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Mapping Buried Archaeology: Experiences of More than Four Decades of Archaeological Prospection in Bavaria

Roland Linck[1, 2,*], Andreas Stele[1], Jörg W. E. Fassbinder[2]

[1] Bavarian State Department for Monuments and Sites, Z V „Zentrallabor & Geo-Erkundung“, Hofgraben 4, 80539 Munich
[2] Ludwig-Maximilians-University Munich, Department for Earth and Environmental Sciences, Institute for Geophysics, Theresienstr. 41, 80333 Munich
* Corresponding author: andreas.stele@blfd.bayern.de

Abstract
Meanwhile, the Archaeological Prospection in Bavaria can look back on more than 40 years of continuous work all over the country, as the first attempts and surveys were already made in the late 1970s. Besides pure geophysics, we also routinely apply aerial archaeology and Airborne Laserscanning to detect and map historical monuments. For some years, our methods have been complemented by the use of drones to acquire photogrammetric 3D models of topographically visible sites. This led to one of the biggest archives of aerial archaeological photos as well as geophysical datasets worldwide. The paper will firstly present a brief introduction to all the methods that we are using. This is accompanied by a short history of their application to Bavarian Heritage Protection. Afterwards, all presented methods are shown in more detail based on practical survey results. This part also gives a short introduction into the range of archaeological sites in Bavaria dating from Neolithic to modern times.
Keywords: Archaeological Geophysics, Aerial Archaeology, Airborne Laserscanning, Photogrammetry, Magnetometry, Ground-Penetrating Radar, Bavaria

1. Introduction

Modern applied geophysics offers a multitude of non-destructive methods to detect and map subsurface archaeological remains. Hence, geophysical prospection became indispensable for archaeological research and for national heritage agencies. In the meantime, Archaeological Prospection became an independent research branch and is no longer regarded as a simple auxiliary science. Nearly every modern archaeological project nowadays starts with a comprehensive geophysical survey. Besides the simple plan of the site, the results provide information about the construction, the usage and the state of preservation of the site. Furthermore, new scientific questions can be deviated from the geophysical results and the excavation work can be optimized.

Besides geophysical prospection, the Bavarian State Department for Monuments and Sites (BLfD) also applied routine aerial archaeology flights for several decades to detect and map archaeological sites all over Bavaria. Meanwhile, also drone prospection plays an important role to map especially sites that are partly visible at the surface via 3D photogrammetry.

In the following, all these methods shall be presented in theory and practice based on several case studies from Bavaria.

2. Methodology

2.1. Aerial archaeology

The main advantage of aerial archaeology compared with the other presented methods is the huge coverage within a short time. Hence, even large settlement sites and historical landscapes can be mapped in a reasonable time.

The first photos of archaeological sites in Bavaria already date back to the years 1914-1917, when they were used as test objects for the aerial reconnaissance of the Bavarian Airforce (Dalman 1925). A systematic mapping of the Bavarian archaeological sites, as well as protected historical buildings, was started in 1975 by Otto Braasch. Since 1989, this task is taken over by Klaus Leidorf. Hence, in the last 45 years, it was possible for the BLfD to build up one of the biggest archives of aerial archaeological images worldwide. Today, our archive comprises more than 800,000 photos of ca. 50,000 sites in Bavaria. Among these, there is also a multitude of archaeological sites that were detected by aerial archaeology for the first time. Whereas the biggest part of the discoveries dates to the pioneering years, when several thousands of sites were detected each year (Christlein and Braasch 1982), also nowadays there are 20-30 new sites per year. For this reason, it is still important to do continuous flying all over Bavaria because depending on agricultural use and weather, the buried archaeological sites are not detectable in each season and sometimes even over years.

Aerial archaeology uses several feature types to map buried archaeology. These are mainly:

(1) *Crop marks:* Depending on the type of a buried archaeological feature, the crop can grow better or worse. In the case of a refilled ditch or a settlement pit, the plants have more water and nutrients available. Therefore, they can grow higher and stay green for a longer time. Vice versa applies to buried stone walls. The occurrence of crop marks is strongly depending on the drought stress of the plants in case of a long time period without precipitation. Hence, the e.g. years 2018/19 had been perfect for aerial archaeology, whereas 2021 is mainly disappointing. In addition, crop marks mainly occur in plants with a dense spacing (e.g. grain); plants with a huge distance in-between (like e.g. maize or sugar beet) are less suitable.

(2) *Soil marks:* If an archaeological feature already lies within the plough horizon, it can get visible in the blank soil based on the different colour of the ditch infill or the stone concentration at the surface.

(3) *Snow marks:* Due to a varying thermal capacity above a humic and humid ditch or a wall, the snow at the surface is melting slower or faster. This fact enables the detection of archaeological sites from the air also in winter periods.

(4) *Flood marks:* If an archaeological feature is still preserved as a small elevation at the surface, it can get visible as a dry area within a flooded region. This is mainly the fact for burial mounds or medieval mottes.

(5) *Shadow marks:* The same archaeological features as in (4) will create a shadow in a flat sunlight as it occurs especially in winter. Hence, even small elevations of a few decimetres become visible.

In Fig 1, the distribution of the archaeological sites mapped by aerial photography in Bavaria is shown. It is very well visible that the sites are not evenly distributed all over the country, but more or less concentrated along the bigger rivers like e.g. Danube or Isar. This is mainly due to be fact that the main historic settlement areas of the last millenniums are concentrated there, as the rivers always depicted important transportation routes. Furthermore, these regions are still nowadays intensively used for agriculture, resulting in high erosion rates, and hence the probability to create crop marks is much higher there. In regions like the Allgaeu or the alpine uplands south of Munich that are mainly used as grassland due to the less fertile soil, these marks only seldom occur. Further limiting factors for aerial archaeology are the huge forested areas e.g., in the Bavarian Forest or the Upper Palatinate Forest in Eastern Bavaria and the no-fly zones along the former Inner German boundary and the one towards the Czech Republic that could not be covered before the early 1990s.

