Geophysical Prospection Monastery Gelati, Georgia, 05/2024

GAIA PROSPECTION

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Report

Project:
Magnetometer and resistivity prospection at the UNESCO World Heritage site Monastery Gelati (Georgia)
May 2024

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Table of contents

Geophysical prospection Gelati Monastery, Georgia

I. Investigation area

Fig. 1 *Gelati. Drone image view from the north-west. May 16th 2024 (Drone image J. Fassbinder, L. Lambers).*

The Gelatin Monastery is a masterpiece of the Golden Age of medieval Georgia, a period of political strength and economic growth between the 11th and 13th centuries. The site is located northeast of Georgia's third largest city, Kutaisi, with around 140,000 inhabitants.

The complex with the monastery is one of the most important buildings in all of Georgia and represented an important spiritual and cultural center in Georgia. For example, the monastery church served as the burial place of Georgian kings, including Dawid IV the Builder. In 1106, Dawid also founded the Gelati Academy, where important scientists and philosophers taught. In addition to the builder of the monastery Dawid, other most important kings are buried in Gelati. UNESCO declared the monastery complex a world cultural heritage site in 1994.

Fig. 2 *Gelati. Drone image showing the current condition and accessibility of the prospecting areas from May 16th 2024 (Drone image J. Fassbinder, L. Lambers, processed by R. Linck).*

II. Geophysical prospection

Geophysical methods to trace and to understand hidden archaeological sites beneath the ground are meanwhile widely applied methods not only to start with an archaeological excavation. But moreover, they also provide an essential scientific method for studying archaeological sites such as UNESCO World Heritage sites without destruction and excavation (Fassbinder & Gorka, 2009; Fassbinder 2010). These methods were developed by European researchers in the 1950s and 1960s and have also been used worldwide in the field of archaeological research. Meanwhile a multitude of case studies from exemplify the potential of geophysical prospecting methods for the preservation and protection of the archaeological heritage and of archaeological features beneath the soil.

Magnetometer prospecting – for the first time applied 1956 in England by Martin Aitken and John Belshé (Belshé 1957, Aitken 1958, Clark 1990; Scollar et al. 1990) – meanwhile has developed to a very powerful tool to map in detail large archaeological sites (Fassbinder 2011; 2015; 2023). But resistance and radar prospecting also play an indispensable role in archaeological monument preservation (Schmidt 2013, Schmidt et al 2015, Fassbinder et al. 2019). Not only the technical and scientific development of archaeological geophysics play an important role, also the acceptance of the method among archaeologists and stake holders of the scientific community is crucial and more so to apply geophysics at first when starting a new excavation (Stone 2023).

The geophysical measurements in Gelati from May 12th to 18th, 2024 represent a certain challenge. Not only will the site be visited by hundreds of tourists every day, but also because there will be a large number of additional technical constructions on the site due to the restoration work.
Nevertheless, in principle the geological, pedological and topographical conditions for geophysical measurements in Gelati are quite suitable for carrying out magnetometer, resistivity and radar studies around the monastery. In a cooperation with Georgian National Museum Tbilisi (Prof. Dr. David Lordkipanize) we started a first geophysical prospecting campaign on the site. We have designed our measurement network in such a way that as many freely accessible areas around the monastery as possible are covered (Fig. 1, 2). Although many areas of the monastery had already been covered with scaffolding and material for restoration since our last visit in May 2023 we were able to cover almost all areas around and between the buildings for magnetometer and resistivity measurements. The prospecting area practically extends around the main building. Starting in the north, east, south and finally in the west, we were able to examine all freely accessible areas.

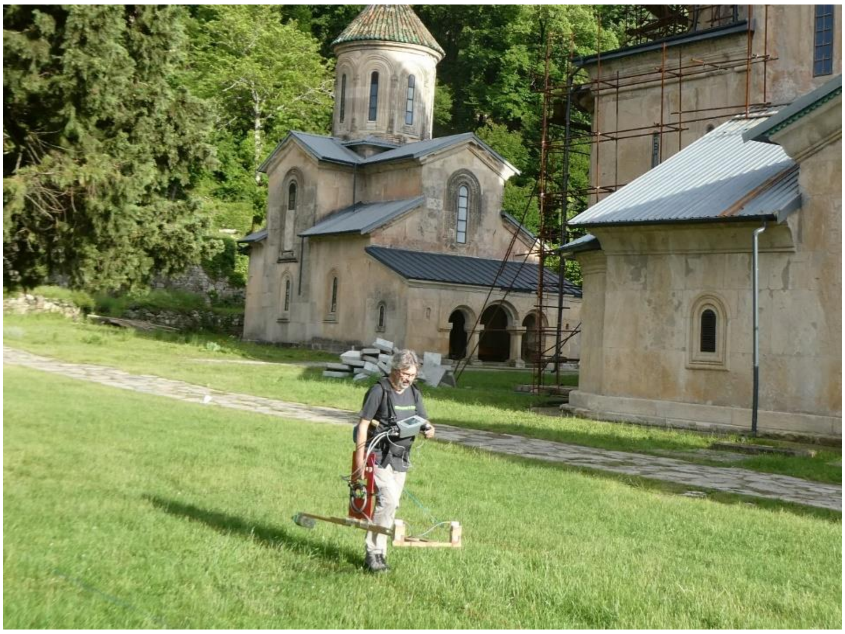

Fig. 3 *Gelati. Magnetometer prospection with the duo-sensor Cesium magnetometer Geometrics G858*

We scanned the area magnetically by a sampling interval of 10 cm x 50 cm traverse interval (resampling to 25 cm × 25 cm) by a Geometrics G858 total field magnetometer in a duo-sensor configuration (see Fig. 3). For resistivity survey we choose the Geoscan RM85 resistometer in dipol-dipol configuration and by sampling rate of 50x100 respectively 50x50 cm interval (Fig. 4).

Fig. 4 *Gelati. Resistivity prospecting with the Geoscan RM85 resistometer in dipol-dipol configuration. By magnetometer prospection we covered a survey area covers of ca. 3.200 square m and ca. 4.800 square m by resistivity measurements*

For non-destructive and large-scale archaeological prospecting, geophysical science provides us with a multitude of different ground-based methods. The most common among them are:
1) Magnetic prospecting
2) Gravity prospecting
3) Resistivity prospecting
4) Radar prospecting
5) Electromagnetic prospecting
6) Seismic prospecting
7) Magnetic susceptibility prospecting

Magnetic- and gravity prospecting are “passive” methods, which measure an existing magnetic or gravity filed, while all other methods are active methods, which generate a physical signal and measure the response of it. The active methods, namely radar and resistivity prospecting, we regard as reasonable methods for the search on stone buildings. Because they are active methods, they can be applied very close to modern and technical constructions, inside a modern city or even inside a building. The application of these methods however is time consuming and requires an intensive and sophisticated data processing to display the resulting data. Furthermore, it is mainly restricted to the search of stone structures. Magnetic prospection is generally among the best suitable methods for the large-scale prospection of prehistoric sites in the open landscape and undisturbed environment such as the archaeological sites of the selected survey areas, which consists mainly of lime-stone, sandstone or brick constructions, ditches, pits, fireplace, kilns, or workshops. However due to a multitude of technical disturbances which we expect around the Gelati complex we decided to apply additionally the resistivity prospecting method.

