



Rufiniana – antikes Mutterstadt – eine römische Stadt am Rhein

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Ptolemy's Roman Rufiniana: Evidence for a Location in the Mutterstadt Area.

by Herbert H.W. Metzger¹ and Kord Ernstson²

Abstract

The quote left by Ptolemy in the year 150, “Rufiniana, situated between Worms and Speyer,” referred to a Roman city on the Rhine that was of extreme importance for military and trade strategy, whose exact location remains unclear to this day and has led to various speculations regarding its location. The view expressed in the 1930s by a local historian and chronicler that Rufiniana could well have been located within the Mutterstadt district has led to extensive new research, considerations, and reconstructions regarding a location between Alsenborn and Ladenburg, which are reported here. As a result, a critical review of earlier archaeological arguments is conducted, and it is demonstrated that the original idea from the 1930s regarding the location of Rufiniana near Mutterstadt can be clearly verified.

Keywords: Rufiniana, Roman settlement, Rhine Valley Road, archaeology, geophysics, digital terrain model

Ptolemy's Roman Rufiniana: New evidence for its location

Abstract.—The statement “Rufiniana, situated between Worms and Speyer,” recorded by Ptolemy in 150, referred to a Roman town on the Rhine that was of great strategic importance for military and trade purposes. Its exact location remains unclear to this day, giving rise to various theories regarding its whereabouts. The opinion expressed in the 1930s by a local historian and chronicler that Rufiniana could well have been situated in the area of the Mutterstadt district has led to extensive new research, considerations, and reconstructions, which are reported here. As a result, a critical review of earlier archaeological arguments is conducted, and it is concluded that the original idea from the 1930s regarding the location of Rufiniana near Mutterstadt must be clearly verified.

Keywords: Rufiniana, Roman settlement, Rhine Valley Road, Archaeology, Geophysics, Digital Terrain Model

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1 Introduction - Current knowledge and assumptions regarding the location of Rufiniana

Rufiniana (not to be confused with the ancient city of the same name in Tunisia) is the name of a site on the Upper Rhine (Fig. 1, Fig. 2), which the Greek astronomer, mathematician, geographer, and philosopher Claudius Ptolemy mentions around 150 as a settlement of the Nemetes in the Roman province of Germania Superior. Historians generally locate it as a Roman customs station in the area between Speyer and Worms; early considerations can be found, for example, in Zangemeister (1898) and Hildenbrand (1913).



Fig. 1. Map showing Rufiniana (arrow).

The most likely location is currently considered to be the Palatinate town of Eisenberg (Fig. 2; approx. 20 km WSW of Worms), where numerous findings—including a Roman road, a commercial vicus (small-town settlement), and recent excavations—point to a strong Roman presence. Iron extraction from ores in the Palatinate Forest has also been documented.

Some scholars, however, locate Rufiniana in the Ludwigshafen district of Rheingönheim, while there is little evidence to support an isolated identification with the Alsatian town of Rouffach (German: Rufach). A proposed location on the right bank of the Rhine

near Heidelberg-Neuenheim (Sprater 1952, Hommel 1954 [cited by Schleiermacher 1955]) was not pursued further.



Fig. 2. Site plan for the presumed Rufiniana near Mutterstadt.

Remaining within the region between Worms and Speyer, Prof. Dr. Heinrich Eyselein, in his local chronicle of Mutterstadt, first placed the existence of Rufiniana within the boundaries of Mutterstadt as well as Ludwigshafen-Rheingönheim and -Maudach (Fig. 2) (Eyselein 1938). He also refers to the hypothesis of a location in the vicinity of the Rheingönheim fort, considers this uncertain, and states in his second local chronicle of Mutterstadt (Eyselein 1967) that Rufiniana “could just as well have been one of the Roman settlements on Mutterstadt soil.” Prof. Eyselein’s ideas were revisited by Metzger (2019), subjected to extensive new research, and are revisited in the following discussion, which regards Mutterstadt as the successor site to Rufiniana.

Whenever the name Rufiniana appears in the following discussion, it is made clear—to avoid the frequent use of terms such as “presumed,” “suggested,” “postulated,” etc.—that, apart from quotations from other sources, the reference is always to Rufiniana, for whose existence and location in the Mutterstadt area evidence is to be presented here.

2 The New Investigations

2.1 Prerequisites

The basis for the new concepts regarding the location of Rufiniana in the Mutterstadt area consists of three essential and fundamental facts, findings, and postulates (Fig. 3):

- a) the intersection of two major Roman roads near Mutterstadt: the well-known north-south route from Basel to the North Sea (the Roman Rhine Valley Road, e.g., Bernhard 2011) and the presumed east-west route from Alsenborn to Ladenburg, which is to be documented here
- b) the network of waterways in the Mutterstadt area as a prerequisite for the location of a major Roman town and its supply of ample water for domestic use (presumably less so for drinking water, which could be drawn from wells).
- c) a nearby port on the course of the Rhine at that time for the transshipment of goods between land and water routes.

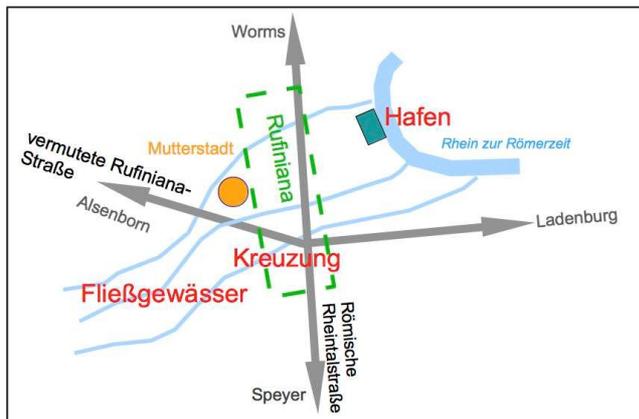


Fig. 3. Schematic map of the three key factors regarding the location of Rufiniana: intersection (a), watercourse (b), and harbor (c).

2.2 Literature Review

A significant portion of the findings regarding the location of Rufiniana near Mutterstadt is based on the observations of Prof. Eyselein in his local chronicles of Mutterstadt (Eyselein 1938, 1967). In a brief overview of key dates in Roman history from 55 BCE (Germanic tribes on the left bank of the Rhine come under Roman rule) to 406 (the right bank of the Rhine as the border of the Roman Empire), around 10 BCE: construction of 50 forts along the Rhine, 41–50 (Emperors Claudius and Valentinianus): expansion of the Speyer fort and the construction of a new fort between Rheingönheim and Altrip (e.g., Schneider 2018), Eyselein mentions the name *Rufiniana* for the first time and speculates that this fort was the location on the Rhine mentioned by Ptolemy. Later (Eyselein 1967), the aforementioned quote appears, suggesting that Rufiniana “could just as well have been one of the Roman settlements on Mutterstadt soil.”

Eyselein (1938) also mentions the construction (by Claudius) of the north-south route from Basel to the North Sea (the Roman Rhine Valley Road), which in some sections also forms the eastern boundary of Mutterstadt. The text describes—noted here in relation to the geophysical measurements—the gravelly subgrade of the road discovered during earthworks and its partial destruction. A ridge interspersed with gravel, which can still be identified in sections today, is also mentioned, as is a continuation from the waterworks toward Frankenthal.

Eyselein lists a wealth of Roman finds in the vicinity of the Roman road, as well as in areas further afield, which, according to Eyselein, prove that settlements existed in the Mutterstadt district during the Roman period. He specifically mentions a Roman-era settlement on the small hill in front of the Unterpforte. Eyselein notes as noteworthy that all finds from the Roman era (up to 1938) were made exclusively east and north of Mutterstadt. The reason for this was the swamp forest, the marshland. This extended from the “Dannstadter Höhe” and stretched, relative to today’s Mutterstadt district, eastward to the very edge of the Rufiniana Road, which, as discussed in detail below, connected Alsenborn, via Bad Dürkheim, with Ladenburg.

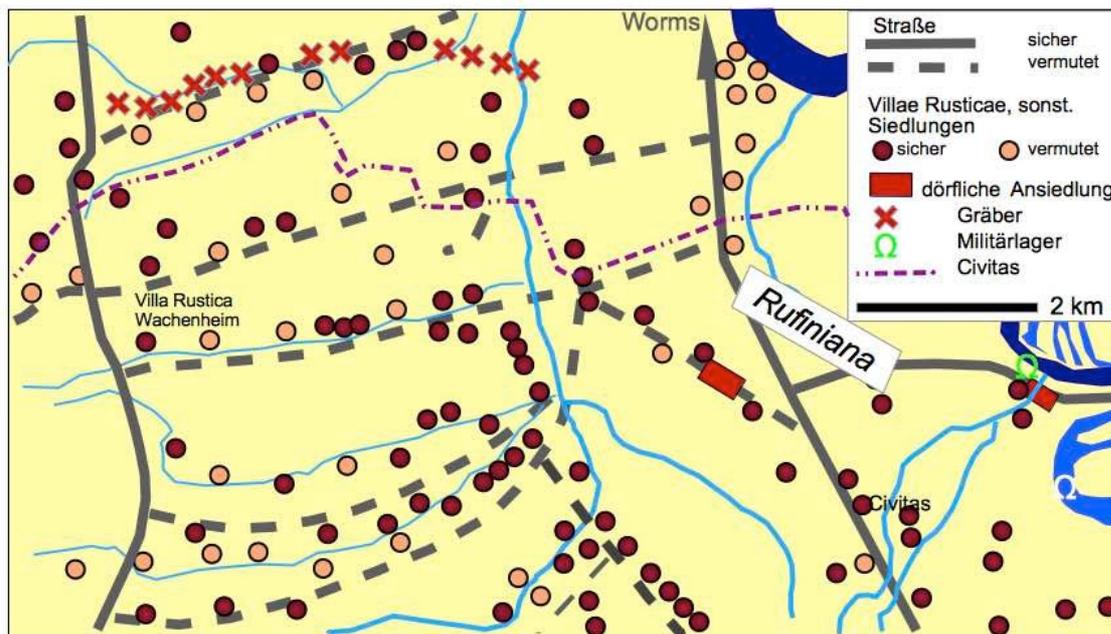


Fig. 4. Location of the presumed Rufiniana in relation to Roman finds, roads, and settlements between the Rhine and the Haardt Mountains. Base map simplified and modified: Bad Dürkheim City Museum.

Fig. 4 shows how the current archaeological evidence from the Roman period in the region of interest here is mapped, including confirmed and presumed settlements and Roman roads. This map will continue to play a role for archaeologists within the framework of the new model proposing the location of Rufiniana.

3 Field Findings

3.1 The Digital Terrain Model

The Digital Terrain Model (DTM 1) describes the terrain surface using data sets from a three-dimensional coordinate system with x-coordinates (X) and y-coordinates (Y) from the standard Gauss-Krüger or UTM grids, or from geographic longitude and latitude, as well as terrain elevation (Z) above mean sea level at regular grid points.

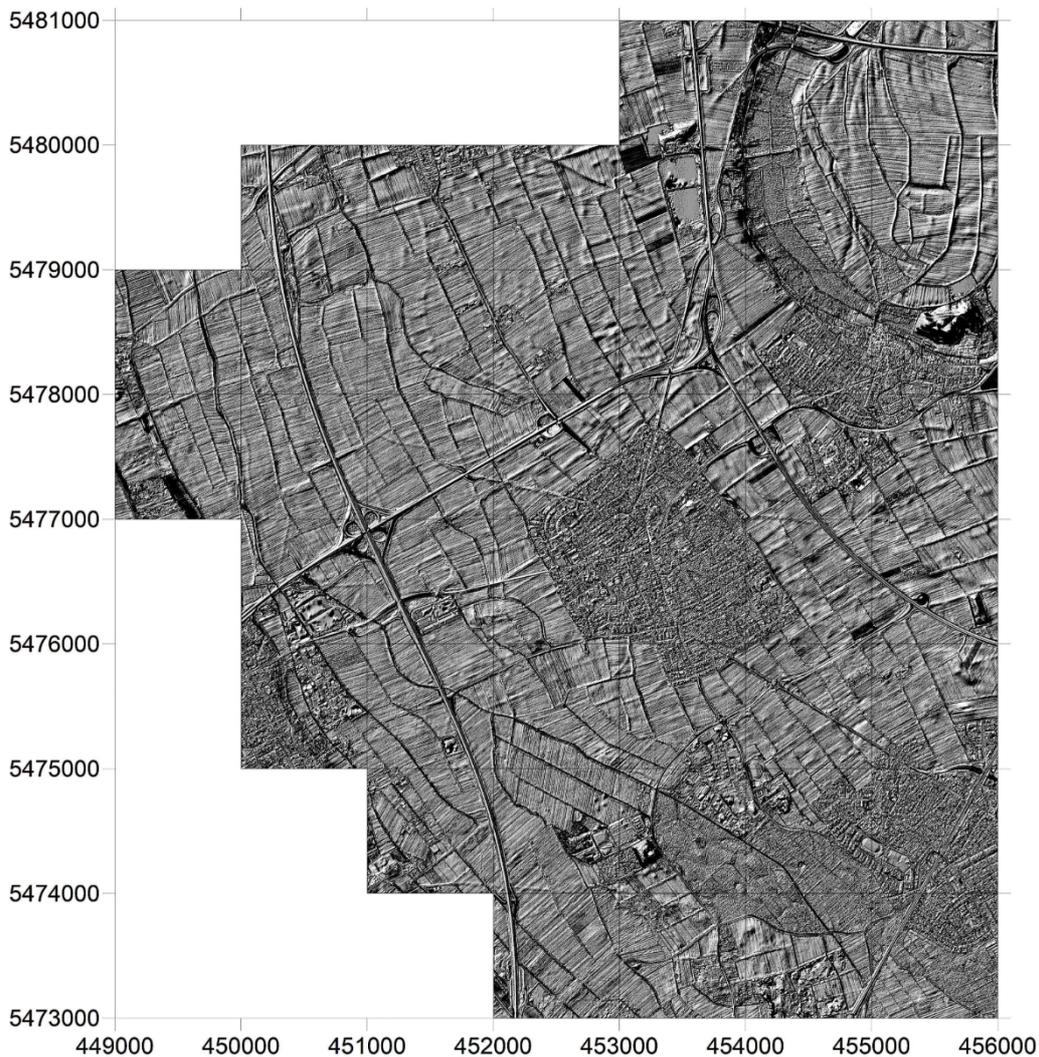


Fig. 5. The Digital Terrain Model DTM 1 for the Mutterstadt cadastral area in the form of a shaded relief map. UTM coordinates. Source: State Office for Surveying and Geobasis Information Rhineland-Palatinate.

The data is obtained from an aerial survey using laser scanning (LIDAR), whereby all buildings and vegetation are removed through data processing, so that the DGM accurately reproduces the ground surface even in forested areas. The dataset name DGM 1 refers to the grid size of the point grid (1 m x 1 m), with a positional accuracy of approximately ± 0.5 m and an elevation accuracy better than ± 0.2 m.

For this study, the original DGM 1 data for the entire Mutterstadt municipal area and its surrounding areas were acquired from the Rhineland-Palatinate State Office for Surveying and Geospatial Information, subjected to a general review (Fig. 5), and have already been analyzed in specific areas, as will be discussed later. Here, a selection of the possibilities is shown, illustrating the range of highly detailed and precise terrain analyses that the DGM 1 offers (Fig. 6).

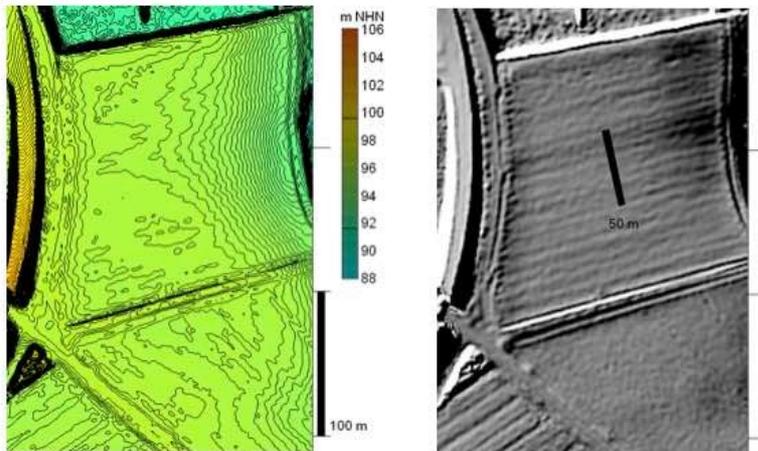


Fig. 6. Sample section of the DGM 1 from the Mutterstadt cadastral area. **Left: Topography, contour interval 10 cm.** **Right: Shaded relief of the same area.** Note the regular pattern (WSW–ENE) on the northern farmland with a spacing of the minimum ground waves of approx. 10 m. A second, weaker system (SSW–NNE) is also visible. Wölbäcker (?) of unknown date.

3.2 Geophysical measurements—ground-penetrating radar, pulsed electromagnetic, geomagnetic

3.2.1 Overview

Geophysical measurements are now standard practice in advanced archaeological investigations. Following preliminary test measurements, such investigations were systematically conducted using three different, complementary measurement methods (Fig. 7) in selected areas relevant to the subject matter at hand. Following this initial general and very brief introduction to the methods, specific results will be discussed in the subsequent chapters.

With regard to the depictions of the survey areas and the field measurements, it is important to note that the results presented here consist largely of test measurements conducted in various parts of the presumed Rufiniana area, which is reflected in the profile spacing of 3–5 m—a distance that is generally too wide for archaeological purposes. While measurements along the profiles are taken at digital *sampling* rates of 3 cm (ground-penetrating radar) and 5 cm (for pulse electromagnetic and geomagnetic surveys), providing extremely high resolution, there are understandably significant gaps in resolution between profiles spaced meters apart.

This also results in the interpolation processes in the areal isopach maps leading to unnaturally elongated anomalies perpendicular to the profile directions—a well-known effect.



Fig. 7. Measurement systems used in the Mutterstadt project (from left): ground-penetrating radar (Transient Technologies VIY3-300, 300 MHz antenna), pulsed electromagnetic (EBINGER UPEX 740 M), geomagnetic (EBINGER MAGNEX 100 B gradiometer with EDAD digital system).

3.2.2 Ground-penetrating radar.

Radar waves are emitted from a transmitting antenna (Fig. 7), reflected off obstacles or layer boundaries, and received by a receiving antenna. Frequencies between 20 MHz and 1000 MHz can be used, with higher frequencies providing higher resolution at a shallower penetration depth. The use of lower frequencies allows for greater penetration depth, whereas the resolution accuracy is reduced accordingly. The measurement data is presented in so-called radargrams, in which the reflected signals are plotted on a profile section as a function of travel time (in nanoseconds, ns) or depth (m) (Fig. 8). The magnitude of the amplitudes is represented by a color-coded scale.

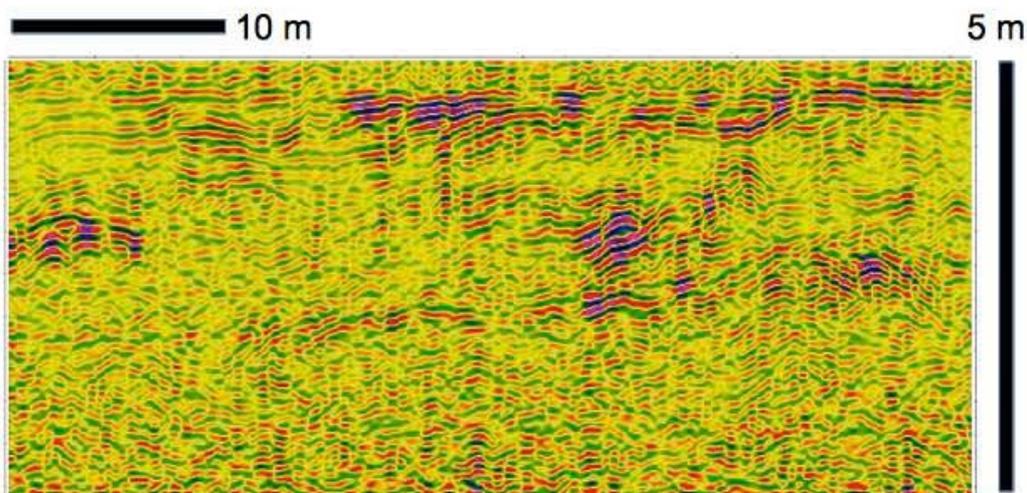


Fig. 8. Example radargram from the Mutterstadt measurement area. Geological causes can be ruled out for the strong reflectivities, some of which end abruptly. The assumption of anthropogenic structures is compelling.

