Under the Surface . The geomagnetic survey at Shahr-i Sokhta in 2017

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در زیرِزمین: بررسی‌های ژئومغناطیسی در شهرسوخته ۲۰۱۷

بئاتریس و توبیاس شولتز

گروه پیش از تاریخی گئورگ- آگوست دانشگاه گوتینگن به عنوان بخشی از گروه مطالعات میان‌رشته‌ای دانشگاه سالنتو در شهر سوخته به سرپرستی انریکو سالنتو در بررسی‌های ژئومغناطیسی شهرسوخته شرکت کرده است. سه بخش از شهر سوخته، این محوطه میراث جهانی طی دو هفته بررسی و مطالعه شد. هدف اصلی این بررسی‌ها روشن ساختن شرایط محلی مرتبط با این روش‌های بررسی‌های ژئوفیزیکال در بخش‌های مختلف این بزرگترین محوطه آغاز تاریخی جنوب شرقی فلات ایران و نیز انجام مطالعات غیرتخریبی در این‌جا بوده است. نتایج محاسبات انجام شده شرایط وضعیت زمین‌شناسی و دخالت انسانی در ساختمان‌ها را نشان داده است. در فضاهای اطراف ساختمان شماره ۲۰ مجموعه ساختمان‌هائی با تقسیمات داخلی تشخیص داده شده است.

As part of the Multidisciplinary Archaeological International Project in Shahr-i Sokhta of the University Salento leaded by Enrico Ascalone, the Department of Prehistorical

History of the Georg-August-University of Göttingen was able to provide a geomagnetic survey at the protourban site of Shahr-i Sokhta. In two weeks three different locations of this UNESCO world heritage site were investigated. The main goals of this geomagnetic survey were the clarification of the local conditions regarding this geophysical method at different regions of this biggest proto-historic human settlement in the Eastern *Iranian* Plateau *as well as the non-invasive identification of archaeological structures. The resulting measurements show geological conditions, recent anthropogenic interventions or archaeologically relevant structures. At the location around Building 20 several distinct building complexes with inner structures could be revealed.*

1. Introduction

The UNESCO world heritage site of Shahr-i Sokhta is located in southeast Iran in Sistan and Baluchistan province. It is situated at a distance of 55 km to the southwest of Zabol and lies along Zabol-Zahedan road 99. The hill rises 19 meters above the surrounding land and lies on the Ramrud terrace belonging to the Pleistocene period. The city was founded around 3200 BC. and was populated during four main periods from 3200 to 1800 BC. In the past this proto-historic settlement was surrounded by a fertile plain irrigated by the Biyaban river. Today this plain is a desert. In this site archaeological artefacts are scattered over an area of 151 hectares. Shahr-i Sokhta has a north-south axis. It is nearly 2220 m long and 1090 meters wide. Because of these large dimensions, today Shahr-i Sokhta is the biggest proto-historic human settlement in the eastern Iranian plateau. After being abandoned around 4000 years ago, it has been subject to erosive factors such as wind and seasonal rains. The low hills surrounding the delta of Biyaban river are considered the most important centres belonging to the Bronze Age. West-east winds have lowered the height of the eastern parts. Furthermore, water erosions have cut vertical gullies on the sides of the hill and on the plateau.

In cooperation between the University of Salento (Italy), the Iranian Research Institute of Cultural Heritage and Tourism and the Department of Prehistoric History of the Göttingen University (Germany), three areas of Shahr-i Sokhta were geophysical examined: the graveyard area in the south, the Workshop 33 in the centre and the Building 20 to the north (Fig. 1).

2. Method, instruments and measurement process

The main objective of these investigations was the clarification of the local conditions on different areas of Shahr-i Sokhta focused to the identification of archaeological findings, especially about possible preserved building structures and the inner organisation of the settlement, by means of this geophysical method.

The applied magnetometer prospection is, besides the ground penetrating radar (GPR) and electrical resistivity tomography (ERT), one of the main geophysical non-destructive prospecting methods. The process utilizes the fact that archaeological structures and the surrounding soil can differ from one another due to their different magnetizability, the magnetic susceptibility. This contrast can be measured and reproduced. The magnetizability is due to the presence of iron compounds. Various processes cause the formation and accumulation of ferrimagnetic minerals in the soil. Chemical processes caused by heat, but also ferro-digesting bacteria are involved in this procedure. Human interventions in the soil in the form of displaced material, which differs from the surrounding existing soil, e.g. the filling of pits, are reflected as disturbances of the natural earth's magnetic field, so called anomalies.

