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INVESTIGATION OF JABUNG TEMPLE SUBSURFACE AT PROBOLINGGO, INDONESIA USING RESISTIVITY AND GEOMAGNETIC METHODS

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ABSTRACT: Subsurface structural estimation has been investigated with dipole-dipole resistivity configuration and magnetic methods for mapping of Jabung Temple Archaeological Site located in Jabung Village, Paiton Sub-District, Probolinggo Regency, East Java with Resistivity meter OYO MacOhm and Proton Precession Magnetometer. This estimate aims to determine the spread and depth of the rocks below the surface of the Archaeological Site of Jabung Temple as well as a source of information for the discovery of ancient objects still buried in the soil. The acquisition of resistivity data was performed on ten measuring tracks and covered the measurement area of ± 37,900 m^2. Six trajectory tracks are located around Menara Sudut Temple and four line are located in the area of Jabung Temple. The acquisition of magnetic data is made around the area of Jabung Temple at 924 points with spacing of 2.5 meters, with the area of 5,200 m^2. Based on the interpretation of magnetic anomaly and resistivity data, the magnetic anomaly value, <16.9 nT is likely to indicate the remains of temple ornaments located at a distance of 20 meters in front and behind the main temple. This is supported by a resistivity value from 33.0 Ω.m to 92.6 Ω.m which indicates the remains of the temple building blocks. The depths of the remains of temple rock are thought to be at an average of 1.8 meters below ground level. Magnetic anomaly is high in the main temple, equal to > 22.6 nT due to andesite rock used as a temple booster (based on information obtained during the restoration of 1983/1984). The results of this study indicate that geoelectric and magnetic methods are very effective for the prediction of subsurface structures, especially in the archaeology field.

Keywords: Archaeology, Jabung Temple, Resistivity, Magnetic

1. INTRODUCTION

Geophysical method is one of the methods without excavation. This method used physical parameters to determine the condition of subsurface. Geopysical methods are used for idetification of landslide, mineral distribution, groundwater, geothermal, seepage zones, petroleum distribution, seawater intrusion, and archaeological traces [1]-[7]. The geophysical method is due its ability to determine the archaeological remains buried and provide information in the form of archaeological structure based on data in the form of resistivity, magnetic anomalies and other physical parameters [7]-[10]. Resistivity and magnetic methods have been developed gradually over the last 50 years to discover hidden objects and are now accepted as effective approaches to archaeological research [8]

Some researchers have conducted research using magnetic, electromagnetic and resistivity methods to predict archaeological remains. The integration of several methods is used to show the location, depth and geometry of the buried archaeological remains [7]-[15].

Indonesia has many archaeological sites in the form of ancient royal heritage temples. One of them is Jabung Temple in East Java (Figure 1a). Jabung Temple is a relic of Majapahit Kingdom founded in 1354 AD [16]. Sites found are two main buildings consisting of one main temple building and one building called Menara Sudut Temple (Figure 1b). What is interesting is the high-quality building material of the red brick temple which is then carved in the form of relief (sculptures on the temple). Over time, the temple has decayed and the boundaries of the yard of the temple are not visible anymore.

Fig. 1. (a) The Jabung temple Building, (b) Menara Sudut Temple located south-west of the main temple

Based on information from East Java

Archaeological Maintenance Agency located in Trowulan Mojokerto, geophysical research on temples in East Java including Jabung Temple, Probolinggo has never been investigated. In 1983 the Department of Education and Culture in the Regional Office of East Java Province through the Ancient Archaeological Remains East Java Maintenance Agency restored the temple of Jabung Temple (Candi Jabung), Probolinggo. Restoration is done mainly on the physical building of the temple because the damage is quite severe. Also, the excavation was done at 10 holes in the entire area of the temple area. The excavation was done to find other buildings that usually exist around the main temple building and also get the pattern and the temple area plan [17].

Based on the refurbishment done between 1983 and 1985, it was possible to restore the Jabung Temple and Menara Sudut Temple to its original condition and clean state. Also, based on the results of excavation and by looking at the side of the Menara Sudut Temple (it should be four temples), the Jabung Temple Restoration team also did an estimation of the temple area layout. In the report of the restoration of Jabung Temple, the restoration team suspected the pattern of the Jabung Temple follows the pattern of the fences. It is possible that the yard is rectangular, and there are three other buildings similar to the Menara Sudut Temple located on the other three corners of the yard and the fence as the area boundary connecting the four buildings. Based on the results of the restoration, this article will discuss the prediction of the structure of the subsurface of Jabung Temple area based on the correlation of geoelectrical resistivity and magnetic methods.