3.2.3 Pulse Electromagnetics.

Transient electromagnetic (TDEM) is a branch of geophysics used to determine the distribution of electrical conductivity in the subsurface. To do this, magnetic pulses are sent into the subsurface via a current-carrying transmitter loop (Fig. 7, center). There, they generate induced currents that propagate depending on the conductivity of the materials and are in turn linked to upward-propagating magnetic field pulses. These are picked up by the loop now functioning as a receiver (on the continuously guided sled—Fig. 7) and converted into an electrical induction voltage, which represents the desired measured quantity. In electrically conductive objects or geological layers, strong currents are induced, whose powerful secondary magnetic field can generate strong induced voltages in the loop, manifesting as noticeable anomalies (Fig. 9).

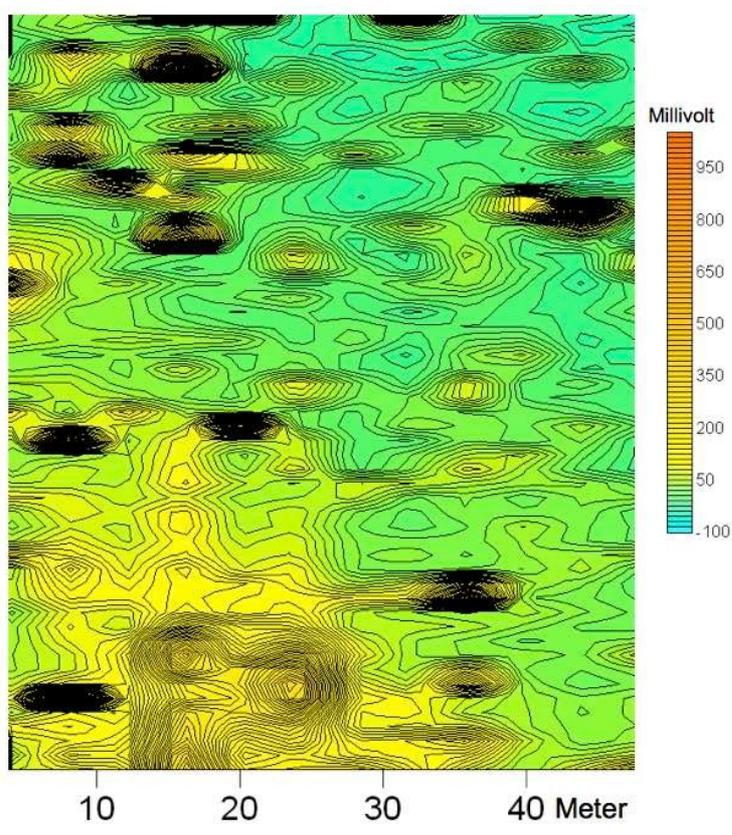


Fig. 9. Example area of pulse electromagnetic surveys (100 μ s delay time) in the Mutterstadt measurement area. In the lower left half, the sharply defined geometric structure, approximately 15 m wide, with accompanying smaller anomalies, suggests an anthropogenic origin. The same applies to the many even more sharply defined smaller, positive anomalies measuring a few meters in size; however, it should be noted that the elongation in the horizontal direction is usually, but not always, caused by the interpolation process using very low sampling rates on widely spaced profiles—a well-known effect. More on the anomalies in the text.

3.2.4 Magnetic field measurements (geomagnetism).

Magnetic field measurements are based on the property of matter to become magnetized within the Earth's magnetic field through an induction process. In the case of specific objects, one can imagine them becoming magnets themselves, with their magnetic fields superimposed on the normal, undisturbed Earth's magnetic field. In most materials, this induced magnetism is very weak and detectable only with highly sensitive measuring instruments. It can be much stronger in iron and steel, but some minerals can also possess strong magnetization, which is primarily responsible for the magnetism of rocks. Fired ceramics can also very often be strongly magnetic due to the firing process of the clay. In recent years, measurements using so-called gradiometers have become standard. With fluxgate-type devices, measurements can be performed continuously at walking pace with digital data logging (Fig. 7, right). If the measurements are taken along equidistant profiles, the computer constructs areal distributions of magnetic anomalies that can be attributed to individual objects or soil structures (Fig. 10).

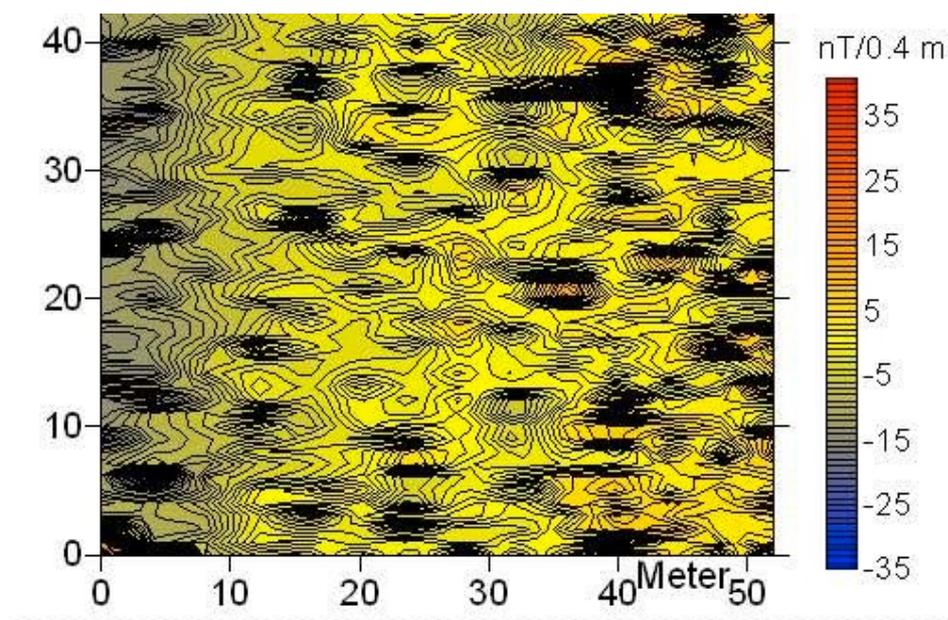


Fig. 10. Example geomagnetic area in the Mutterstadt survey zone with countless sharply defined positive anomalies within an overall magnetically disturbed field. Regarding the elongation of the anomalies, the remarks made previously in Fig. 9 apply, although their character and areal distribution share similarities. More on this is provided in Fig. 11 and in the text.

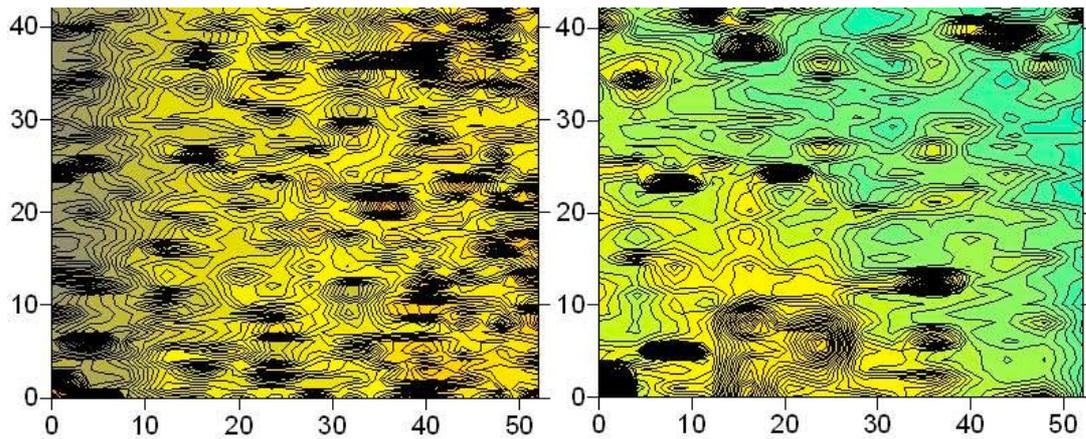


Fig. 11. Direct comparison of magnetic field measurements and pulse electromagnetics on the same area shown in Figs. 9 and 10. Note that the anomalies, which are roughly the same size, partially coincide, although their relative amplitudes vary greatly. More on this in the text.

A notable feature has emerged from the geophysical surveys conducted for archaeological exploration in the Mutterstadt area. As illustrated in Fig. 11, there is, in some cases, a good correlation between the magnetic field measurements and the pulse electromagnetic (PEM) readings. This is not fundamentally unusual, considering that ferrous metal objects are generally highly magnetic but can also cause strong induction effects. Confusing in this context are the strong positive electromagnetic anomalies (Fig. 11, right), which one would like to attribute to metallic (ferrous or non-ferrous) objects. The question of the nature of the objects in the subsurface—which, according to the note on Fig. 9, must in some cases be up to several meters in size—arises following the measurements taken on a completely ordinary field with no other distinctive surface features. Regular structures such as cast-iron pipes are out of the question, although a ferrous component must still be considered due to the correspondence between the two geophysical fields.

A potentially more plausible explanation suggests itself when considering Roman artifacts. Rock magnetic analyses of brick fragments collected from the field (Fig. 12) reveal strong magnetism, which is known to arise—though not necessarily—during the firing process of the clay material due to the formation of highly magnetic minerals (e.g., magnetite). What is unique about these brick fragments is their reaction to pulse-electromagnetic devices, which indicate an apparently strong metallic conductivity that, of course, does not exist but is a consequence of a very specific type of magnetism. This superparamagnetism, which is bound to micro- and nanoparticles in the material, causes metal detectors operating on the pulse principle to react as they would to metallic objects.

Therefore, it is postulated here that many of the isolated strong pulsed electromagnetic anomalies are not reactions to metals in the subsurface,

but rather indicate fired ceramics (e.g., small structures or, more generally, accumulations of bricks). In terms of size, Roman heating structures, such as those mentioned by Eyselain (1938) from the Mutterstadt area, well systems, or even brick kilns could be possible candidates. Without excavation findings, this assumption must remain unanswered; however, it will be addressed again in later chapters.



Fig. 12. Roman brick fragments from a well-known field with abundant surface finds in the Mutterstadt survey area. Rock magnetic measurements on the samples show strong magnetization with an apparently significant proportion of superparamagnetism. See the text for further details.

3.2.5 Scope of the measurements

Based on previous considerations regarding the location and extent of the presumed Rufiniana formation, geophysical surveys were planned and conducted in three areas (Fig. 13). In the area near the presumed road junction, ground-penetrating radar measurements as well as pulse electromagnetic and geomagnetic measurements were conducted over an area of 100 m x 100 m. In a central area, an area measuring 100 m x 30 m was surveyed using the same methods, and two radar profiles, each 200 m long, were acquired across the Roman road. At the presumed boat harbor, following the terrain drop-off to the Maudacher Bruch, a 100 m x 100 m measurement area for ground-penetrating radar was established with a profile spacing of 4 m. On the same area, pulsed electromagnetic measurements were conducted with a delay time of 200 μ s. In addition, magnetic field measurements and pulse electromagnetic measurements with a delay time of 100 μ s were conducted on a sub-area measuring 50 m x 60 m. It should be noted that with longer delay times, information is primarily obtained over greater depth ranges, while the effects of smaller objects are suppressed. The opposite is true for short delay times.



Fig. 13. The geophysical survey areas.

4 The new model of Rufiniana's location near Mutterstadt

4.1 The roads

The model presented here of the location of the Roman town of Rufiniana near Mutterstadt essentially covers the region between Worms and Speyer, with a particular focus on the area between Alsenborn (Kaiserslautern) and Ladenburg (Fig. 3, Fig. 14). In this context, the north-south arterial roads (the well-known Roman Road through the Rhine Valley passing by Mutterstadt) and the east-west arterial road postulated here and named the Rufiniana Road, with an intersection in the Mutterstadt study area, both integrated into a wide-ranging supraregional and cross-state transportation network, play a decisive role (Fig. 14) (see also Rösch and Rösch 2010). The following sections of this east-west arterial road—Alsenborn

– Bad Dürkheim (Fig. 15), the section around Bad Dürkheim/Villa Rustica Wachenheim (Fig. 16), the route from Villa Rustica – Mutterstadt (Figs. 17, 18), the intersection area (Figs. 19–22), and the section on the right bank of the Rhine, Mutterstadt–Ladenburg (Fig. 23).

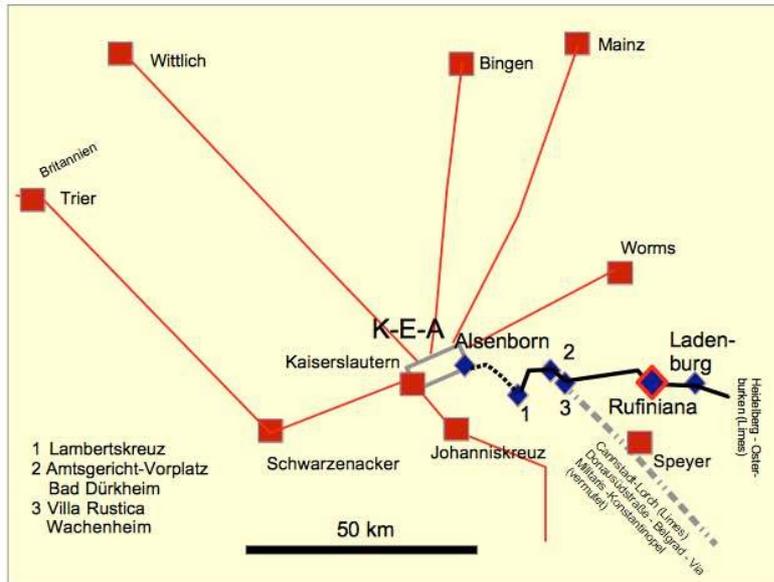


Fig. 14. Roman transportation hub area Kaiserslautern – Enkenbach – Alsenborn (K-E-A) as a “feeder” to the east-west main road of the Rufiniana Road (blue) discussed in the article. The following figures present in detail the results of the new research on the Roman town of Rufiniana, in which the main road plays a significant role.

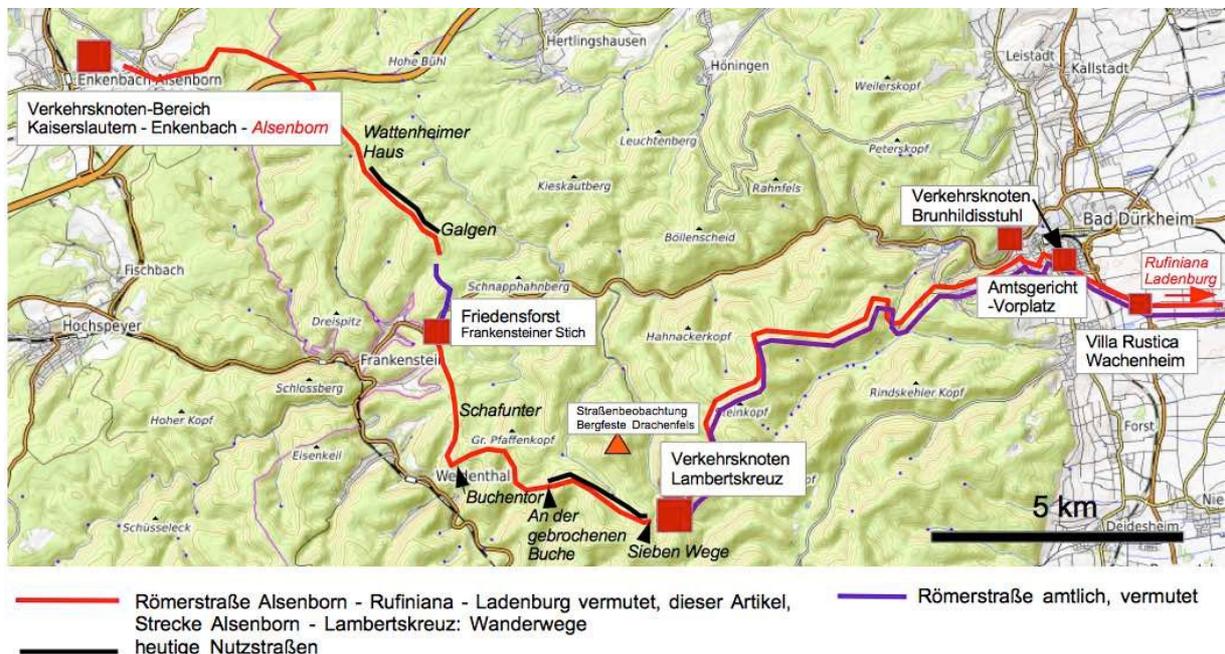


Fig. 15. 1st century: Alsenborn–Villa Rustica Wachenheim section of the favored Roman west-east thoroughfare from the Kaiserslautern–Enkenbach–Alsenborn transportation hub via the Rufiniana to Ladenburg. Excavations confirm the existence of a Roman road junction at Lambertskreuz, which was guarded by a mountain fortress (Drachenfels).

The Alsenborn–Bad Dürkheim section. - The presumed designated route from Alsenborn to the Lambertskreuz transportation hub crosses the Haardt-Höhe without passing through any valleys (see the shaded relief in Fig. 15) and, with consistently very gentle gradients, enables heavy-load transport by oxen with significant time savings on the routes Trier–Alsenborn - Bad Dürkheim - Speyer and Bad Dürkheim - Rufiniana - Ladenburg. A conceivable direct route without gradients from the Frankenheim branch to Bad Dürkheim in the Isenach valley (along today’s B 37) was out of the question, as in Roman times all valleys were generally subject to constant weather disasters and were impassable due to rockfalls and fallen trees. High-altitude or hillside roads were therefore the norm.

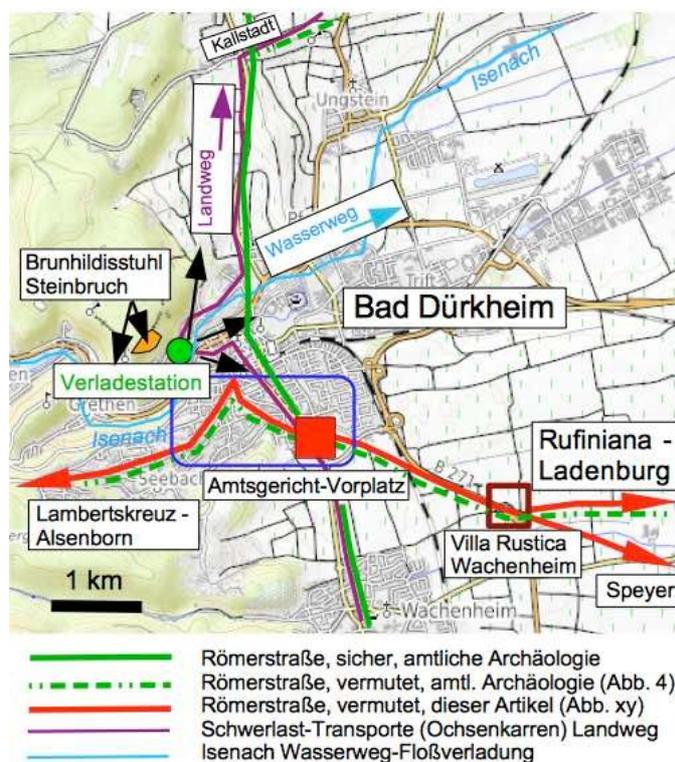


Fig. 16. 1st century: Map of Roman infrastructure near Bad Dürkheim (map base: OpenTopoMap). Presumed traffic junctions: District Court forecourt, Villa Rustica Wachenheim, and Brunhildisstuhl—loading station for the quarry dumping area.