2.2 Airborne Laserscanning

Since 2001, the Bavarian Topographical Survey has provided airborne laserscanning (ALS) data of the whole Bavaria in a resolution of up to 1 m (Fassbinder et al. 2019). The method is based on the emission of a short-pulsed laser signal. Any object at the ground scatters the signal back to a receiver; this can be the Earth's surface as well as obstacles like buildings, trees, other vegetation etc. From the signal's travel time, it is possible to calculate even small height differences in the local relief. As the laser signal partly penetrates vegetation, the sensor records multiple backscatters of the same point at the surface. By discriminating between the varying travel times, the generation of a terrain model with or without vegetation is enabled (Doneus and Briese 2011). Therefore, ALS data can also be used for the Archaeological Prospection, especially for sites preserved at the surface as small elevations. Mainly in forested areas, the ALS prospection is often the only method that can be applied.

2.3 Drone photogrammetry

As a result of the development of cheap drones and powerful data processing software, drone photogrammetry became a new instrument for the Archaeological Prospection in the last years. The method of photogrammetry as a tool for 3D mapping of topographical marks is based on the coverage of a region with a multitude of single photos with a huge overlap of more than 80%.

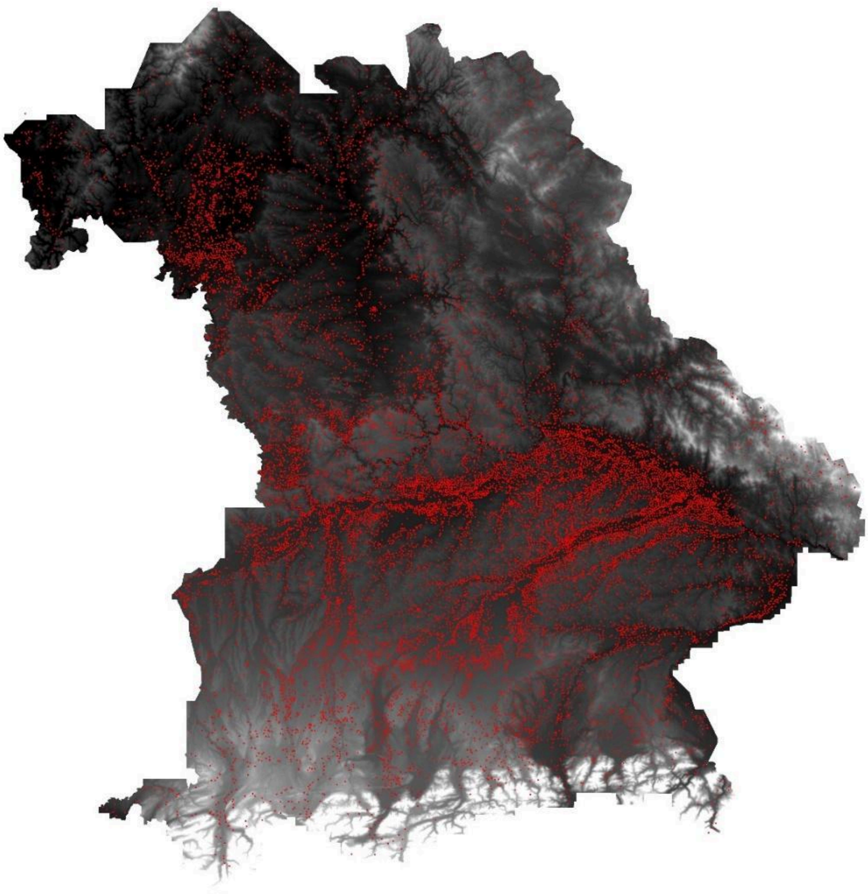

Fig 1. Geographical distribution of the sites mapped by aerial archaeology in Bavaria. Note the concentration of the sites along the big rivers. © Roland Linck (BLfD)

This ensures that each point in this area is visible from different angles and perspectives in the different photos. Hence, the creation of a dense point cloud comparable to the one known from laserscanning for years is possible. The result of the photogrammetry has the same accuracy as the one of an ALS survey, but often the resolution is much higher (i.e., some centimetres for photogrammetry compared with 50-100 cm for ALS) due to the lower flight altitude. On the contrary, a disadvantage of drone photogrammetry is that it is not successful in densely vegetated and forested areas because the method cannot look under the vegetation, as it is based simply on optical images.

Another possible application for drones in Archaeological Prospection is small-scale aerial archaeology. Due to the limited flight time and legal reasons (mainly the restricted flight radius around the take-off point of some hundreds of metres), drones cannot substitute the “normal” airplane in this topic, as they can only be used in areas with known marks to get further and higher resolution images of a site.

2.4 Geophysical Prospection

Applied Geophysics comprises a multitude of different survey methods. Within them, mainly three are the most relevant ones for Archaeological Prospection: magnetometry as a passive method and the active survey methods of ground-penetrating radar and resistivity mapping. Passive methods use an anthropogenically influenced deviation in a natural field e.g., the Earth’s magnetic field. On the contrary, for active methods, the signal is artificially created and the modification due to the buried archaeology is recorded.