By heating clay, e.g. by producing ceramics in kilns, the oxidation and reduction is resulting in the formation of solid iron compounds, which have a very high magnetizability. The validity of the magnetometer prospecting thus depends crucially on the characteristics of the archaeological structures and those of the upcoming soil as well as the contrast between them. Depending on the degree of magnetizability, these objects are more or less distinct which leads to a more or less evident anomaly. Of course, the magnetics not only depict archaeological findings, but also other, for example, geological structures that have an influence on the magnetic field. To a considerable extent, metallic objects, especially iron, disturb the magnetic field, appear as strong dipolar anomalies in the magnetic image, and may superimpose weaker anomalies. Metal objects, such as recent garbage or electricity and water pipes, can therefore significantly limit the informative value of a geomagnetic measurement. The magnetic flux density is given in Tesla. Anomalies based on archaeological structures usually range around ± 8 nT (nanotesla, 10^{-9} Tesla).

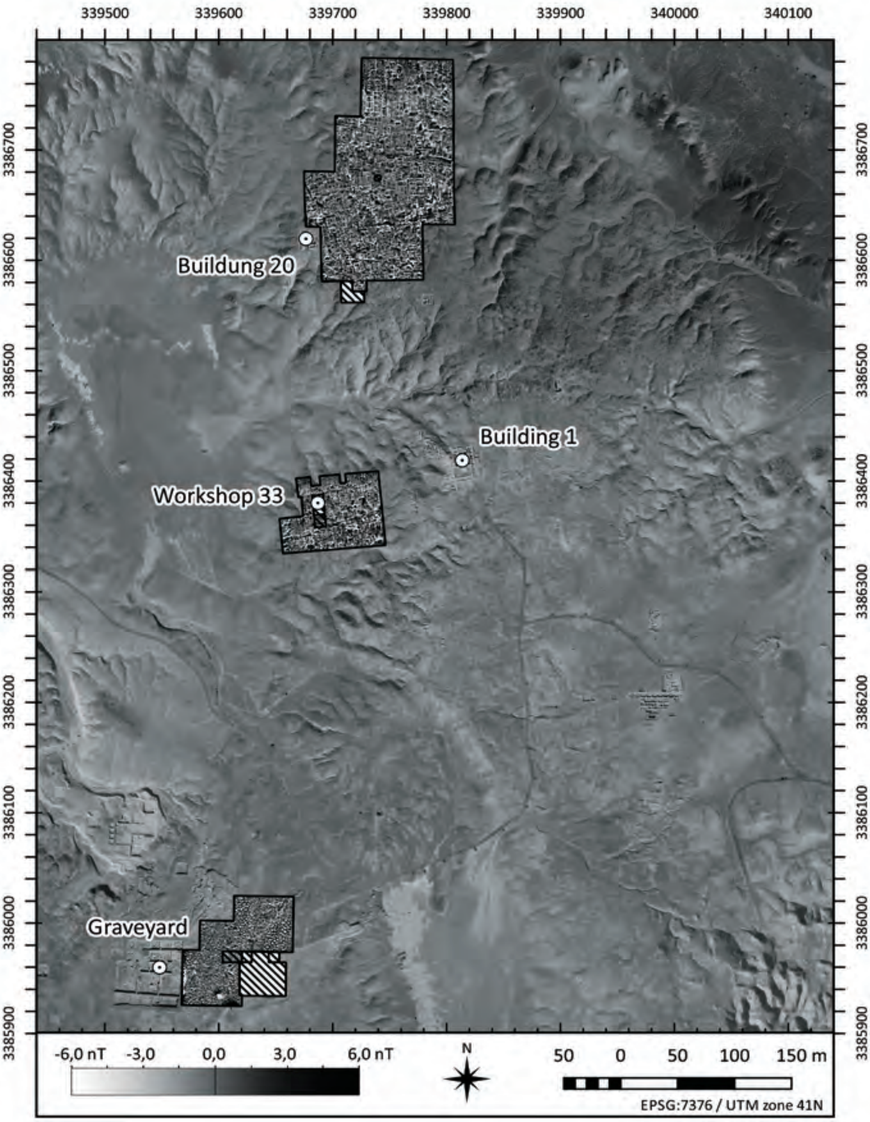

Fig. 1: location of the sites from geomagnetic survey 2017. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