Bad Dürkheim - Wachenheim, Villa Rustica. - At the forecourt of the district court, the official north-south road intersects with the Roman road to Mutterstadt (as hypothesized by authorities) and the extension of the Alsenborn Magistrale to Speyer and Mutterstadt (Rufiniana) assumed in this article. Included in the diagram here is the postulated important land/water transshipment station for the Brunhildisstuhl quarry

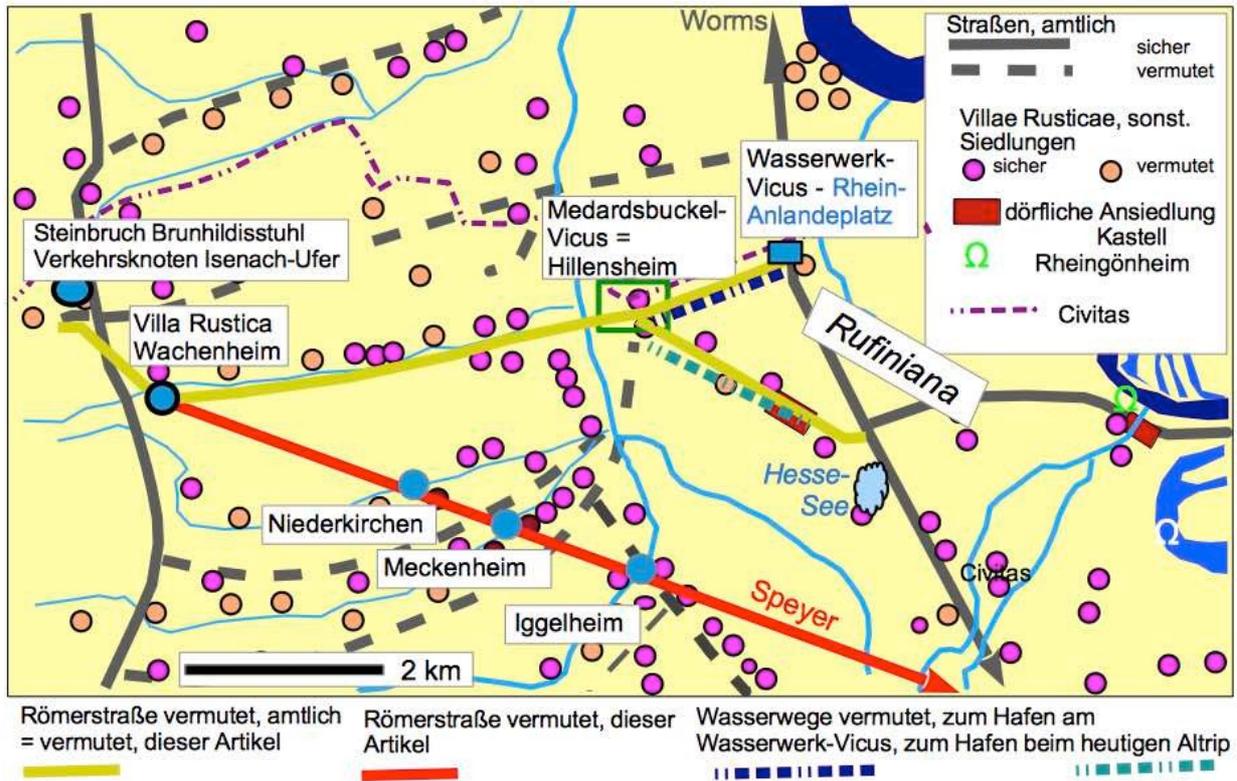


Fig. 17. 1st century, research: road network, official and—deviating from this—presumed (this article) between the Bad Dürkheim/Villa Rustica transportation hub and the Rufiniana with the northern Rhine landing site (Wasserwerk-Vicus). More on this in the text. Map basis: simplified and modified, Bad Dürkheim City Museum. 1. For better orientation, the stream network is shown with the artificially created Floßbach following its current course (see Fig. 25).

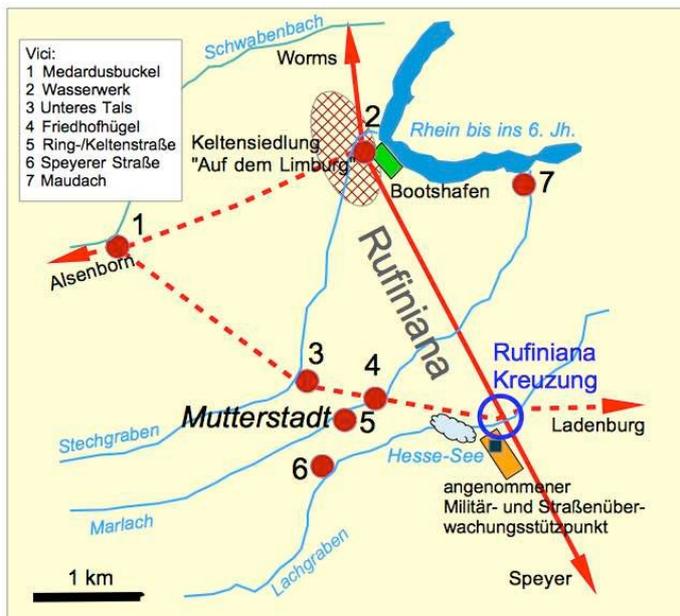


Fig. 18. Research: Rufiniana (from 10, at the latest from 70) and seven vici as successor settlements to the Celtic oppidum of the Mediomatrici “Auf dem Limburg.” The Roman roads (red) were upgraded Celtic paths. The Rufiniana intersection (see also Fig. 17) is a fundamental feature of this research. More on the waterways in section 4.2.

Villa Rustica – Mutterstadt (Rufiniana). – It is officially hypothesized (Fig. 17) that a Roman road route extended from Bad Dürkheim, splitting at the Medardusbuckel vicus into an eastern and a southeastern branch. The assumptions in this article also follow this route, as shown in greater detail in the diagram in Fig. 18. According to this, the eastern branch turns directly toward the Roman Rhine boat harbor postulated here, while the southeastern branch leads to the Rufiniana Crossroads; both of these are discussed in greater detail in the following sections.

The Rufiniana Intersection, - The road intersection, whose exact location has been unknown until now, is depicted very precisely in the shaded relief map of the Digital Elevation Model (Fig. 19). The same applies to the course of the east-west thoroughfare from the intersection over the cemetery hill—with its rich excavations of Roman artifacts—through Mutterstadt toward Medardusbuckel (Fig. 20).

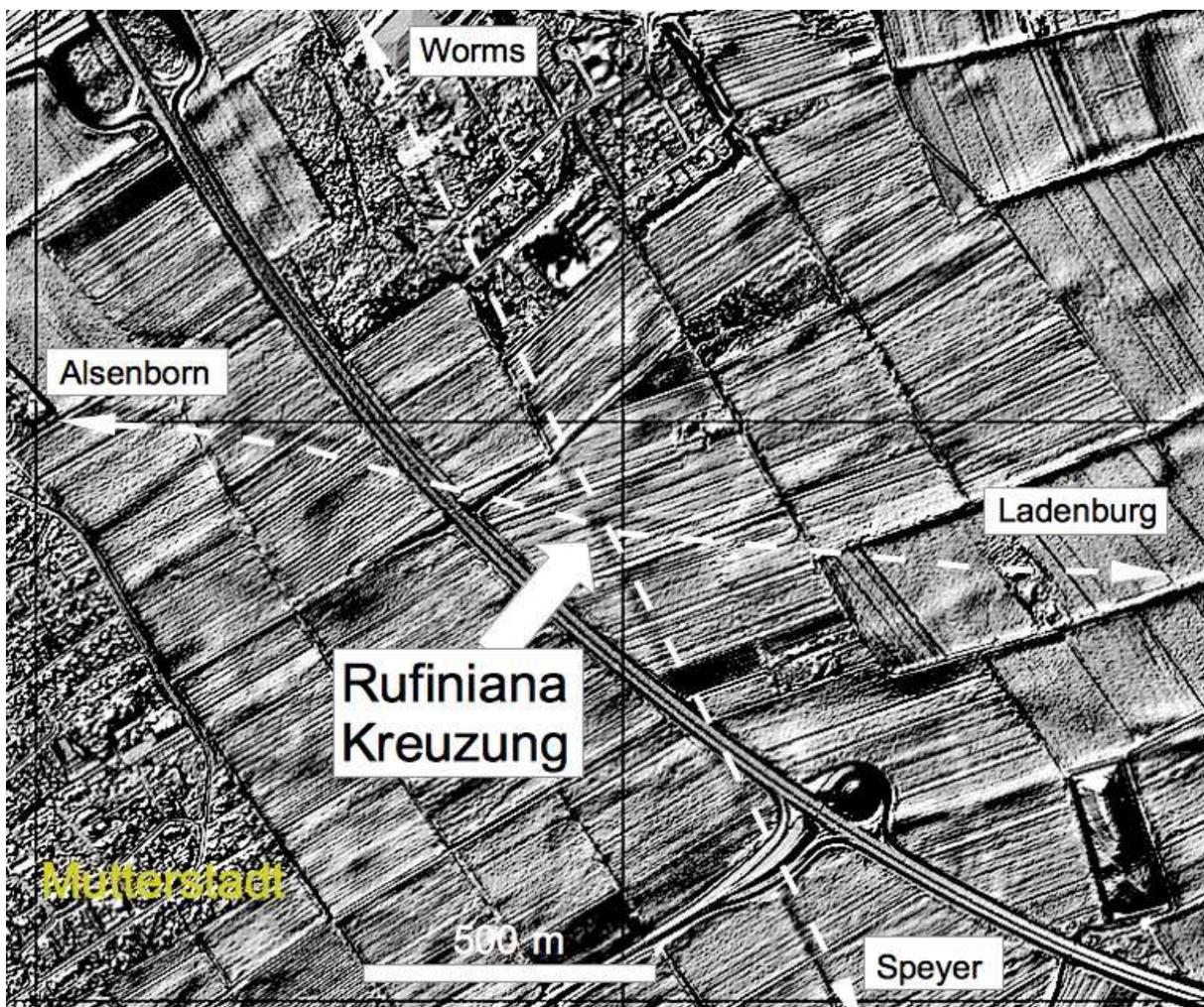


Fig. 19. The Roman road from Worms to Speyer and the intersection with the Rufiniana Road in the Digital Terrain Model (DTM) 1.

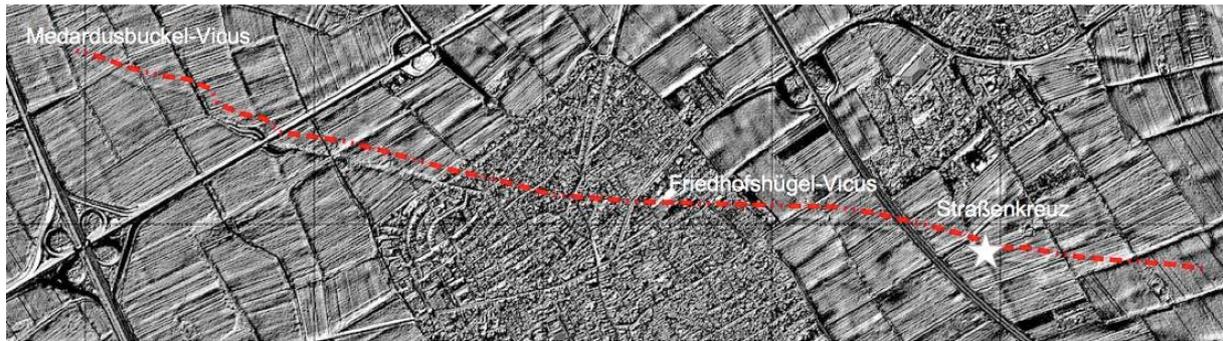


Fig. 20. Clearly visible in the Digital Terrain Model: the presumed east-west Roman road from the crossroads over the Friedhofshügel vicus and the Medardusbuckel vicus toward Alsenborn.

Ground-penetrating radar over the Roman road. - A look beneath the surface of the Roman road using ground-penetrating radar is revealing (Figs. 21, 22). This is a preliminary analysis that does not yet take terrain morphology into account. The strong reflections in the center of the road (Fig. 21) may be related to the road's construction. The block-like individual reflections on the right edge of the radar image could belong to the same objects that are also visible in the geomagnetic and pulse electromagnetic surveys (Fig. 11). More information on the geophysical measurements at the road junction can be found in Section 4.3.1. A comparison with a ground-penetrating radar profile of the Rhine Valley Roman Road near Maudach reveals a significantly different structure, which is also conveyed by the DGM 1.

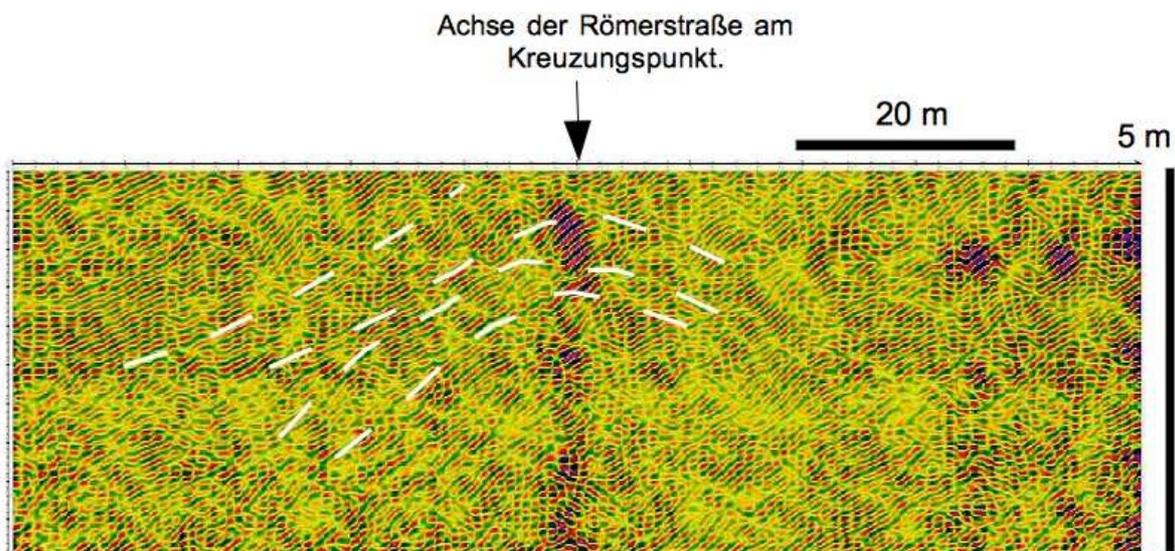


Fig. 21. A section of the Roman road as shown in the ground-penetrating radar measurements.

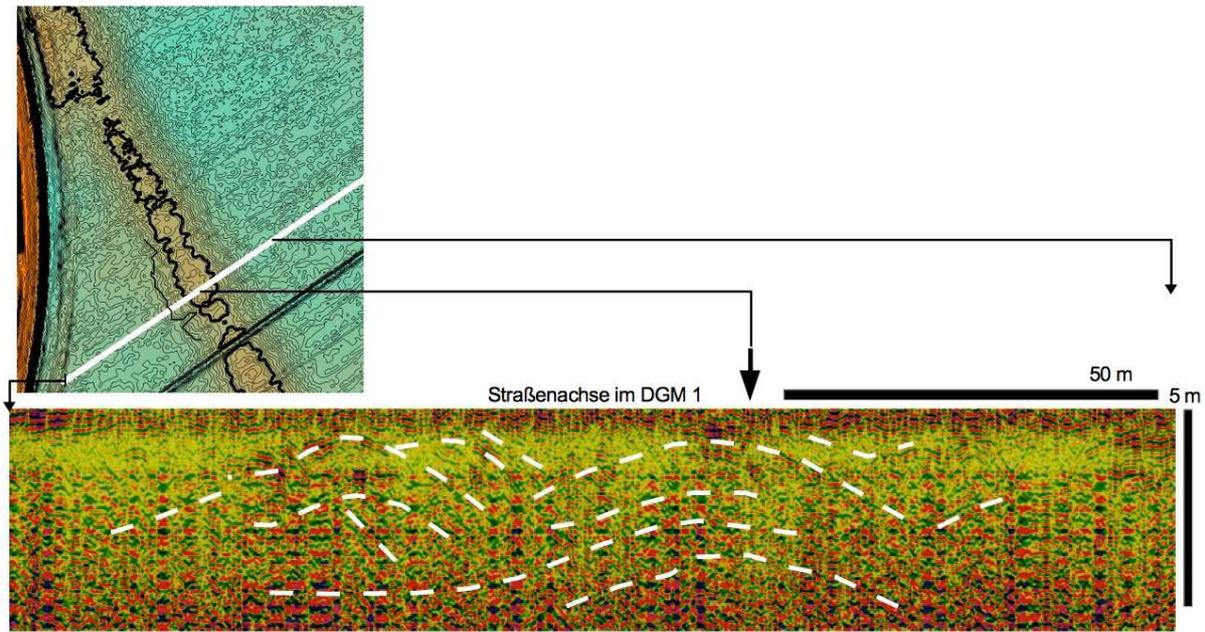


Fig. 22. Extended ground-penetrating radar profile of the Roman road northwest of Maudach (location shown in Fig. 13). A wider double structure within an overall very complex structure appears to be indicated in the radar image. There may be a connection to a road widening in the Digital Elevation Model in the area of the profile cross-section (marked contour lines). It is notable that the road substructure apparently extends to a depth of at least 5 m, which also applies to the road intersection in Fig. 20.

Regarding the construction of the Rheintal-Römerstraße in the Mutterstadt area, it should be noted that none of the cross-sections recorded using ground-penetrating radar (e.g., Fig. 21, Fig. 22) revealed any traces of the original condition, not even in the form of relics. Furthermore, the radar image lacks the expected distinct reflectors of the typical layered structures of a solid subgrade described in the literature. It is presumed that when the road structure was abandoned, the peripheral and deeper stone foundations were excavated and repurposed for other uses.

As far as the measurements indicate, the road structures—which are morphologically most visible in the DGM 1—appear in the radar images as relatively faintly contoured elevations in the subsurface, measuring several meters in depth and over 30 meters in width; however, these generally extend down to the radar detection depth of 5 meters. It is possible that this approach ensured that the road in the Rhine Valley near Mutterstadt remained flood-protected, firmly anchored in the subsoil, and passable in all weather conditions.

The section of the Rufiniana Road on the right bank of the Rhine. - The continuation of the Rufiniana Road from Mutterstadt across the Rhine to Ladenburg is assumed to run toward Altrip near the present-day tributary of the Neckar (Fig. 23). A second ancient Rufiniana boat landing on the Rhine is also assumed to have existed near Altrip, though this has not yet been confirmed,

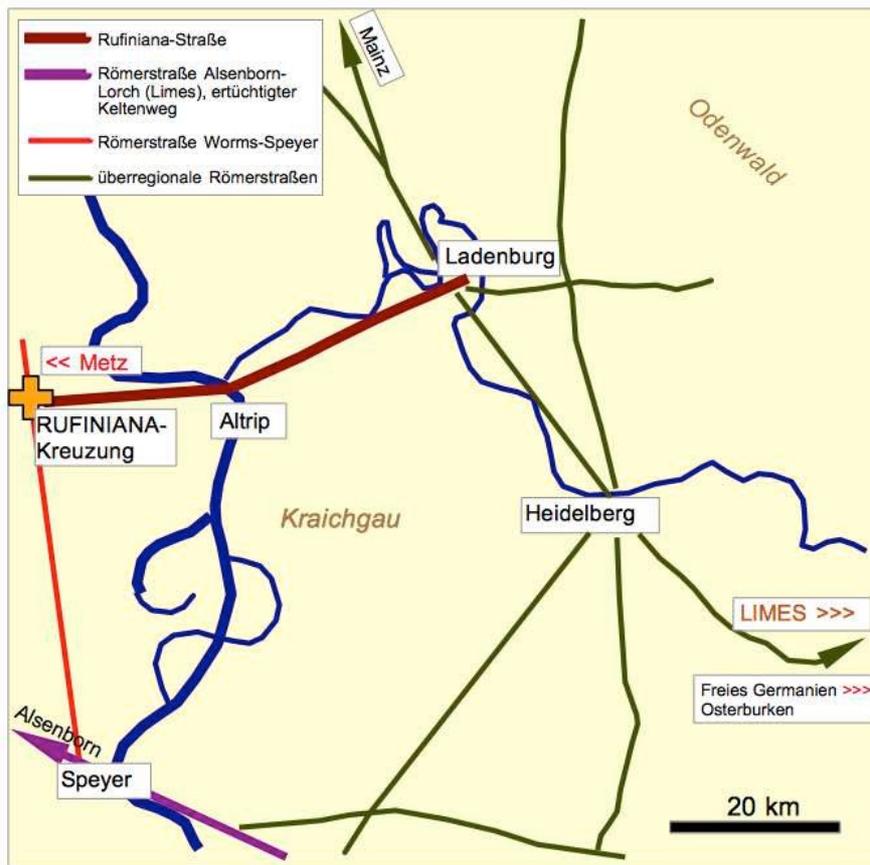


Fig. 23. The Rufiniana Road on the right bank of the Rhine: Rufiniana – Altrip – Ladenburg, connected to supraregional Roman roads. Map source (in part): Lobdengau Museum, Ladenburg.

