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Land Subsidence Investigation in Negeri Sila, Nusalaut Island, Using Resistivity Method

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Abstract **-** The phenomenon of land subsidence in Negeri Sila of Nusalaut Island was caused by an earthquake in Ambon Island and surrounding areas on September 26, 2019 with the magnitude of 6.5. This research had been conducted using a resistivity method with a dipole-dipole configuration. Land subsidence occurred due to seawater intrusion around the area. The earthquake around Ambon Island was the trigger, so soil creep occurred.The purpose of this study is to obtain a weak resistivity zone area that indicates subsidence. The results showed a low resistivity value of 1-10 Ohm meters which indicated a weak zone of potential subsidence of the ground surface, and the presence of sea water intrusion into the area.

Keywords: land subsidence, soil creep, dipole-dipole, resistivity, seawater intrusion

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Introduction

Indonesia is a country with a high level of earthquake disaster vulnerability, which is located between four tectonic plates: Eurasian Plate, Indo-Australian Plate, Pacific Plate, and Philipine Sea Plate, causing Indonesia to have complex tectonics (Irsyam *et al*., 2017). Eastern Indonesia has active tectonics. History records that on February 17, 1674 a very powerful earthquake occurred in Ambon Island, then followed by a tsunami with a height of up to 100 m on the north coast of this island (Pranantyo and Cummins, 2019).

The history of the big earthquake in Ambon is one of the important references in earthquake disaster mitigation, because this proves the existence of active faults around Ambon. Active faults in Ambon and its surrounding areas cause the areas to become an earthquake-prone zone (Pranantyo *et al.*, 2017). In addition, besides causing direct material loss, an earthquake can also trigger new faults and other disasters accompanying it, namely landslide and subsidence. On September 26, 2019, an earthquake with a magnitude of 6.5, 128.39^{o}E, 3.53^{o}S, and a depth of 10 km shook Ambon (Yuliatmoko *et al.*, 2019). It caused 41 fatalities, 12,137 houses were damaged, and over

103,301 people had to be moved out (Wibowo, 2019). The earthquake also caused land subsidence in Negeri Sila, Nusalaut Island.

Resistivity method is one of geophysical methods that can be used to investigate the structure of subsurface layers. With this method, the subsurface layers are determined based on the change in the resistivity value with depth. The range of specific resistivity values indicates a change in the mass of a certain rock. The use of resistivity in the investigation of shallow structures had been carried out. One example is the Basaltic Lava Tunnel investigation in Jordan (Al-amoush and Rajab, 2018). In addition, this method can be used to determine submarine groundwater discharges in corals controlled by fractures formed (Cantarero and Siringan, 2019). This method can also map groundwater resource, the path of sea water intrusion and bed rock such as a research conducted in Andaman, India (Island, 2016). In Indonesia, a research using this method had also been carried out in Ambon to determine the level of sea water intrusion around mangrove habitats (Damayanti *et al.*, 2020).

Tectonic Settings

The region of eastern Indonesia is a complex tectonic area with four tectonic plates. The Pacific Plate moves from east to west, the Australian Plate moves from southeast to northwest, the Eurasian Plate moves from northwest to southeast, and the Philippine Plate moves from north to south. The Maluku Sea region is within the complex zone of interaction among the Pacific Plate, the Philippine Plate, the Eurasian Plate, and the Australian Plate (Irsyam *et al.*, 2017). The present condition of the Maluku Sea Plate is subducting along the eastern boundary under the Halmahera Arc and the western boundary under the Sangihe Arc (Hatherton and Dickinson, 1969). The Halmahera and Sangihe arcs are colliding with each other, turning the Maluku Sea into a collision zone. In the southern part of the collision zone, there is an area where the ridge is strongly deformed consisting of a thick sedimentary layer of low-density sedimentary material (Irsyam *et al.*, 2017). The Maluku Sea region has an inverted "U" shape and has an eastward slope under Halmahera and westward under the Sangihe Arch (Figure 1). The Banda arc subduction zone causes many faults to form and has Weber Deep and Banda Detachment (Pownall *et al.*, 2017a and b).

