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The use of magnetic and geoelectrical methods to locate buried ancient artificial canals and wells around the cultural heritage of Indrapatra Fort, Aceh, Indonesia

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ABSTRACT: The application of magnetic and geoelectrical methods for archaeological study is presented in this paper. The study was intended to map near-surface structures around the Indrapatra Fort, the 16th-century fortification built during the Early Aceh Sultanate in the north of Sumatra. Some of the structures around the fort have been buried after the 2004 Indian Ocean Tsunami or even by previous paleotsunami deposits. The ground magnetic measurements were performed over an area of 6 750 m^2 using a high-resolution Proton Precession Magnetometer G-19 Geometric. Total magnetic field data were acquired as a 3-m grid station along survey lines spaced 3-m apart. Total magnetic field anomalies were calculated by diurnal and International Geomagnetic Reference Field corrections. To clarify the position of objects causing the anomalies, analytical signals and tilt derivative filters have been applied to the total magnetic field anomalies. The method found several structures with contrasting physical properties to those of the surrounding material. Both filters were able to identify the presence of circular, elongated, and square anomalies around the Indrapatra site. The archaeological interpretation of such structures is in terms of wells, canals, and road floors. The structures are made of limestone boulders buried within the uppermost sand layer. The burning process to cement the boulders causes their magnetic properties to be different in contrast to the layer of sand that covers them. Based on magnetic interpretation, three geoelectrical profiles were measured crossing the targeted objects using Supersting R8/IP 56 Electrode Electric Resistivity. Wenner configuration with 1-meter electrodes spacing was applied for a better model resolution. The inverted models of apparent resistivity data show an agreement with magnetic interpretation at shallow depth. The models also imaged the depth and geometry of the objects based on the electrical resistivity properties of subsurface materials. It is expected that the structures preserved tsunamigenic deposits, so the discovery of the structures will be able to contribute to further research on paleotsunami in Aceh.

Key words: geophysics, magnetic, geoelectric, archaeology, cultural heritage

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1. INTRODUCTION

The 2004 Indian Ocean tsunami has become the deadliest disaster in history, an earthquake measuring Mw 9.2 triggered a tsunami with a height of 30 m and caused infrastructure damage and casualties of 230,000 people, one of them in Aceh Province, Indonesia (Borrero et al., 2006). One of the reasons that the 2004 tsunami was so devastating was the lack of public knowledge about a potential tsunami event so they were not prepared to face this devastating event. Although there are several documents about tsunami events in the past in the same area, their occurrence ranges over hundreds of years (Meltzner et al., 2010). At that time, it was not widely known that there was neither cultural knowledge nor written records of the peoples along with the Indian Ocean coast nor in the scientific literature (Sieh et al., 2015; Daly et al., 2019). Thus, the devastating waves came spontaneously without prediction. The completeness of paleoseismic or paleotsunami records can at least be able to enrich references to predict future tsunami and earthquake events in an area. Paleotsunami studies are often carried out in nature such as tidal and freshwater marshes and coastal embayment, lake, or swales by identifying anomalous beds of sand in low energy

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environments (Jaffe et al., 2003; Jankaew et al., 2008; Monecke et al., 2008; Meltzner et al., 2010; Martin and Bourgeois, 2011; Kelsey et al., 2015; Rubin et al., 2017). In this way, not only humans can be saved from the disasters but also properties, economic or environmental loss, including cultural heritage.

Cultural heritage is a nation's wealth that is important for understanding and developing history, science, and culture, so it needs to be protected and preserved. Preserving cultural heritage can foster awareness of national identity and national interests. Damage to cultural heritage can be influenced by age of the building, climate, and location (Nicu, 2017; Carroll and Aarrevaara, 2018; Sesana et al., 2021). When the location of the cultural heritage is close to disaster-prone areas, it can damage the structures after a disaster occurs (Sieh et al., 2015; Hoffman et al., 2018; Daly et al., 2019). To revitalize a cultural heritage structure that has been damaged, either due to age or disaster, multidisciplinary studies need to be carried out before development. In this case, a near-surface geophysical survey plays a very important role in mapping the remains of buildings buried beneath the surface. Aceh waters were one of the important areas in Southeast Asia in ancient times. Its location is very strategic in the Indian Ocean and the gate of the Strait of Malacca, making Aceh an important part of the sea trade silk route in the past (Fig. 1a). Along the coast of Aceh, many neglected relics can be used to study the settlement process in the past as well as traces of ancient disasters that occurred in the areas. Figure 1 shows some archaeological objects from the 11th to 15th centuries found along the northern coast of Sumatra. It is suggested, the area experienced two tsunami events that occurred between 1390 and 1450 (Sieh et al., 2015), this indicates that archaeological objects along the northern coast were inundated by several tsunamis during the past so that there are parts of the objects that have been damaged and buried by sediment deposits.