Magnetometer prospection

Magnetometry, among other geophysical methods, is a successful and cost-effective tool for detailed mapping of large areas in a reasonable time. For our purpose, and in order to reach the high-est possible sensitivity combined with a maximum speed of prospection, we applied the modified cesium Geometrics G-585 magnetometer as total field magnetometers in a so-called “duo-sensor” configuration (see Fig. 3) and (Linford et al. 2007; Fassbinder 2015; Hahn et al. 2022; Parsi et al. 2023). The profiles were oriented preferably in east west in direction order to minimize technical disturbance of the magnetometer probes. During the measuring period 05/2024 solar activity and the diurnal variation frequency induced by the solar wind were extremely high during our measurements (see: http://www.ips.gov.au/Space_Weather). Nevertheless, due to the high magnetic sig-nal of the geological background these conditions were not affecting our results and allowed us to reduce the diurnal variations to the mean value of all data of each 40 × 40 m grid (Fassbinder & Gorka 2009).
The sampling frequency of the magnetometer (10-20 readings per second) provided the measurement of a 40 m profile of the grid (40 × 40 m) in less than 30 s, maintaining the spatial resolution of approximately 10 cm at normal to fast walking speed. Every 5 m, additionally to the magnetic data, a manual switch set a marker. This helps us to perform the best and correct interpolation of data during the subsequent laboratory processing work. Additionally, we removed the linear changes in the daily variation of the geomagnetic field by the gradiometer configuration. To create discrete field values, we used a re-sampling program setting the data to 25 × 25 cm. Additionally, by applying this procedure, we obtained the difference between the measurements of the magnetometer probes of the z-component of the Earth’s magnetic field. This intensity difference gave thus the z-component of the apparent magnetic anomaly, caused by the magnetic properties of the archaeological structure, the soil magnetism and the geology. Either the stronger anomalies we ascribe to burnt structures, to lightning strikes or to pieces of iron shrapnel’s and iron rubbish. In situ burning, pieces of iron and the traces of lightning strikes are easily distinguishable by their different direction of magnetic dipole anomalies but also by their high intensities (> ± 50 nT).

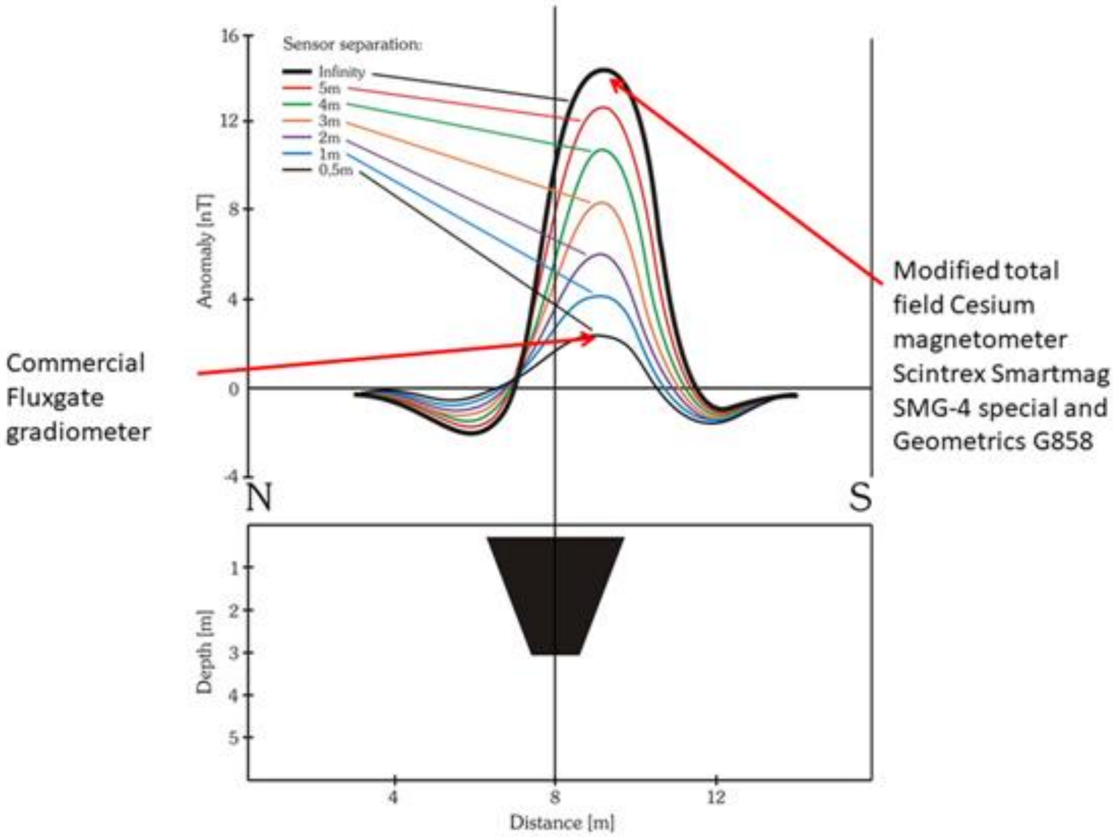

***Fig. 5** Dependence of the intensity of a magnetic anomaly of a typical prehistoric feature such like a ditch on the sensor separation (gradient) of two magnetometer probes. The total field measurements with the so-called duo-sensor configuration provides signal to noise ration which is up to five times higher than those measured by a fluxgate gradiometer.*

The advantage of this configuration is that the resulting intensity of the magnetic anomaly reaches 5 times higher values than those measured by a commercial fluxgate magnetometer (see Fig. 5). On the other hand, the near geo-archaeological features become also invisible. The data were stored as binary files on the read-out unit and later downloaded to a handheld notebook and unpacked to ASCII data. Image processing and further treatment of the data (resampling) we do by a special self-made software (Resam2), the image processing by the program Geoplot (Fa. Geoscan Ltd. UK) and by Surfer (Golden Software, USA). The visualization as a grey scale image (magnetogram) allows us to trace even smallest anomalies originated by the shade of the features beneath the sur-face. The application of a high-pass filter removes the deeper and mainly geological features and gives us supplemental information on the type of the anomalies. The later results can be displayed by a second magnetogram image.

For the integrated interpretation, we try to classify the findings:

1) by the shape of the feature (based on archaeological background knowledge)
2) by the intensity of the magnetic respectively resistivity anomaly
3) by the direction and intensity of the remanent magnetization
4) by the induced magnetization (volume magnetic susceptibility)
5) the morphological analyses of the topography of the site (based on ground observations and assessment of the orthophotos and the DEMs provided by the drone).

Point 2-4 depend from the theoretical background on applied geophysics and the knowledge on rock-, mineral-, and soil magnetism.