Nusalaut Island is geographically located in the east of Ambon Island. The island is bordered by Saparua Island in the north, by Seram Sea and

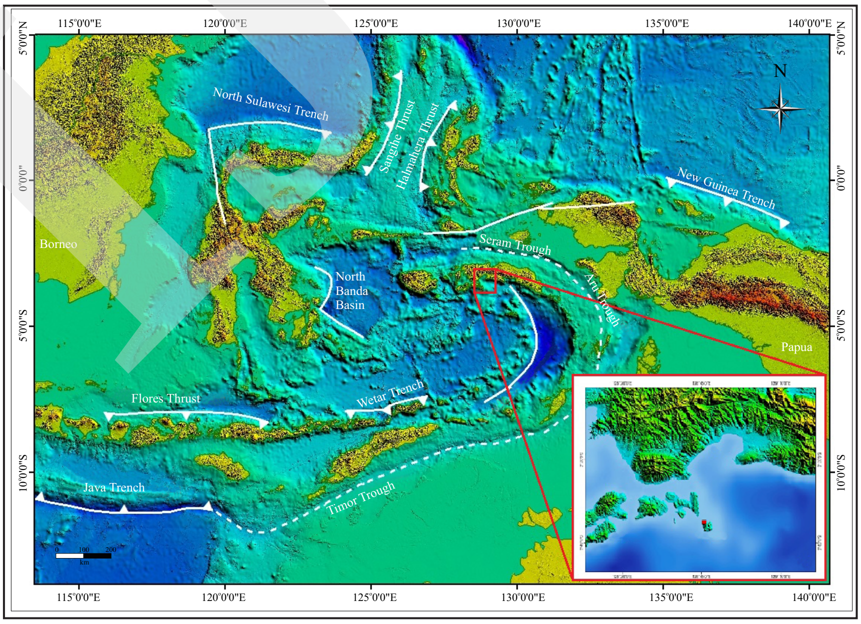

Figure 1. Tectonic map of eastern Indonesia and Nusalaut Island (modified from Pownall *et al.*, 2017a and b; Pranantyo and Cummins, 2019).

Serua Island in the east, and by Molana Island in the west (Figure 2). The history records that Nusalaut Island experienced an earthquake that caused a large tsunami with the height of more than 5 m in 1674 (Pranantyo *et al.*, 2017; Pranantyo and Cummins, 2019). Geologically, Nusalaut Island mainly consists of Ambon volcanic rocks (TPav) which in a few coastal areas are unconformably overlain by coral limestone (Ql) (Tjokrosapoetro *et al.*, 1993).

Methods and Materials

Methods

This research was conducted on December 6 - 9, 2019, in Negeri Sila, Nusalaut, Central Maluku, with the coordinates of 03°38’ 47.5” N and 128°45’ 53.1” E. The instrument used is resistivity meter with dipole-dipole configuration. Resistivity method is one of the geophysical methods utilizing the electrical properties of the earth, such as subsurface resistivity values generated by measuring the potential difference from an electric current that is injected into the earth.

MiniSting resistivitimeters have a measurement accuracy of 400KΩ to 0.1 milli Ω, with a maximum measurement resolution of 30 nV. The tool calibration was done digitally by using a microprocessor and stored in memory. This tool consists of two electrodes to inject current and two electrodes to measure potential differences. The geoelectric acquisition was done with a dipole-dipole configuration, and a spacing between the electrodes is 10 m. Data were inversed by using the Res2DInv programme to get the resistivity value of each line. The resistivity value was then mapped so that a map is obtained which will be interpreted later.

Materials

The equipment used in this study were: resistivity meter (MiniSting), handy talky, compass, and GPS (Figure 3). The survey was carried out by taking data on strike, dip, and fracture aperture that occurred in Negeri Sila (Figures 4a and 4b). This was done to design a resistivity survey in order to get the target anomaly value, which is the weak subsidence zone. Furthermore, the survey design was made in the form of a resistivity survey lines perpendicular to the