One object that is very vulnerable to the threat of tsunamis and other coastal hazards is the fort of Indrapatra (Fig. 1b). Indrapatra is a coastal fortification located in Ladong, Aceh Besar District, approximately 19 kilometers to the east of Banda Aceh, the capital city of Aceh Province. Based on the shape of the building, Indrapatra Fort is a heritage building from the 7th century AD, when Hinduism entered Aceh (Regional Office for Cultural Properties Preservation in Aceh Province, 2005). In the early days of the arrival of Hindus in Aceh, the building was used as a place to live in addition to the royal family, it was also used for carrying out religious rituals (McKinnon, 2009). However, in the 16th century, during the Islamic sultanate, this building changed its function as a fortress. This is evidenced by the existence of a horseshoe-like shaped structure that generally functions as cannons and an arsenal site (Zainuddin, 1961).

The area of this fort is 70 × 70 meters, and initially, there were three buildings, but currently only two buildings with two stupas. Apart from the main building, other buildings in the vicinity were used as places for laying down cannons and ammunition. As an important building in its time, the Indrapatra Fort was equipped with wells for water consumption and channels around it for defense. However, at this time, the remains of the ditches and the wells are hardly seen because they were buried by sediment deposits, either due to slow erosion, man-made activities, or natural disasters. The devastating tsunami of 2004 has proven how these buildings were damaged by natural disasters. Therefore, the rediscovery of these locations will be able to reopen information about ancient tsunamis disaster events that may have been deposited in the structure in the form of a basin on the ground surface. In this study, we used geomagnetic and geoelectrical methods to locate several old trenches and wells in the Indrapatra Fort area which is thought to have stored paleotsunami deposits in the past. Geophysical exploration has been used for archaeological identification and excavation of the archaeological features in the subsurface; including resistivity and seismic (e.g., Leucci et al., 2007), electromagnetic (e.g., Wang et al., 2013), and magnetic methods. Magnetic is the most frequently conducted survey for the observation of various sub-surface archaeological objects and has been used successfully in several archaeological cases (e.g., Herwanger et al., 2000; Herbich, 2018; Urban et al., 2019).

Applications of magnetic methods can provide clues to the historical evolution of human settings during archaeological and historical times preserved on the nearsurface. The magnetic method is one of the most important techniques for searching for buried anthropogenic objects such as buried walls, trenches, tombs and cavities, holes, or pottery (Dirix et al., 2013; Herbich, 2018; Colombero et al., 2020), especially when the structures are made of materials with relatively high susceptibility, or has undergone changes with high temperatures, such as ceramics, bricks, and metal objects, were subject to survey. In addition, magnetic method measurements can be carried out quickly, widely, and with high mobility (Mekkawi et al., 2013). The level of detail can be varied based on the measurement object. The detail of this method can be determined by varying the spacing based on anomalies. On the other hand, geoelectrical methods are usually reliable in clarifying subsurface model resolution for shallow investigation based on the electrical properties of the material. The conventional geoelectrical survey makes use of electrical current injected through a pair of current electrodes and measured its potential difference using a pair of potential electrodes. With a multi-electrode cable, hundreds of resistivity measurements can be obtained simultaneously thus creating a 2D profile. The 2D geoelectrical method is potentially applied to delineate buried cultural and archaeological objects (Reci et al., 2015). Thus, to study tsunami deposits that are directly related to past community activities, we used magnetic and geoelectrical methods to investigate ancient trenches and wells in the Indrapatra Fort. Both cultural objects are suspected of being stored in tsunamigenic deposits.

2. GEOLOGICAL AND ARCHAEOLOGICAL REVIEW OF THE AREA

Banda Aceh is a waterfront city surrounded by the northern side of Malacca Strait and the Indian Ocean. The Krueng Aceh River divides the city of Banda Aceh into two parts so that the city develops on the west side and the east side of the river. In a broader view, the city of Banda Aceh looks like a valley. The Krueng Aceh River flows in a very wide valley between Tertiary and Quaternary volcanic mountains on the east side and mountains formed from limestone Cretaceous on the west side (Culshaw et al., 1979). The valley is covered with relatively young material in the form of alluvial deposits and marine sediments with a thickness of nearly 200 meters (Polom et al., 2008).

The low lying of the Banda Aceh landscape was caused by a tectonic graben structure, i.e., bordered by two faults on both sides. The Aceh fault is along the western side and the Seulimeum fault is along the eastern side. Therefore, the city of Banda Aceh is located at an altitude of fewer than 5 meters above sea level. While the terraces on the east and west sides of the city reach a height of 30 meters above sea level (Culshaw et al., 1979). This very low surface condition makes the city of Banda Aceh easily inundated by floods, tsunamis, and tides. These processes caused the presence of alluvial deposits and very thick marine sediments.