Geophysical methods have been applied as standard tools for Archaeological Prospection at the BLfD since the early 1980s. Claus Colani had already executed the first test surveys in this research field in the 1960s. Since 1982, there has been the unique chance of two permanent positions for geophysicists (Helmut Becker 1982-2006, Jörg Fassbinder 1986-2020, Roland Linck since 2018 and Andreas Stele since 2020). This offers the possibility not to interpret the prospection results solely archaeologically, but also from a geophysical point of view. As the method had to prove its value and impact on archaeological research in its pioneering years, the first surveys concentrated on single-phased sites of remarkable archaeological interest. This resulted in several prospecting projects of selected archaeological periods e.g., Neolithic ring ditches, Iron Age enclosures, Roman forts, Roman Villas and Early-Medieval fortifications. Within these periods, almost all known sites in Bavaria were geophysically prospected. In the last years, the focus of the working group was more on single small sites that nevertheless provided perfect results and significant impact on the archaeological research. Currently, the BLfD has an archive for geophysical prospection results of ca. 1000 sites of different epochs and categories spread all over Bavaria (Fassbinder et al. 2019).

Besides our own archaeo-geophysical research projects, our department of the BLfD also provides a special prospecting service to developers and local authorities.

Developers, in order to minimize destruction and in order to get an overview of the costs of an excavation, very often apply geophysical prospection prior to an archaeological excavation. For such projects, which are explicitly undertaken by commercial companies, the geophysicists of the BLfD provide advice and guidance (Fassbinder et al. 2019). Guidelines for the use of geophysics in archaeology are available via the webpage of the BLfD. (https://www.blfd.bayern.de/mam/abteilungen_und_aufgaben/denkmalforschung_und_denkmalerfassung/zentrallabor/standards_geophysikalische_prospektion_2023_09.pdf). These guidelines are very similar to those of the European EAC (Schmidt et al. 2015). Nevertheless, the Bavarian ones are stricter with regard to the sampling interval of 25 x 50 cm. Digital copies of the geophysical data from such projects have to be evaluated by the geophysicists of the BLfD and are also digitally archived there. Within the last ten years, there has always been a comparable number of commercial prospection projects to the one by the BLfD, with a slightly increased value for the heritage research work done by the BLfD (Fig. 2).

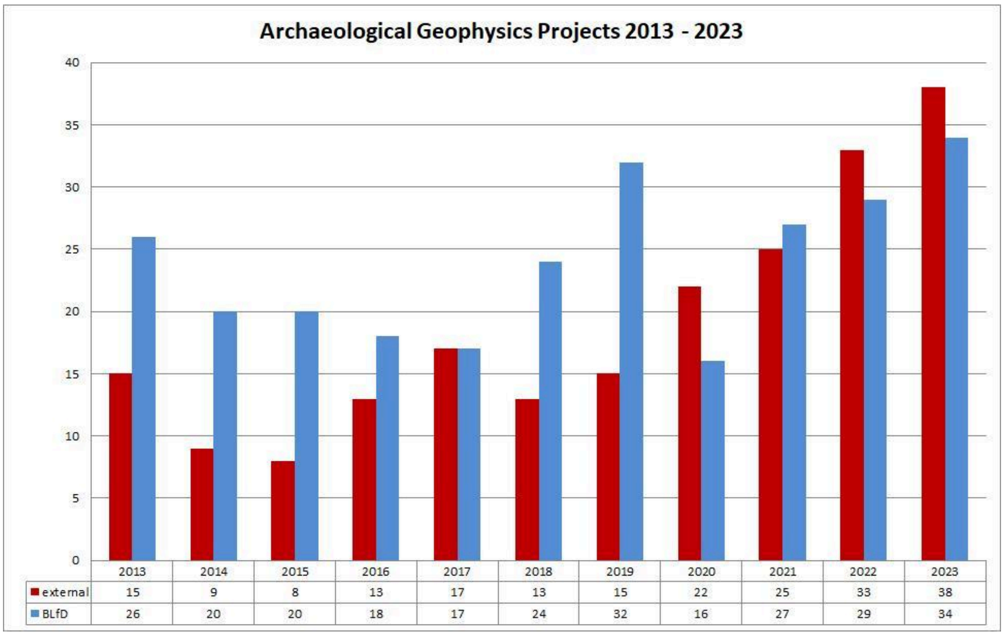

Fig 2. Number of projects in the field of Archaeological Prospection per year for the time 2013-2023 that were executed by the BLfD and commercial geophysical companies. In 2020 more external projects were recorded than BLfD internal ones due to travel restrictions by the Covid pandemic. The last two years were characterized by a huge amount of construction work (especially due to energy transition) affecting archaeological sites and therefore the need for many geophysical projects associated with this and done by commercial companies. © Florian Becker, Roland Linck (BLfD)

Since some years, the working group at the BLfD furthermore is embedded in a model project on archaeological surveys in early planning stages. In case of planning for a development project nearby to a known archaeological site, there is always the question regarding the actual size of such a site and whether it is affected by the development area. These geophysical surveys are provided without any additional costs for the developer. The surveys are accompanied by trial trenching or small excavations to get a detailed dating of the features and to verify the geophysical interpretation. This approach allows the developer to eventually change their plans and preserve the archaeological features *in situ* (Fassbinder et al. 2019).

In the following paragraphs, we present the different geophysical methods.

2.4.1 Magnetometry

The magnetometer prospection is the most sensitive, fastest and cheapest prospection method to detect buried archaeological remains. Nevertheless, for a robust archaeo-geophysical interpretation it requires a rather quite large area that is free of any modern and technical disturbances like buildings, roads, fences, modern pipes etc.