A five-channel magnetometer system was used for the prospecting. The device can be equipped with tires and pushed like a cart as well as carried on shoulders. On the prospected sites, it was possible to conduct all measurements wheeled. The five measuring probes are equipped with fluxgate sensors. For later processing the raw data was exported to a geographic information system and converted to a raster image. The magnetometer measures the magnetic flux density in the near-surface soil; statements about the depth of a structure that causes an anomaly cannot be made. Significant anomalies can be caused by objects on or near the surface as well as by strong magnetic structures deep underground.

For a geomagnetic measurement, rectangular measuring grid, a compass direction oriented, were created and marked. These are measured alternately in east-west or north-south direction in two-meter-wide lanes with the geomagnetic instrument. Every 10 cm, the magnetic susceptibility is measured and stored in the data logger. After the measurement, the data is exported and processed into a greyscale image. Usually the visualization and scale of the nT values is displayed from white for the negative to black for the positive values. Later on world coordinates for the measuring grid should be provided geodetically. Some fixed points per area were marketed permanently, so the measuring net can be easily restored for a renewed search of the area. Since most of the building structures in Shahr-i Sokhta are N-S respectively W-E orientated it is for further geomagnetic surveys suggested to measure in a 45°-angel, like NW-SE respectively NE-SW, to avoid that these linear structures are not in the same direction as the measurement.

3. Results

It was possible to create a total amount of 23 measuring fields and thereby geomagnetically examine an area of 31.663 sqm (3,17 ha) within nine days of measuring (Fig. 1). In turn, one site, around Building 20, was investigated for the first time using this method.

The existing local coordinate system with the corresponding cardinal points was taken into account; although for all three locations a local coordination system for the measurement has to be created. The corner points of these geomagnetic grids were measured in UTM world coordinates by means of a hand-held GPS device. The application of the individual rectangular measuring fields was carried out only on the basis of measuring tapes and with the help of the cursing over several pegs. The use of a total station for creating the geomagnetic measurement grid was limited.

Around the Workshop 33 a lot of smaller fields had to be created due to the central excavated area and the surrounding erosion gullies. On the two other areas the reconstructed structures and the more or less distinct erosion gullies required the elaborate creation of smaller fields. The alignment of all field grids was adapted to the local excavation area in order to obtain as few and sufficiently large measuring fields. On all locations the field grid could be aligned by bearing a compass north-south orientation with the accuracy of the excavation borders. After a more or less elaborate preparation, such as the removal of excavated material, slug fragments or larger stones resting on the surface and filling some slopes of the erosion gullies, the geomagnetic device could be pushed in all measurements. The georeferencing of the individual fields into the overall local coordinate system of Shahr-i Sokhta was carried out by a Italian team of topographers (Giuseppe Ceraudo, Veronica Ferrari, Paola Guacci, University of Salento) using a total. The pegs of the individual measuring fields were left stuck until the final measurement took place.

The surface at Shahr-i Soktha consists of a silty-sand silica conglomerate with inclusions of small round pebble stones with different concentration. This is strongly solidified in some places and is showing a strong influence by wind erosion and distinct erosion gullies. The overall relief of the site is relatively flat with steep slopes at the edges. Some erosion gullies use to have steep slopes also. Interpretable magnetograms are obtained on all three measured locations, showing geological conditions, recent anthropogenic interventions or archaeologically relevant structures.

4. The graveyard area

The northern part of the graveyard area (Fig. 2 and 3) is showing two large areas with honeycomb structure like anomalies. These were first interpreted as graves, but the weak signal of the over 1.0 m deep lying graves could be covered by geological structures, it is therefore recommended to clarify these anomalies with a small excavation trench. Maybe these structures were caused by salt deposits or frost patterns (Fig. 4). Due to their chemical structure, these would cause a comparable rash in the magnetogram. In the west of the image could be some linear anomalies identified. Some of these could belong to a building consisting of two approximately 5 x 5 m rooms to the northwest of a fulfilled excavation trench. The anomalies in the west and south of the investigated area have very high amplitudes. They are clearly a result of the modern graveyard restoration and an information sign made of metal.