Both of these methods were used to predict, subsurface structures of the area including rock layer structures, the construction of remains of foundations around the temple including the remnants of the foundation fence without excavation. If the remnants of the foundation of the fence can be found, then the researcher will try to predict the pattern of the temple's area, and make the map prediction.

2. FIELD SITE STUDY

Probolinggo regency is one of the districts located in East Java Province at longitude 112^0 50 '- 113^0 30' East and latitude 7^0 40'- 8^0 10' South, with an area of about 1,696.17 km^2 (1.07% of total area of East Java Province). Probolinggo Regency is adjacent to Madura Strait in the North, Situbondo and Jember Regency in the East, Pasuruan Regency in the West and Lumajang District in the South.

Probolinggo Regency is a region that has a variety of topography in the form of lowland, hills and mountains, most of which are located at altitudes between 100 - 1,500 meters above sea level (Figure 2). Jabung Temple is located in Jabung Village, Paiton Subdistrict, Probolinggo District. It is located about 35 km from Probolinggo City and is in the middle of a village located about 500 m from the Probolinggo-Situbondo highway. This temple is Hindunese, has a main temple building which is 13.13 m long, 9.60 m wide and 16.20 m high. Originally, this temple stood on a plot of land measuring 35 m x 40 m (1400 m^2) but in 1977 this was expanded to 20,042 m^2.

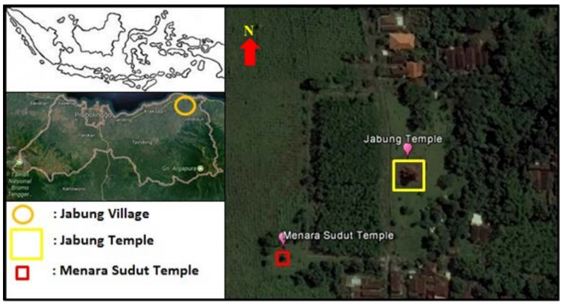


Fig. 2. Field Site Study (Jabung Temple)

From the observation, the area of Jabung Temple is quadrilateral. On the west corner of the main temple, there is a building called Menara Sudut Temple. This building is the corner of the temple courtyard. The temple is located at an altitude of 8 meters above sea level. On the west side of the main temple building, there are parts that faces to the front. Part of this building is a ladder up to the entrance to the main temple building, meaning this temple faces the west. There are other buildings around the main temple, and there is a pond/trench located to the west of the main temple about 30 m in front of the main temple. Furthermore, the physical building of this main temple is made of brick material.

3. THEORITICAL BACKGROUND

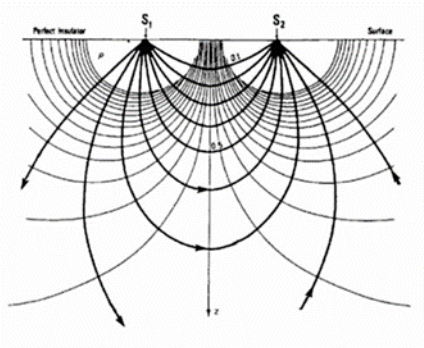
This research used two methods, which are geoelectric resistivity and magnetic methods

3.1 Geo-electric Resistivity Method

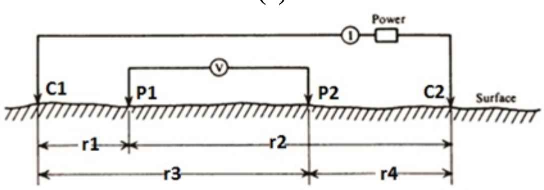
The resistivity method uses an artificial current source which is injected into the ground through two electrodes. This procedure is performed to measure potentials in two other electrodes that are in the vicinity of the current flow. Current is also measured so that it can be used to determine subsurface apparent resistivity [18].