4.2 Waterways and Water Management

4.2.1 The ancient stream tributaries to Rhine and the local (public) water supply

Given the known intersection of two Roman highways at the municipal boundary between Ludwigshafen-Rheingönheim and Mutterstadt, a settlement was presumed to have existed at this geographical point. According to the Mutterstadt local chronicle (Eyselein 1938), the settlement's water supply (industrial water, and possibly also drinking water, which was likely drawn from wells) via a flowing watercourse was identified as necessarily coming from the Lachgraben, Marlach, Stechgraben, and Schwabenbach, which run from west to east and originate in the Haardt Mountains. In 1742, their flow toward the Rhine was interrupted, and their water was diverted into a canal under construction (Fig. 24). This canal was named Floßbach, and a source was invented for it. The fact that it was an artificial watercourse fell into oblivion but is addressed again in the new local chronicle of the municipality of Mutterstadt (2017). For the sake of simplicity and clarity, further significant

Findings and interpretations regarding the local water supply of a larger Rufiniana settlement.

Digital terrain models and geophysical surveys may have yielded further important findings supporting the existence of a Roman town at Rufiniana near Mutterstadt, particularly regarding the essential need for a water supply, which is discussed separately in sections 4.3.2 and 4.3.4.

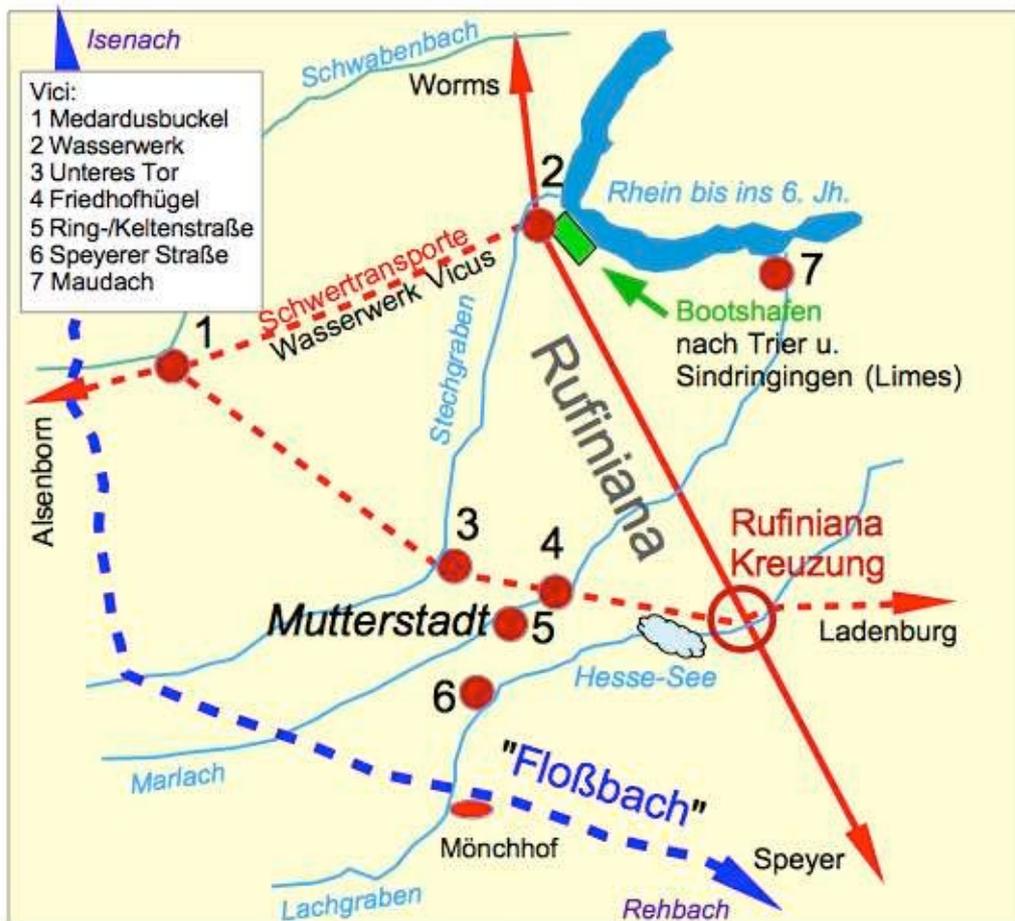


Fig. 24. Map showing the reconstructed course of streams during the Roman period. In 1742, a canal—later known as the “Fleißbach”—was dug between the Isenach and the Rehbach, cutting off the water supply from the Schwabenbach, Stechgraben, Marlach, and Lachgraben to the Rhine, which also led to the silting up of Lake Hesse and the Mutterstadt village ditch as protective waterways (see Fig. 26). In the archaeological maps currently in use, the canal is presented as a stream named “Fleißbach” from Roman times, for example in the Bad Dürkheim City Museum.

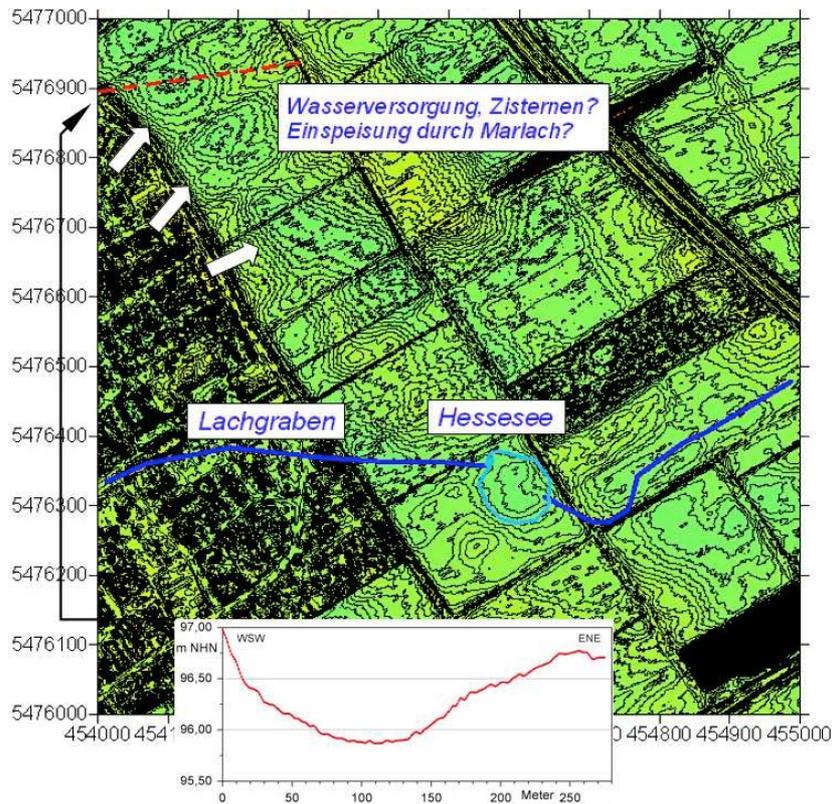


Fig. 27. Digital Terrain Model DGM1: Evidence of the construction and use of basins (including Hessensee) and cisterns fed by Marlach and Lachgraben. The lower profile shows the cross-section of a circular basin.

4.2.2 The Port on the Ancient Rhine and Neckar Tributary - Geophysics

The preferred location of Rufiniana at the Roman-era confluence of the Neckar and the Rhine (Eckoldt 1983) as a major waterway-land route junction (Fig. 28) is particularly evident in light of the presumed Rufiniana boat harbor, whose existence is strongly supported by the geophysical measurements presented here. Figs. 29–31 show an aerial photograph and the Digital Terrain Model (DTM 1) of the area previously favored for the location of a harbor, where the first geophysical measurements using ground-penetrating radar, pulse electromagnetic, and geomagnetic methods were conducted. In particular, the DGM, with its high-resolution topography (10 cm contour interval), reveals structures in the Maudacher Bruch that can morphologically be interpreted as remnants of ancient harbor basins. Here, the capabilities of the DGM become particularly evident, as the ground structures are discernible even within the dense forest vegetation.

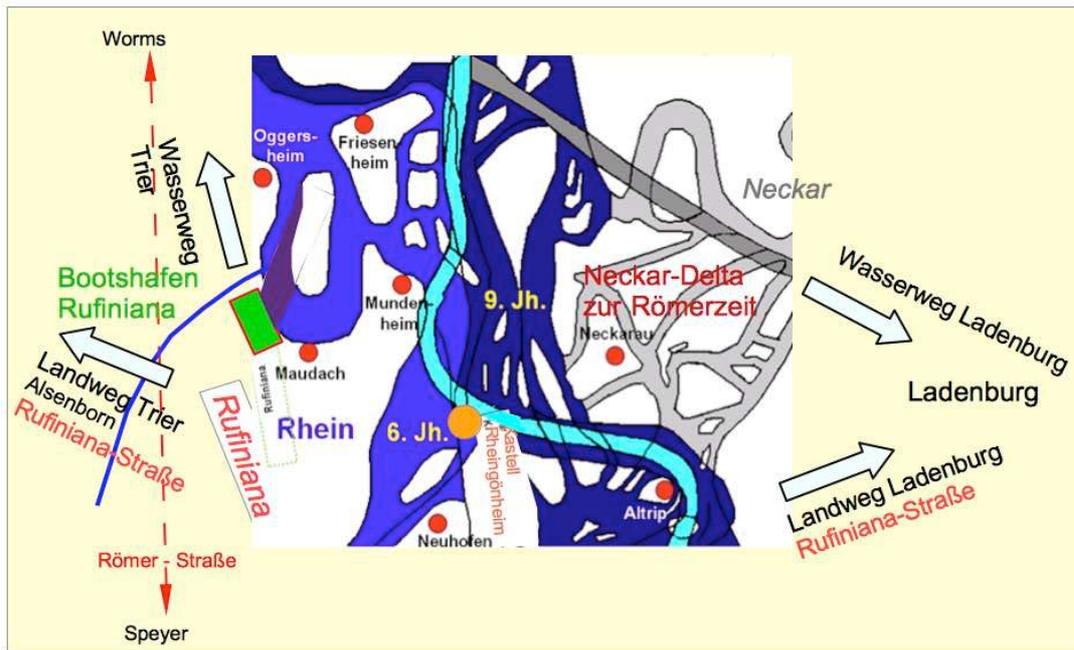


Fig. 28. The preferred location of Rufiniana at the Roman-era confluence of the Neckar and the Rhine as a major waterway-land route junction with the presumed Rufiniana boat harbor. Using https://de.wikipedia.org/wiki/Datei:Rhein_an_der_Neckarmuendung.png; Author Immanuel Geil. For the map's source, see Appendix (3). The course of the drainage ditch shown here (see Figs. 24, 25) is intended to illustrate that the harbor complex may have additionally incorporated a canal-like widening for a potential water transport route from the west.

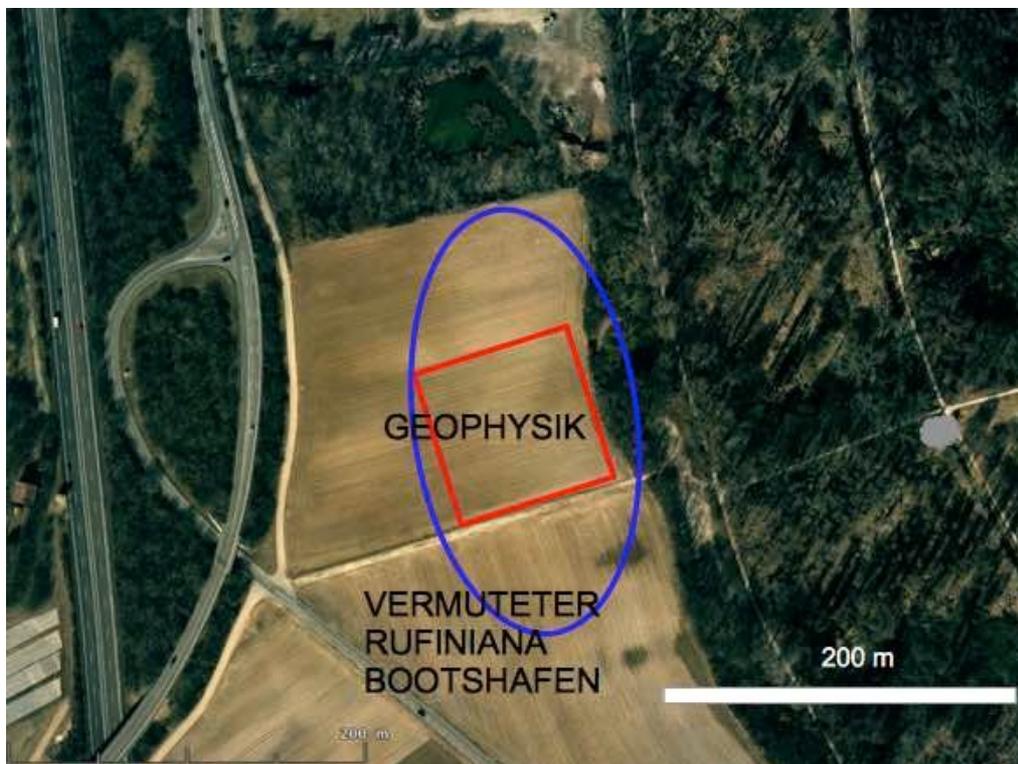


Fig. 29. Site plan of the geophysical survey (red) at the presumed Rufiniana boat harbor (blue). Gray: presumably a boulder made of Roman concrete. Google Earth.

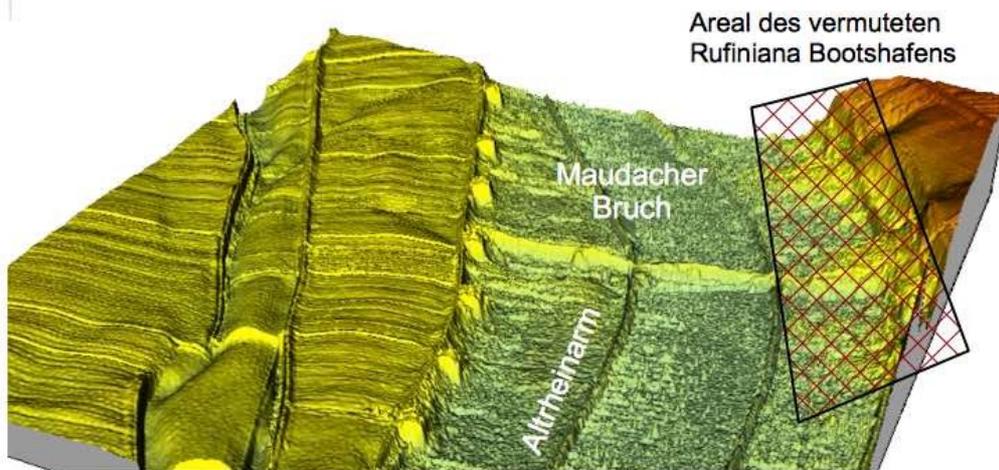


Fig. 30. Digital terrain model in a 3D representation of the terrain surface: A section of the Maudacher Bruch with the area of the presumed Ruginiana boat harbor on this old Rhine arm (view toward the south; see Fig. 29).

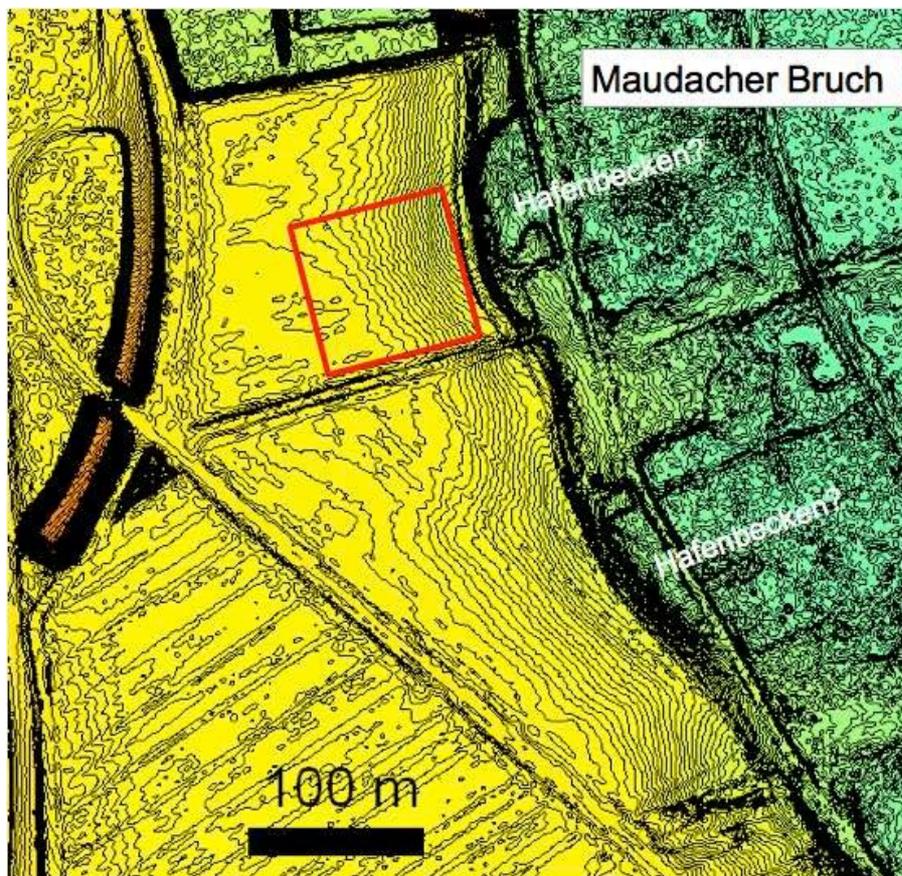


Fig. 31. Digital Elevation Model (DEM) 1: topographic map of the area of the presumed Ruginiana boat harbor on the Old Rhine branch (today: Maudacher Bruch). Contour interval 10 cm. Preliminary interpretation: A steep bank widening toward the west with a harbor basin complex separated by landing piers extending eastward. Red: geophysical measurements indicating the presumed harbor settlement (Figs. 32–34).

The existence of a Roman Rufiniana boat harbor is strongly supported by geophysical measurements. The relatively sharply defined bands of high reflectivity in the ground-penetrating radar in Fig. 32 unambiguously indicate anthropogenic structures (walls, foundations?) down to a largely uniform depth of 3 m. Layered structures are frequently observed.

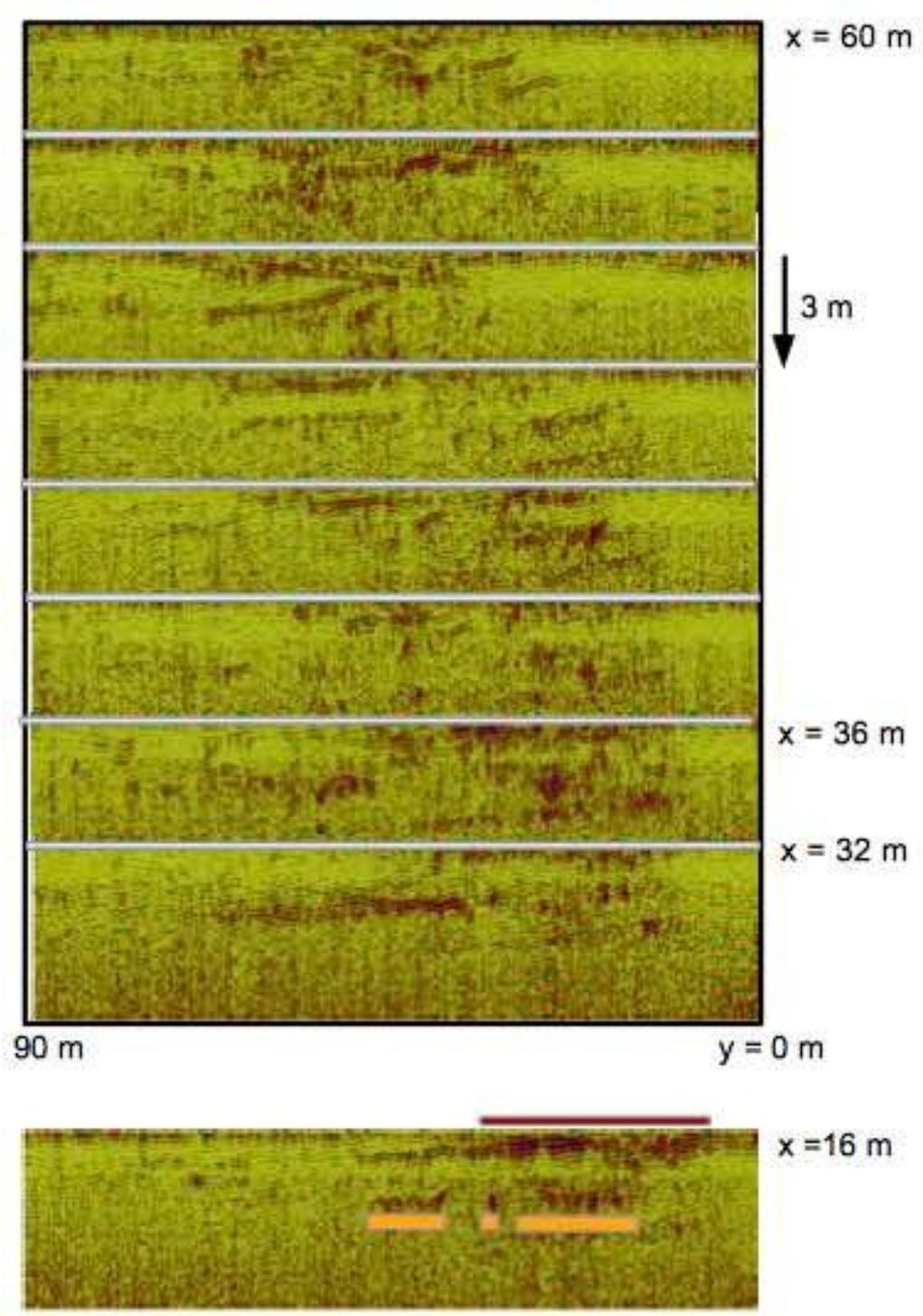


Fig. 32. Selection of characteristic ground-penetrating radar profiles from the survey area at the presumed Rufiniana boat harbor (central section). Distance between profiles: 4 m.

