Mapping buried ancient structure using gravity method: A case study from Cot Sidi Abdullah, North Aceh

N Ismail\textsuperscript{1,2,3}, M Yanis\textsuperscript{2}, F Abdullah\textsuperscript{1,2}, A Irfansyam\textsuperscript{3,4} and B S W Atmojo\textsuperscript{4}

\textsuperscript{1} Department of Physics, Faculty of Mathematics and Natural Sciences, Syiah Kuala University, Jl. Syech Abdurrauf No.3 Darussalam, Banda Aceh 23111, Indonesia
\textsuperscript{2} Department of Geophysics, Faculty of Engineering, Syiah Kuala University, Jl. Syech Abdurrauf 7, Darussalam, Banda Aceh 23111, Indonesia
\textsuperscript{3} Graduate Program in Disaster Science, Syiah Kuala University, Jl. Tgk. Hamzah Fansuri No. 3 Darussalam, Banda Aceh 23111, Indonesia
\textsuperscript{4} Office for Archaeological Heritage Conservation of Aceh, Jl. Banda Aceh - Meulaboh, KM 7.5 Peukan Bada 23352 Aceh Besar, Indonesia

nazli.ismail@unsyiah.ac.id

Abstract. Samudra Pasai was an important area for trade, religion and political in Southeast Asia region for several centuries since the first millennium. The existence of the kingdom in the past is evident with the abundance of ancient graves and structures found along North Aceh coast. However, some of them are damaged or buried beneath the surface. We have applied gravity method to detect and delineate buried structure of Cot Sidi Abdullah, one of the remaining constructions of the Samudra Pasai Sultanate. Gravity method is a non-invasive geophysical technique that is proper for archaeological exploration. Foundation of Cot Sidi Abdullah structure is covered by a thick sandy layer, hence geometry of the building itself remains unknown. To delineate the suspected structure, gravity data were acquired on a 50 m by 30 m grid with station spacing of 2 m on the study area. The measured data were applied drift, latitude, free air, Bouguer, and terrain corrections. The residual complete Bouguer anomalies implied the presence of a possible man-made features. Horizontal derivative anomalies were used to delineate shape of the buried structure. Positive horizontal anomalies map shows that foundation of Cot Sidi Abdullah structure has rectangular shape and some detail small rectangular structures inside it. The map also shows some buried artefacts situated around the site.

1. Introduction

Recent studies in paleotsunami show that at least two tsunamis have occurred around the 14\textsuperscript{th} century that changed settlements in Aceh [1]. The first Islamic sultanate of Samudra Pasai also achieved glory period around this century. However, evidences of the sultanate's glory after its fallen are hard to trace. Most of structures built during the time have been buried by sediment deposits beneath the surface. The sediments probably transported by natural, man-mad or catastrophic processes in the past. Cot Sidi Abdullah site in Kuta Krueng, Samudera sub-District, North Aceh is one among the relics that has been damaged and abandoned by people. The site is so named since nearby there is the tomb of Sidi
Abdullah, the finance minister of the kingdom. He descended from the Abbasiyah Dynasty and died in 1407 [2]. This means, Samudra Pasai was an important part of the maritime silk route during the period.

To revitalize the importance of this site, it is necessary to conduct in-depth studies in the area. One of the studies that has to be done is to map the entire structure by archaeological excavation for further conservation efforts. However, excavating the site without the preliminary information of the existence of the ancient artifacts will appropriately take a very long time and cause damages to the structure. To avoid the possibility of destruction, geophysical survey is considered as a non-invasive, fastest, economic, and informative method to map subsurface condition of archaeological sites. Gravity method is one of the reliable geophysical techniques that can be used for this purpose. In this paper, we explain a successful application of gravity method for mapping of buried structure of the Cot Sidi Abdullah site, North Aceh.

2. Theory and Method
In gravity method, spatial variation of measured gravitational field data are responses of spatial variation of density of subsurface material [3]. Practically, gravity methods are rarely used in archaeological geophysical surveys. However, the method is considerably reliable for mapping buried structures. Most of ancient structures in Aceh are made of stones and bricks. The structures are mostly covered by top soil or sandy layers, in this case density contrast between the buried structures and the sediment layers are sharply different. Hence the gravity method will be potentially used for this purpose.

In mapping, gravity data are measured in grid. For a regional survey, the grid measurement varies from 2 to 3 stations per km$^2$. For exploration of hydrocarbon, number of stations are usually from 8 to 10 stations per km$^2$. For a detail surveys to detect high resolution features, distance between stations can be decreased up to 5 to 50 m. In microgravity measurement, the distance of the station could be 0.5 m [3]. Therefore, gravity method is potentially used in archaeological exploration.

Measured data in the field do not reflect directly density variation of subsurface. Some external effects must be removed from the measured data. Using gravimeter CG-5, the instrument has a repeated standard field of less than 5 μ Gal. The corrections of Earth tides, tilts of the measuring system, temperature changes and a long-term drift were applied by the instrument during the data collection. The base station readings were recorded every hour during the survey to acquire diurnal variation of gravity data. Complete Bouguer anomaly data are obtained after drift, latitude, free air, Bouguer, and terrain corrections treated on the measured data set. The complete Bouguer anomaly data are ready to be interpreted, however there are some methods that can be used for qualitative interpretation.

To delineate the subsurface condition of the ancient structure, we used horizontal and vertical derivative techniques. The methods are quite simple, it just calculates the two first-order derivatives of the field with respect to horizontal or vertical directions [4].