The method uses the alteration in the natural Earth's magnetic field caused by human activity. Hence, e.g. in settlement pits or refilled ditches, there is an accumulation of magnetic minerals due to the decay of organic matter caused by magneto-tactic bacteria (Fassbinder et al. 1990; Fassbinder and Stanjek 1993). A strong magnetic anomaly can furthermore be created under the influence of fire (Le Borgne 1955). By heating the material above the so-called Curie point of 570°C for magnetite, several iron oxide minerals transform into maghemite or magnetite and form anomalies in the range of several hundred Nanotesla (Le Borgne 1960; Fassbinder 2015).

In the presence of limestone walls in the subsurface, the magnetic anomaly normally will be negative, as the non-magnetic limestone compared with the undisturbed soil will weaken the local magnetic field.

As shown above, the magnetometry is suitable for nearly each archaeological site because ditches and settlement pits as well as stone fundaments can be mapped by magnetically contrasting minerals in the soil. Hence, the magnetometry is the most often applied geophysical method.

2.4.2 Resistivity mapping

For the resistivity mapping, a synthetic electrical current is actively sent into the soil. Depending on the specific resistivity of the subsurface, the current gets stronger or weaker. This resulting current is recorded at the survey device again. Normally stone features in the subsurface will result in a positive anomaly, as the resistivity of the stones is higher than for the surrounding soil. On the contrary, ditches appear negative, as there is an accumulation of humus and conductive material and the soil moisture is higher there. As the resulting anomaly is maximum for stone features, this method is mainly used to detect buried stone fundaments of Roman, Medieval or Modern times. As for magnetometry, resistivity mapping needs an unsealed soil to penetrate the electrodes. As resistivity mapping is a point sampling method compared with the continuous survey for magnetometry and radar, it is quite time-consuming and therefore only applied to small areas. Further details regarding the methodology can be found in Schmidt (2013).

2.4.3 Ground Penetrating Radar (GPR)

GPR uses synthetic electromagnetic waves that are sent into the ground by a transmitter antenna. These waves are reflected by material boundaries in the subsurface and recorded by a receiver antenna again. The frequency range is between 250 and 900 MHz for the purpose of Archaeological Prospection. As a higher frequency means a higher resolution, but a lower penetration depth, always a compromise between these two influencing factors has to be found before each survey (Linck 2013).

A successful application of GPR depends on a significant change in the subsurface material. Hence, GPR also is mainly used for the detection of stone features. One advantage of GPR compared with the other methods is, that it can be applied on sealed surfaces like roads or parking lots and even inside of buildings as well. Another advantage is that GPR directly provides the depth range of the archaeological structures by the signal travel time. Therefore, in some rare cases, it is even possible to provide a relative archaeological chronology simply based on the geophysical results (e.g. Linck and Becker 2020; Linck and Haberstroh 2021).

2.4.4 Time-domain reflectometry (TDR)

The successful application of GPR in the Archaeological Prospection is strongly depending on the material parameters of the subsurface. The main influencing factors are the dielectric permittivity, the conductivity, and the soil moisture. As these values can only hardly be determined directly with the GPR antenna, a simultaneous acquisition by other methods like Time-domain reflectometry is advisable.

The TDR principle is based on the transmission of a short voltage pulse between two short probes penetrating the soil. There is a first reflection at the top of the probes and a second one at the end. Via the time difference between the two reflections, the dielectric permittivity can be determined. The other two parameters afterwards can be simply calculated. A deeper insight into the theory of the method as a tool for Archaeological Prospection can be found e.g. in Linck & Fassbinder (2014).

3. Case studies for the different survey methods

3.1 Aerial archaeology

The Neolithic ring ditch of Künzing-Unternberg (Lkr. Deggendorf, Lower Bavaria) was one of the first prominent archaeological sites that were documented by Otto Braasch in Bavaria (Fig. 3). Since its first discovery in 1977, the site was mapped several times in the last decades. The aerial photo in Fig. 3 shows clearly the double-ring ditch as a positive crop mark in the maturing grain west of the unpaved farm road. Furthermore, one of the entrances to the site can be identified quite well, as the two ditches are connected there and form an earthen bridge. The eastern part of the ring ditch system is only faintly visible; even in the same crop type. For this reason, it is important to fly at a suitable season of the year and to repeat surveys of such important archaeological sites over decades to get a comprehensive map of the site.

A first magnetic prospection took place already in 1984 and 1985 by Helmut Becker. The corresponding results as well as those later executed at the site in 1999 and 2012, surprisingly show that the part of the ring ditch that is best visible in the aerial photo nowadays seems to be nearly destroyed by excavation, erosion and agriculture, whereas the eastern part is very well preserved. This fact often occurs in Loess soil, where the crop marks only appear when the archaeological remains are nearly completely destroyed.

3.2 Drone photogrammetry and ALS

The Roman *villa rustica* near Erlstätt (Lkr. Traunstein, Upper Bavaria) still nowadays is preserved as a small heap of rubble below the grassland. Hence, there are perfect circumstances to show a comparison between a terrain model (DEM) created by drone photogrammetry and by ALS. *Villae rusticae* are agricultural estates operated by veterans of the Roman army that provide the supply for the troops garrisoned in the province.

