Geomorphological impact of Palu earthquake

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Abstract. Sulawesi and Maluku islands are tectonically under a collision area of four earth crust plates, those are Eurasia, Philliphines Islands, Pacific Ocean and Australian-India Ocean. Palu city in Central Sulawesi island in particular is geologically an area of complex structure. A fault zone of north-west to south-east direction has formed Palu area as a block being squeezed by Palu-Koro strike-slip fault zone. The aim of this research is to know the impact of earthquake happened on October 28, 2018 has caused the fault to activate of being dynamic movement of the area. Using hand camera photos, a morphological survey and analysis show the landslides and slumps could be clearly identified. Rock and soil slide and movement was also strengthened by liquefaction of hydrological fluid content within the Palu block. Morphology of Palu-Koro fault plane was also affected significantly causing landslides and slumps on the fault plane exposed in the earth surface.

1. Introduction

Indonesia is a country that is geologically a three junction for collisions of the plate’s and is a place where explosions of magma form a series of volcanoes, known as the ring of fire. In September to October 2018 there have been two tectonic earthquakes which occurred in Lombok (end of September 2018) and then followed in Palu and the surrounding area (end of October 2018). Both of them caused quite severe geological and geographical impacts in the form of suffering directly affected by the communities around these two regions. Geologically, the two earthquakes need to be studied to obtain data, information that needs to be evaluated to be able to provide input for mitigation and anticipate the possibility of the impact of aftershocks.

In the event of the Palu earthquake, not only were victims of human life dead, but the geological impacts such as land movements, hillside avalanches, etc. appeared to be severe. Geological survey was conducted from 3-5 November 2018 after the Palu earthquake. A number of lanes and location points have been taken photos. The research team has analyzed photo data to obtain information on the morphological appearance that has been formed due to the Palu earthquake and the surrounding area.

The occurrence of the Palu earthquake caused considerable damage. On the basis of the understanding that Sulawesi is a collision area for the plate, specifically the construction that took place in Palu and its surroundings to the Sigi area, is estimated to be due to the activity of the Palu-Koro strike slip fault. The impact that occurs is not only the dynamics of the composition of the land cover (rocks and soil), but also the occurrence of liquefaction where the water fluid suddenly seeps into the surface of the earth due to the formation of cracks resulting from activation of the muscular and fault fields.
Research of the impact of the earthquake of Palu Koro fault formed a new geomorphological appearance, which had never been discussed by previous researchers.

1.1. Geology and physiography of Indonesia

Indonesian tectonics is complicated but very interesting because of its position in plate convergence. Three provinces form the Indonesian Archipelago: western Indonesia, central Indonesia, and eastern Indonesia. (Picture 1). Western Indonesia (Sumatra-Natuna Kalimantan-Java-Bali) is located in the south-eastern part of the Eurasian Plate. This extension manifests the extrusion of the Eurasian Plate due to a collision with India. Eastern Indonesia (Papua-Timor) shows the expansion of the Australian Plate with rifting and drifting. Central Indonesia (Sulawesi-Halmahera Maluku-Flores-Lombok) is an island arc formed by plate interactions (Eurasia, Pacific, India-Australia).

![Figure 1. Plate tectonic of Indonesia.](image)

On the basis of geological and geophysical characteristics, Simandjuntak and Barber distinguished five regions of crust of different origins in Indonesian region [1]. Tectonic Impact to physiography in Indonesia Area The current physiography of the Indonesian archipelago can be directly related to the orogenic Neogen event. Simandjuntak and Barber divide these events into six orogens [1]: (1) Sundanese orogeny in Java and Nusa Tenggara, (2) Orogeny rows in Sumatra, (3) Talaud orogeny in North Maluku, (4) Sulawesi orogeny in Sulawesi, (5) Banda orogeny in the Banda Bow and (6) Melanesian orogeny in Papua. These events include: plate convergence with subduction below the Sundaland boundary to produce Cordilleran orogeny types, collisions of unique arcs in Maluku, plate formation in Eastern Indonesia, arc collisions with microcontinents like those in Sulawesi and with major continental blocks such as in Timor, construction mountain belts, transretion and tension along major slip faults, demolition and foreland fold construction and push belts, back-arc thrusts, and subduction polarity reversals. Earthquake Impact to surface morphology by observing natural phenomena in Palu area, it is estimated that morphological changes generally occur even on a small scale from the view of aerial photography. This research was conducted to find and strengthen evidence of the occurrence of morphological changes due to tectonic earthquakes in Palu and the surrounding area [1, 2].

2. Methods

Research methods are divided into three stages, which are study of literature, data collection and data analysis. Literature studies include the geology of the island of Sulawesi whose emphasis is on tectonic and geomorphological analysis.

2.1. Geological analysis of Sulawesi Island

Buton-Tukang Besi – Banggai-Sula – East Sulawesi Collisions and Sulawesi Tectonic Escapes. Sulawesi Islands in Central Indonesia provides a good place to examine collision and post-collision Buton-Tukang Besi - Banggai-Sula - East Sulawesi Collision and Tectonic Sulawesi Blur. The Sulawesi Islands
in Central Indonesia provide a good place to check tectonics off collisions and post-confrontation (Figures 2, 3). The islands are assembled by terrain collisions and have been modified by post-collision runaway tectonics. Sulawesi Island has collided with microcontinent from Buton-Tukang Besi and Banggai-Sula [3,4]. Recently discussed the evolution of Sulawesi collisions and the release of post-colalactic tectonic explosion escape tectonics (Figures 2, 3). The islands were assembled by collision of terranes and have been modified by post-collision escape tectonics. Sulawesi Island has been collided by microcontinents of Buton-Tukang Besi and Banggai-Sula [5-7]. Recently discussed the evolution of Sulawesi collision and post-collision tectonic escape.