The landscape around the Banda Aceh coast is generally dominated by land, in the form of deltas formed by river activities. The densely populated area is even above the delta, which is in the western part of the main Krueng Aceh River branch. While the eastern part of Krueng Aceh is a progression area between coastal ridges and swales. Much of the Banda Aceh delta area has undergone significant changes in recent decades. Based on the interpretation of satellite imagery and aerial photographs, there has been a very significant change in coastal geomorphology in the Banda Aceh area (Meilianda et al., 2010). Changes in the shape of the coast are very complex, both constructive and destructive, from the mid-Holocene to the end of the Holocene. Part of the coastal landscape of Banda Aceh was transformed into water between the 1970s and 2004. The number of archaeological finds in the water area indicates that the past settlements were located in shallow submarines today.

Along the coast of Banda Aceh and Aceh Besar, many important sites in the past were built from the beginning of the

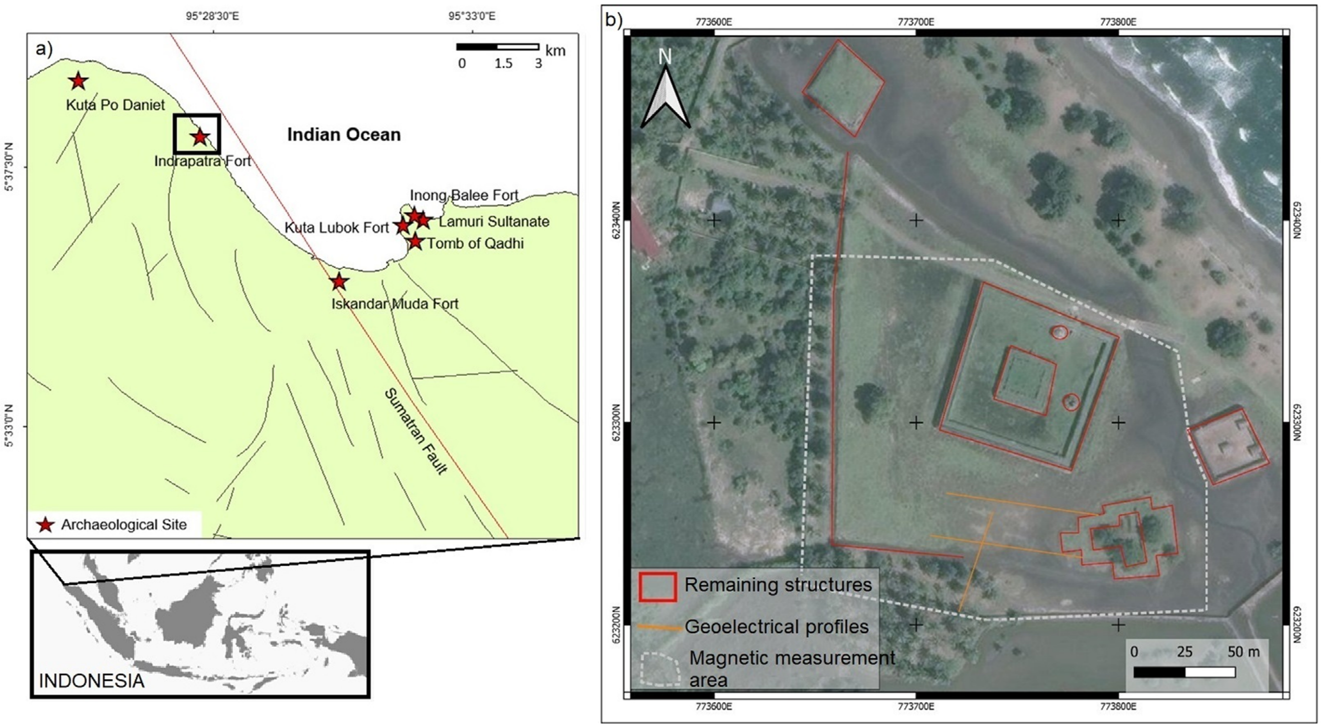

Fig. 1. (a) Map north tip of Aceh Province, Indonesia, showing the distribution of archaeological objects from the 11th to 15th centuries along the coast. This archaeological object is directly facing the Indian Ocean, which allows the deposition of tsunami deposits when disasters occurred in the past. (b) Aerial photograph of the Indrapatra Fort. The existing structures are shown in red lines. The dashed line shows the area of measured magnetic data. The geoelectrical profiles are shown by yellow lines.

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first millennium to the 19th century. Aceh, strategically located at the confluence of the Melaka Straits and the Indian Ocean, was an important node in maritime trade since at least the 9th century (Daly et al., 2019; Tai et al., 2020; Feener et al., 2021). Fortifications and mosques are the most remaining old buildings along the east coast of Banda Aceh (Fig. 1a). The area was known as Lamri, one of the old kingdoms in Southeast Asia. The first record of the kingdom and other territories was found in the Tanjore inscription in 1030 (McKinnon, 2009). Based on geological, archaeological, and historical studies (Sieh et al., 2015), it is known that the area around the Lamri coast had been destroyed by at least two tsunamis in 1394 and 1450. The twin tsunamis caused Lamri to be empty from settlement and were taken time about a century for recovering. Until now, the area has returned to being inhabited by modern settlements.