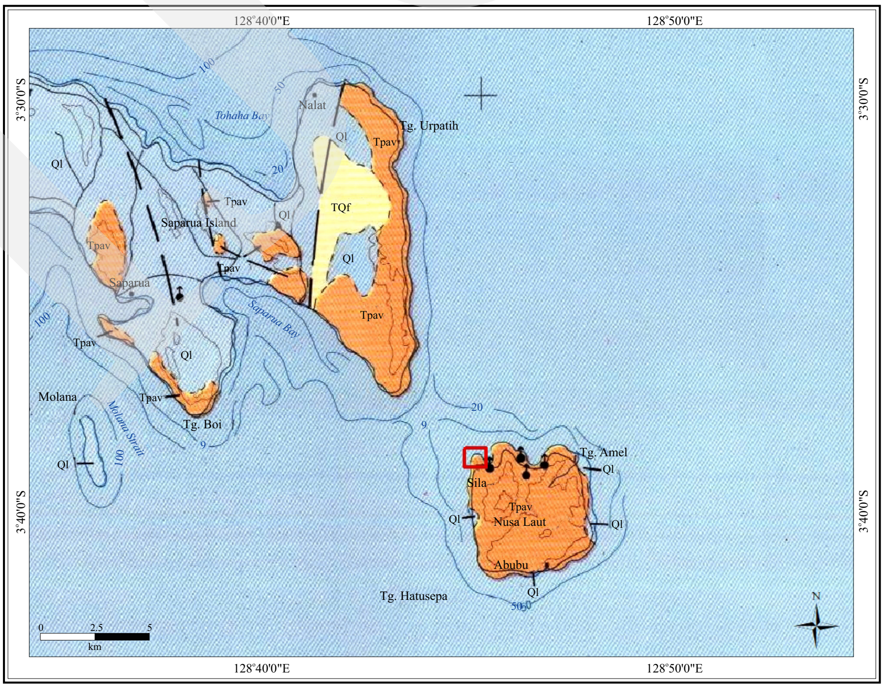

Figure 2. Nusalaut regional geological map (Tjokrosapoetro *et al.*, 1993).

Figure 3. Equipment used in the research.

fracture plane (Figure 4). In this survey, seven lines of resistivity data were collected, with 10 m of spacing and 100 m in length.

Figure 4 shows the process of measuring fracture direction, survey design, cable extension, and current injection using resistivity meter to obtain subsurface resistivity data.

Results

Figure 5 shows the design of the resistivity survey lines that had been done. This was designed to be perpendicular to the direction of the fracture due to subsidence in the Negeri Sila. Resistivity data was initially in the form of the magnitude of the injected current (I) and the amount of potential difference (ΔV) due to current injection. With resistivity survey equipment, the apparent resistivity amount would be obtained at the measurement points. The apparent resistivity value was then analyzed using the Res2DInv programme to get the true resistivity value of each point in the cross section. The results of data shown on the line 1 are in Figure 6.

Based on all resistivity sections on Figure 6, resistivity value can be categorized into three categories: low, medium, and high. Low resistivity zones, 1 Ωm to 10 Ωm, are interpreted as areas with soil creep and saltwater intrusion or

Figure 4. a. Strike, dip, apperture of fracture measurement. b. Resistivity survey line in the fracture area due to subsidence. c. Spread of electrode cables near residents' homes. d. Current injection process.

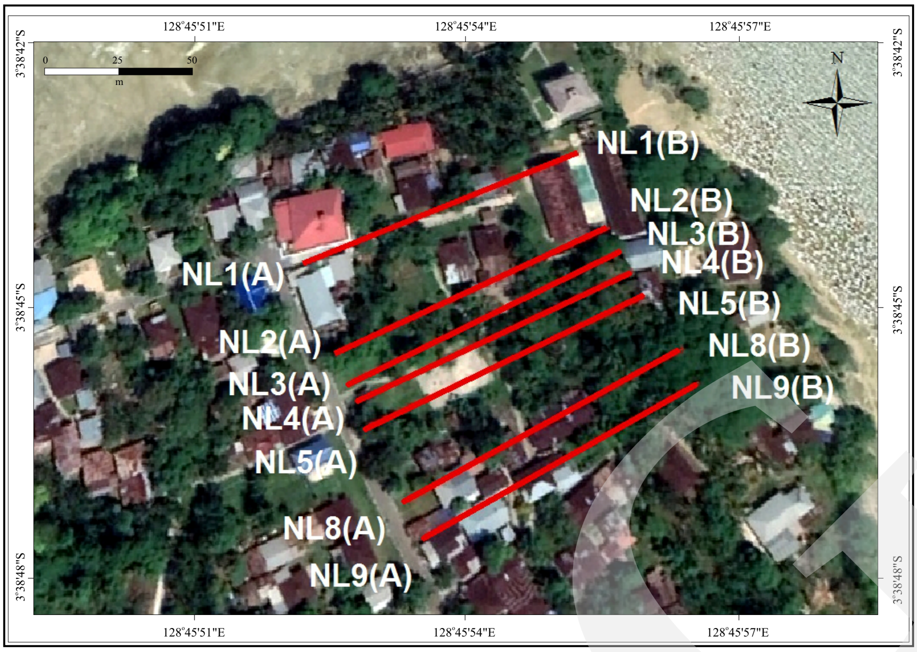

Figure 5.Resistivity survey lines at the researched location.

weak zones. Zones with resistivity value from 10 Ωm to 100 Ωm, or medium resistivity zones, are interpreted as soil. High resistivity zones are areas with resistivity value of more than 100 Ωm and interpreted as limestone.