Illustration of two couple electrode on the homogeneous medium surface is shown in Figure 3a and equipotential area for couple electrode is shown in Figure 3b.

The dipole-dipole configuration (Figure 3c) uses four electrodes i.e., two current electrodes and two potential electrodes. The current electrode is positioned first and then followed by the potential electrode. The current electrodes (C1 C2) and the potential electrodes (P1 P2) have spaces "a". Initially, the distance between electrode C1 C2 and P1 P2 is "a". As the P1 P2 electrode is moved to the right until the maximum distance, the distance between C1 C2 and P1 P2 becomes "na". Furthermore, the C1 C2 electrode moves to the right as far as "a". And the potential electrode (P1 P2) moves back to the left as far as "a" of C1 C2. Then, P1 P2 moves right to the maximum distance.



(a)



(b)

(c)

Fig. 3. (a) Equipotential area for two current electrodes on the homogeneous medium surface[18], (b) A couple of current electrode on the homogeneous medium surface [19], (c) Dipole Configuration [20]

Apparent resistivity (ρ_a) with geometry factor of dipole-dipole configuration can be formulated as:

$$\rho_a = \frac{\pi n a(n+1)(n+2)\Delta V}{I} \qquad (1)$$

where ρ_a = apparent resistivity (Ω.m), a = spacing (m), ΔV = potential difference (Volt), I = current (A), and n = layer.

3.2 Magnetic Method

Magnetic method is a very attractive and inexpensive approach to detect of metals, magnetic minerals etc. This method is usually used to determine the location of tanks or buried drums, mineral exploration, geothermal exploration, and archaeological studies for the buried foundations.

The magnetic data are taken by measuring the points at the surface using magnetometer. Each point is measured at least three times and then these values are averaged. After the data is taken, it is processed to have the total magnetic field anomaly value. There are several corrections made to get the residual anomaly value to interpret in the magnetic method. Those corrections are daily correction, IGRF correction and pole reduction.

The daily correction can be calculated with the following formula:

$$B_D = \frac{(t_n - t_{bs})}{(t_{ak} - t_{bs})}(B_{ak} - B_{bs}) \qquad (2)$$

where B_D is the intensity of the diurnal magnetic field, B_{ak} is the intensity of the magnetic field at the last point, B_{bs} is the intensity of the magnetic field at the base station, t_n denotes the measurement time at the corresponding measuring point, t_{bs} represents the measurement time at the base station, t_{ak} denotes the measurement time at the last point in a day.

IGRF Correction (International Geomagnetic Reference Field Correction) is a general model of spherical harmonics of the Earth's magnetic field source from an internationally agreed core of the earth. This study used IGRF value in 2009 that amounted to 44,849 nT. After IGRF correction is obtained, the total magnetic field anomaly can be calculated by adjusting the measured total magnetic field intensity value by the daily correction and IGRF correction, as in the formulation below:

$$\Delta B = B_{obs} - B_D - B_o \qquad (3)$$

where ΔB is the total magnetic field intensity anomaly, B_{obs} is the intensity of the measured magnetic field and B_o is the induced magnetic field IGRF.

The reduction to pole process is made as magnetic anomaly has negative and positive polarity, unlike a monopole gravitation anomaly. Reduction due to pole is used to remove from magnetic anomaly data the distorting effect of the inclination an azimuth of the magnetization vector [21].

4. RESEARCH METHOD

The location of the study is shown in Figure 4, wherein the red lines indicate the measurement line of the geoelectric method, the green box is the survey area of the magnetic method. Geoelectric measurement at Jabung Temple area used Resistivity meter, OYO MacOhmEL Model2119D. Geoelectric data collection was done for seven days, from September 17th until September 23th,2011. In Figure 4, there are ten tracks measuring the measurement area covering ± 37,900 m^2. The measurement tracks 1 until 6 over the Menara Sudut Temple have a length of 12 m and use a value "a" = 0.5 m, and "n"=10. Lines 7 and 8 extend from South to North over the Jabung Temple and are, 150 m long with "a"= 10 m and "n"=6, while line 9 and 10 extend from West to East, 200 m long with "a" = 4 m and "n"=3.