3. MAGNETIC AND GEOELECTRICAL METHODS

The magnetic method is an efficient technique to investigate subsurface condition by measuring the variation of the earth's magnetic field which correspond to magnetic susceptibility using a magnetometer (Diarte-Blasco et al., 2020). In an archaeological study, the target magnetic bodies are archaeological objects such as artifacts made of magnetic or non-magnetic materials (Sarris and Jones, 2000). The magnetometer is very sensitive to the presence of objects, such as metals, bricks, potteries, and minerals contained in rocks, around it. Most of the archaeological objects are made of this material. Meanwhile, non-magnetic objects such as soil and organic material remains are easily detected around the magnetic materials. Some artifacts in archaeological sites have undergone temperature changes during the manufacturing process so that it changes a magnetic field in them. Therefore, the location of archaeological objects can be interpreted based on measured magnetic field anomalies.

Ground magnetic measurement was conducted using the Proton Precession Magnetometer (PPM) GSM-19 of Geometrics. This equipment has a high-resolution sensitivity of 0.1 nanoteslas (nT) and an absolute accuracy of 0.05 nT. Total magnetic intensity data were collected on 4010 stations with a spacing of 3 meters covering the area of the fortification (Fig. 1b). The sensor was mounted on a pole 2 m high from the ground during the measurement. To observe the temporal variation of the magnetic field, a base station was continually measured at a fixed location. The measured data were processed by diurnal and International Geomagnetic Reference Field (IGRF) corrections to obtain total magnetic field anomalies. The diurnal correction data is obtained by subtracting the observation data from the data at the base station. Analytic signal and horizontal derivative transformations were applied to the total magnetic field anomalies for a better interpretation (Nabighian, 1972; Roest et al., 1992).

The analytic signal is equal to the square root of the sum of the squares of the horizontal and vertical gradients of a magnetic anomaly. The analytic signal data are regardless of the direction of the measured anomaly magnetization, so it represents a response to an object that is vertical without being influenced by the remanent magnetization, inclination, and declination. Mathematically the analytic signal (*AS*) can be written as

$$AS(x,y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2}, \tag{1}$$

where T is total magnetic field anomaly, while x is northing, y is easting, and z is positive down in the magnetic coordinate system.

To emphasize the boundaries of shallow archaeological objects, tilt derivative transformation was also used here. The tilt derivative is represented by the arctangent of the ratio of the vertical derivative of the total magnetic to its total horizontal derivative (Ibraheem et al., 2019). The horizontal derivative (*HD*) is calculated by the equation:

$$HD = \left[\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2\right]^{\frac{1}{2}}, \tag{2}$$

while the first-order vertical derivative (*VD*) is expressed by the equation:

$$VD = \left(\frac{\partial T}{\partial z}\right). \tag{3}$$

Using the Equations (2) and (3), the tilt derivative (*TD*) is formulated as:

$$TD = \tan^{-1}\left(\frac{VD}{HD}\right). \tag{4}$$

Archaeological objects are manmade and mostly have specific patterns, for example, shaped in form of lines, circles, rectangles, or squares. In this case, the derivative calculations of the total magnetic field anomalies will be useful for locating the objects.

Delineation of buried cultural and archaeological objects using geoelectrical methods relies on physical properties contrast, penetration depth, and resolution (McGrath et al., 2002). The basic concept of the geoelectrical method is based on Ohm's Law to measure the electrical resistivity of the subsurface. In practice, an electrical current (I) is inserted into the ground with two current electrodes and measuring the electrical potential difference (ΔV) using 2 potential electrodes on the surface. The cultural and archaeological objects can be imaged when there is a contrast in electrical properties between targeted objects and their surroundings. Depth of penetration depends on current electrodes distance, the longer electrode spacing the deeper structures can be imaged. The apparent resistivity of the subsurface in the heterogeneous media is derived by Equation (5).

$$\rho_a = k\frac{\Delta V}{I}. \quad (5)$$

The k Parameter is a geometric factor that based on electrode configurations applied.

For ERT measurement, a two-dimensional (2D) model of resistivity distribution in the subsurface is generated based on the collection of vertical sounding and horizontal profiling simultaneously using a multi-electrode system. In this study, 3 profiles data were acquired using unit Supersting R8/IP 56 Electrode Electric Resistivity spacing of 1 m with 55-meter-long each profile (Fig. 1b). To obtain a better lateral and vertical resolution of the shallow subsurface, the Wenner electrode configuration was used in this project (Reci et al., 2015). The 2D electrical models were inverted using the 2D inversion using the RES2DINV code (Loke, 2003).