There are two continuities of low resistivity zones. The first continuity is on the eastern part of the lines. The depth of the zone is more than 5 m. The second continuity of low resistivity zone is on the western part of the lines. The depth is relatively shallow, less than 5 m. High resistivity zones dominated the most of subsurface area along the lines. Medium resistivity zones are between high and low resistivity zones.

The existence of low resistivity zones which are interpreted as weak zones has caused soil subsidence which was triggered by the earthquake on September 26, 2019. These zones also have the potential for soil subsidence to happen if an earthquake occurs again in the future.

Discussion

Soil subsidence can occur due to various factors, such as very low groundwater level, surface compaction due to buildings or tectonic activity (Sriyanti *et al*., 2019). While soil creep can be defined as rock or soil mass displacements due to gravity (Pawlik and Pavel, 2018). The phenomenon that occurred in Nusalaut was thought to be a result of soil creep.The phenomenon of land subsidence in this place occurred due to an earthquake on September 26, 2019, which caused the weak zone between the limestone cavities and crack, and caused the intrusion of seawater into the cavities, so the sediment in the limestone cavities was eroded by seawater intrusion, causing soil creep to occur.

Figure 7 is a three-dimensional model of the resistivity values obtained. It can be seen that the weak subsidence zone due to soil creep forms a fairly large field. Figure 7a shows the subsidence plane, whilst in Figure 7b the side view can be seen as a weak field caused by sea water intrusion entering the surface of the ground, making a weak field consisting of a layer of sediment causing it to crumble and shrink that leads to soil subsidence.

Based on observations, processing, interpretation of data, and literature review, it can be analyzed that this researched area comprises coral limestone with the resistivity of 100 - 4000 Ωm (Figure 7c), and the material which is filled by unconsolidated sediment. Thus, if there is inter-