The lower radar plot shows characteristic reflection bands, as depicted in the two-dimensional representation of the structures in Fig. 33 and as applied to the entire measurement area in Fig. 34. It should be noted, however, that this bar assignment represents a significant simplification and that there is rarely a sharp boundary between sections of greatly increased reflectivity. However, the general distribution of these elements across the measurement area, which is also roughly based on the morphology (Fig. 34), is accurate.

No elevation correction has yet been applied to the radar profiles. The terrain slope along the profiles is approximately 2 m. When accounted for, some of the incident reflectors shift more or less to the horizontal, while others become steeper.

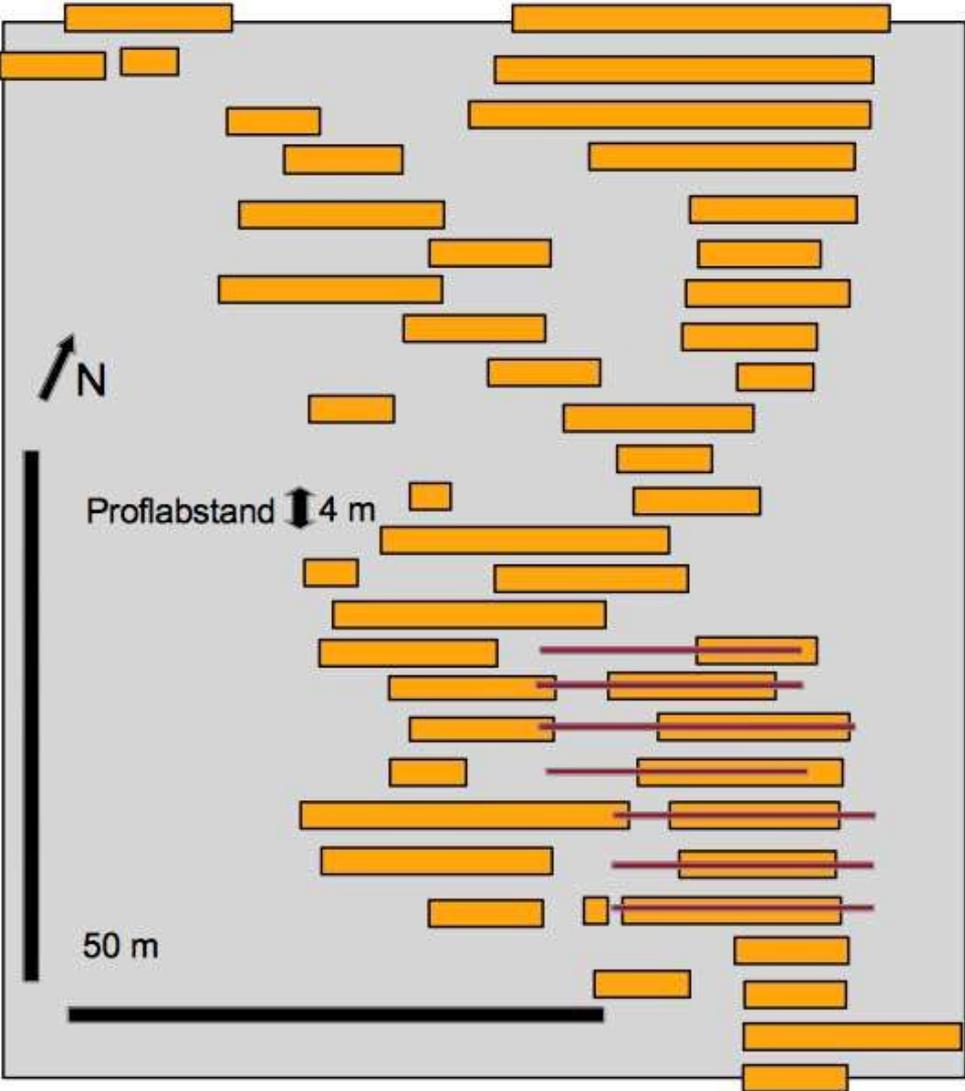


Fig. 33. The measurement area for the ground-penetrating radar measurements at the presumed boat harbor, with a very rough marking (from Fig. 32) of the reflection structures on the measurement profiles.

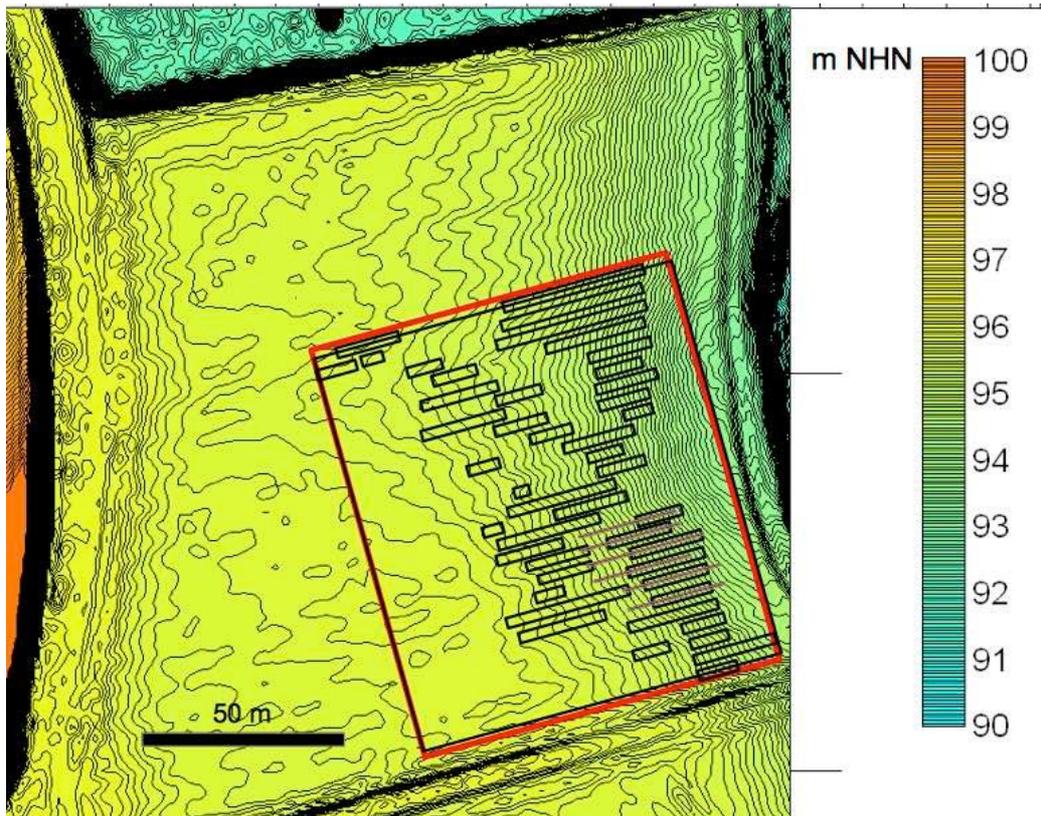


Fig. 34. Overlay of the radar structures from Fig. 33 onto the topographic map of the DGM 1. Contour interval: 10 cm. There appears to be a very rough correlation between the distribution of radar signals and the terrain features within the same measurement area.

The geomagnetic (on a reduced area) and pulse electromagnetic surveys conducted on the same measurement area at a profile spacing of 5 m confirm the assumption of widespread anthropogenic subsurface structures, although other structural elements also become apparent given the completely different measurement parameters. When examining the map of magnetic field anomalies (Fig. 35), one must first consider a profile-parallel strip pattern which, apart from the $x = 0$ m profile, is likely related to the strip pattern already identified in the DGM 1 in Fig. 6. There, it was already interpreted as an agricultural feature, e.g., medieval arable fields. The red strip of increased amplitudes is likely an effect of the gas pipeline running parallel to the road.

The elongation of many anomalies, which was discussed earlier (Figs. 9, 10), is related, on the one hand, to the interpolation of data when the profile spacing is large and the sampling rate on the profiles is low; however, in this case, it is not the only cause. This is demonstrated by the field of the directional horizontal derivative (horizontal gradient, Fig. 36) calculated from the data, which—as a side effect—eliminates the general striped pattern parallel to the profiles, but also specifically amplifies vertically oriented anomalies. Thus, Fig. 36 clearly shows that long-persisting strip-shaped narrow magnetic anomalies extend across several traces

run straight as an arrow and extend up to 50 m across the field toward the edge of the Mauracher Bruch.

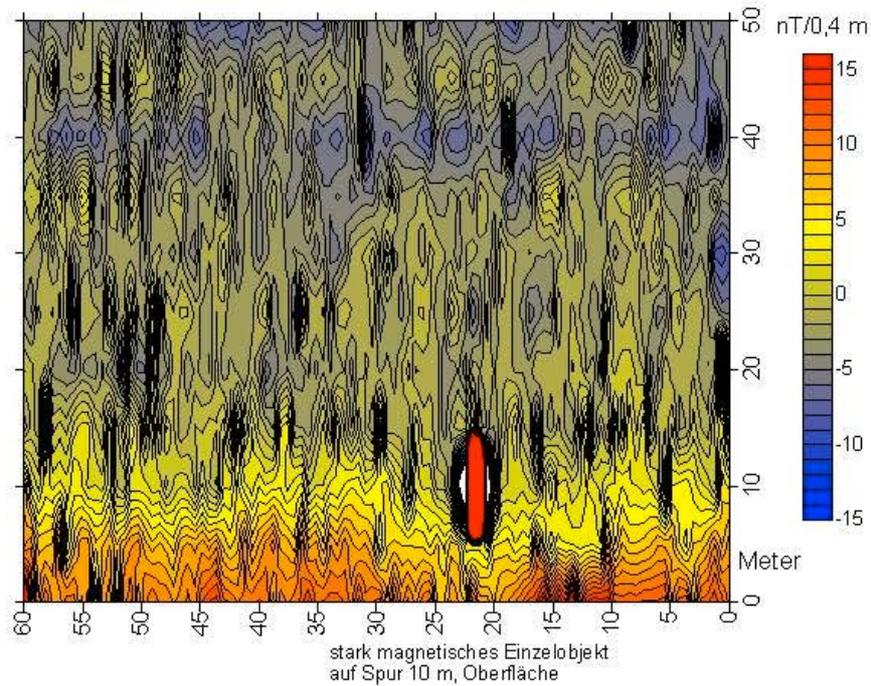


Fig. 35. Anomalies in the vertical gradient of the vertical component of the Earth's magnetic field. Measurement area = southeastern quadrant of the entire geophysical survey area (Fig. 31).

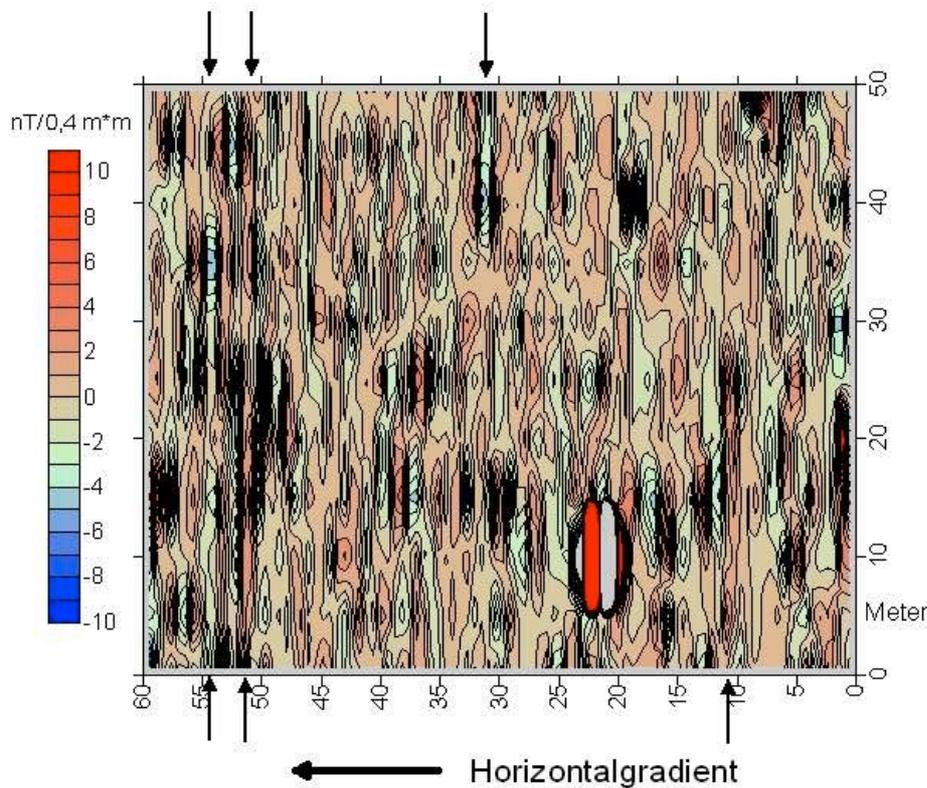


Fig. 36. Map of the calculated directional horizontal gradient (arrow direction) of the magnetic field measurement from Fig. 35. In the gradient, the horizontal strip pattern disappears, and perpendicular strike directions are emphasized. Small arrows mark anomaly strips running straight across multiple tracks. More on this in the text.

When the results of the pulsed electromagnetic measurements—which cover the entire 100 m × 100 m area (Fig. 37)—are added to the data, the pattern of anomalous strip-shaped structural elements becomes more pronounced toward the edge of the escarpment.

One possible interpretation is that these are remains of structures that may be associated with the presumed harbor facilities (quay walls?) and accompanying buildings. The magnetic strip anomalies could be attributed to wall remains made of fired bricks, but structures made of Roman concrete are also a possibility. The concrete boulder marked in Fig. 29 at the bridge over the ditch exhibits the typical characteristics of Roman concrete, and a measurement with the magnetometer shows a clearly measurable magnetization.

Overall, the geophysical measurements using three different methods seem to allow for no interpretation other than that of a man-made structure extending over at least 100 m. The results strongly support the identification of the presumed Rufiniana boat harbor.

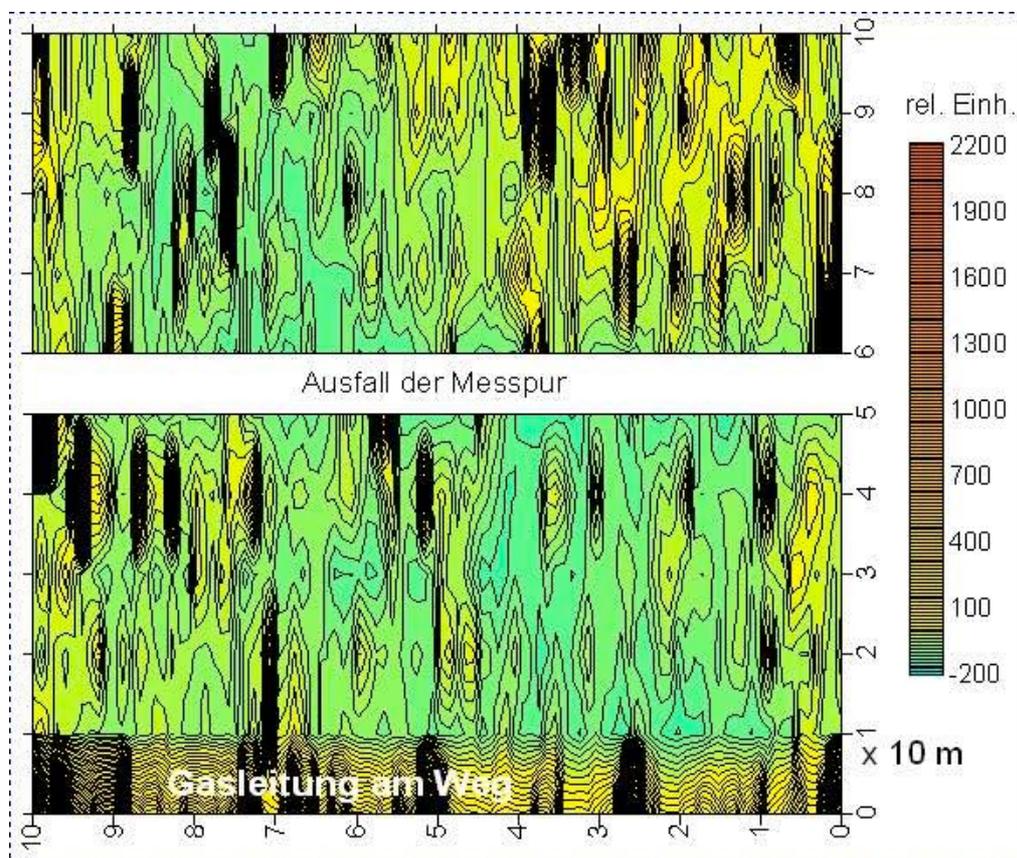


Fig. 37. Map of pulse electromagnetic measurements on the geophysical survey area (delay 100 μ s). Even without gradient formation—which is unnecessary due to the absence of a strip pattern—narrow, linear conductivity structures are visible perpendicular to the measurement profiles on the gently sloping terrain. Double structures approximately 5 m wide appear to occur in several places.

4.3 Evidence of settlement

4.3.1 Overview

It is the norm in the region that Roman settlements were established on top of Celtic settlements, and this was most likely also the case in the Mutterstadt district. Therefore, the excavation of the largest Celtic settlement in the Palatinate in 1898 in the "Auf dem Limburg" field provides a significant clue to the location of Rufiniana. The Roman settlement of Vicus "Wasserwerk" likely developed on what is also known here as the Celtic oppidum, in the immediate vicinity of the Rufiniana boat harbor. The Celts, and later the Romans, settled in "Auf dem Limburg" because the banks of the Rhine were located there until the 6th century. This location made it possible, on the one hand, to travel by boat via the Rhine and Moselle to Trier, or, on the other hand, via the Neckar and Kocher to Sindringen on the Limes. If one undertook a 28-kilometer walk, one could reach Constantinople (formerly Byzantium) via the Neckar, Danube, and Black Sea by merchant or military boat.



Fig. 38. Digital Terrain Model DTM 1 (shaded relief) showing the location of the vici in the Mutterstadt district. Labeling as in Fig. 23. The yellow arrow points to a geophysical survey area running immediately parallel to the Rhine Valley Roman Road (Section 4.3.4), while the white arrow points to the intersection of the Roman roads. It is not always clear whether the marked locations were Vici or merely Villae Rusticae.

Additional Roman settlements are presumed to exist within the Mutterstadt district, and the locations of the vici—whether confirmed by finds and excavations or merely presumed—are shown in Fig. 38 (after Eysel (1938, 1967)). Abundant new excavation findings support the existence of the cemetery mound vicus, which is specifically marked in Fig. 38. During the expansion of the “New Cemetery” at the end of the 20th century, a very large number of Roman artifacts were found, so that a systematic excavation was avoided. The relevant area was mounded into a hill of sufficient height to preserve the function of conducting burials without encountering Roman artifacts during the excavation of the graves.