4. RESULT AND DISCUSSION

Total magnetic intensity (TMI) data measured on the Indrapatra fortification area vary from 41500 nT to 42000 nT as a typical value at near low latitude geomagnetic areas. Approximately, the intensity of the Earth's magnetic field also varies from 70000 nT at the South Pole down to 30000 nT at the equator and back to 60000 nT at the North Pole (Nordling and Osterman, 2006). However, the measured data do not reflect directly the presence of targets within the subsurface. The TMI data contains the main magnetic field from the earth, the external magnetic field, noises, and target magnetic bodies called anomalies. However, the TMI values can also be affected by the presence of strong magnetic objects on the surface. They can be easily recognized in the TMI map since most archeological objects in this study have basic geometrical shapes such as squares, rectangles, or circles representing fort walls. The existing fort walls are made of cemented limestone boulders. While the target magnetic bodies buried below the surface are represented by total magnetic field anomalies. The total magnetic field anomalies were extracted from the TMI data using standard diurnal and International Geomagnetic Field Reference (IGRF) corrections. The anomalies range from −200 nT to 200 nT, approximately. The existence of outcrops in the form of fort walls in the middle of the area, the modern concrete fences to the west and the south, as well as road construction to the north of the fort, are well depicted in the total magnetic field anomaly map (Fig. 2). The total magnetic field anomaly intensity depends both on the magnetization and the depth of an object. The deeper objects tend to exhibit broader anomalies. Typical ancient cemented structures in Aceh were built through a burning process of limestone plaster. An object

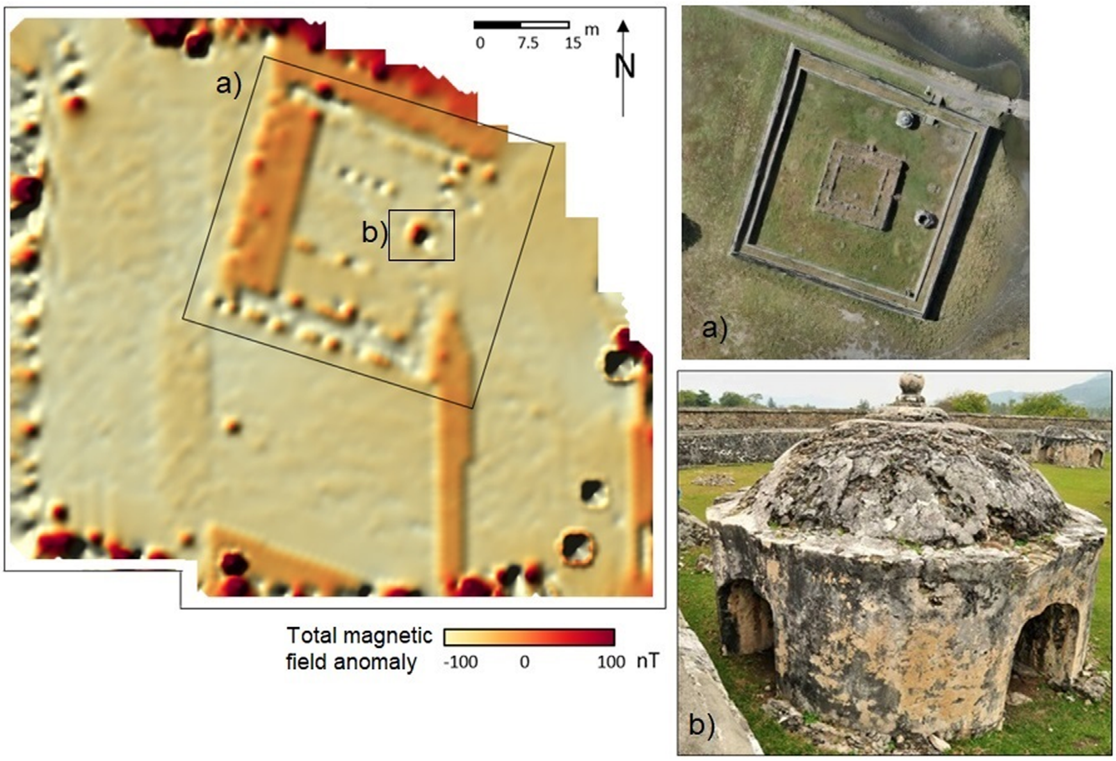

Fig. 2. Total magnetic field anomaly map. The inset images show an aerial photo of the fort building (a) and one of the remaining domes on the east side of the fort (b) with their position on the total magnetic anomaly map.

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that experienced heating to about 700 °C can increase its magnetic susceptibility, for example, archaeological objects with thermoremanent magnetization can exhibit a positive anomaly intensity of ten to hundreds of nT. The elongated pattern along the west and the south sides of the area may come from the modern concrete fence wall and the existing canal. The high total magnetic field anomalies at the northern of the fort are caused by modern road construction. Meanwhile, the circle-like forms at the south-east, some the north-south direction of parallel stripes ended at the south-east corner of the fort, and the east-west direction located in the center along the south side of the area cannot be confirmed since very few outcrops that can be found on the surface that may correlate with these data.