5. Around Workshop 33

The area around Workshop 33 is characterized by large erosion gullies and small hills along the edges of the dried out inner lake. The magnetogram shows the same structures as seen in the aerial photography of this area in the west of the central spared out excavation trench and even some more anomalies to the south west and south east, which could be building complexes. In the geomagnetic image (Fig. 5 and 6) it is clear to see that none of these building are directly connected to the excavated Workshop 33.

6. North-east of Building 20

The best results were acquired at Building 20 (Fig. 7 and 8). The whole magnetogram from this year excavation shows building complexes that are similar to the complex of Building 20. There is one very interesting large building structure in the eastern part. The building is oriented east-west and measures 12.6 m x 13.8 m. Along the northern and southern sides there are four to five small rooms measuring 1.3 m to 2.5 m x 2 m to 3 m. In between there are larger rooms or corridors. At a distance of only 1.3 m, there is another building complex with the same orientation and a similar inner structure. There are also freestanding single buildings and yet uncounted linear structures close together with only a few free spaces between them. Disadvantageous are the few deep N-S oriented erosion gullies disturbing the geomagnetic measurement. The building structures reach to the edge of the plateau and even beyond. This could be a sign of a tight housing situation, although the utilization phases of these buildings are unknown. In the southwest of the area we see a conspicuously arrangement of circular anomalies with changing positive and negative values of nT. They form a square structure with five single anomalies laying south of it in a row. This anomaly structure is very uncommon and could not be identified.

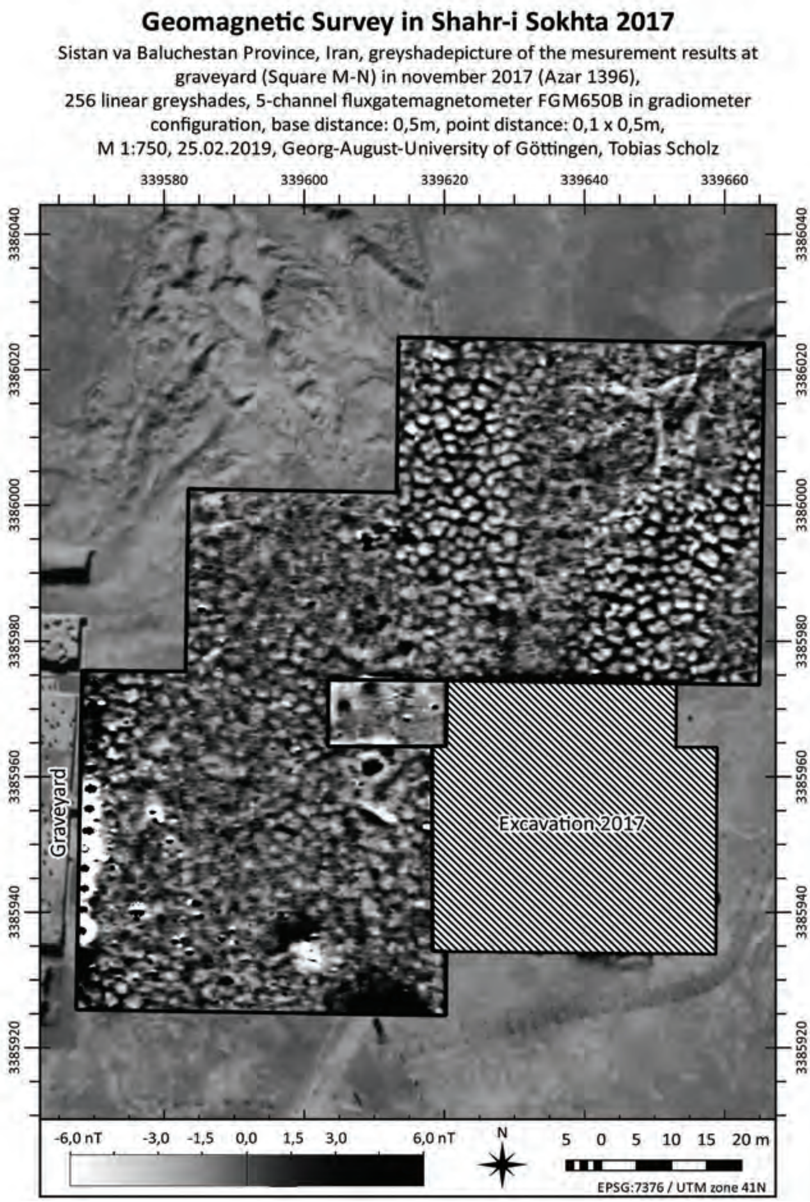

Fig. 2: results of geomagnetic prospection at the Graveyard. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