The northern and southern areas, which stand out due to their concentration of anthropogenic, geometrically defined ground structures, are hatched in Fig. 38 (see Sections 4.3.2 and 4.3.3).

The location of the vici shown in Fig. 38, which—together with the hatched areas—suggests that the Roman town of Rufiniana may have existed as a larger settlement at the intersection of two Roman roads, invites a comparison with the important Roman town of Regensburg, as illustrated in Figs. 39 and 40.

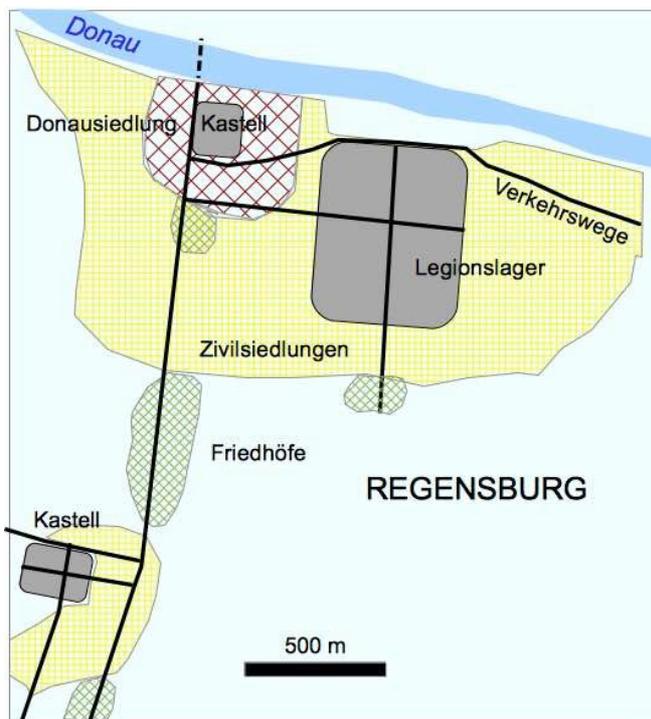


Fig. 39. For comparison with Rufiniana: the significant Roman city of Regensburg on the Danube; founded around 80 CE. Possibly a small fort under Emperor Claudius prior to this. Archaeologists have recently been conducting an intensive search for the Roman Danube port, which certainly existed. Highly simplified map from Bayerische Archäologie, 3/2019 (rg).

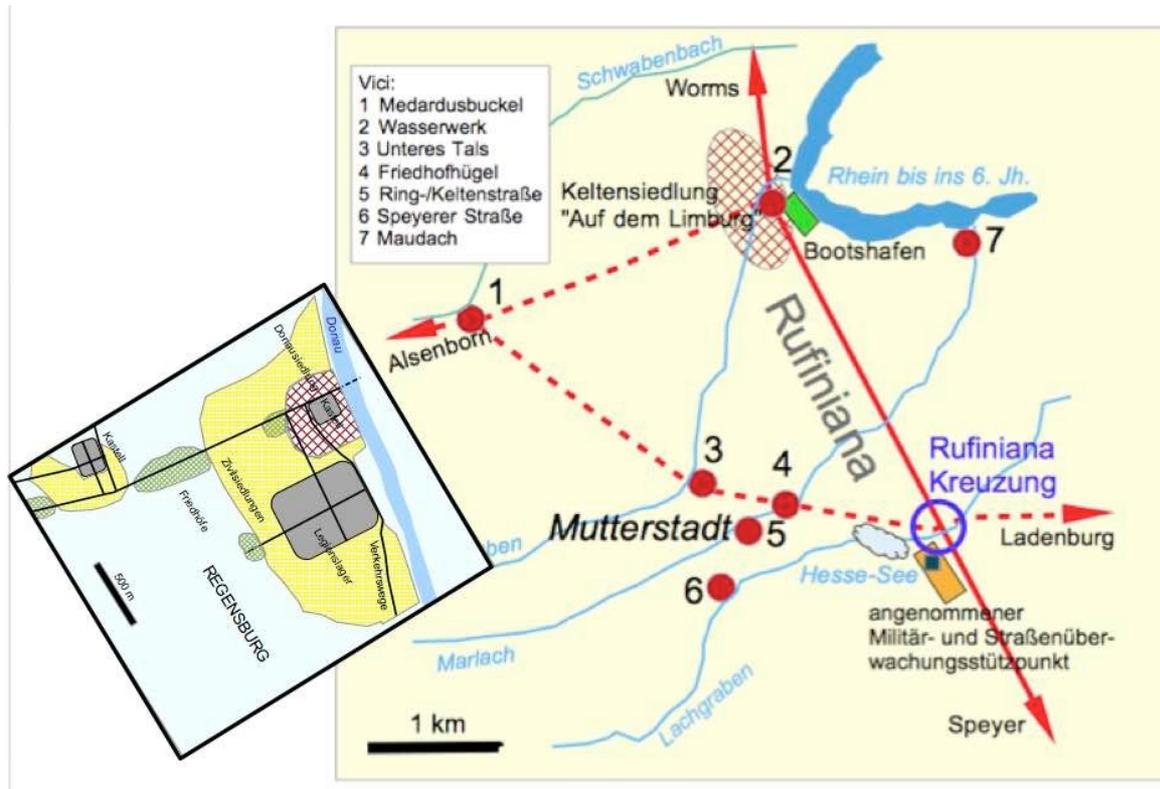


Fig. 40. Comparison of the Roman city of Regensburg (from Fig. 39) with Rufiniana (Fig. 18) at roughly the same scale. In addition to its strategically important location on major rivers, Rufiniana would also fit into the same “class” of Roman cities in terms of size and layout.

4.3.2 The southern part of a presumed settlement cluster (Fig. 38)

While no significant anomalies in the DGM 1, the pulsed electromagnetic survey, or the geomagnetic survey indicate the presence of hidden settlement remains northeast of the intersection (survey area shown in Fig. 41), the question of whether such structures exist west of the intersection toward Mutterstadt must remain open from a geophysical perspective due to the lack of measurements in that area. However, the DGM 1 (Fig. 41) shows morphologically striking terrain structures in the southwestern corner of the intersecting roads, featuring geometric, partly right-angled shapes whose orientation forms a distinct angle to the current directions of agricultural cultivation. Overlapping settlement structures (buildings, water supply) suggest themselves, which will be discussed further below following the geophysical analysis.

A potentially significant correlation with the ground-penetrating radar results on the survey area, which is almost entirely occupied by the road intersection (Fig. 41).



Fig. 41. In the southwestern corner formed by the intersecting roads, the DGM reveals 1, morphologically striking terrain structures with geometric, partly right-angled shapes, whose orientation forms a distinct angle to the current directions of agricultural cultivation. Overlapping settlement structures suggest themselves. The geophysical measurements there (Fig. 34 A, B) were conducted within the marked square.

Pulse Electromagnetics. - The southern concentration of structures west of the road intersection as well as the pulse electromagnetics survey area (location in Fig. 41) are summarized in Fig. 42.

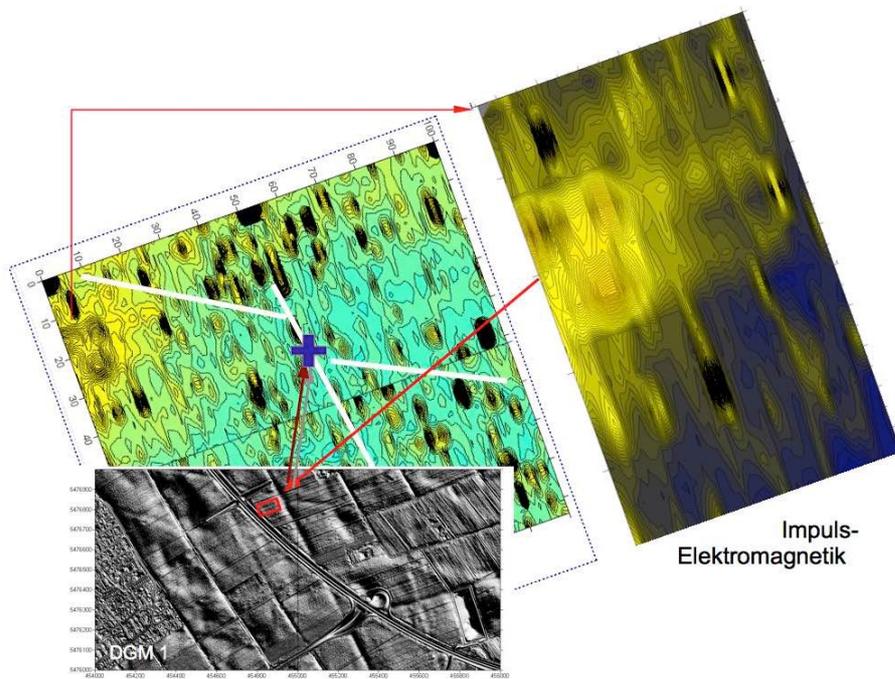


Fig. 42. The DGM 1 and the pulse electromagnetic survey area (location in Fig. 41). The conspicuous anomaly with rectangular structures, shown here as a larger inset, is depicted as a small rectangle on the shaded relief map of DGM 1; it lies exactly at the intersection of the two roads and could indicate the military/surveillance site (Burgus?) already suspected to be located there.

Distinct anthropogenic features in the conductivity distribution are represented by a small rectangle on the DGM 1 shading map. There, precisely at the intersection of the two roads, the geophysical data may indicate the presence of a military/surveillance site—as had already been suspected—which the subsequent radar results appear to corroborate (perhaps in the truest sense of the word). The geomagnetic data, however, remains unremarkable (not shown here). Based on its dimensions and structure, this could be the remains of a Roman burgus (see Fig. 43).

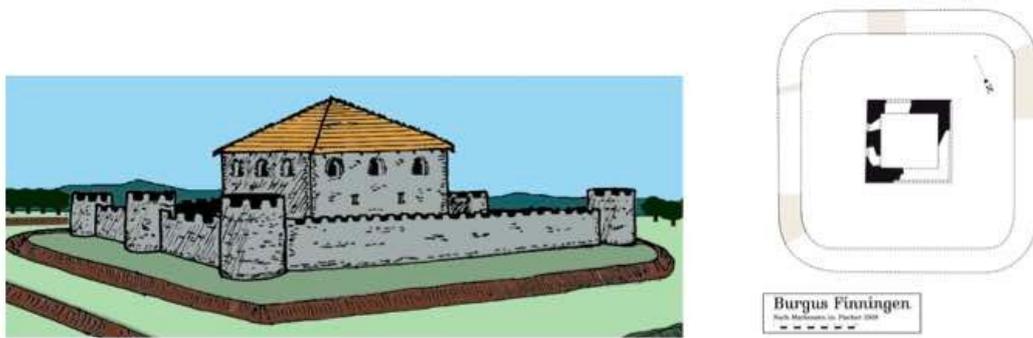


Fig. 43. Reconstruction attempt of the late Roman burgus at Goch-Aspergen and floor plan of the burgus at Finningen (Danube).

Sources: WIKIMEDIA COMMONS

https://upload.wikimedia.org/wikipedia/commons/5/5e/Sp%C3%A4tr%C3%B6mischer_Burgus_in_Goch-Asperden_%28D%29.png

and https://upload.wikimedia.org/wikipedia/commons/1/1b/Burgus_Finningen_Neu-Ulm_Bayern.png

Ground-penetrating radar. - The ground-penetrating radar, with its radar profiles, presents a completely new situation that apparently attaches special significance to the intersection point, apart from the Burgus presumed based on geoelectric measurements. Clearly visible in the radar measurements, and across the entire measurement area, is a distinct layered structure of the subsurface down to a recorded depth of 5 m. An interpretation of the radar findings very clearly distinguishes four different horizons from one another, as illustrated in Figs. 44 and 45.

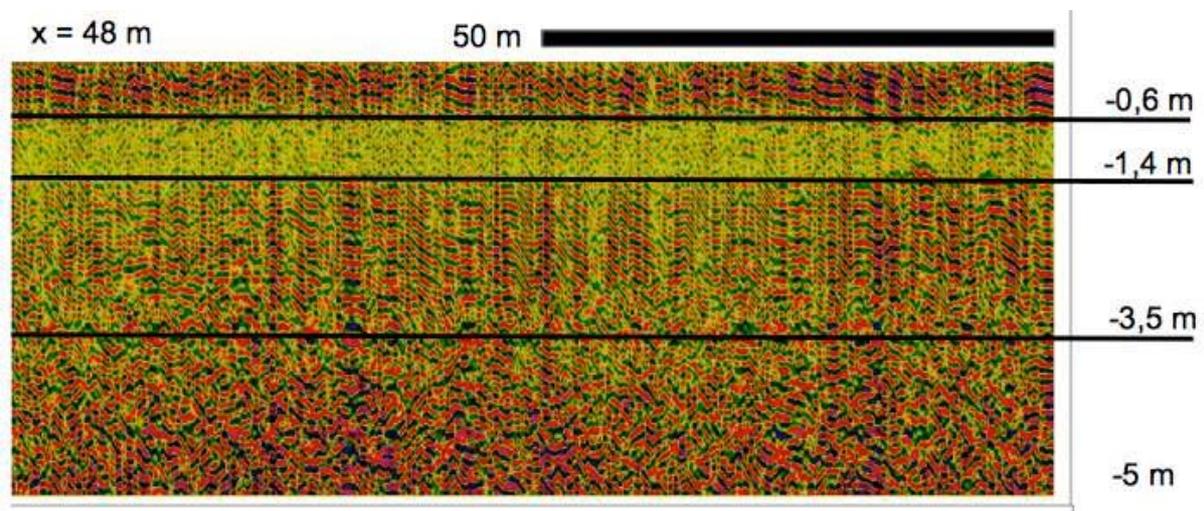


Fig. 44. Radar profile of the survey area at the cross: example of subsurface stratification

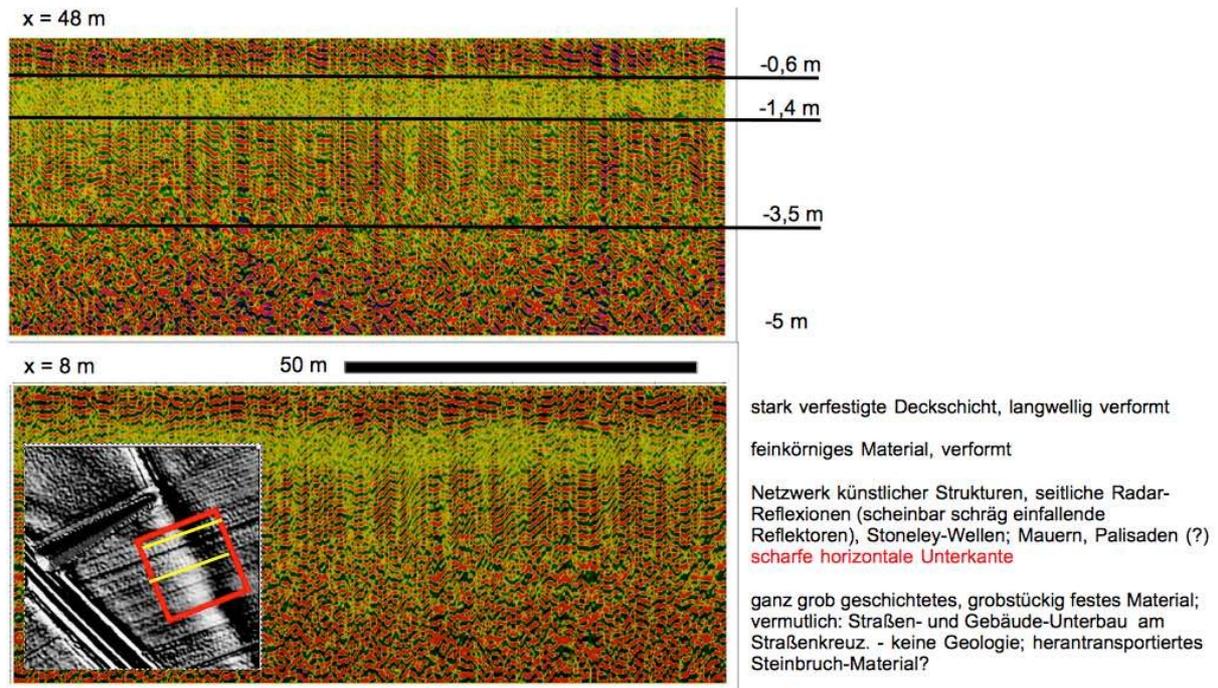


Fig. 45. The radar profile from Fig. 44 and a radar profile from the center of the measurement area at the cross (profile trajectory along the yellow lines): an example of the subsurface stratification, which, according to the analysis of all 26 radar profiles, extends more or less similarly across the entire measurement area.

Particularly significant are structures along the measurement profiles that, based on the radar signals, can be described as zigzag structures alternating with linear structures. Individual elements typically have a width of roughly 5 m, though they often vary from this, being narrower or wider (Fig. 46). Furthermore, it is significant that zigzag and linear elements occupy the entire time scale from approximately 1.4 to 3.5 m (Figs. 44, 45) without any noticeable attenuation of energy. An attempt at an explanation is schematically outlined in Fig. 46: The corresponding reflections in the time range between 1.4 m and 3.5 m originate from elements positioned laterally recessed with a relatively sharp lower boundary. They form a small angle of about 10° or slightly less with the direction of the radar track, which can be derived from the time delay in the zigzag elements and the radar wave velocity. The more or less constant amplitudes in the reflection bands can presumably be explained by the propagation of so-called Stoneley waves, which propagate along interfaces between different materials. In Section 4.3.4, these waves apparently also occur in a different context, which is explained in more detail in Appendix (1). The somewhat inconsistent pattern of these unusual reflection bands across the measurement area is certainly related to complex geometric structures in the subsurface, which may of course also result from different orientations of the parallel radar profiles relative to remnants of previously unknown, presumed structures in the subsurface.

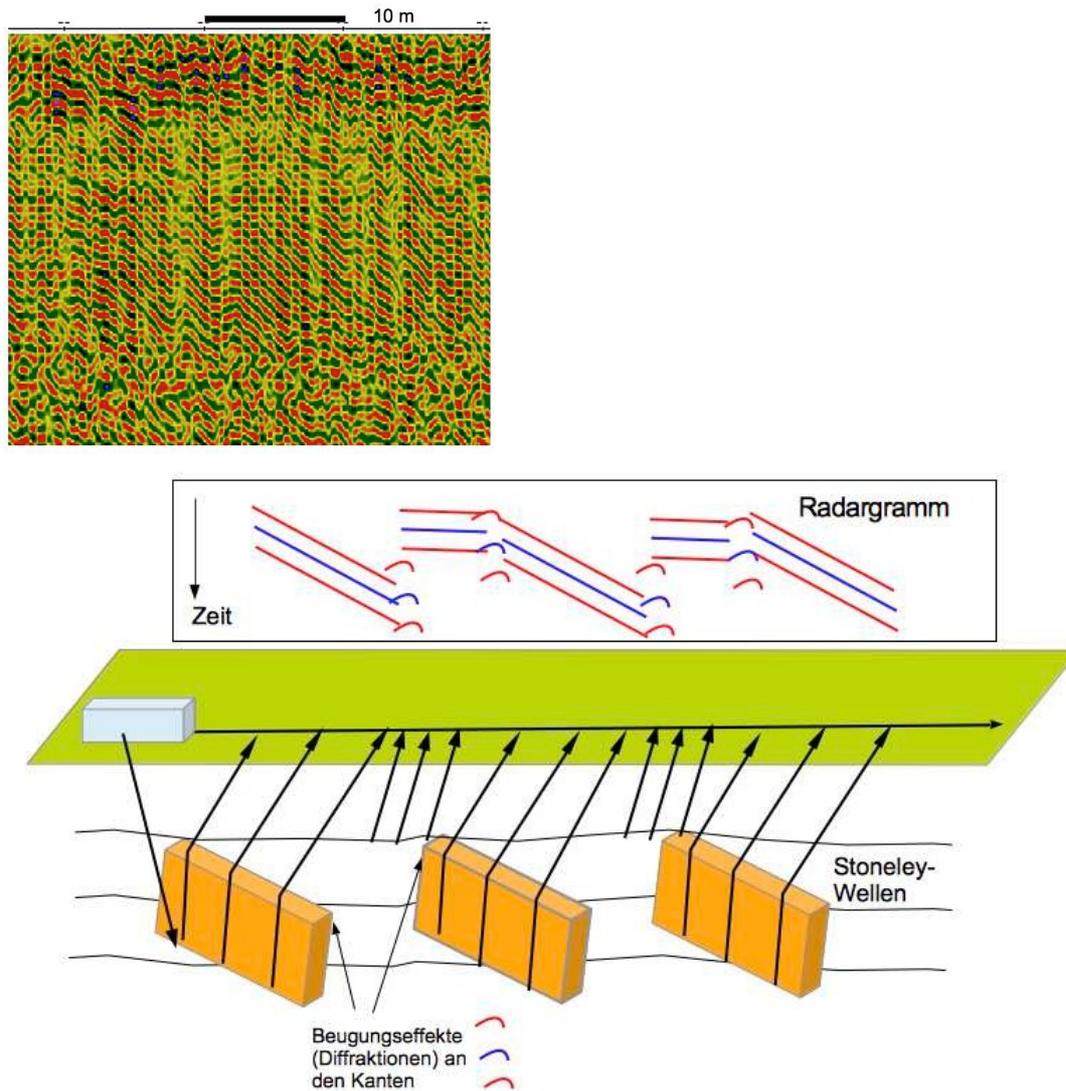


Fig. 46. Top: Enlarged section of the radarogram showing characteristic reflection bands. Bottom: Schematic illustration of how the radarogram was generated at the measurement site above the intersection. Explanations of the Stoneley wave phenomenon are provided in the appendix (1).