Several techniques in magnetic data processing can be applied to clarify objects causing anomalies below the surface. Signal analytic calculation can be used to determine object boundaries. The method exhibits maximum amplitudes over magnetization contrasts of the objects. The analytic signal map shows clearly the modern concrete fence as a strike line along the west side of the area (Fig. 3). A similar pattern is also seen along the south side which can be also confirmed as a concrete fence. The analytic signal map shows the fort wall as a square with some features inside the fort which are related to fort domes as shown in Figure 2. A similar pattern was also seen in tilt derivative data of the total magnetic field anomalies (Fig. 4). When the analytic signal data exhibit a relatively smooth map, the tilt derivative data show more detailed anomalies around the area.

The analytic signal and tilt derivative maps show at least 4 circle-like and 4 elongated features situated the southeast of the area. These features can be recognized by their maximum peaks of the analytic signal and tilt derivative values, especially when a single shallow source exits within the measurement area (Ibraheem et al., 2019). Simple excavations were done over the anomalies to prove the sources. For the circle-like features, it is confirmed that the structures have a circular wall made of cemented limestone boulders. Each wall has a diameter of about 2 meters filled with silts, sands, and gravel. The structures probably functioned as wells in the past (Fig. 3). There are four features expected as ancient wells, two of them are confirmed by simple excavations. One well that remains in the main fort building as seen in Figure 3 still has water inside. The well is covered by a concrete dome and is also depicted by the anomaly map. This confirmed that the circle-like features of the anomalies are caused by the ancient wells.

There are three north-south elongated patterns found in the southeast of the area. Based on the field observation, a couple of patterns connected the northeast corner of the fort to the south side of the area are confirmed as an ancient roads. The former gate is still visible at the corner, but it has been renovated due to conservation works. At the south, there is another almost elongated pattern with a direction northwest-southeast parallel to the south wall of the fort but close to the southern concrete fence. Based on excavation, this is confirmed as an ancient canal. The canal wide is about 5 meters in length. Therefore the north-

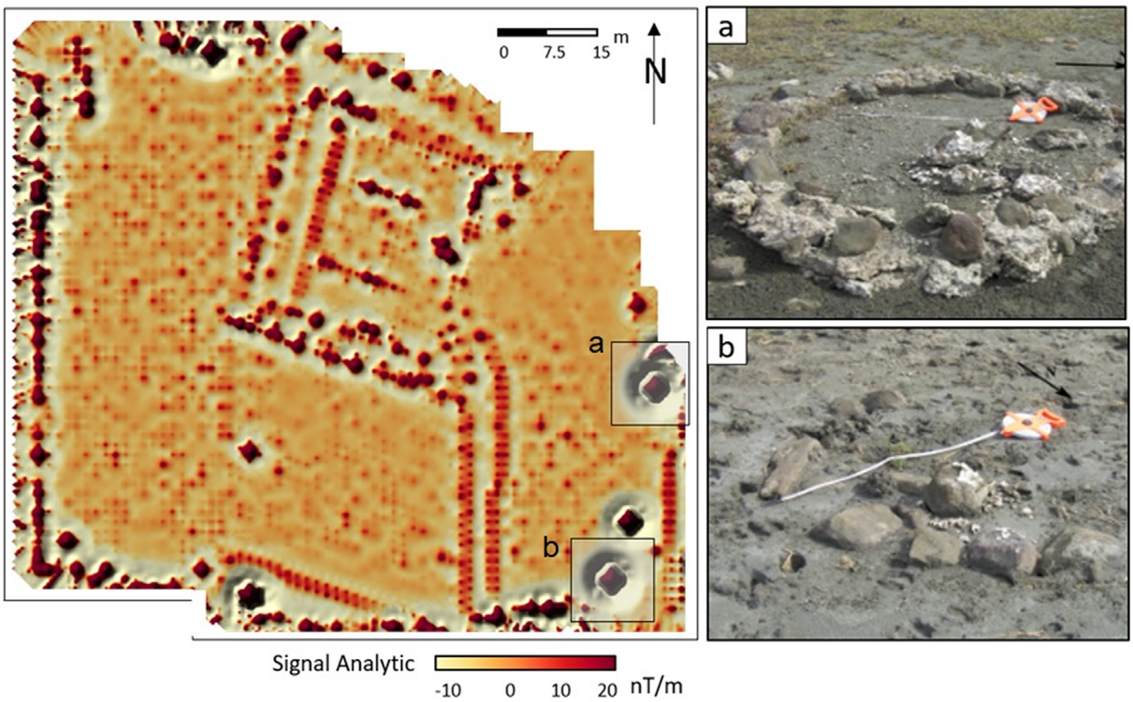

Fig. 3. Signal analysis of total magnetic field anomalies. Two circular anomalies are connected with outcrops in the form of an arrangement of cemented limestone structures (insets a and b).