Different authors have different interpretations on the mode and timing of collision of Buton-Tukang Besi and Banggai-Sula microcontinents. Hall reconstructed the detachment of the microcontinents from the Bird’s Head of Papua, their transfer to the west, and their collisions with eastern Sulawesi [5]. At 20 Ma (Early Miocene), these microcontinents were dismembered from the Bird’s Head by Sorong Fault splay. At 15 Ma, a strand of Sorong Fault propagated westward, at 11 Ma Buton-Tukang Besi collided with Sulawesi [8-13].

The front part of the collision of the Banggai-Sula Microcontinent is the development of faults in the East Arm. Balantak, Toili, Ampana, and Wekuli Faults. Post-colloidal tectonic escape is followed afterwards. They begin with rotation of the Sulawesi arm, opening of the Gulf of Bone, Sulawesi’s main slip formation, and the incidence of extension fractures [7,14-17].

The occurrence of the Palu earthquake caused considerable damage. On the basis of the understanding that Sulawesi is a collision area for plates, particularly the construction that took place in Palu and its surroundings for the Sigi region, is estimated to be caused by the fault activities of the sorong attacking Palu-Koro. The impact that occurs is not only the dynamics of the composition of land cover (rock and soil), but also the occurrence of melting where the liquid water suddenly flows to the surface of the earth due to the formation of cracks due to activation of the muscle field and errors.

2.2. Survey geology of Sulawesi Island

By observing natural phenomena, it is estimated that morphological changes generally occur even on a small scale from the view of aerial photography. This research was conducted to find and strengthen evidence of the occurrence of morphological changes due to tectonic earthquakes in Palu and the surrounding area.

Morphological surveys were carried out in the valley of Palu and surrounding areas mainly to trace the Palu-Koro fault line on the western slope of the Palu valley. Figure 2 shows the locations where the survey will be conducted. Location is the area around the village of Pasaku (Wisolo, Rogo, etc.),

![Figure 2](image_url)

Figure 2. Location of geological observation on the western slope the valley area of Palu.

Geology equipment geological compass and hammer to be used in this survey. In addition to the basic equipment, supporting equipment is also needed, namely GPS and camera.
3. Results and discussion
Overall, the structure of the Palu stratigraphy is composed of three groups of rocks, namely: Pre-Tertiary rock groups, Tertiary rock groups and Quaternary Rock Groups [5,18-20]. Pre-Tertiary rock groups can be found in marine sedimentary rocks and are metamorphic rocks which are both breached by granite and granodiorite rocks that are of Tertiary age, and oppressed not aligned with the Group of Quaternary rocks which consist of several deposits, namely: sedimentary deposits, river deposits, abundant sedimentary deposits and ancient alluvium fan deposits. Coastal deposits that can be in the form of beach sand and rock fragments are often found around the bay of Palu Geographically the plains of Palu City are formed because of the graben process. Graben process that makes some land surface raised quite high (forming hills to mountains) as seen along the western coast of Palu Bay. The Palu City area is characterized by the main form of the valley (graben) where the city center is located in the middle of the valley. This valley orientation follows the main direction of the mountain path on both sides, which is relatively north-south [21]. Based on the results of studies from the Indonesian earthquake map revision team, the active geological structures that pass through the City of Palu are in the form of PKF (Koro Fault Hammer) and MF (Matano Fault) both active faults found around the Palu valley. The Palu-Koro (PKF) fault is trending North-South while some of them are trending Southwest - Northeast. The active faults which are in the North-South direction are active faults due to rejuvenation of old structures that can be reactivated, while the faults trending Southwest - Northeast are very active structures today [22].

Triggered by the movement of soil and rocks, there was soil flow and rock destruction due to the pores and matrix space of rock filled with water with high pressure. In the Palu valley which experienced liquefaction due to the earthquake and water flow to the soil cavity, rocks and alluvial deposits. The destruction of the earth's skin due to burial and fault that moves dynamically during an earthquake.

Morphology at North to South Palu area which removes images of growth, human culture (home, etc.) so that topographic maps can be seen without the appearance of plants or the closure of human cultural results. Figures 3 display photographs of landslides and slumps around Wisolo village, southern Palu which are then converted into topographic maps by geomorphological analysis.

![Figure 3. Landslides and Slumps formation resulting from active Palu earthquake at Palu-Koro Fault line in Wisolo, South Palu area.](image)

4. Conclusions
Research on the morphology of the Palu area and its surroundings by conducting surveys and evaluating field data including aerial photographs can be concluded that: The Palu earthquake has caused the dynamics and activation of geological structures (faults and burrows) as well as movements and landslides of lands and rocks in various locations including on hillsides. Fault, stocky and ground motion activities lead to the formation of new openings and openings which result in seepage of water to the
surface through rock pores resulting in liquefaction. The results of field data analysis in research can be used as input in the context of mitigation and anticipation of the possibility of a subsequent natural disaster or other natural disasters (landslides, floods, etc.).

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