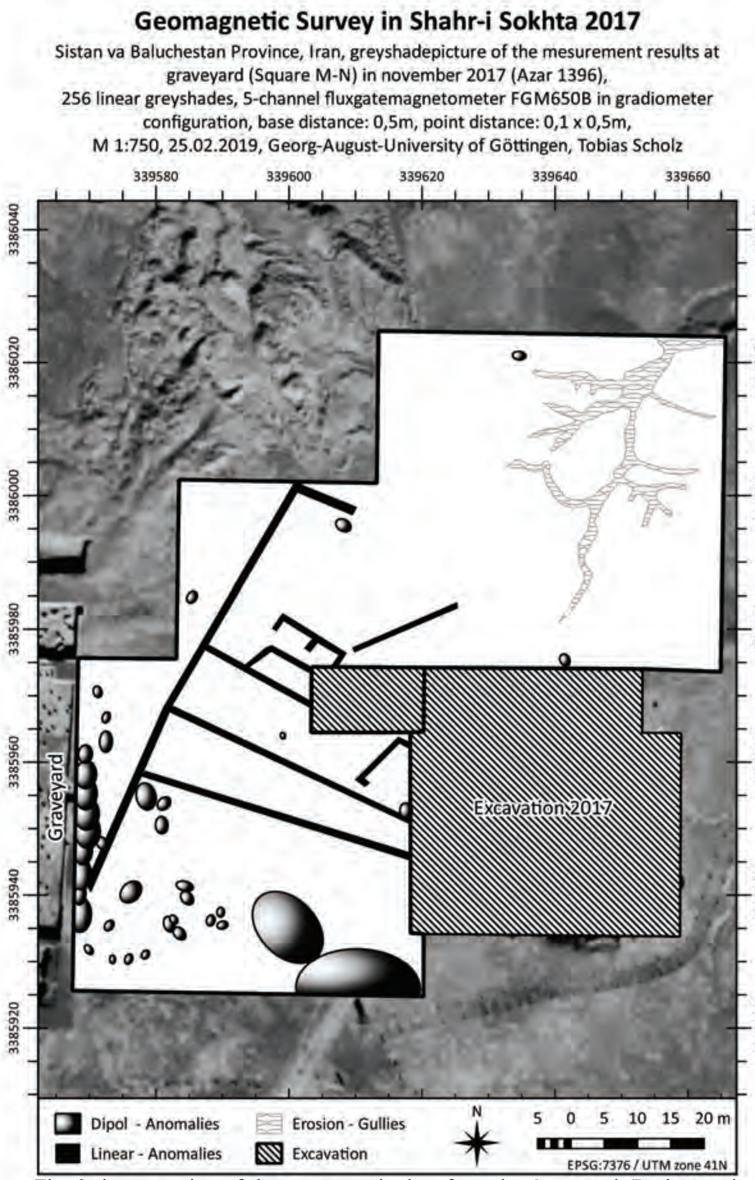

Fig. 3: interpretation of the geomagnetic data from the Graveyard. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

7. Conclusion

Interpretable magnetograms are obtained on all three measured locations, showing geological conditions, recent anthropogenic interventions or archaeologically relevant structures, like building complexes, even to the level of their room layout.

It is recommended to clarify the polygonal anomalies in the graveyard area with a small excavation trench to verify the interpretation as salt deposits or frost patterns.

The geomagnetic picture around Workshop 33 shows that none of the building complexes is connected to the excavated area. Regardless of that, it is very clear, that not all existing walls give an observable geomagnetic signal. Therefore, some of the mudbricks should be analysed according to their differences in composition or manufacturing.

Even on the northern downhill slopes of the tepe are identifiable building complexes, but no perimetrical wall. Most linear anomalies are N-S or W-E orientated, therefore all further geophysical prospections should have an 45° angle to the existing measurement grid, to avoid that these linear structures are not in the same direction as the measurement. At least a safe investigation of geophysical findings can only be made by soil digestion and a negative geophysical finding does not allow any conclusions about the presence or absence of archaeological remains. But the geophysical method provides an informative basis for further investigation and in this case the results show where further excavations are worthwhile.