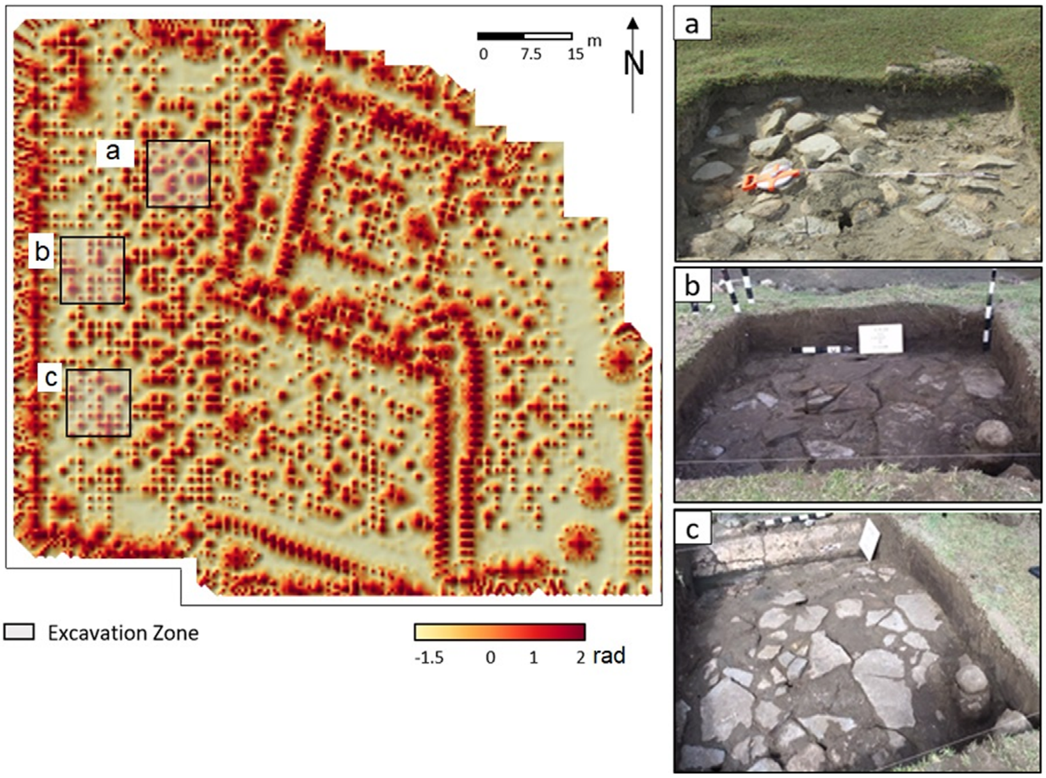

Fig. 4. Tilt derivative data of the total magnetic field anomalies. Three excavations show the fort yard floor made of flat limestones (insets a–c).

south elongated pattern close to the east side of the area can be interpreted as an ancient canal as well. It can be imagined that the fort was surrounded by canals in the past.

The ancient well and canal structures are clearly shown in both analytic signal and tilt derivative maps. However, the analytic signal map shows more simple anomaly patterns than the tilt derivative map. The tilt derivative map introduces many spot anomalies in the fort yard as shown in Figure 4 which may be caused by very shallow magnetic bodies. They are poorly imaged in the analytical signal. The analytic signal has limitations in enhancing anomalies caused by the existence of shallow and deep bodies simultaneously (Cooper, 2009). While the tilt derivative method can be used to detect both shallow and depth objects (Verduzco et al., 2004; Ibraheem et al., 2019). We have done three shallow excavations along the western yard of the fort to prove objects that generate the anomalies. We found a construction built by limestone chunks that have been flattened on one side at a depth of about 25 cm for all the trenches. We suspect that the arrangement of these boulders functioned as the floor of the fort's courtyard in the past.

The three meters measurement grid has not been able to accurately resolve the size of the object. Therefore, only objects larger than two meters in size can be mapped, such as the ancient buried wells and artificial canals. To increase the characterization of small magnetic field anomalies, denser sampling is required. In large areas and the position of the objects being searched for is uncertain, we have reduced the duration of data acquisition by performing geoelectrical measurements on the object of interest. It is expected that the resistivity models obtained from the inversion of geoelectrical data will resolve the size of the objects better. Based on the magnetic map, the southeast part of the area is one of the interesting spots for further investigation. Three geoelectrical profiles were measured along the area. Two profiles crossing the expected ancient road construction and wells as shown in the magnetic map in a west-east direction, approximately. The other profile is directed at almost north-south crossing the expected ancient canal and one of the profiles for data calibration. Figure 5 shows a 3D pseudo section of 2D electrical resistivity models inverted from measured apparent resistivity data. All the resistivity models agree.