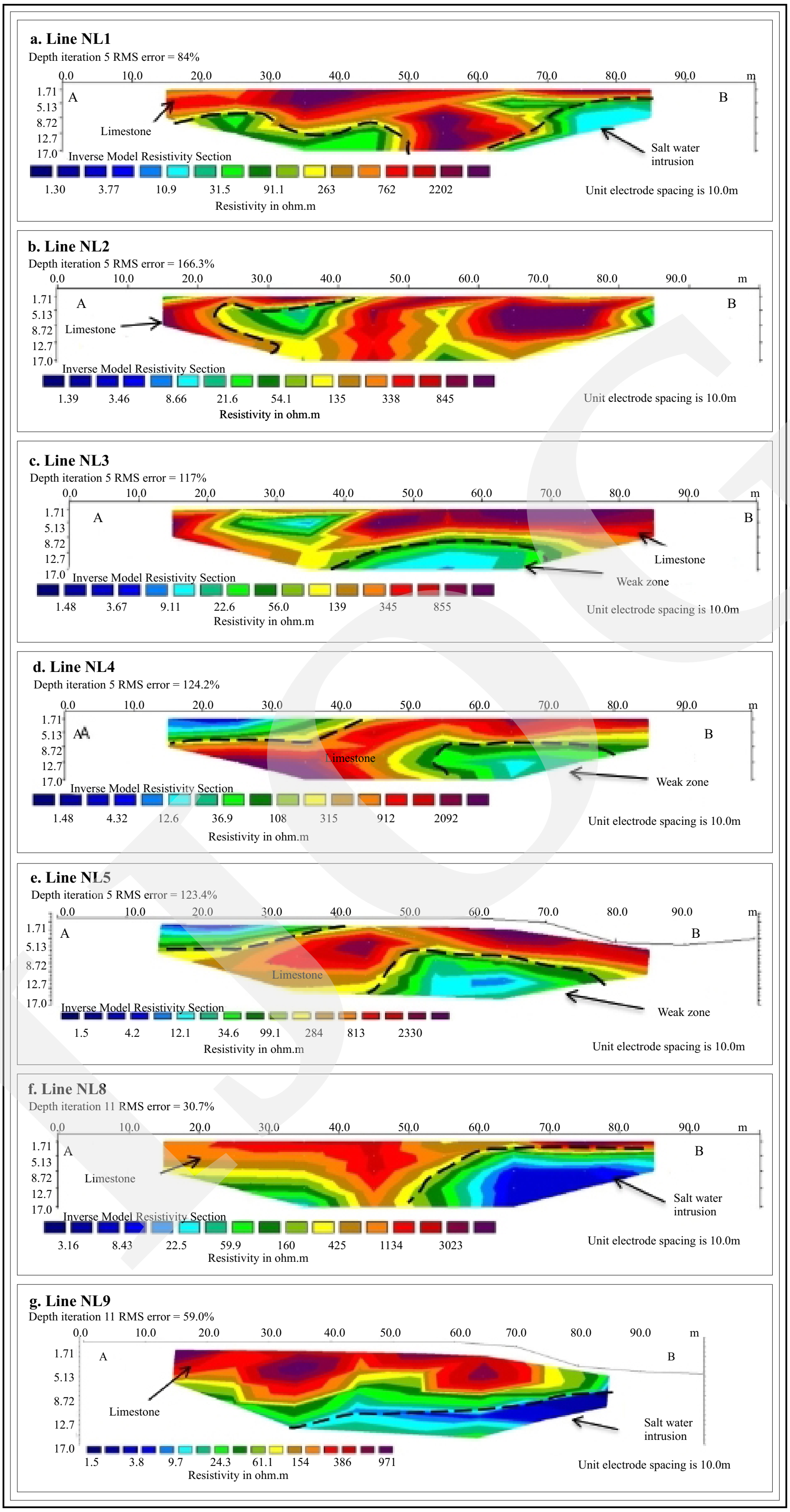

Figure 6. True resistivity from Res2DInv inversion.

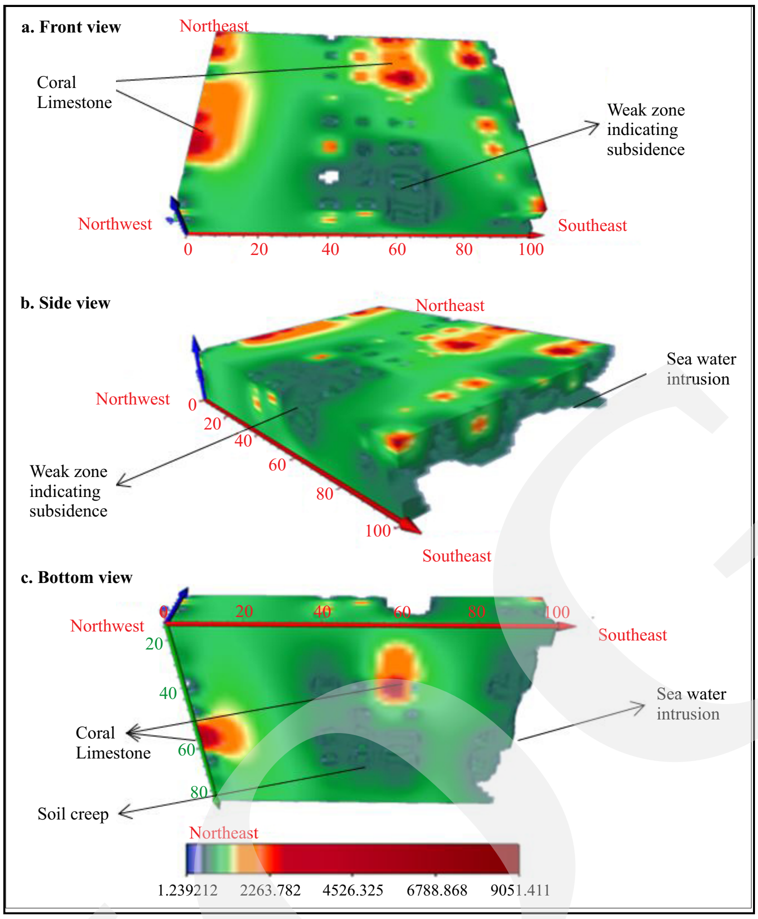

Figure 7. Three-dimensional model of resistivity inversion.

ference with the material such as an earthquake or sea water intrusion, it will cause creeping or creep land which results in soil subsidence (Kolawole *et al*., 2017).

The resistivity cross section shows the west and east areas of the track that have low resistivity values. This zone is interpreted as a weak zone-with the resistivity 1 - 10 Ωm that has the potential to cause soil creep and saltwater intrusion.

Conclusions

Weak zones in the subsurface at NegeriSila has caused soil subsidence. This soil subsidence was triggered by the September 26, 2019 earthquake. The resistivity method verified these zones with low resistivity values on the west and east areas. These low resistivity zones are interpreted as unconsolidated sediments with seawater intrusion. These areas are also potential for soil subsidence to happen in the future if an earthquake occurs again.

Based on the data analysis and discussion conducted, it can be concluded that the material of the Negeri Sila consists of bedrock of coral limestone filled with unconsolidated sediments. There is a sea water intrusion in the this area, causing the unconsolidated material to be disrupted and dislodged, then causing soil subsidence to occur. From the three-dimensional model, it is found that the weak zone of potential soil subsidence due to soil creep is quite wide.

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