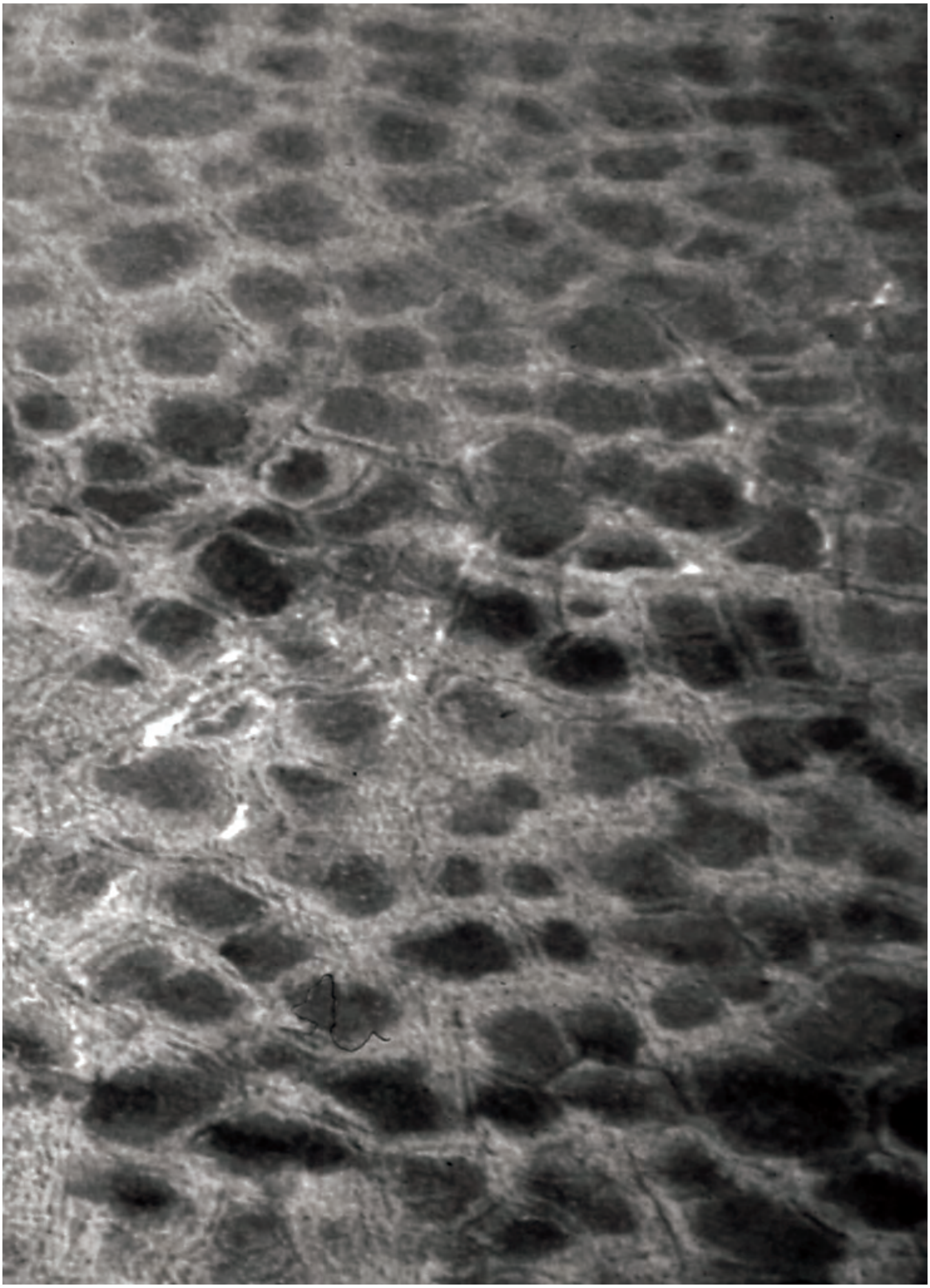

Fig. 4: aerial photography of a frost patterned ground with ice polygons (Dennis Cowals 1973, National Archives and Records Administration, NAID 550392).