Fig. 4 Geoelectric, dipole-dipole configuration Line and Magnetic Measurement in Jabung Temple area

Data processing was performed based on the 2D inversion algorithm, which is called Res2dinv programme. The preferred inversion method is the smoothness-constrained least-squares method. The advantages of this least-squares method have been described in several publications [19]-[22]. The result of the inversion process is a 2D subsurface structure model with a real resistivity value with true depth variation.

Geomagnetic data collection was done in two days on September 24th and October 15th, 2011, by using a set of Proton Precession Magnetometer (PPM) Geometrics type G-856/27616. The data obtained at the data retrieval stage was 924 data points with the distance between points 2.5 meters. The value obtained from the measurements in the field is called an observation magnetic field that still mingles with the magnetic field from within the earth and is also influenced by the magnetic field outside the earth. The subsequent treatment consists of daily correction and IGRF correction to determine the total magnetic anomaly. After the total magnetic anomaly is obtained, anomaly separation is done by using continuation upward and also the reduction transformation to the poles. The data processing uses a Geosoft Oasis Montaj software.

5. RESULT AND DISCUSSION

The interpretation of the rock resistivity values in terms of the rock type is shown in Table 1.

Table 1 Subsoil surface distribution

No.	Contour Colour	Resistivity ($\Omega.m$)	Rock Type
1.	Dark Blue	4.3-7.2	Clay, Wet Silty
2.	Light Blue	9.0-12.0	Clay, Silty
3.	Tosca-Light Green	14.0-20.0	Sandy Clay/Temple Rock Remaining
4.	Dark Green-Yellow-Brown	24.0-55.6	Sandy Clay/Temple Rock Remaining
5.	Red-Purple	59.0-154.0	Dry Silty Sand/Temple Rock Remaining

Interpretations and sketches for the result of measurement of resistivity method for Menara Sudut Temple are shown in Figure 5. The lenght of line 1 until 6 is 12 m, with the distance between the electrodes is 0.5 m. Furthermore, if the line 1 through 6 is combined, it will be seen as in Figure 5. The brick layer and the foundation of the Temple fenced yard (red contour) has resistivity value around 33.3 - 92.6 Ω.m at a depth of 0.0 - 1.8 m. A wet rock layer is shown as a blue-green contour. This is because the area around the Menara Sudut Temple is the area of rice fields and fertile land, often cultivated with crops and tobacco crops.

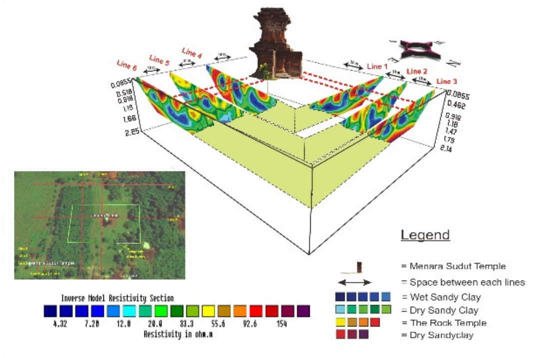
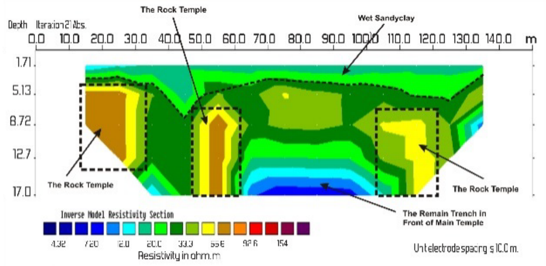
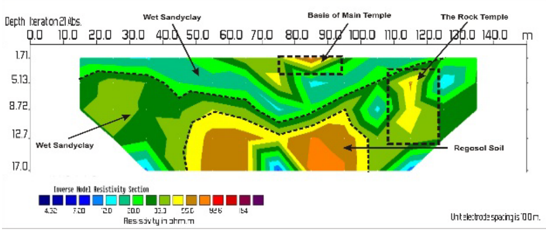


Fig. 5 Vertical cross section of resistivity in line 1 to 6 around Menara Sudut Temple

The geoelectric data processing and interpretation on line 7, 8, 9, and 10 (Figure 6), at a depth of 0 - 5 m, most of the rocks are wet silt type with resistivity values ranging from 12.0 to 33.3 Ω.m. This shows that the area of Jabung Temple is not too dry, so this area is fertile and excellent for agriculture and plantation.