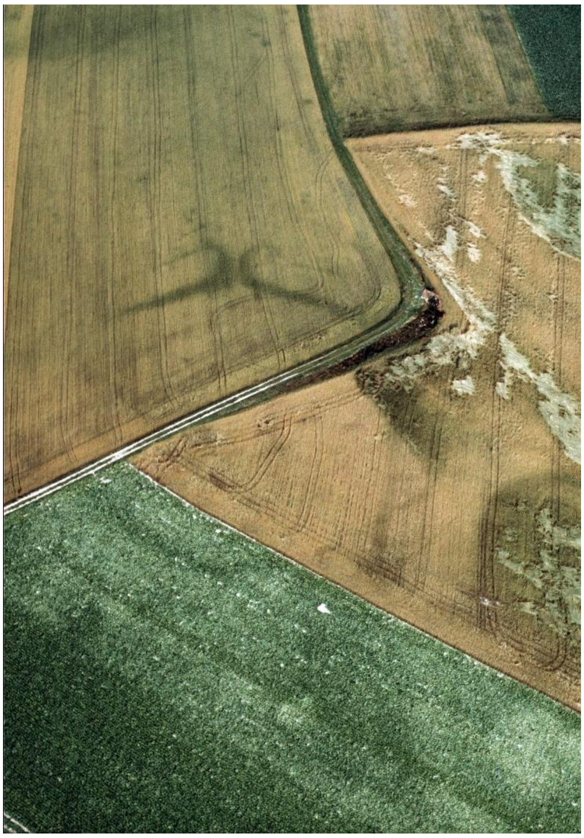

Fig 3. Crop marks of the Neolithic ring ditch of Künzing-Unternberg that was detected through aerial photography in 1977 by Otto Braasch. North is at the top right corner. BLfD Aerial Archaeology Archive, Photographer: Otto Braasch, Date: 12/07/1977, Archive-Nr. 7344/007 Image-No. 0000-01. © Otto Braasch (BLfD)

As Fig. 4 shows, the main building of this *villa rustica* has a rectangular layout of 70 x 35 m. It is oriented towards the northwest and has the typical risalites at both sides of the entrance. The inner layout of the building that also can be identified as small elevations in the terrain resembles more the one known from Italy than those of the Northern provinces like *Noricum*. In total, eight single rooms can be distinguished southeast of the risalites. Further eight rooms are located on both sides of a central courtyard.

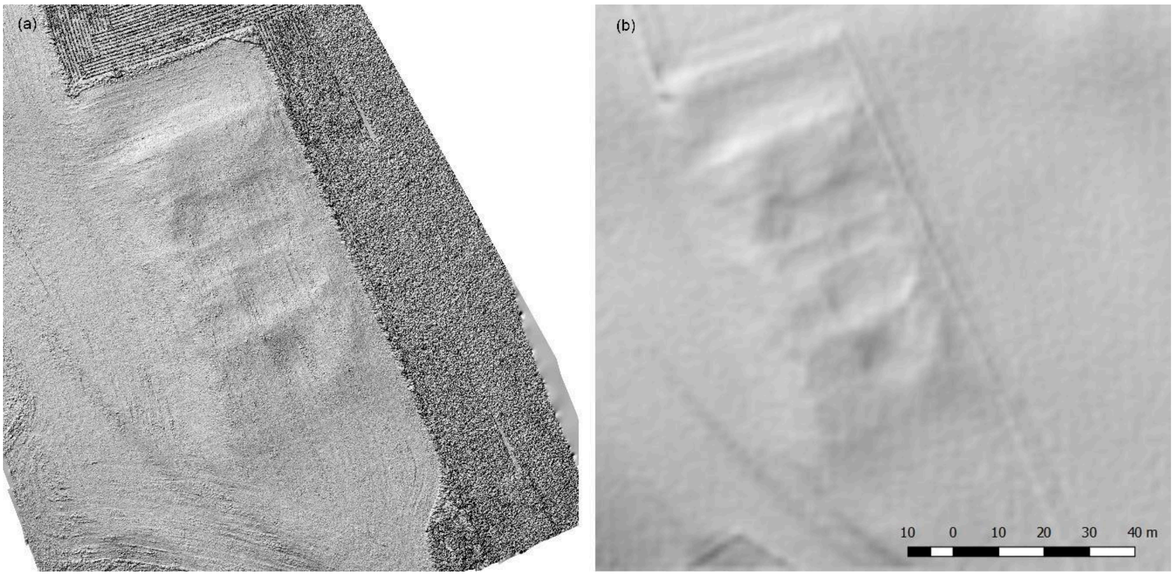

Fig 4. Terrain model of the main building of the Roman *villa rustica* near Erlstätt. (a) Data acquired by drone photogrammetry. Resolution: 2 cm, survey date: 30.06.2020, Archive-No. Erl20uav. (b) DEM created by an ALS-flight of the Bavarian Topographic Service. Resolution: 100 cm. © (a) Roland Linck (BLfD); (b) Bayerische Vermessungsverwaltung.

Both DEMs show the main archaeological features quite well. Nevertheless, they are much more pronounced in the data acquired by drone photogrammetry, as the drone DEM has a resolution of 2 cm (Fig 4a) compared with 100 cm by the ALS (Fig 4b). Therefore, especially faint archaeological remains can be much better resolved with a drone DEM due to the much lower flight altitude. Mounting a laserscanner underneath a drone, of course, would provide data with the same high resolution. In addition, the comparison shows the fact that vegetation cannot be removed in drone photogrammetry, as the high maize plants north and east of the *villa rustica* show.

3.3 Magnetometry

On top of the Hahnenberg (Lkr. Donau-Ries, Swabia), a small hill in the centre of the famous Ries meteor crater, an Iron Age enclosure was built. It dates to the Hallstatt period, i.e. 800-400 B.C. The site covers the oval plateau of the Hahnenberg and a rectangular enclosure was built on top (Fig 5). The southern palisade has a length of ca. 112 m. The western one can be traced over 85 m in length, whereas the eastern part is only clearly visible over 40 m. Under the assumption of an angle of 85° and 88° for the south-eastern and south-western corners of the enclosure, the northern palisade can be reconstructed as 85 m long. Some further palisade parts in the south can probably be assigned to a later phase or repair work. Therefore, the enclosure seems to have existed over a long period. Possibly, the whole site was additionally enclosed by a ditch system in 5 – 18 m distance. The magnetic survey revealed corresponding traces in the south and east. As there is no interruption in the palisade and ditch visible in the parts covered by our survey, it has to be assumed that the entrance could have been in the north (Fassbinder et al., 2014).