Resistivity Prospection

Resistivity prospection methods, are successful and cost-effective tools for detailed mapping of stone and rock features beneath the ground. For our purpose, and in order to reach a rapid area measurement combined with high sensitivity of prospection, we applied the RM85 Resistance Meter (Geoscan Research UK) in a 0.5m twin array. The “dipol-dipol” configuration of the system allows a penetration depth to the ground of about 1m and is especially designed to trace shallow wall fundaments beneath the soil (see Fig. 4, 6).

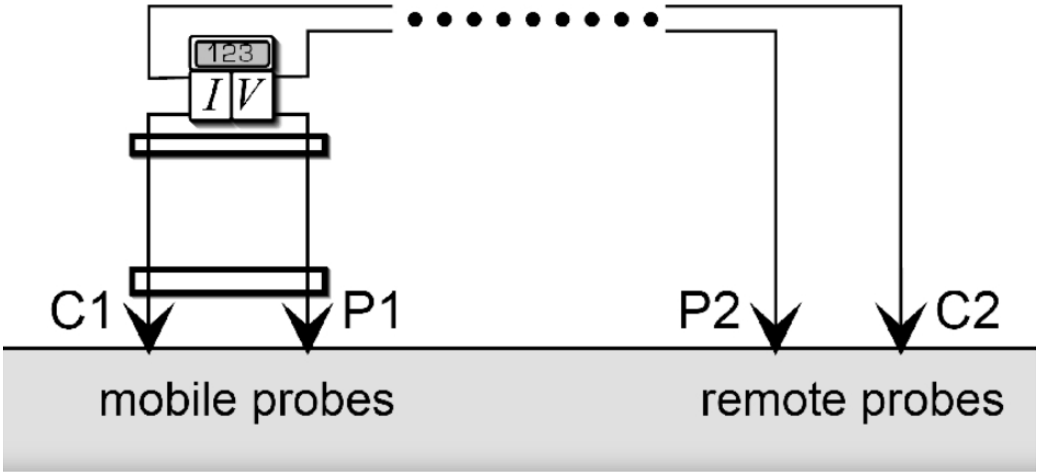

Fig. 6 *Single 0.5m twin array (after Schmidt, 2013)*

III. Results of the magnetometer prospecting

The ground was never ploughed. Traces of looting if so where not visible. Unusually strongly magnetic sandstone combined with a partly very flat layer of topsoil and strong magnetic interference from iron structures in Gelati make highly sensitive magnetometer measurements practically impossible. Nevertheless, the measurements provided important and additional information about hid-den structures in the subsurface that cannot be obtained using other geophysical methods. Of particular note here is the course of a canal and a large number of pits that are not visible on the surface, as well as evidence of a building complex south of the church.

The magnetometer prospection on the area Glt24a covers all accessible areas around the church.

As expected, the measurements were heavily disturbed by scaffolding, building materials and iron manhole covers. By the first view, the data reveal mainly the heavy contamination of the surface with large layers of old debris (magnetic anomalies of more than +/-50 nT) and the topographical irregularities of the site (Fig. 7). By applying a high-pass filter to the original data, the dynamics of the magnetic field disturbance could at least be reduced to a minimum so that a large number of archaeological structures became visible. At first glance, the measurement image shows a large number of very strong anomalies that stand out as black and white spots. In the southwest of the measurement area we find a strong linear anomaly about 1m wide directly under the modern path that leads to the southwest gate of the monastery complex (see Fig. 7-9). All of these strong anomalies are due to modern findings, with the linear structure being either an electrical or a water pipe. The strong black and white spots, on the other hand, are caused by iron manhole covers.

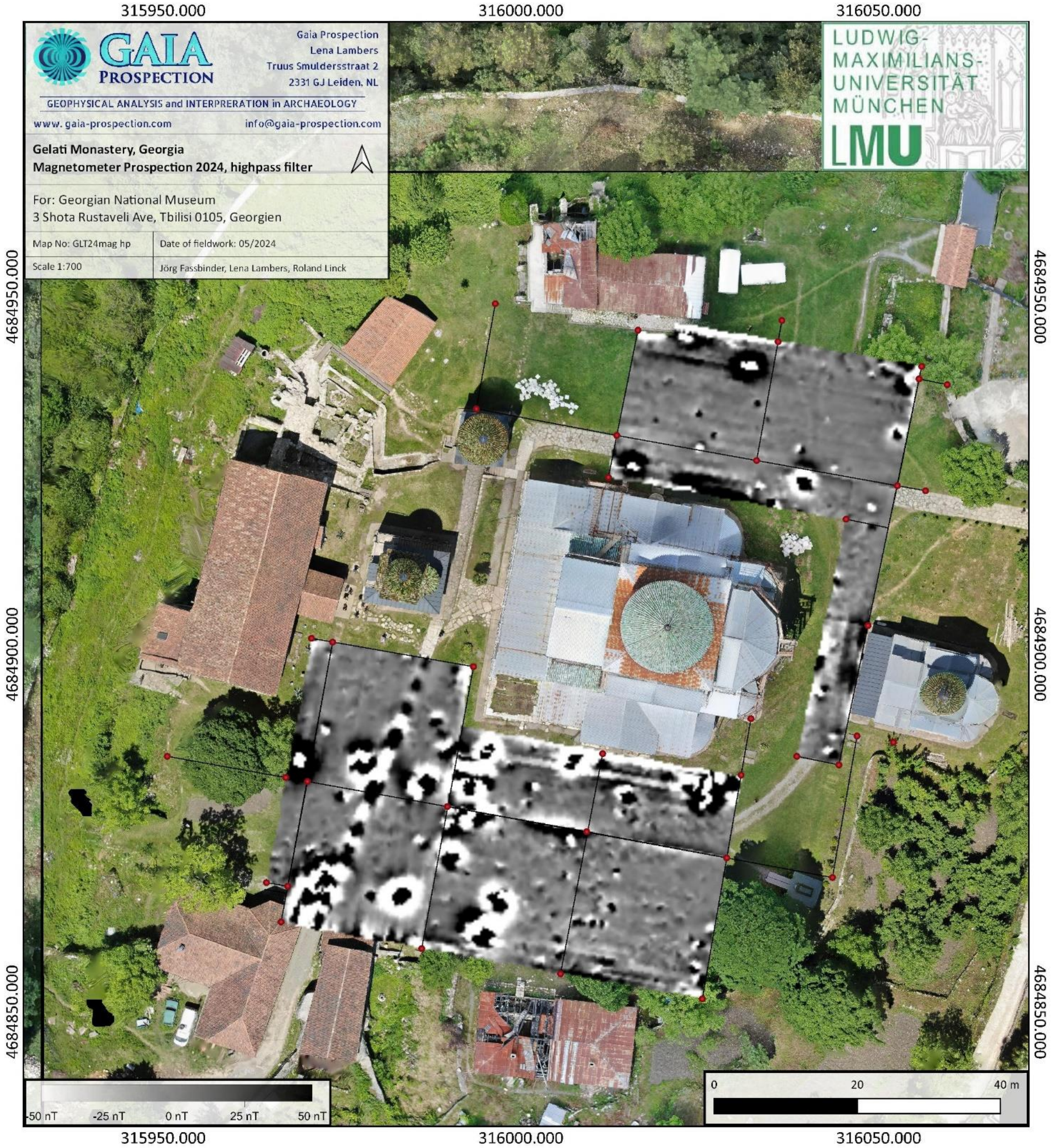

Fig. 7 *Gelati. Magnetometer measurement of the survey area Glt24A (80 × 40 m) and Glt24B (40x20 m) superimposed on the drone photo from Mai 16th 2024. Caesium total field magnetometer Geometrics, G 858-special in duo-sensor configuration and high-pass filter of the data. The total Earth's magnetic field at Gelati 05/2024, 49.910 ± 50 Nanotesla, standard deviation, sensitivity ± 10 Picotesla, sampling density 25 × 50 cm;*