3. Data and Discussion
The study area is situated in Kuta Krueng Village, Samudera sub-District, North Aceh. Figure 1 shows graphical view of site location. The area is very easy to distinguish because it is a relatively higher mound than around. The name of ‘Cot Sidi Abdullah’ in the local language (i.e. Acehnese) is literally translated as ‘Mound of Sidi Abdullah’. The mound is situated at the south Sidi Abdullah’s tomb (shown as green rectangular (B) in figure 1). The mound mostly consists of about 1.5 meters thick sand deposit covering the suspected structure. The structure is drawn in grey square shape (A) in figure 1. Based on cores collected close to the site, the sand layer is superimposed on dark silt deposit at depth. Surface water was found within this silt deposit. Except at the east, the area study is surrounded by river and private ponds.

Gravity data were collected on a suspected buried structure of Cot Sidi Abdullah. The data collection covered only half of the study area at the east side, showing by red dashed grid in figure 1.
There is no data measurement at the east-south grid, hindered by artificial pond (blue rectangular in figure 1). To obtain a better resolution of the subsurface image, 2 meters spacing of gravity stations were made for an area 50 meters by 40 meters. The data were acquired using CG5 AutoGrav. The AutoGrav is a microprocessor-based automated gravity meter that has a measurement range of over 8000 mGals and a reading resolution of 0.001 mGal. This accurate specification enables the AutoGrav to be used for detail archaeological surveys.

Figure 1. Map of Sidi Abdullah (A) and Sidi Abdullah’s tomb (B). Grid shows area of data measurement. Blue indicates water area, green is building, and grey is footpath.

Measured data from the field were processed with drift, latitude, free air, Bouguer, and terrain corrections. These corrections produced complete Bouguer anomalies that actually ready to be interpreted. However, the Bouguer anomalies are mixing with regional and local anomalies. We have removed regional effect on the anomalies to obtain local anomalies that may reflect shallow depth targets. Most of archaeological objects are buried at near surface, i.e. less than 2 meters in this case.

We found some challenges in the local Bouguer anomalies for interpretation. We could not figure the structure based on the anomalies. Some effects come from local topographic still can be seen here. The map shows parallel pattern of the anomalies in north-south direction (the figure is not shown here). The patterns reflect undulation of topographic on the area. Similar patterns are also found at the east side. In order to enhance the data, we have filtered the data using derivative horizontal and vertical techniques. Positive anomalies in horizontal and vertical derivative maps can be interpreted as presence anomaly bodies in the subsurface, zero values mean boundaries between anomaly bodies and their hosts, while negative anomalies can be interpreted as homogenous of density of subsurface [4].

Figure 2 (left) shows the horizontal derivative map of the study area. Based on the map, presence of artefacts can be connected with positive anomalies (0.01 to 0.05 mGal/m). These anomalies show structured patterns, i.e. two patterns elongate in west-east direction at the north and middle of the anomalies map and one pattern elongates in the north-south crossing of the anomalies map. By drawing lines along these patterns, we can interpret a man-made structure as a foundation of old building. An abundance of broken bricks was found along these lines that could be come from wall of the structure.

Vertical derivative anomalies map shows more detail shape of the structure (figure 2, right). Positive values of the anomalies elongated in the map could be interpreted as presence of the structures within subsurface. All the elongated anomalies form a rectangular shape. Most of ancient structures found in Aceh have rectangular or square shapes [5]. At the west and east sides of the structure, the map is also covered by positive anomaly possibly caused by ruins of the main structure.
Outcrops show the structure made of non-cemented burned soil bricks. Gravitational process and human activities around the site have eroded the bricks from the wall. Outside the structure, some 5 circles or spots of positive anomalies are also found. These spots may come from artefacts buried around the site. One cylindric artefact made of a massive igneous rock found at 1.5 meters depth beneath the south wall after excavation. Location of the artefact coincides with the positive spot anomaly situated outside the west-east elongated structure at the middle.

Figure 2. Horizontal derivative (left) and vertical derivative (right) gravity anomaly maps of the Cot Sidi Abdullah. The dashed line shows suspected the archaeological structure.

4. Conclusion
The ancient structure of Cot Sidi Abdullah has been successfully mapped using gravity method. The method is considerably fast, cost effective and non-invasive to be applied for archaeological investigation. Most of archaeological objects are buried at near surface, therefore separation between local and regional from gravity anomalies are needed. Horizontal and vertical derivatives of gravity anomalies are able to impress shape and location of the structure and artefacts in the area study. Finding from this research is potentially used as preliminary information for further archaeological excavation stage.

References
[1] K. Sieh, D. Patrick, E. E. McKinnon, J. E. Pilarczyk, C. Hong-Wei, B. Horton, C. M. Rubin, S. Chuan-Chou, N. Ismail, C. H. Vane and M. R. Feener, "Penultimate predecessors of the 2004 Indian Ocean tsunami in Aceh, Sumatra: Stratigraphic, archeological, and historical evidence," J. Geophys. Res. Solid Earth, vol. 120, 2015.

[2] T. Muhammad, Daulah Shalihayah di Sumatera, Lhokseumawe: CISAH, 2011.

[3] J. M. Reynolds, An Introduction to Applied and Environmental Geophysics, 1st ed., UK: Geosciences Ltd, 1997.

[4] Cooper, Gordon; Cowan, Duncan:, "Edge enhancement of potential-field data using normalized statistics," Geophysics, vol. 73, no. 3, pp. H1-H4, 2008.
[5] Yanis, Muhammad; Bakar, Marwan Abu; Ismail, Nazli;, "The Use of VLF-EM and Electromagnetic Induction Methods for Mapping the Ancient Fort of Kuta Lubok as Tsunami Heritage," in 23rd European Meeting of Environmental and Engineering Geophysics, Malmo, 2017.