Additionally to the enclosure, also traces of the former internal structure of the settlement are visible (Fig 5).

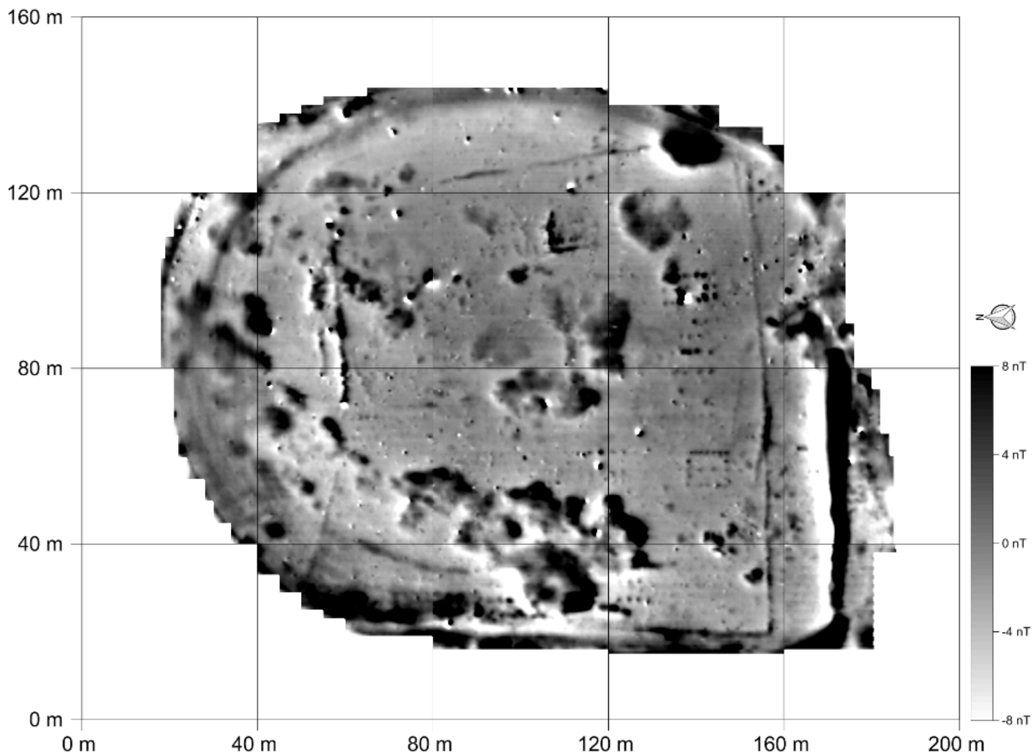

Fig 5. Magnetogram of the Hallstatt-enclosure on top of the Hahnenberg. Caesium-Magnetometer Scintrex Smartmag SM4G-Special, Duo-Sensor-configuration, Dynamics ±8 nT in 256 greyscales, sampling rate 50 x 25 cm, interpolated to 25 x 25 cm, 40-m-grid. Archive-Nr. Hah13a. © Jörg Fassbinder (BLfD)

The houses can roughly be categorized into two types: post-built houses and pit houses. The last ones have a size between 3-4 m x 5-8 m. As they have a wide range of size, orientation and shape, they cannot be dated to a specific epoch. However, all post-built houses inside the enclosure are oriented in north-south direction and resemble those excavated by H. Parzinger at the nearby Goldberg (Parzinger 1998). Most of them show a strong magnetic anomaly in their interior, which can be caused by a fireplace in the case of a residential building or by cesspits in the case of stables. Some of the 4-posthole houses without a strong magnetic anomaly in the centre possibly were used as storage buildings. In total 14 post-built houses can be identified and the survey results show a typical layout of such a Hallstatt-period settlement (Fassbinder et al., 2014). Due to the high sensitivity of the utilized caesium magnetometer, it is possible to map each single post-hole of these houses. Such small and faint features normally cannot be clearly detected with the commercial fluxgate magnetometer systems that are commonly used in Archaeological Prospection.

The huge irregular pit complex in the western part of the magnetogram possibly is caused by quarry activity or is a remnant of rock shelters and caves of the Paleolithic period. An exact classification of these features is only possible by archaeological excavations (Fassbinder et al. 2019).

3.4 Resistivity prospection

A Roman *villa rustica* can also be found in Burgweinting (Lkr. Regensburg, Upper Palatinate). For a detailed mapping of the preserved remains, the BLfD executed a resistivity prospection over an area of 140 x 120 m. The results show a typical layout with a trapezoidal enclosure wall erected from stone (Fig 6). It has a width of 50 – 85 cm and could be traced at three sides. The entrance to the site can be reconstructed in the west due to an interruption in the wall (Irlinger and Fassbinder 2000).