By the measurement of the area we aimed to delineate possible prominent features of the site (see Fig. 8 and 9). We identified a building with several rooms. The associated drainage pipes are made of plastic and cannot be recorded in the measurement image in the vicinity of the strong anomaly of the manhole covers. However, a more detailed analysis reveals a few, weak and diffuse anomalies, particularly in the southwest of the measuring area. An integrated evaluation together with the resistance measurements allows us to interpret the findings as a trace of settlement. We can clearly ascribe to traces of walls and archaeological features in the underground.

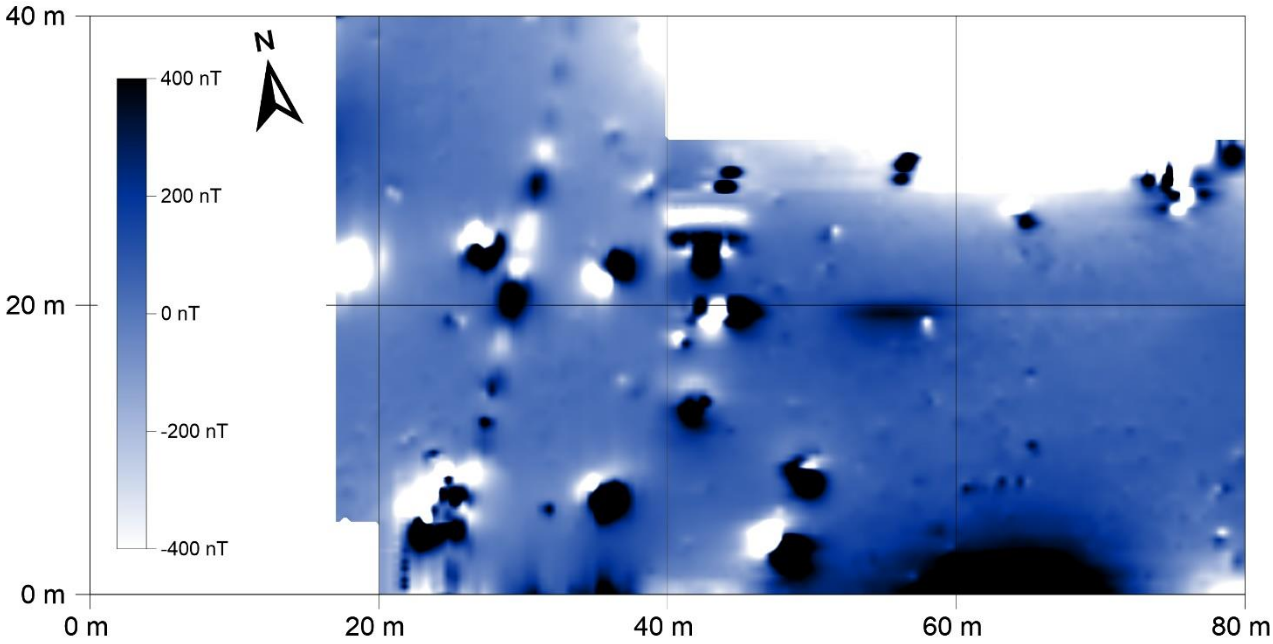

Fig. 8 *Gelati. Magnetometer measurement of the survey area Glt24A (80 × 40 m). Caesium total field magnetometer Geometrics, G 858-special in duo-sensor configuration, 10x10 high-pass filter total Earth's magnetic field at Gelati 05/2024, 49.910 ± 50 Nanotesla, standard deviation, sensitivity ± 10 Picotesla, sampling density 25 × 50 cm; (Fassbinder/Lambers).*

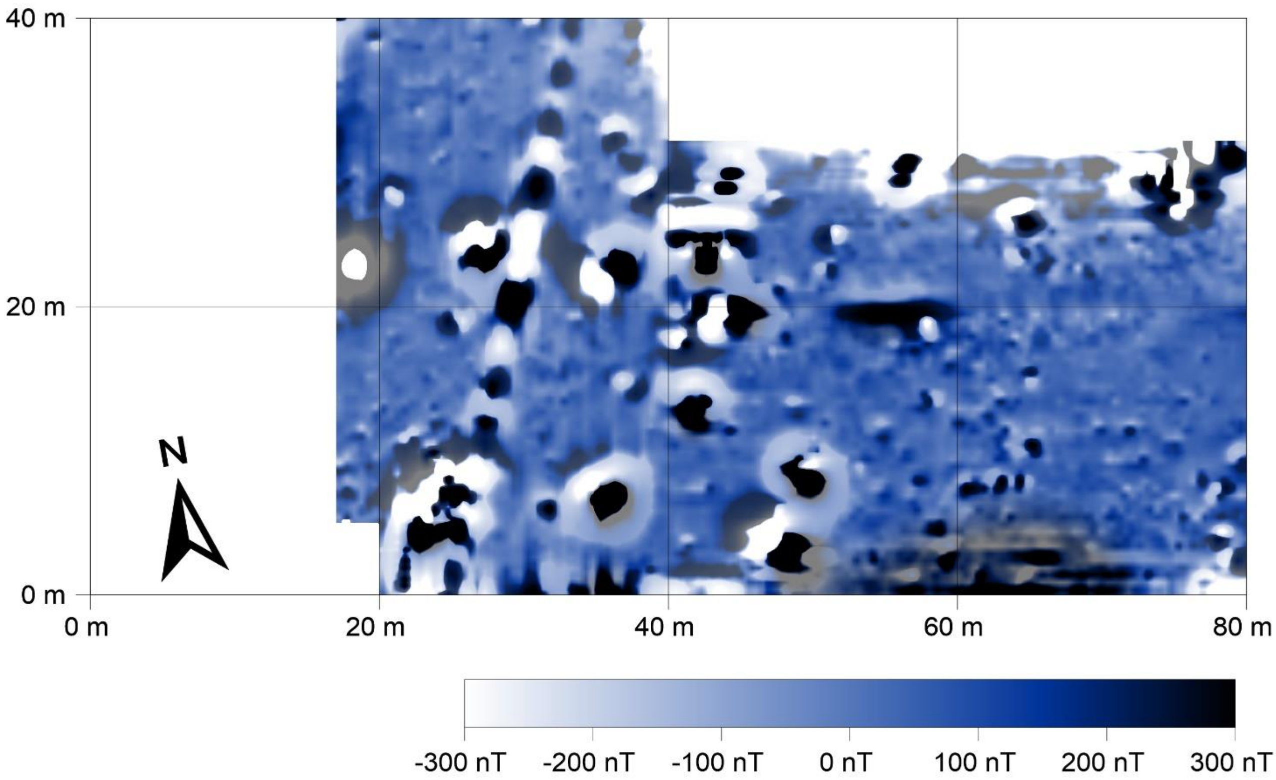

Fig. 9 *Gelati. Magnetometer measurement of the survey area Glt24A (80 × 40 m) after application of a high-pass filter. (Fassbinder/Lambers). All the strong black/white spots and the linear feature are of modern origin.*