The interesting archeological structures interpreted from the magnetic data are well depicted by the 2D resistivity models. The ancient wells are characterized by high resistivity values than other constructions. Based on outcrops and excavation data, the wall of the wells is constructed with cemented limestone boulders. The wells themselves were filled with other materials found around the area such as breakdown of limestones, sand, silt, and clay. Therefore, in the absence of water, the resistivity of

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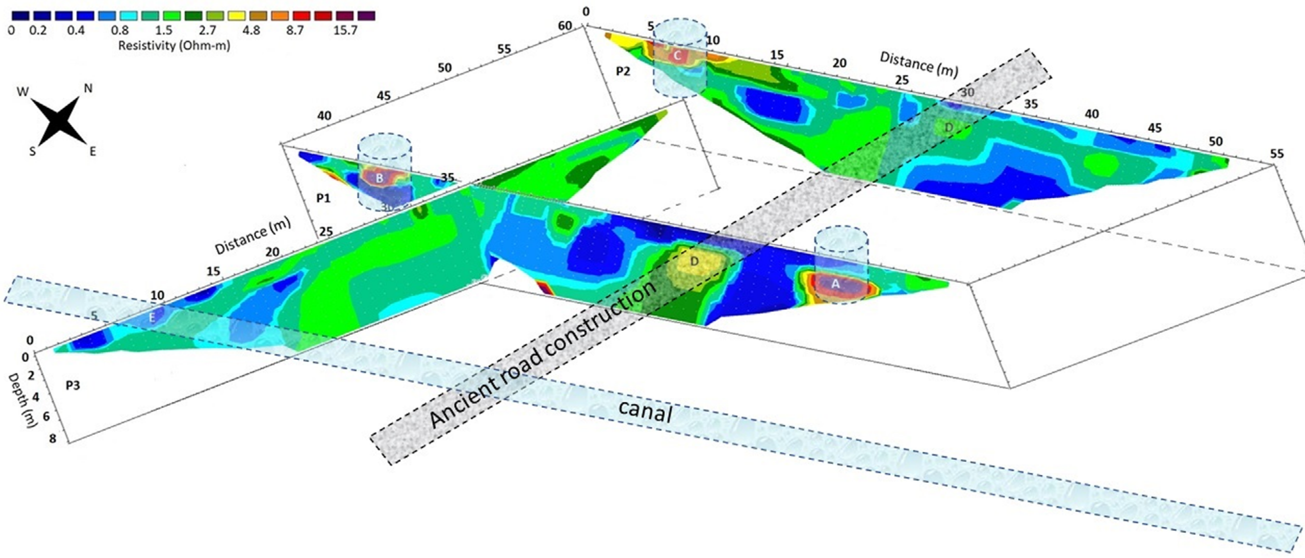

Fig. 5. 3D view of 2D resistivity models inverted from geoelectrical apparent resistivity data set. Two profiles (P1 and P2) cross the expected ancient road (D and E) and wells (A, B, and C). The other profile (P3) is directed at almost north-south crossing profile P1. The models are superimposed with a sketch of wells in form of vertical cylinders. The elongated rectangles show the position of road and canal constructions.

wells is relatively high (i.e., above 4.8 Ohm-m). The remaining ancient road construction is specified by medium resistivity values. Although the resistivity values of expected road construction are different, rectangle-like shapes (shown by the letter D in Fig. 5) and the position of the anomalies (i.e., at a distance of 30 to 33 m along with the profiles) are in agreement in both resistivity models of profile 1 and profile 2. The construction has been covered by a very conductive sandy layer with a thickness of around 2 to 3 meters. The presence of salinity within surface water caused high conductivity of the uppermost layer in general. The canal itself is characterized by resistivity values below 0.8 Ohm-m (shown in letter E in Fig. 5). The canal is still intact along the west, north, and east side of the fort, but along the south trace of the canal has been buried by a sandy layer. Recent excavations prove the existence of the canal (Fig. 6). The presence of saline water within the uppermost layer caused very conductive values in the inverted resistivity models. Since the existing canal along the west, north, and east sides of the fort are connected, we ensure the most conductive value found at a distance of 5 to 15 meters along with profile 3 is caused by the buried ancient canal.

Fig. 6. The remains of the canal walls made of limestone were found after excavations. The excavation was conducted at distances 0 to 15 meter along P3 of ERT profile as shown in Figure 5.

5. CONCLUSIONS

The objective of the study was to map the buried structures using magnetic and geoelectrical methods at an ancient Aceh sultanate fortification of Indrapatra. Besides as a monumental cultural heritage, the fort also preserves key information about the past. Based on magnetic and geoelectrical surveys, some archaeological structures were found around the southern yard of the Indrapatra Fort including ancient road construction, the continuation of missing artificial canal, and surface wells. The objects were buried because of sedimentation deposits. Such artificial objects can be mapped using high-resolution magnetic data measurement. By applying data enhancement techniques of analytical signal and tilt derivative, the objects have been able to be localized and recognized by their geometrical shapes. The geoelectrical method with an electrode spacing of 1 meter can be used to model small-scale archaeological objects based on electrical resistivity variation. Both methods are complementary. The magnetic method can be operated cost-effectively with a large area without missing any interesting magnetic objects. On the other hand, the geoelectrical method provides more detailed near-surface structure. Joint interpretation of magnetic and geoelectrical data and excavation results enabled precise determination of the lateral and vertical extent of man-made objects buried around the Indrapatra Fort. The results fit well with the old floor known from excavation reports and the present topography. For further investigation, the location of artificial canal and surface wells are suitable to be proposed for paleotsunami studies. Sediment deposits filled these archaeological objects possibly transported by tsunami waves that occurred in the past.

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