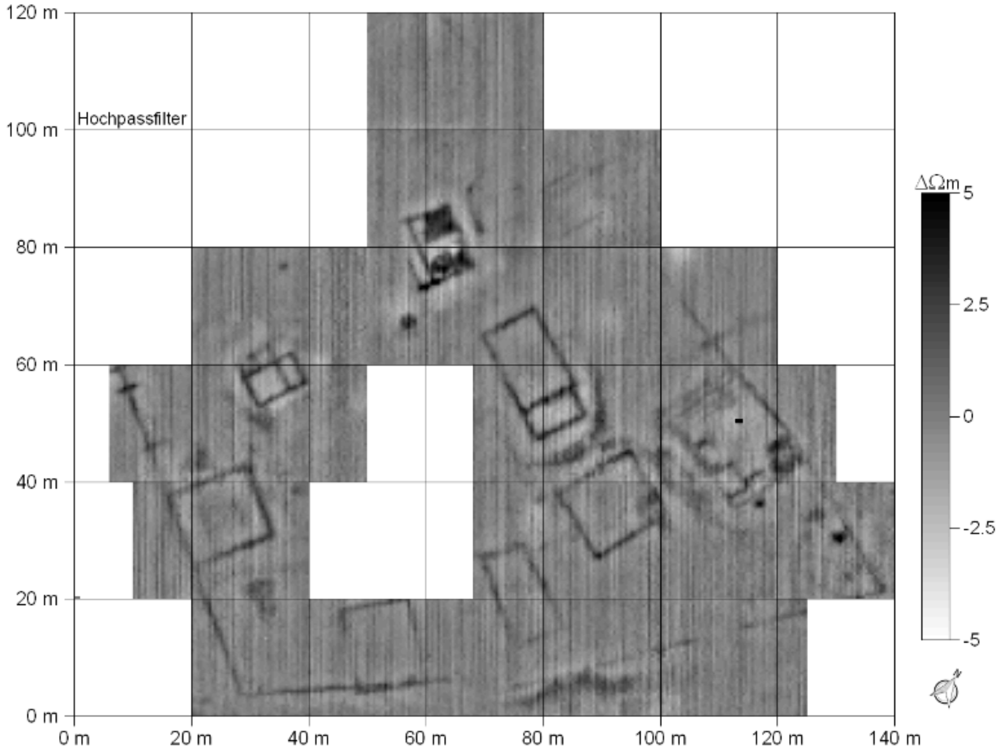

Fig 6. Resistogram of the Roman *villa rustica* in Burgweinting. Geoscan RM15, Dipole-Dipole-configuration, dynamics: ± 5 Δ Ohm m, sample interval 50 x 50 cm, interpolated to 25 x 25 cm, 20m-grid, processing as high pass-filter. Archive-Nr. Bweooe. © Jörg Fassbinder (BLfD)

Directly attached to the enclosure wall, five buildings were erected. Most of them do not show a division into single rooms; only the south-eastern one is subdivided into minimum four rooms. The last building is supposed to be the main residential building of the *villa rustica* with a size of 22 x 16 m, as M. Ontrup (2020) supposes based on the results and corresponding excavation results. The square-like rooms in the south then have to be the risalites at both sides of the entrance. Directly south-west, another nearly quadratic building of 15 x 13 m size gets visible that had a small internal subdivision. Archaeological excavations following the geophysical survey have shown that this was a Roman drying kiln for grain (Ontrup 2020). Inside the enclosure of the *villa rustica*, another four buildings of unknown function can be identified. The northern one shows preserved floor pavements as laminar high resistive anomalies in the survey result. Also, the south-western and southern houses had a division in single rooms. The circular anomaly in the centre of the courtyard possibly depicts a Roman stone well.

3.5 Ground-Penetrating Radar

Near Heroldingen (Lkr. Donau-Ries, Swabia) a Baroque summer residence was built at the end of the 17th century. For the construction, a natural hill was artificially levelled and hence a plateau was created that is flat towards the north and steep towards the other sides. After some decades, the palace was re-used as a faience manufacture. However, already in the middle of the 18th century, the complete building complex was ruinous and all buildings were completely removed. So nowadays only the flat plateau gives a hint to the former size of the site (Linck and Fassbinder 2018).

The former layout of the residence is known from an old Baroque plan by Johann Paul Thomas Edel (around 1730) that shows an elongated single-storey main building. North of the main building, a huge courtyard that was flanked by several subsidiary buildings existed. The northern closure of the courtyard had been a trapezoidal enclosure wall with attached barracks for the palace guards.

As it is not sure, how accurate this old plan is, the BLfD executed a magnetometry survey of the whole residence area and a small-scale GPR survey on an 80 x 80 m grid covering the north-eastern part of the trapezoidal enclosure. Here, only the radar results will be treated further. The radargrams show the stone remains of the residence at a depth of 20 – 120 cm below the modern surface. Hence, only the lowest 1 m of the foundations are preserved; all other walls had been removed during the deconstruction of the residence. In the north, the radar depth slices show the eastern part of the barracks as an elongated building bent by 135° (Fig 7).