IV. Results of the resistivity survey

Due to the expected modern disturbances on the site, we decided to use another active prospecting method. We applied resistivity prospecting as a further geophysical prospecting method. Unlike magnetometer prospecting, electrical resistivity prospecting is heavily dependent on temporary weather conditions and the associated ground conductivity. Due to persistent rain before and during our measurements in May 2024, the conditions for the resistance measurements were ideal. This also explains our outstanding and somewhat spectacular measurement results (Fig.10).

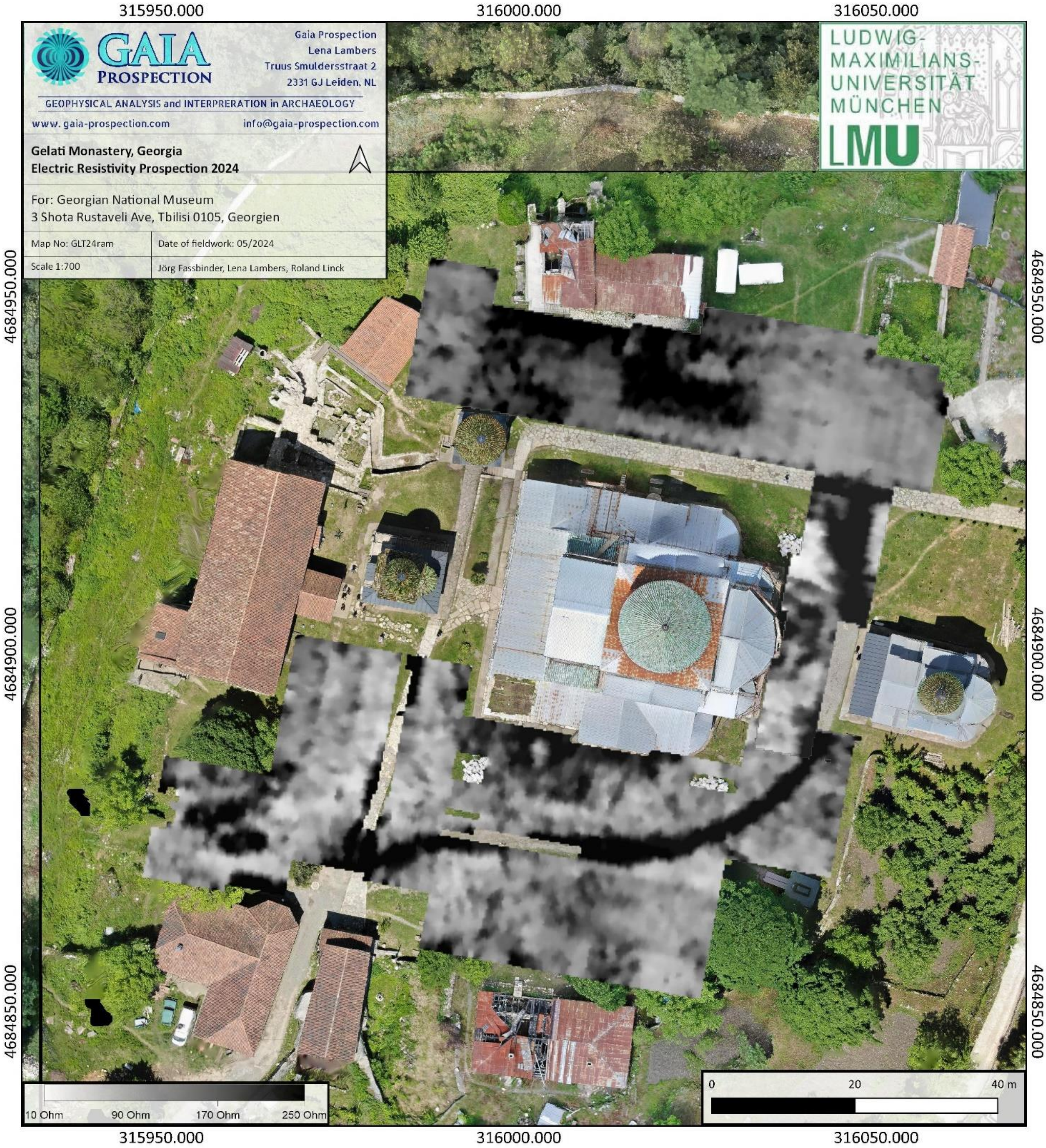

Fig. 10 *Gelati. Resistivity measurement of the survey area Glt24R ca. 120x40 m in the south and ca. 80x20 m in the north of the main church superimposed on the drone photo from Mai 16th 2024. Geoscan RM85 resistometer in dipol-dipol configuration. The resistogram shows the original data. Sampling density 50 ×100 cm interpolated to 25x25 cm.*