This attempt at an explanation must suffice for now, although only a very general interpretation is possible. Apparently, the entire subsoil in the intersection area—which, according to the DGM 1, almost completely occupies the 100 m x 100 m measurement area—consists of a structure at least 5 m thick and largely horizontally layered. The lowest 3.5 m recorded likely consist of very coarsely layered, very coarse stone material serving as a foundation for a stable subsoil. It seems plausible that this material was transported here along a west-east route from the Bad Dürkheim quarry by land and/or water. This subbase, once leveled, then served as the foundation for structures with specific geometries, creating a uniformly stable intersection area and/or facilitating the construction of buildings (the burgus?) and fortifications of a small fort. Certainly, more far-reaching interpretations are possible if we move from the relatively large geophysical profile spacing of 4 m currently in use to much narrower measurement intervals.

Possible water supply. - When switching in the Digital Elevation Model from the shaded relief view (western half of Fig. 42) to the contour lines of a topographic map (Fig. 47/Fig. 27, with a contour interval of 10 cm here), the features are outlined much more sharply than in the shaded relief map. In this context, the now silted-up Hessesee, which had previously been discussed in connection with the Lachgraben (Fig. 24, Fig. 25) in the context of the Rufiniana water supply, is joined by conspicuous, partly circular depressions with suggested embankments, which could be regarded here as possible components of additional service water reservoirs (together with the supply from the Marlach) at the edge of the Rufiniana settlement extending southward.

If one follows the hatched southern area in Fig. 38 northward, it extends all the way to the cemetery hill, which is crossed by what is referred to here as Rufiniana Street (the east-west thoroughfare to Alsenborn) (Fig. 21). Road connections in this area, from the Hessesee depression to the cemetery hill, are indicated in the DGM 1 and suggest a potentially enclosed area in the wider vicinity of the road junction, as well as the possible significance of a large Rufiniana settlement.

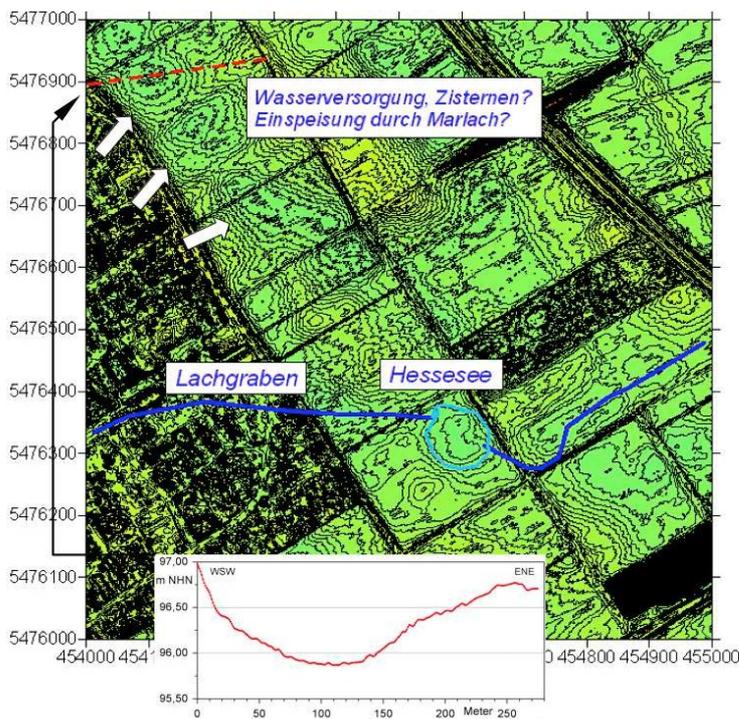


Fig. 47. Once again, the Digital Terrain Model DGM1 from Fig. 27: The indications of the construction and use of basins (including Hessesee) and cisterns, which were fed by Marlach and Lachgraben, fit well with the settlement structures assumed here.

4.3.3 The northern area of a presumed settlement concentration

Even more clearly than the southern area in Figs. 41–42, the northern area in the shading map of Fig. 48 (here with a slightly modified color scheme) conveys a

A very distinct, clearly anthropogenically shaped subsurface structure. The numerous, clearly defined geometric terrain features covering an area of roughly 10 km²—and of unquestionably anthropogenic origin—are unmistakable in DGM 1. These ancient structures, which are significantly rotated relative to today’s land-use patterns (NW–SE, SW–NE), underscore the site’s unique character. Nowhere in the immediate or wider vicinity of Mutterstadt are there even remotely comparable findings in DGM 1 (apart from the much smaller southern structure), raising the question of whether the center of the Rufiniana settlement was not located here, which would need to be verified by further targeted investigations, potentially also aimed at identifying evidence of more recent settlements (medieval?). The locations of the vici (or villae rusticae) proposed in the previously shown illustrations (Figs. 25, 38) as evidence of Roman settlement are not invalidated by this when one draws a comparison with the Roman city of Regensburg and its smaller external civilian settlements (Fig. 40). Since the (Merovingian) Franks in the 5th century generally did not settle directly in Roman settlements, such as Rufiniana, but merely used their waterways and (long-distance) road infrastructure, it makes sense that the site of Ruchheim (Fig. 48) emerged as a Frankish settlement decidedly on the northwestern edge. Whether the marked road route from Ruchheim to the main road between Worms and Speyer was a Roman structure or was established later by the Franks must remain open for the time being. No geophysical measurements are currently available for this area.

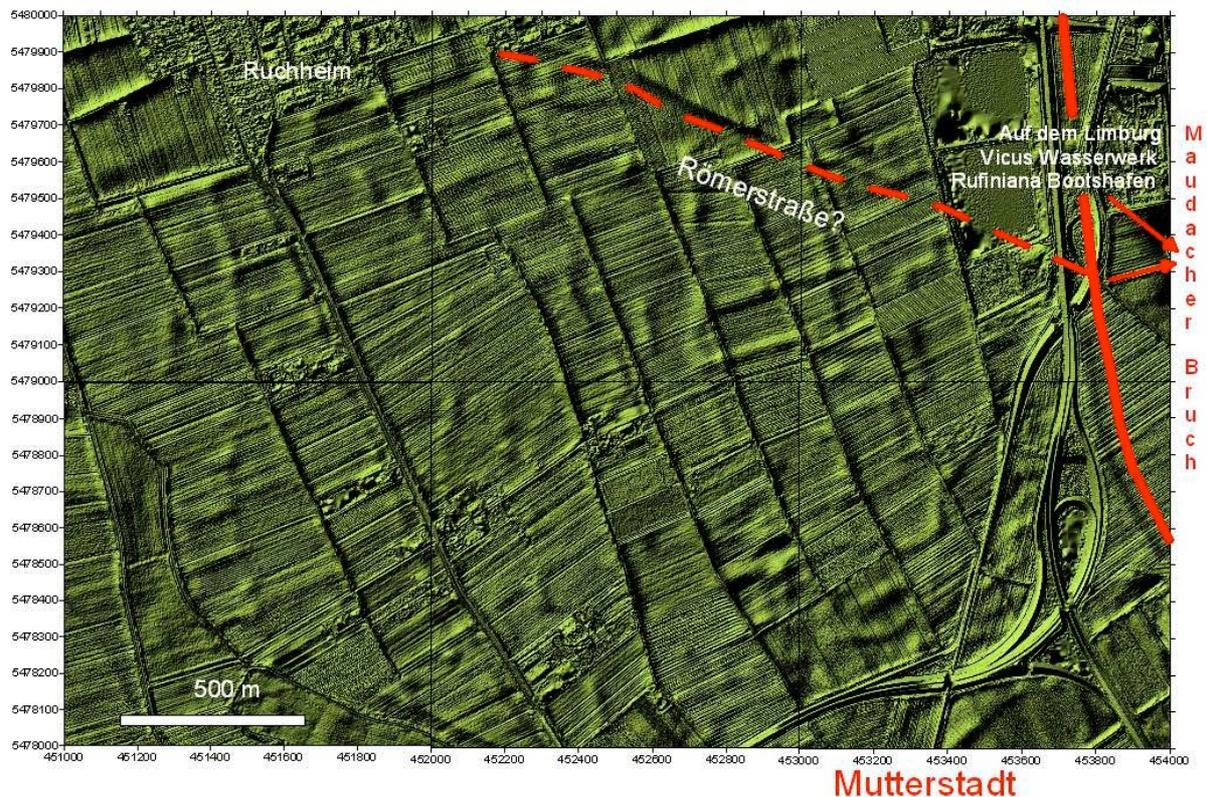


Fig. 48. Digital Elevation Model (DEM) 1, shaded relief, north of Mutterstadt and immediately west of the Worms–Speyer Roman road near the Maudacher Bruch, showing the presumed Rufiniana harbor (Figs. 29, 30).

4.3.4 Unresolved conditions in a central area

Pulse Electromagnetics. – Geophysical surveys along the Roman Rhine Valley Road near the western tip of Maudach have revealed an unexplained situation (Fig. 49, shading map). While magnetic field measurements remain relatively unremarkable, ground-penetrating radar and electromagnetics reveal conspicuous structures that, for the time being, defy interpretation. A distinctive feature in the electromagnetic field (Fig. 49) is the presence of very small-scale anomalies, uniformly 3 m wide and marked in green along the 100 m-long measurement profiles. Due to the steepness of the anomaly boundaries, the objects or their upper edges are generally not expected to lie very deep.

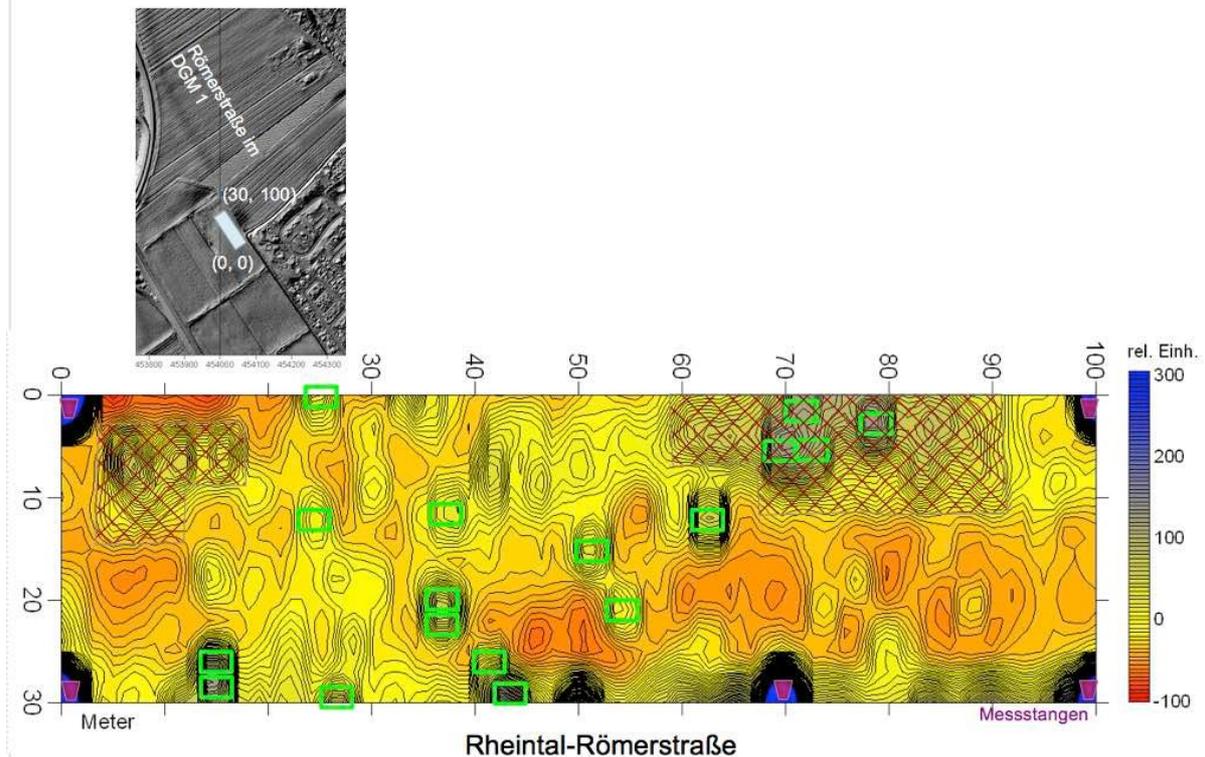


Fig. 49. The pulsed electromagnetic survey area near Maudach, adjacent to the Roman road, showing uniformly configured anomalies approximately 3 m wide. See the text for more details. The strip of higher resistivity (reddish) running alongside the road may be related to the road's subgrade.

The width of the anomalies perpendicular to the measurement profiles must not be misinterpreted due to the interpolation process mentioned earlier; with a few exceptions, the anomalies do not extend to the neighboring profiles three meters away. These could therefore be square objects or round objects with a diameter of approximately 3 meters. In two areas (hatched), there also appear to be clusters of such objects or structures. In terms of relative measurements, the yellow to blue colors correspond to relatively higher electrical conductivities, and the yellow to red colors to relatively lower conductivities (= higher resistances). Metallic objects as the cause of the higher conductivities can be largely ruled out, since in the radar image on the

no distinct reflection signals (diffractions or so-called "ringing") corresponding to identical measurement traces can be observed. A plausible explanation appears to be the superparamagnetic properties of certain types of fired ceramics mentioned above, which can generate strong, seemingly metallic signals when detected by pulsed electromagnetic devices (including standard metal detectors used by prospectors). In the case of the anomalies observed here, structures made of fired bricks, for example, should therefore be considered. An interpretation of their function, as well as an age assessment, remain unclear, although ground-penetrating radar measurements (see the following section) can provide important supplementary information.

Ground-penetrating radar. - Interestingly, the results of the geoelectric survey find equivalents in the ground-penetrating radar measurements. As in the pulse electromagnetic survey, no settlement structures in the form of foundations or wall remains hidden in the subsurface are observed. Instead, narrow vertical reflection bands (Figs. 50, 51) with a width of 3 m (Fig. 50, bottom) are conspicuous, extending down to the radar detection depth of 5 m.

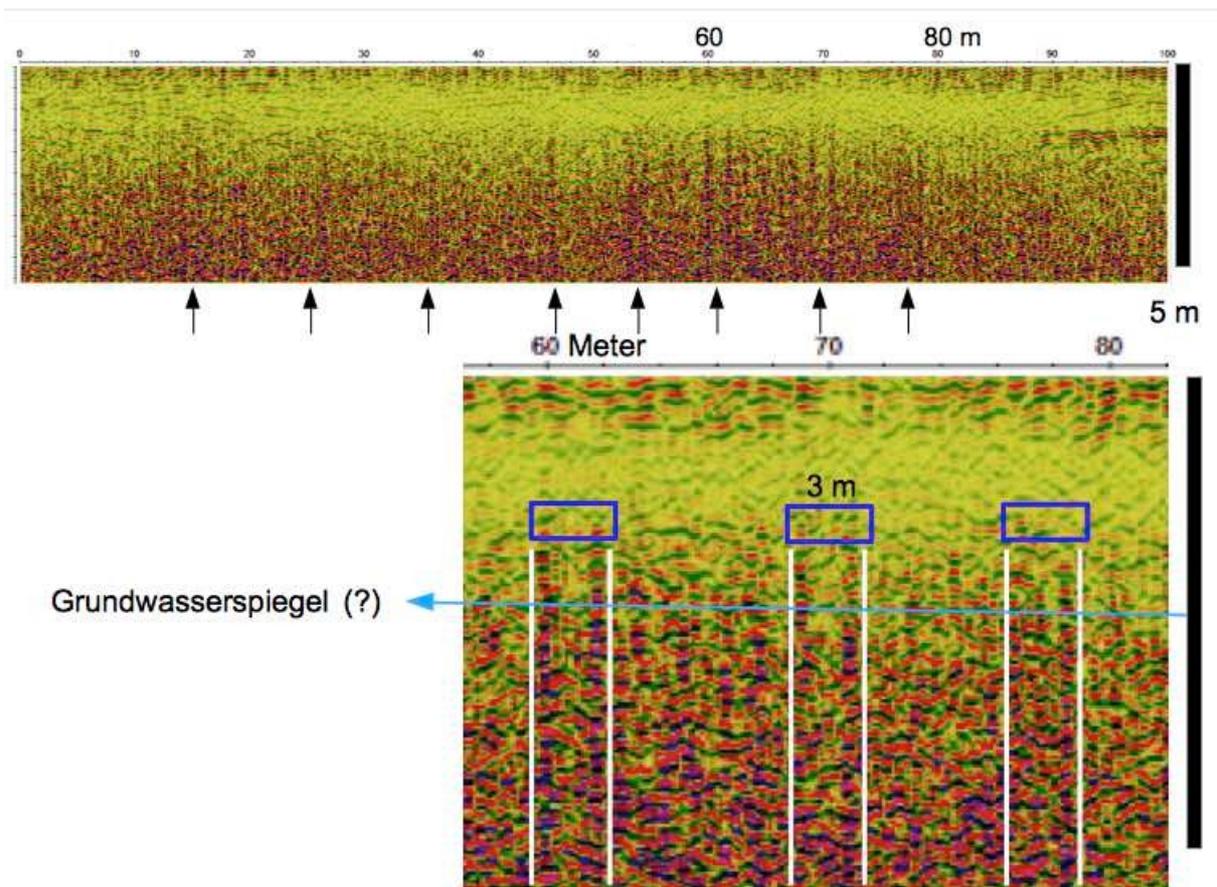


Fig. 50. Radar profile $x = 6$ m in the area shown in Fig. 49. Arrows indicate conspicuous, vertically oriented double-band-like reflections of increased amplitude. In an enlarged view, the width measures quite uniformly about 3 m.

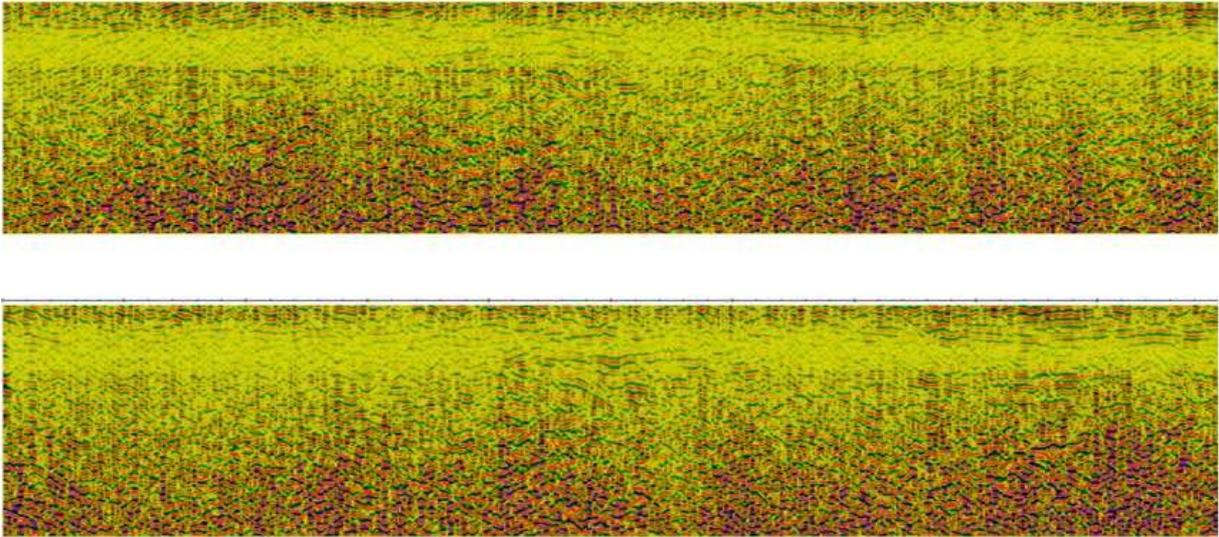


Fig. 51. The same narrow vertical reflection structures on the radar profiles at $x = 24$ and $x = 27$ (Fig. 49) demonstrate the widespread nature of this phenomenon.