(a)



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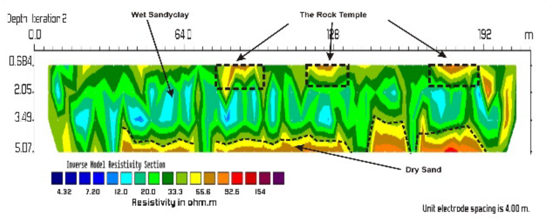

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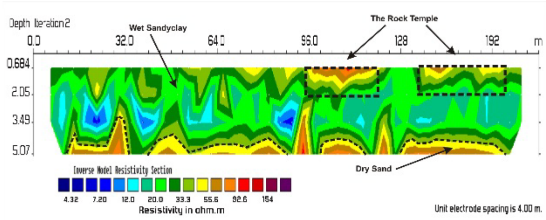


(d)

Fig. 6 Two Dimension (2D) Resistivity Cross Section (a) Line 7, (b) Line 8,(C) Line 9, and (d) Line 10

On line seven which is + 40 m apart from the main temple, at the centre of the track at a depth of 12 m is a layer structure with a low resistivity value (blue). Presumably, the layer is the rest of the pond/trench that serves to clean people (saint) before entering the sacred area near the main temple building. On the left-hand side of the pond appears a structure with resistivity ranging from 55.6 - 92.6 Ω.m. That part may be the remains of the supporting buildings that are in front of the main temple.

On line eight that passes through the main temple building from South to North, just below the main temple building at 9.0 m, is a sandstone clay or regosol soil with a considerable resistivity value that ranges from 55.6 to 92.6 Ω.m. It shows that part of the rock is solid and impermeable. While on line 9 and 10 shows the existence of the remaining temple rock found in the eastern part of the main temple at a depth of approximately 2 meters below the soil surface.

Contour analysis of the reduction to the poles on high residual anomalies is marked with dark circles. This place is the position of the main temple (Figure 7). From Figure 7, it is seen that the main temple has the negative value, while the positive value anomaly is attracted to the south. However, the magnetic contrast value is strengthened compared to before reduction to the poles processes. This is due to the unaffected value of the inclination in the study area. The low anomaly with magnetic contrast below -39 nT, with the red circle, is interpreted as a temple ornament for a place of worship and ornaments of Jabung Temple. From the contour, the anomaly gets larger or wider and shifts southward than before it is processed to the reduction to pole. This is also because its value is not affected by the inclination. The medium magnetic anomaly behind the main temple stretches from the North to the South to form an area, indicated with a blue border. It is interpreted as a foundation for former monk housing foundation and royal guests accomodation.

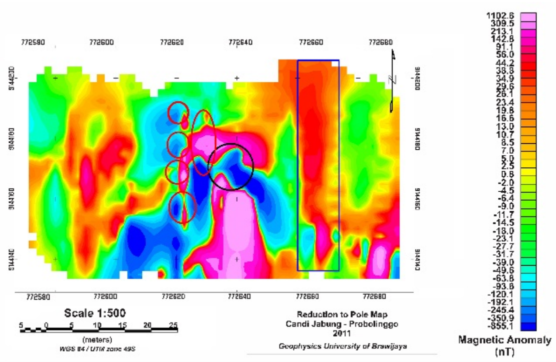
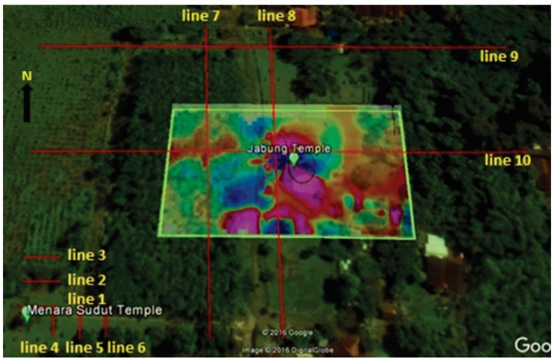