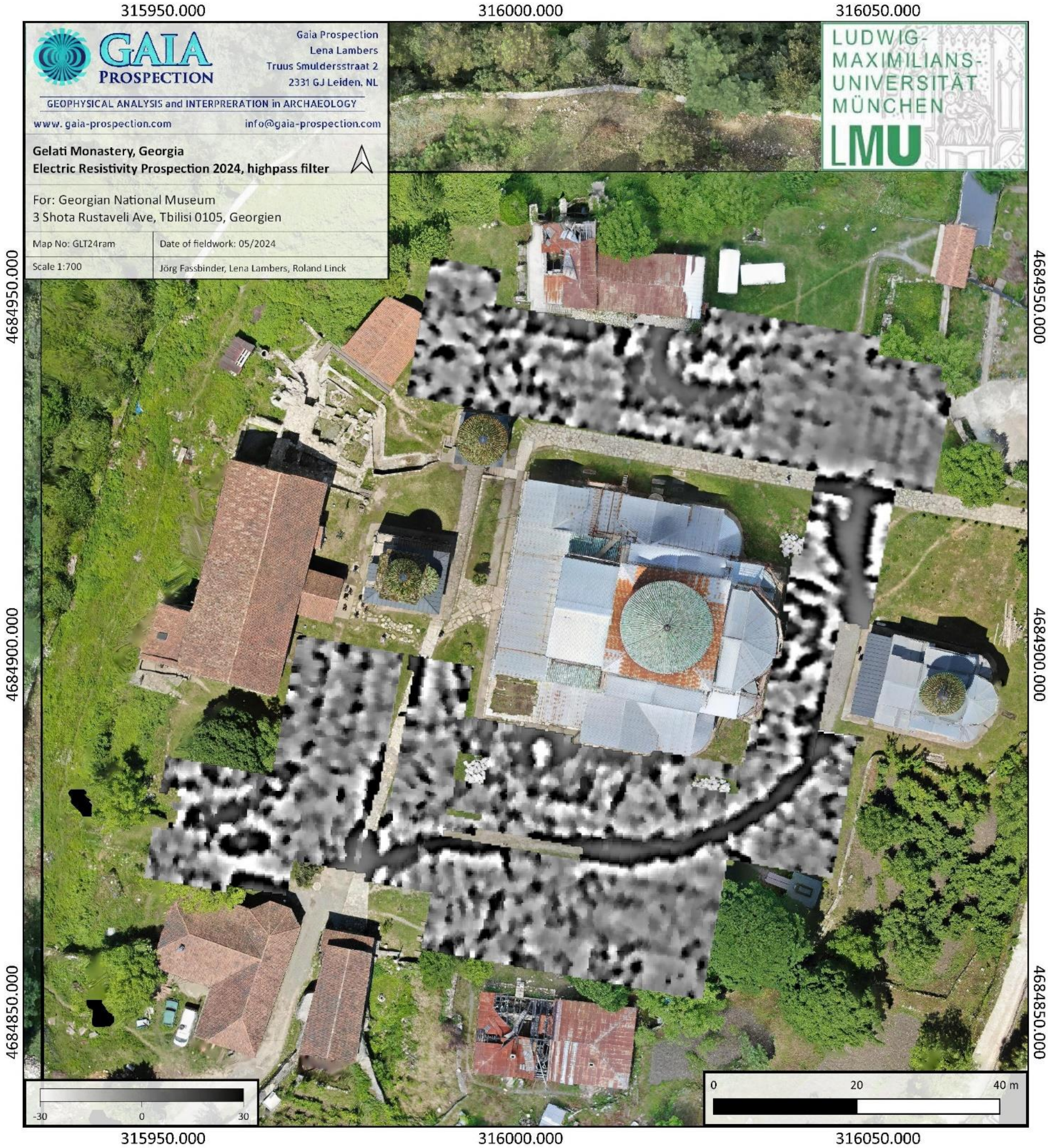

Fig. 11 *Gelati. Resistivity measurement of the survey area Glt24R ca. 120x40 m in the south and ca. 80x20 m in the north of the main church superimposed on the drone photo from Mai 16th 2024. Geoscan RM85 resistometer in dipol-dipol configuration. The resistogram shows the high-pass filter of the data. Sampling density 50 ×100 cm interpolated to 25x25 cm.*

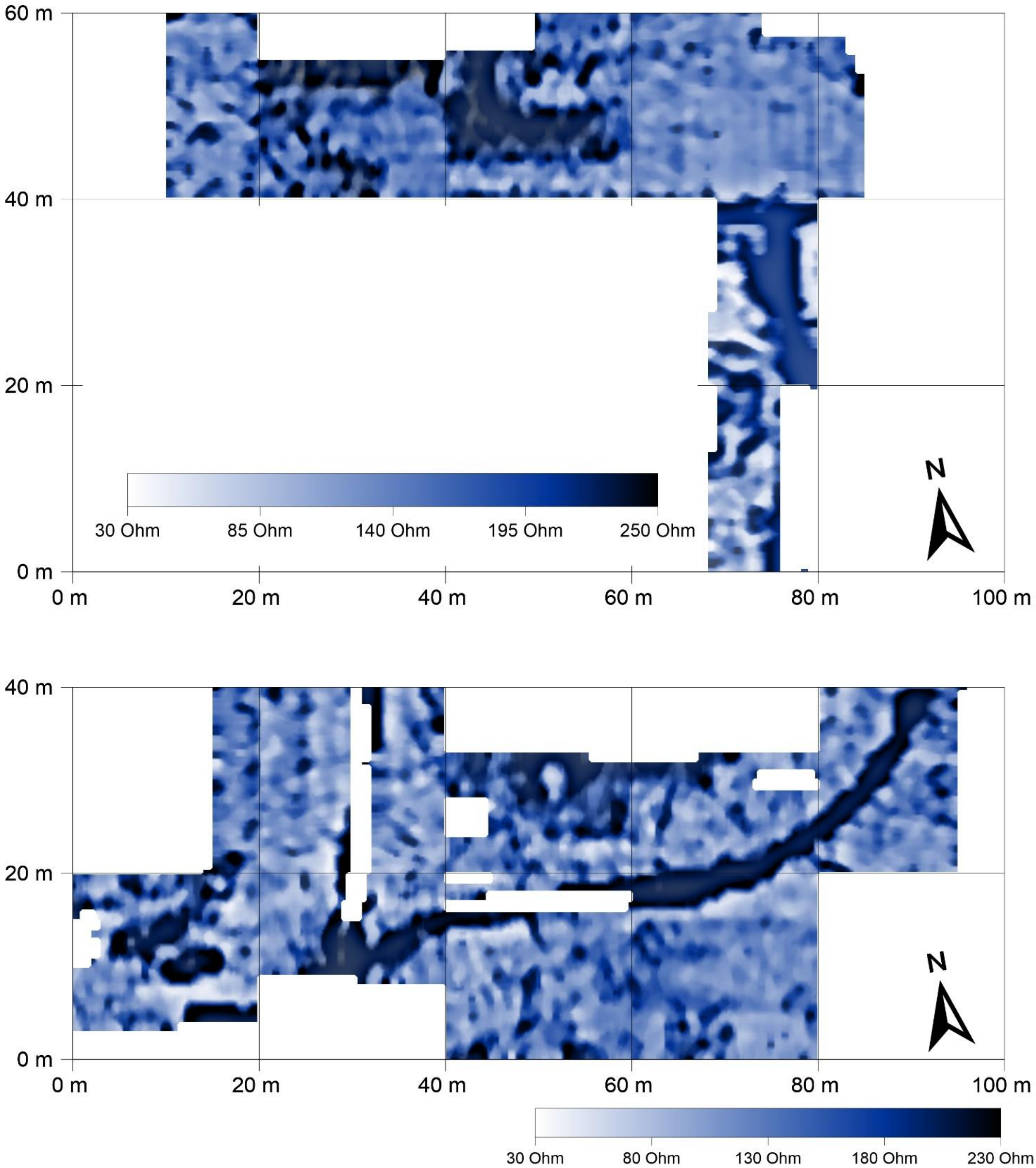

***Fig. 12** Gelati. Resistogram showing the raw data from the resistivity prospecting north east and south of the main church*.