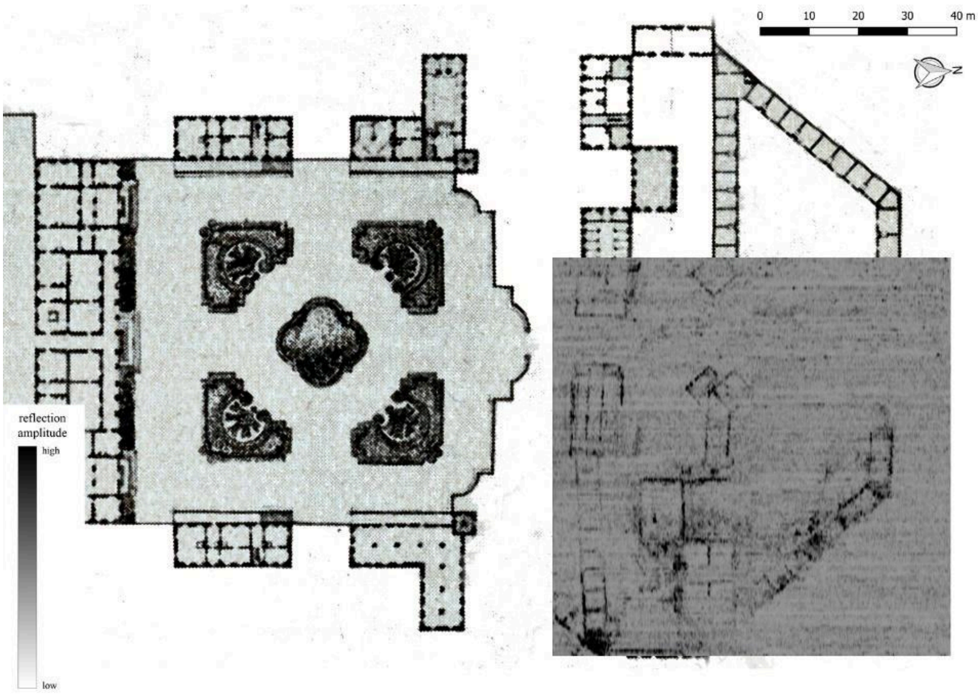

Fig 7. Overlay of the Baroque plan of the summer residence at Heroldingen with the GPR depth slice of 60 – 80 cm. GSSI SIR-3000 with 400 MHz antenna, sample interval: 2 x 50 cm. Archive-Nr. Hdg14rad. © Roland Linck (BLfD)

The soldiers' rooms have a standardized size of 2.5 m. After 35 m in length, the structure bends towards the west and ends in a squarish entrance gate, which has a counterpart on the other side of the access road. In the southern part of the radar images, another similar structure running east-west can be identified that never has been documented before. This structure ends in a 16 x 10 m sized building in the west that already was mapped by Edel. At the same place, another slightly shifted building of 17 x 9 m size with two parallel walls is preserved. This can be interpreted as remains of renovation work. In between several further walls can be identified and reconstructed to further buildings of 12 x 8 m and 7 x 12 m size. The linear structures in the south-eastern corner of the depth slices can be interpreted as parts of a former sewage system. At the same location the remains of a Baroque pavement have preserved (Linck and Fassbinder 2018).

3.6 Time-domain reflectometry

Simultaneously to each GPR survey, we acquire the relevant soil parameters in a constant time interval during the survey time. This enables to map diurnal changes in the parameters that can possibly influence the radar data. Due to the importance of the soil parameters, once we also applied a laminar survey of the parameters in a 2 x 2 m raster at the example of a Roman picket in Hienheim (Lkr. Kelheim, Lower Bavaria) to get an impression whether the archaeological remains also show up in the soil parameters. The corresponding results can be found in Fig 8. The conductivity map shows that even in the topmost few decimetres, the buried limestone walls of the picket lower these values. In the north-eastern corner of the 30 x 30 m grid, the conductivity values are maximum. Hence, in this area, an accumulation of electrolytes can be assumed, as this is the lowest point of the area. A similar distribution can be seen in the map of the soil moisture. Again, the central part with the limestone foundations shows up with lower moisture due to the debris that cannot store the water in the same manner as the undisturbed surrounding soil (Linck and Fassbinder 2014).

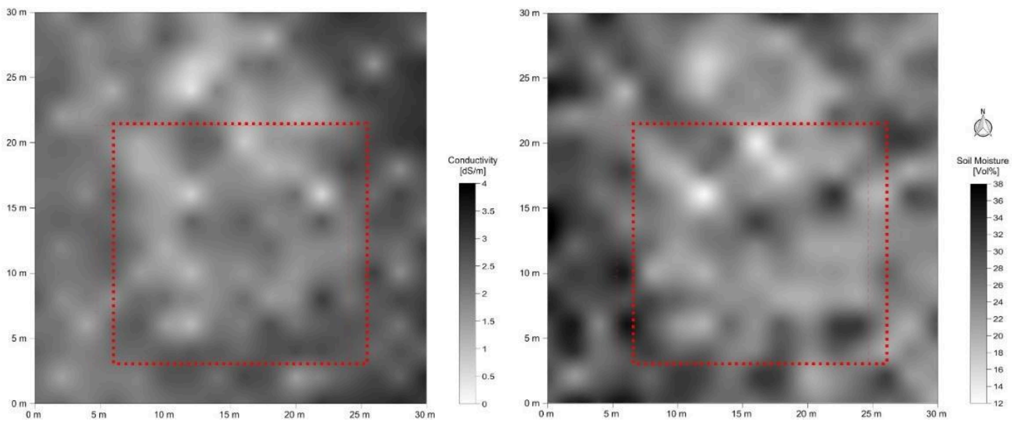

Fig 8. Distribution map of the conductivity (a) and soil moisture (b) above the Roman picket in Hienheim. IMKO TRIME-PICO64 time-domain reflectometry device, point density: 2 x 2 m, 256 grey scales from white to black. © Roland Linck (BLfD)

4. Conclusion

The presented results show that the Archaeological Prospection plays an indispensable role in heritage protection in Bavaria. The data depicts an important tool for archaeological research as well as the planning of construction work. The unique possibility to host even two huge archives with aerial photos and geophysical data in a single institution enables a fast and efficient workflow in the day-to-day-routine of heritage protection. By the possibility to apply a multitude of different geophysical methods, it is furthermore possible to react to the specific requirements of each monument. Because depending on the size of a monument and the used building material, the most relevant method can be chosen. Often an integrated survey with different methods provides the best overview and ensures that each structure is mapped.

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