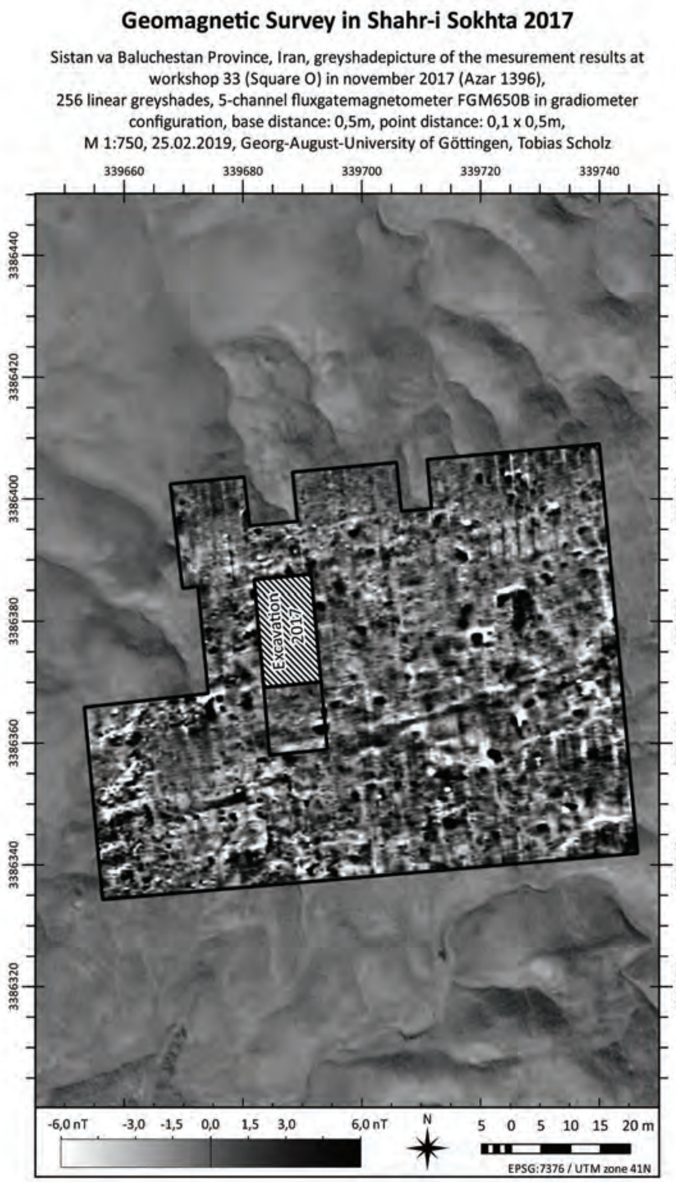

Fig. 5: results of geomagnetic prospection around Workshop 33. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