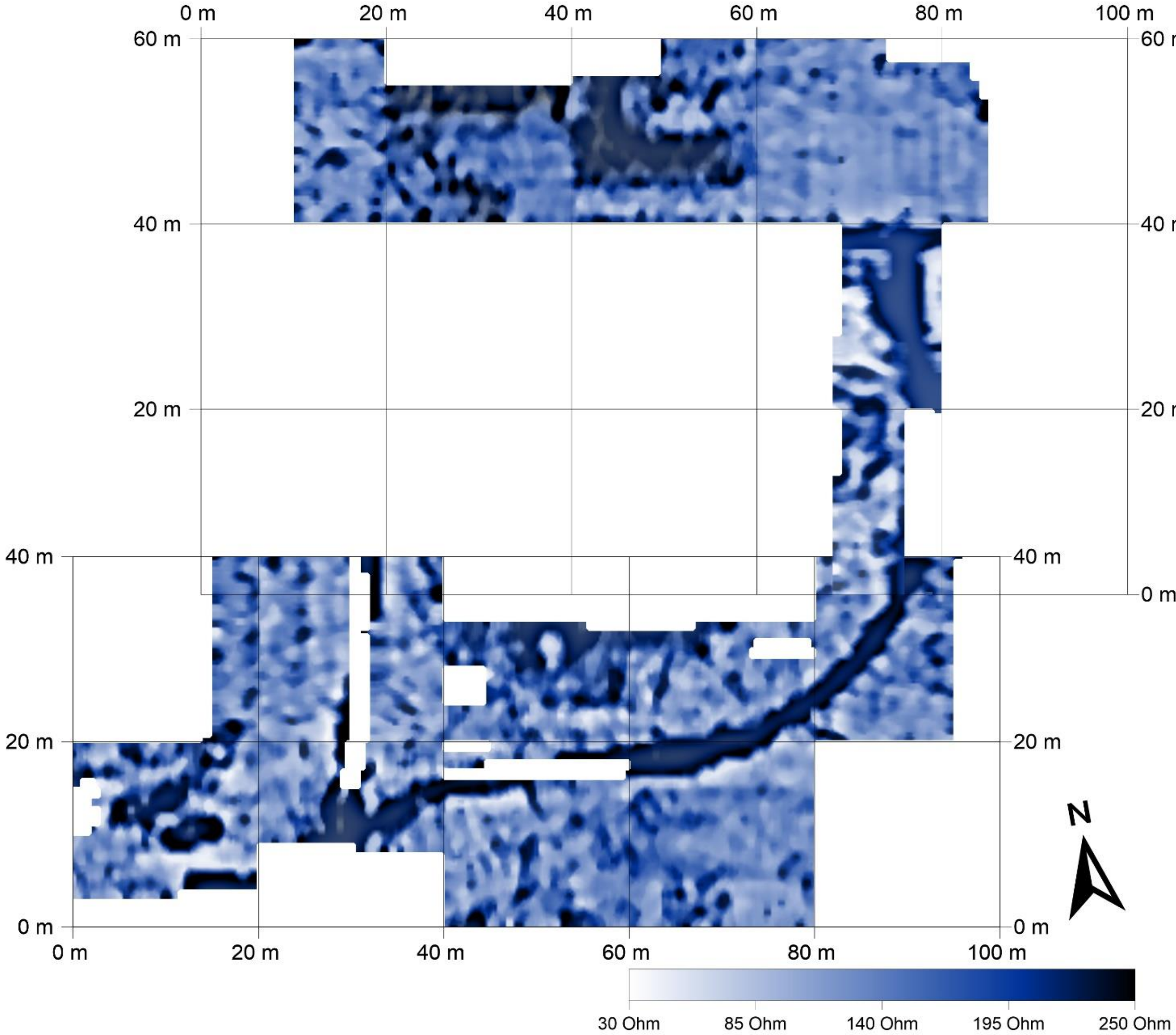

Fig. 13 *Gelati. Resistogram showing raw data of the resistivity survey areas around the main church. The strong (black) linear anomaly in the west, south and east of the resistogram is due to the high resistivity values on the paved road.*

V. Interpretation

For interpretation, we integrate all available information, all our geophysical measurements as well as additional in situ analysis using a portable kappa meter SM30 to assess the magnetic properties of the soil and construction materials (Fig. 14). Some of the linear anomalies mark hidden remains of walls in the ground. Others (three of them to be exact) can be expanded to create a rectangular house floor plan (see Fig.15,1,3,4). Two of them north and south of the church (Fig. 15.1 and 15.4) also show traces of a paved floor. Their orientation is parallel to the main building of the monastery. There is also another apse to the east of the church, as well as further extensions to the south of the main building. Directly adjacent to the east wall of the main building there are two semicircular walls parallel to each other, which we interpret as the apse of a previous church (see Fig. 15.2).

The anomaly Fig. 15. 5 marks the trace of a pipeline or alternatively an electrical powerline. It was detected only by the magnetic measurements – since it is right beneath the modern paved road.

In the west of our survey area two electrical anomalies indicates another wall and west to it very probably a sewer pipe which initially runs parallel to the building but then widens in a wide arc towards the slope and emerges at the edge of the slope (Fig. 15.6). Here it forms somehow an erosion gully which is partly refilled with rocks and sand.

