbed in several ways in the Sulawesi region: it involved counter-clockwise rotation of Western Sulawesi (together with Borneo and Java), and contraction, uplift and erosion in East and SE Sulawesi [6]. Hall has advanced an alternative model that envisages the vertical movements to be the result of lithospheric flow in an overall extensional environment [6].

3. Location and Analytical Methods
Location Sampling The Neogen Granitic rock [7] for paleomagnetic analyses were performed mainly along two area across the Palu bay, one in the western part of the bay and the other in the eastern part of the bay. 40 oriented Granitic block samples were collected from 8 sites; Kabonga (0.76 S, 119.77 E), Watusampu (0.82 S, 119.78 E), Salena (0.79 S, 119.80 E), Matantimali (0.90 S, 119.79 E), Layana (0.82 S, 119.94 E), Taipa (0.77 S, 119.94 E) and Rano (0.75 S, 119.92 E). of the exposed rocks of Palu Koro Fault Zone (PKFZ) (Figure 1). All the samples were drilled and cut into standard specimens (2.2 cm length and 2.5 cm diameter) [9]. As the earth’s magnetic field is a vector, samples need to be oriented in situ to get a geographic unambiguous position and orientation in order to provide a reference system to which refer the data obtained during the laboratory analyses. Therefore, samples are oriented in the field by a magnetic compass coupled to an orienting device with hand waterpass [8,9,10].

The main laboratory analysis consists in progressive demagnetization of the samples and the subsequent measurement of the NRM in order to identify and isolate the different paleomagnetic components recorded during the rock-geological history. Progressive demagnetization of the samples can be achieved by alternating field demagnetization (AFD) using a Molspin AF demagnetizer. The Minispin is a low cost, high sensitivity portable fluxgate spinner magnetometer, manufactured by MOLSPIN, Ltd. [8,11]. Vector directions are described in terms of declination (D) and inclination (I). After the complete demagnetization of the samples, these directions are displayed with a projection that depicts threedimension information on a two-dimension environment [9,11]. Although projections on a sphere are commonly used, the most common representation of results of progressive demagnetization are vector end point or orthogonal projection diagrams, also known as Zijderveld diagrams [12]. Magnetic components are then extracted from the Zijderveld diagrams), and the most stable and
consistent component that can be isolated is referred to as the characteristic remanent magnetisation (ChRM) [3,12].

Figure 1. Map Showing Sampling Sites (Red Solid), With the name of the sample as follows; Kabonga (KAB), Watusampu (WTS), Salena (SLN), Matantimali (MTL), Poboya (PBY), Layana (LYN), Taipa (TPA), Rano (RNO). Note. Qa, Alluvium; Km, Amphibiolit; Qtms, Limestone; Qal, Clay; Kls, Sandstone, Conglomerate, gr, Granitic rocks

4. Results and Discussion
Paleomagnetik studies using samples of granite has been done by researchers [13,14,15]. Some rock specimens used in this study provide good results in stability testing magnetism. Natural Remanent Magnetization intensity rock sample from Palu granitic showed between 0.348 (mA/m). With the average value was 40.083 (mA/m). Result of the stability properties of intensity and direction of the magnetic field measurement Alternating Field/AF Demagnetization can be seen in Figure 2. The result CharacteristicRemanent Magnetization (ChRM) as presented in Table 1.

Based on test stability with decay curve, Zijderveld plots and equal-angle stereoplots have been done obtained the movement magnitude of paleomagnetic on the site research, they are Matantimali by 54.01°S, for Rano indicate -21.43° S, for Salena sites indicate a movement is 19.17° S, for the Taipa -31.01°S to 61.76° S, for the Watusampu sites indicate a movement is 42.8° S, for Layana -44.16°S, for Poboya -45.17° LS, and Kabonga sites shows a movement is 67.06°S.
Figure 2. (a) Decay curve, (b) Zijderveld plots and (c) equal-angle stereoplots of Alternating Field demagnetisation behavior of selected samples.
Table 1. Characteristic Remanent Magnetic Results (ChRM) for the Palu granites

| Specimen | R  | N  | K   | a95 | Dc(°) | Ic(°) | λp(°) | Φp(°) |
|----------|----|----|-----|-----|------|------|-------|-------|
| KBG      | 8.999 | 9 | 31487.58 | 0.29 | 247.1 | 58.8 | -37.26 | 111.27 |
| WTS      | 10.978 | 11 | 15708.41 | 0.36 | 222.8 | 29.1 | 14.24 | 119.66 |
| SLN      | 7.998 | 8 | 40455.4 | 0.27 | 19.2 | 35.5 | 33.37 | 180.69 |
| MTL      | 5.890 | 6 | 45.64918 | 10 | 234.1 | 9.4 | -29.69 | 122.90 |
| PBY      | 9.490 | 10 | 1766.173 | 1.15 | 314.8 | 25.1 | 52.55 | 106.54 |
| LYN      | 9.044 | 10 | 9410.033 | 0.49 | 135.8 | 41.7 | -51.55 | 120.18 |
| TPA      | 13.867 | 14 | 9767.061 | 0.40 | 61.8 | -26.8 | -32.09 | 119.96 |
| RNO      | 8.997 | 9 | 3656.871 | 0.85 | 338.6 | 18.2 | -4.29 | 264.36 |

Note. R, resultante; N, total number of samples from the site; K (kappa), concentration parameter; a95, radius of the confidence circle; Dc, mean declination; Ic, mean inclination; λp, Pole Latitude; Φp, Pole Longitude.

5. Conclusion
Based on remanent magnetic analyses for specimen samples from 8 sites within the Palu Granites, located in Palu Koro Fault Zone (PKFZ), we conclude the following:

- The samples acquired a stable magnetization in the presence of an apparently normal and reversed geomagnetic field. This field direction has been accurately recorded within the granitic rocks.
- Determination of tectonic processes seen on the site movement. This process can be determined based on the parameters paleomagnetic that is based on the value of ChRM.
- The paleomagnetic data are complex and some may have rotated, but motion direction paleolatitude site research is predominantly directed research area from southwest to northeast.

Acknowledgements
The authors would like to thanks to all my student in Tadulako University for grate help on the sampling process. Thanks also to SEACG 2016 committee for immeasurable help of publishing this paper.

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