Fig. 7. Map of the reduction to the poles

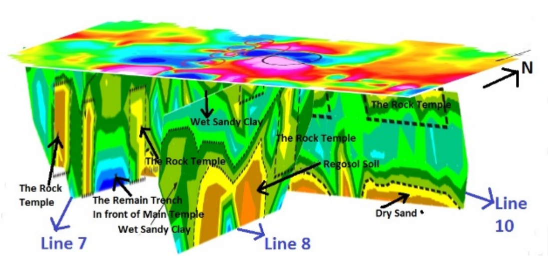
If these two methods are correlated, there is a similarity of results between the geoelectric resistivity and magnetic methods. In geoelectric resistivity method, there is a resistivity between 33.2 Ω.m and 92.6 Ω.m, indicating an existence of the remaining temple building. In the magnetic method, there is a low anomaly less than -16.9 nT interpreted as the remains of temple ornament. In the resistivity measurement, there are some lines passing through the magnetic survey location, so the results can be correlated for both methods, i.e. for mapping the remnants of temple ornaments.

Figure 8(a), shows the overlay result of all geoelectric line measurements and magnetic anomalies resulting from the reduction to the pole on the Google Earth map. The indication of Jabung Temple, which is interpreted with high magnetic anomaly is correlated to the map. Some geoelectric line measurements; lines 7, 8 and 10, have several precise points passing through the magnetic survey location.

To be more clear, if we were to zoom for the magnetic measurement area through lines 7, 8 and 10 of geoelectric measurements, there are visible correlation resistivity with magnetic anomalies. Figure 8(b) shows the magnetic anomaly of the pole reduction correlated to the line resistivity in lines 7, 8 and 10. The point interpreted as the rest of the temple rocks on the resistivity measurement (33.2 Ω.m - 92.6 Ω.m) is also supported by a low anomaly interpretation, <16.9 nT on magnetic anomalies showing the remains of temple ornaments. At the location of the Temple Origin which shows a high anomaly, in addition to red brick composition, it also contains andesite (volcanic rock).



(a)



(b)

Fig. 8. (a) Overlay of Pole Reduction anomaly on Google Earth map, (b) Cross-section of Magnetic Anomaly and Resistivity on lines 7, 8 and 10

Figure 8(b) shows that the remains of temple ornaments are seen in the front or back of the main temple. About 20 meters in front of the main temple are remnants of ornaments, probably a place of worship. While 20 meters behind the main temple, it is interpreted as the remains of the foundation of monk housing. The existence of a correlation between the magnetic and resistivity results can then be used to predict the plan of the Jabung Temple location, which can then be used to interpret the locations of the remains of the temple ornaments (Figure 9).

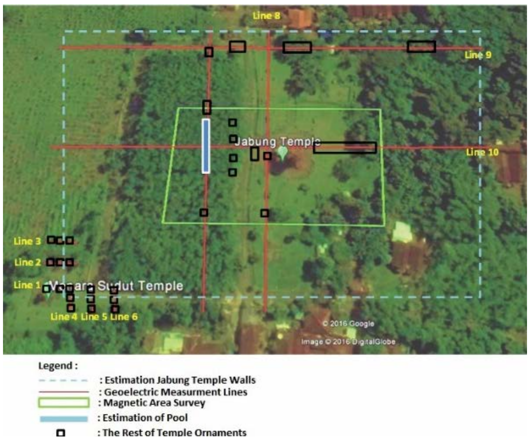


Fig. 9. Prediction of Remains of Jabung Temple Ornament

6. CONCLUSION

The geoelectric resistivity method of dipole-dipole configuration and geomagnetic method were successfully utilized to predict the subsurface structure of Ancient Site of Jabung Temple, Probolinggo, East Java, Indonesia. We conclude that there are still parts of the temple site/remnant of the temple buried beneath the soil surface with a range of resistivity values between 33.0 and 92.6 Ω.m and magnetic anomaly values <16.9 nT. The value is interpreted as a brick which is the building block of foundation or the fence of the temple yard (the rest of the temple ornament). Besides, it was found that the temple of Menara Sudut is the corner of the temple fence. The soil in the area of Jabung Temple is a fertile soil with high water content subsurface. This is demonstrated by the low resistivity value of the shallow layer near the surface. Also, it is estimated that the Temple Origin is above the rock layers of the hardest part which is indicated by the high magnetic anomaly value of > 22.6 nT due to andesite rock as the compiler of the main temple.

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