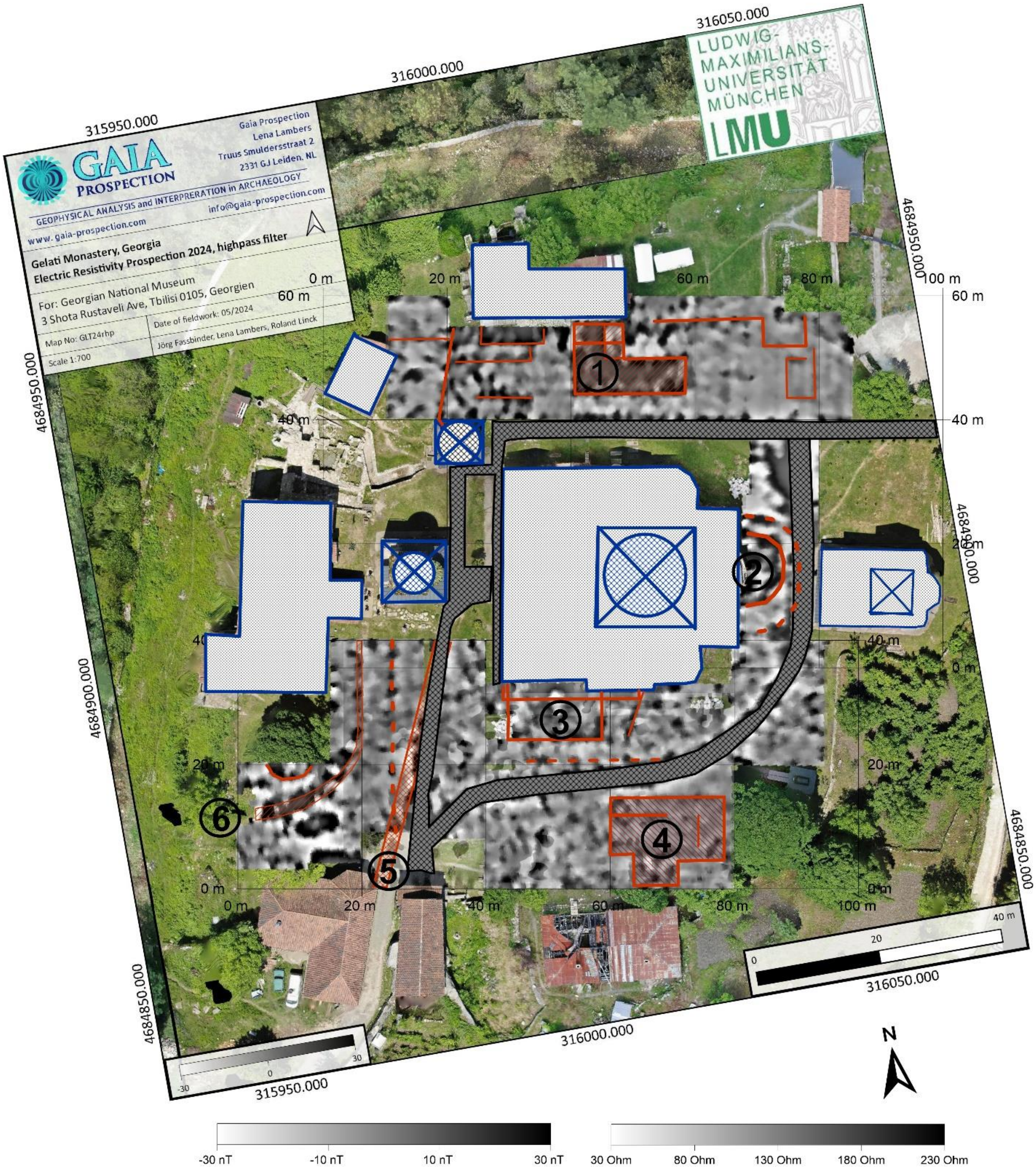

***Fig. 14** Gelati: Integrated interpretation of all geophysical data of the measurements and the drone image.*

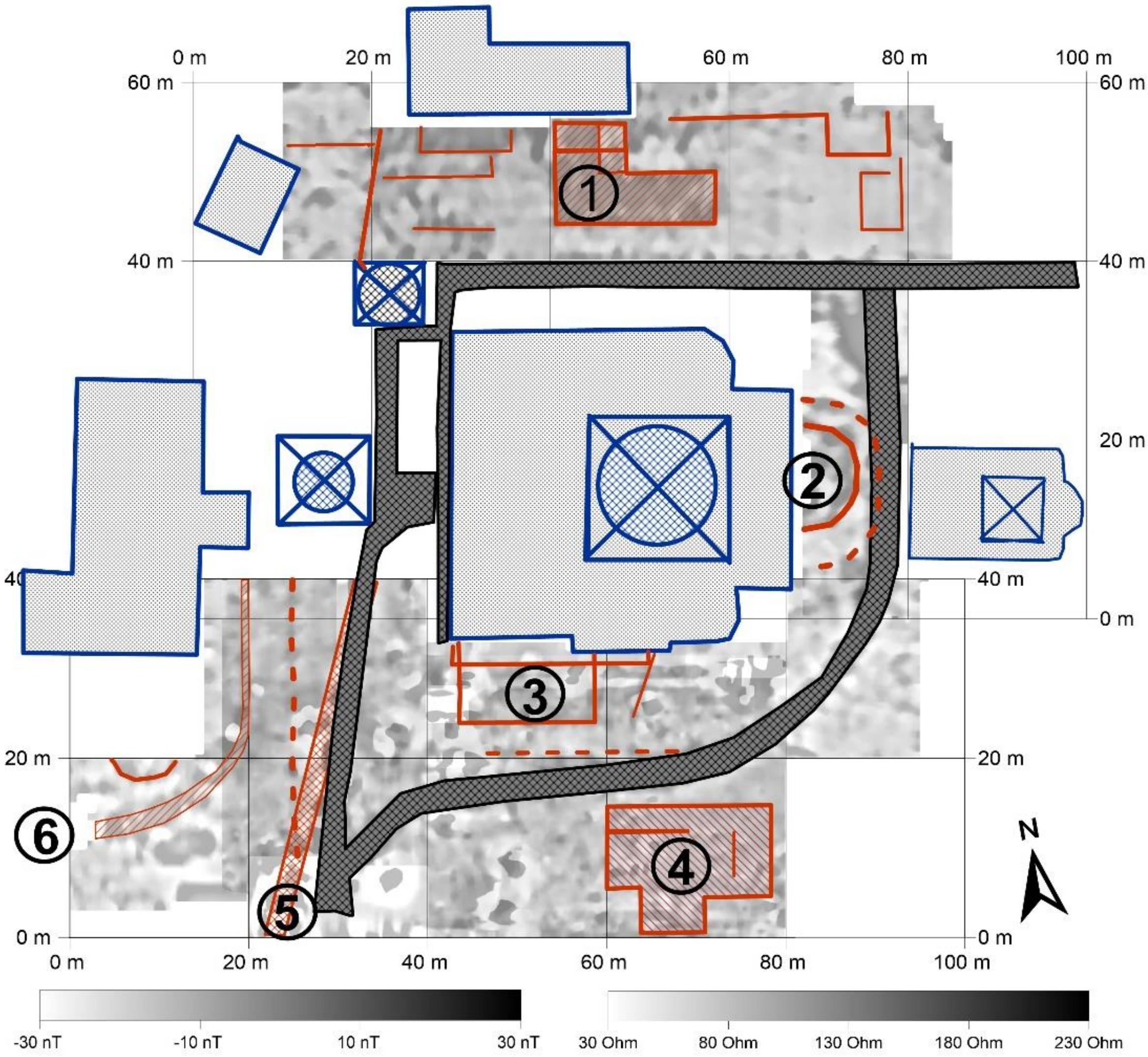

***Fig. 15** Gelati. Archaeo-geophysical interpretation (red) of the integrated data analysis.*

VI. Conclusion

The geophysical results discussed above reveal clearly several archaeological features on the selected survey area. Almost all of these features we can very probably and definitely identify as archaeological features. The shapes of the archaeological traces are very typical and specific for the medieval period. In many areas the magnetometer and resistance measurements complement each other and corroborate our interpretation. Exact depth information for the findings would be speculation - but their upper edge is only a few decimeters below the surface. Exact depth information on the archaeological findings cannot be obtained using the methods we use. However, exact depth information could be determined using radar measurements. The question of precise dating and archaeological classification of the findings must also remain open.

We therefore recommend using ground radar prospecting as a next step. This method could also be used on sealed floors and inside the main buildings. In this way, the floor plans of previous buildings and the exact depths of possible additional graves and cavities under the church could be determined.

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