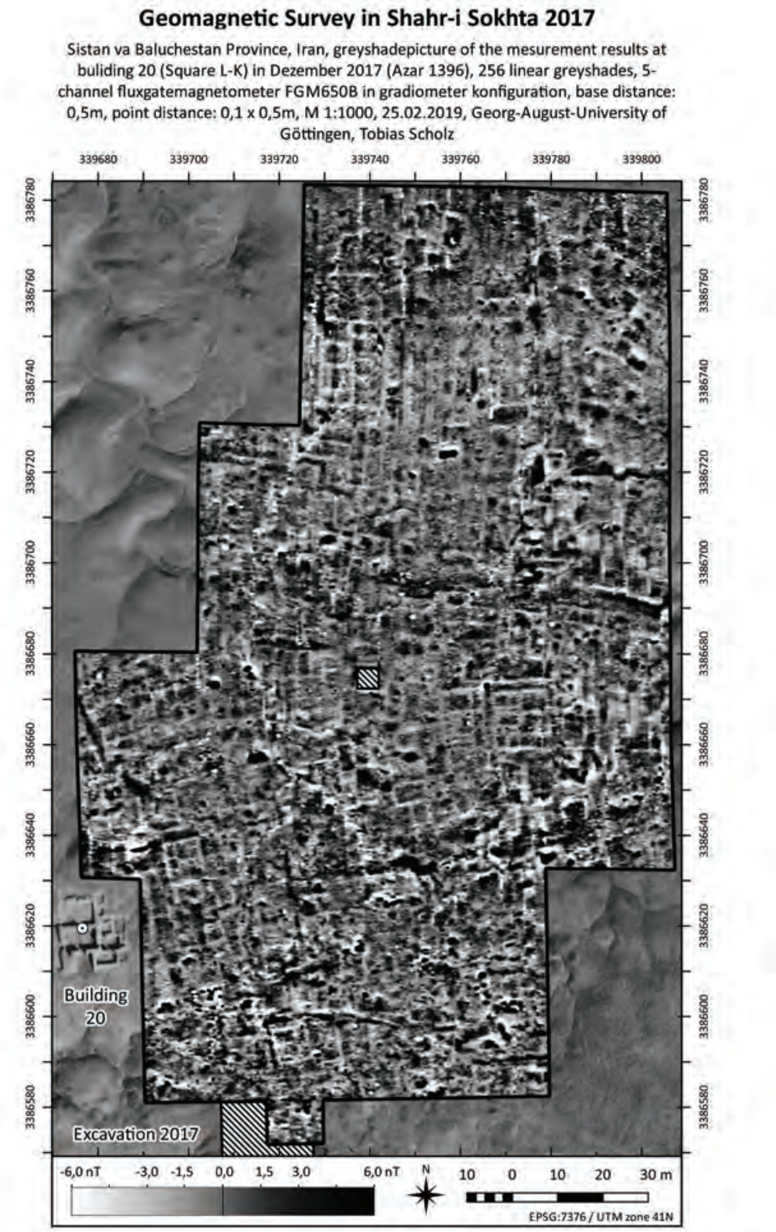

Fig. 6: interpretation of the geomagnetic data around Workshop 33. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

Fig. 7: results of geomagnetic prospection east of Building 20. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).

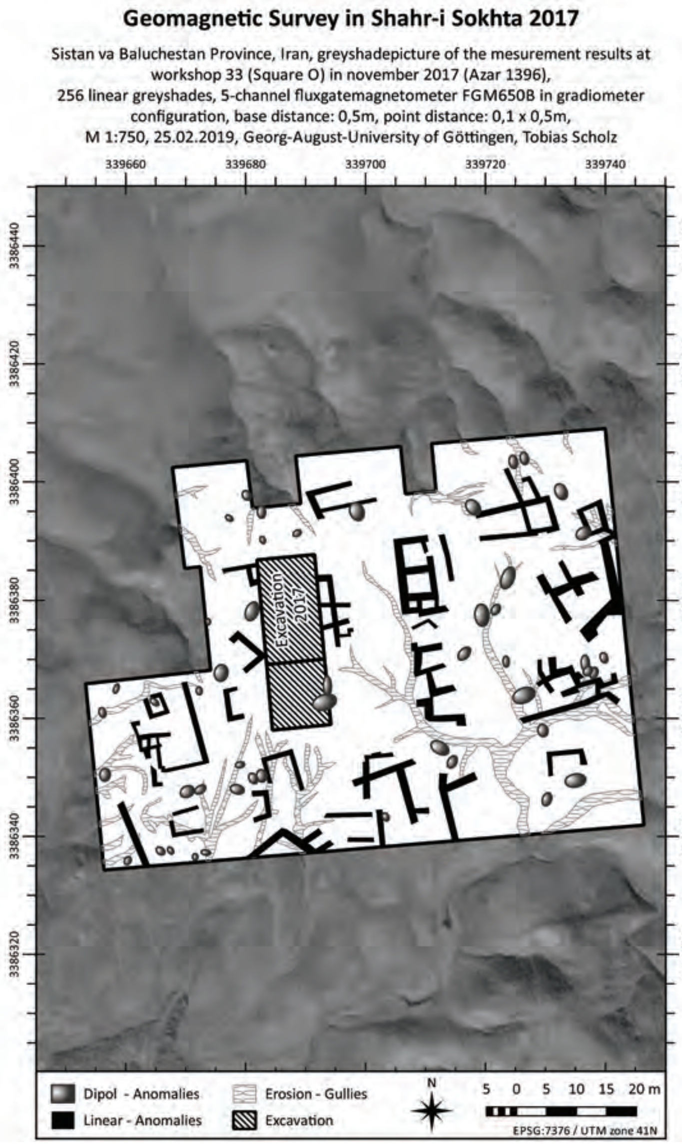

Fig. 8: interpretation of the geomagnetic data east of Building 20. Background picture: aerial photography by Seyedeh Media Rahmani (University of Tehran) merged by Giuseppe Ceraudo (University of Salento). Additions and georeference by Tobias Scholz (University of Göttingen).