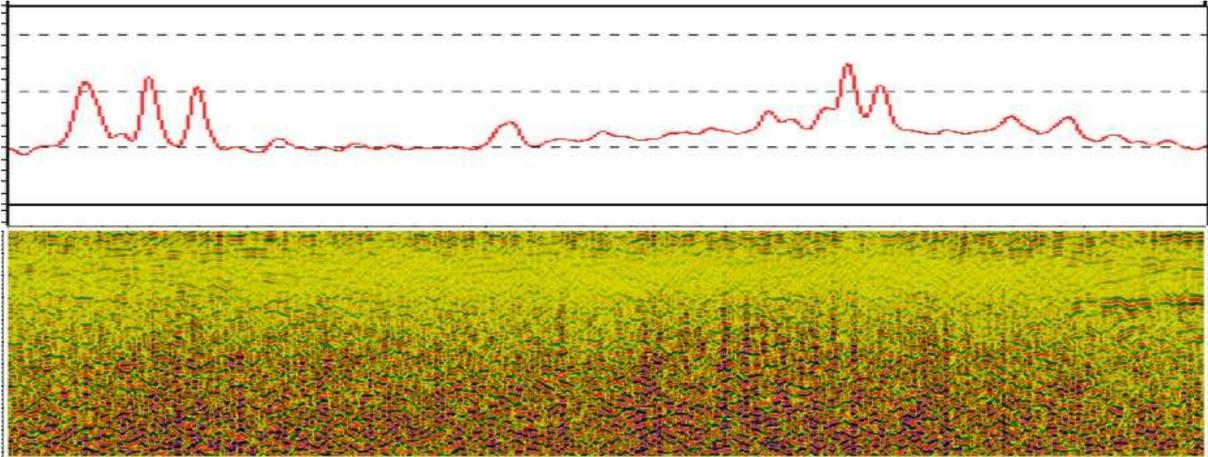


Fig. 52. Correspondence between the 3-m electromagnetic pulse anomalies and the 3-m-wide vertical radar reflection bands. Radar track $x = 3$ m.

When the electromagnetic measurement traces and the radar traces are plotted on the same tracks, a good correlation is regularly observed, though not always clearly (Fig. 52). The common origin of the radar and electromagnetic signals is unmistakable, as is particularly evident from the close alignment between the two 3-meter anomalies in Fig. 53. If such a precise alignment is not always present, it must be considered that the measurement profiles are 3 m apart and the measurement systems do not record linearly arranged data; rather, for example, the radar antennas also receive signals from the side and from objects positioned there, and the transmit-receive loop of the pulse electromagnetic system, with its 1 m x 1 m dimensions, likewise receives side information. Strong radar indications therefore do not necessarily correlate with strong electromagnetic indications.

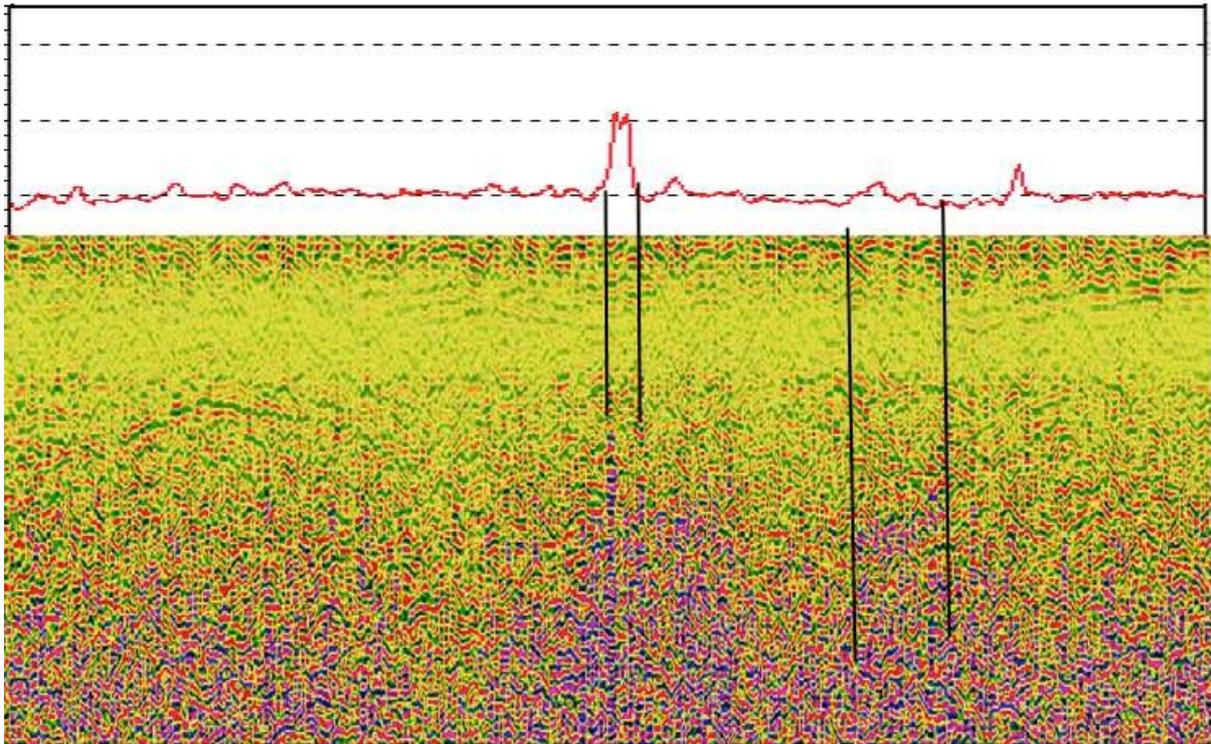


Fig. 53. Exact correspondence between a 3-meter pulse electromagnetic anomaly and a 3-meter-wide vertical radar reflection strip.

Interpretation. - The correlation between the two measurement methods suggests an explanation that is supported in particular by the conspicuous radar signals. This can be attributed to an effect that is primarily known from geophysical seismic measurements, occurs equally in ground-penetrating radar measurements, and is referred to as Stoneley waves. In Appendix (1), the effect, which was already observed in the ground-penetrating radar measurements at the road intersection (Fig. 46), is explained in greater detail; here it suffices to know that Stoneley waves occur during seismic or radar excitation in tubular structures, primarily in boreholes, but also at interfaces between different materials, particularly at the interface between fluid and solid phases. Because the high-amplitude vertical radar signals are not observed directly on adjacent profiles, shaft-like or tubular structures with a diameter of about 3 m can be assumed, and brick-lined wells extending down to the groundwater would be equally consistent with the results of ground-penetrating radar and electromagnetic surveys.

In terms of size, Roman wells (typically 2–7 m in diameter, Albrecht [2014]) would be a possibility; given their proximity (500 m) to the Old Rhine (Maudacher Bruch) and the minimal elevation difference, they would not have required digging very deep to reach the groundwater discharge point. According to the Digital Elevation Model, the groundwater table is less than 5 m deep (about 3 m according to local residents), which would align well with the results of the radar measurements. The extent to which the immediate proximity to the Roman road may have played a role also remains unclear. Except

Apart from isolated Roman finds in the Maudach area, there is no evidence of Roman settlement (from the DGM or the geophysical surveys conducted there) in the vicinity (unless such evidence has not yet been discovered in the Maudach area), which initially does not strongly suggest a well site. However, if, in addition to the previously discussed supply of service water via the streams, a reliable drinking water supply was sought for a more extensive Rufiniana settlement area, well galleries for uncontaminated water outside denser settlements are conceivable, though this remains subject to further investigation. Perhaps the apparent irregularity of presumed well locations within the area of the geophysical measurements should come as no surprise at all when one reads about the methods of water prospecting for well development in Roman times (see Appendix (2)). For the Rufiniana Roman town complex near Mutterstadt, this would be a possible additional “building block,” although much younger structures, such as those for a medieval Maudach, are conceivable.

5 Discussion

In the discussion regarding the boundary between the Lower Rhine and Upper Rhine regions, Ptolemy is cited in connection with Speyer (Neomagus), Rufiniana, Worms (Borbetomagus), and Strasbourg (Argentoratum), though their order is incorrect (e.g., Reichard 1830). In the spirit of Ptolemy, who apparently mentions only Rufiniana in connection with Worms, Speyer, and Strasbourg (Fig. 54) as an important Roman settlement directly on the north-south highway and on the Rhine as it was then, Eisenberg makes little sense as the currently most frequently cited location. Located on the Worms–Metz route via Kaiserslautern, Eisenberg certainly played a significant role, perhaps as a mining settlement, according to the extensive excavation findings; it was likely not Rufiniana.

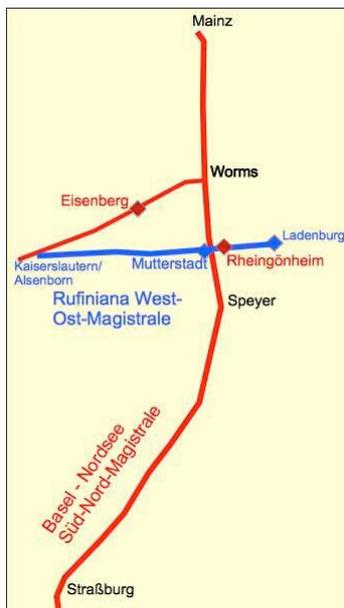


Fig. 54. The previously proposed locations for Rufiniana near Eisenberg and Rheingönheim

The Rheingönheim fort, one of approximately 50 forts built by Claudius along the Rhine (e.g., Ulbert 1969), which was also abandoned in 74 CE following fires in 70 CE (Kolb 2006), is unlikely to have attracted Ptolemy’s particular attention around 150 CE. Rouffach (German: Rufach), mentioned in the introduction, and a location on the right bank of the Rhine near Heidelberg-Neuenheim are not considered further.

A recent study on early Roman camp sites—which are presumed to have been established along the Rhine at intervals of 12 miles each—deserves attention (Eiberger 2019). Mutterstadt, with its Roman excavation on Bohligstraße (Eyselein 1967, Bernhard & Doll 1985), is mentioned as one of the sites, and it is not ruled out that there is a direct connection to the survey in the Rhine Valley. In the same context, *Rufiniana* (with a question mark) is explicitly mentioned in a table as a presumed survey point for storage sites with the coordinates 49°28’41.3”N 8°21’33.7”E, directly along the route of the Roman Rhine Valley Road (Figs. 55–57). The distance (as the crow flies) to Worms and Speyer would be exactly 12 miles in each case (Fig. 56).



Fig. 55. Presumed Roman camp site Rufiniana (?) on the Roman Rhine Valley Road between Worms and Speyer (after Eiberger 2019). Google Earth.



Fig. 56. Presumed Roman site of Rufiniana exactly halfway between Worms and Speyer. Arrow: Distinctive ground features in the digital terrain model (Fig. 36).

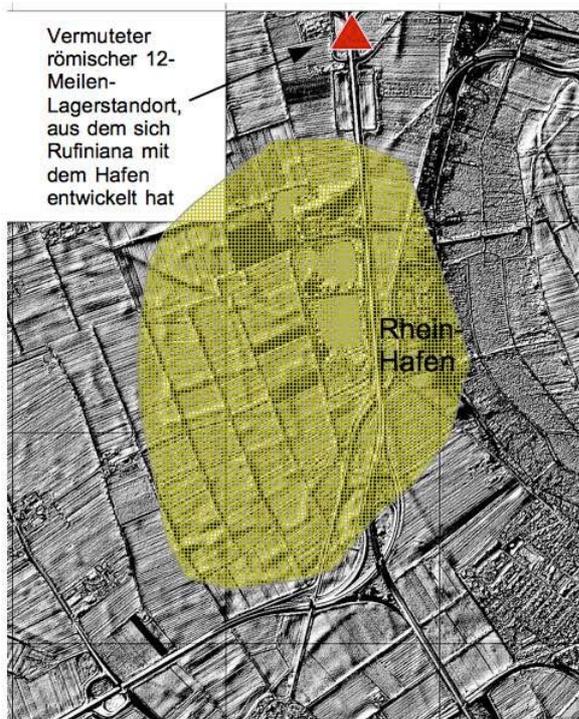


Fig. 57. The Rufiniana (?) settlement site from the Roman 12-mile survey (Eiberger 2019).

This brings the Mutterstadt Rufiniana back to the center of the discussion, as Eyselein (1967) had already suggested was worth considering, and whose opinion may also have inspired the author of the theory regarding the equidistant Roman settlement sites.

In summary, the key points of the argument for the existence of Rufiniana in the Mutterstadt area and the east-west main route of a Rufiniana road connecting Alsenborn and Ladenburg can once again be presented here as the focus of supraregional considerations. From a technical standpoint, the Romans were largely guided by the maxim of routing their road connections according to the principle of the shortest distance between two points.

This meant that Rufiniana was destined to be located there, perhaps already foreshadowed by the 12-mile survey points. On the one hand, a large settlement was subsequently able to develop southward along the Basel-North Sea highway all the way to the area of present-day Mutterstadt, where the tributaries of the Lachgraben and Marlach, together with Lake Hessesee, provided the necessary water supply. On the other hand, and even more so, the development of Rufiniana proved to be predestined by its unique location at the intersection with a west-east highway connecting the major transportation hub of Kaiserslautern–Enkenbach - Alsenborn via the intermediate stations – Lambertskreuz – Bad Dürkheim/Villa Rustica Wachenheim, crossing the Haardt Mountains on a carefully selected route without significant uphill and downhill gradients, making it easily manageable for heavy-duty traffic (Figs. 14, 15, 16). This additional route, named Rufiniana Road here, running eastward from the intersection then encountered an equally significant transportation situation with the Rhine loop, which at that time extended far to the west, and—particularly attractive—the delta-like Neckar tributary that existed precisely in this area at the time.

Rufiniana had thus become an important water and land transportation hub (see also Bockius et al. 2013), which not only connected via Ladenburg (on the Neckar) to the overland route eastward through Heidelberg to the Limes, but may also have linked, on a much larger scale, via Speyer to the *Via Militaria* Balkan – Constantinople (then Byzantium) (Figs. 58, 59). If we add the additional aspect—strongly supported by geophysical evidence—of the port’s founding at the ancient oppidum “Auf dem Limburg” (Vicus Wasserwerk), directly opposite the former mouth of the Neckar, then the waterways via the Neckar (Ladenburg) to the south and via the Rhine and Moselle to Trier are also integrated (Figs. 58, 59). All of this also makes it easier to understand why Ptolemy specifically mentioned Rufiniana.

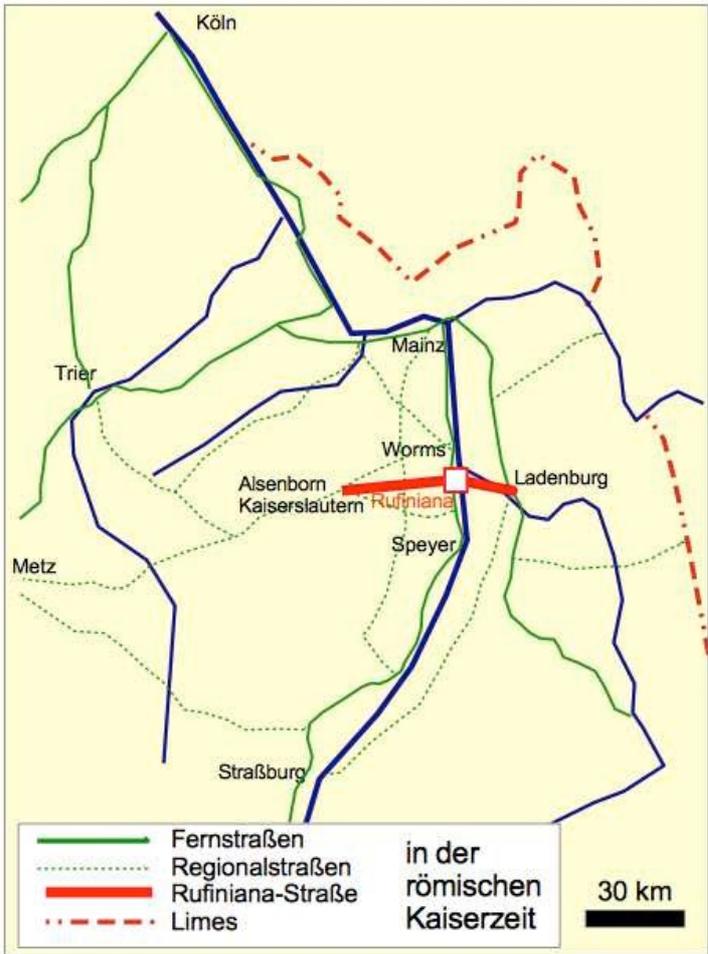


Fig. 58. The Rufiniana and the Rufiniana Road as part of the regional and national road network, with connections to the waterway network via the former course of the Rhine and the former confluence with the Neckar.

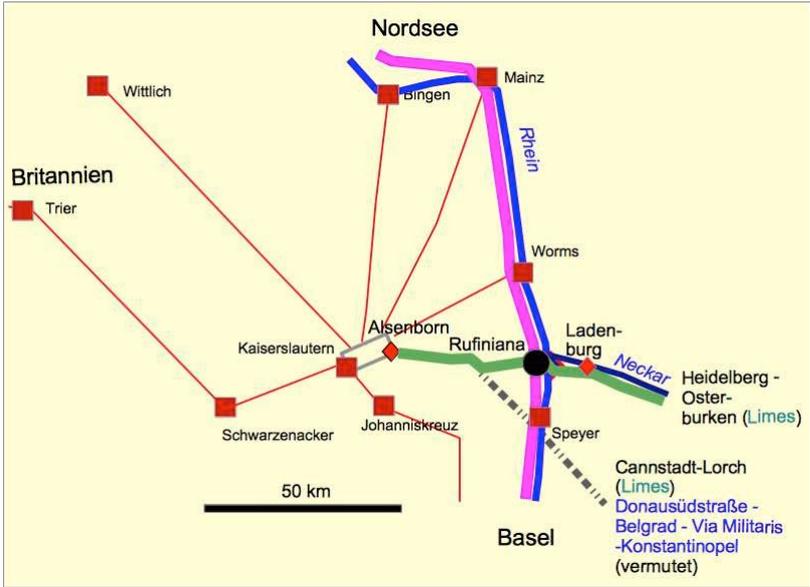


Fig. 59. The Rufiniana, integrated into the broader Roman transportation network with the Kaiserslautern-Enkenbach-Alsenborn junction.

Since the postulated port of Rufiniana at today's Maudacher Bruch plays a key role in the conceptual model of the Roman town of Rufiniana near Mutterstadt, it is necessary to address a potential objection concerning the silting up of the ancient Maudacher bend of the Rhine. To this end, we draw upon a study by Müller and Firbas (1949) that deals with an excavation at the Maudacher Bruch. From this excavation, which uncovered an Iron Age bronze sword in a layer of peat, Prof. H. Gropengießer had sent samples to the authors in 1942 for botanical analysis. At the site of the find—which cannot be precisely reconstructed but is described in the article as being 4 km southwest of Ludwigshafen, at the Kreuzgraben, about 250 m west of the Schießhaus, the bronze sword in question was found 1.6 m below the surface; Gropengießer dated it, along with ceramic shards, to the early Hallstatt period and approximately 900 BCE. Consequently, the authors conclude that the pollen recovered in the peat immediately above and below the sword dates to the Hallstatt period and that the vegetation at the excavation site was Hallstatt in character. The general significance of this pollen association cannot be addressed here, but the authors' conclusions must be strongly questioned. They write: "Since the silting up apparently proceeded rapidly, this is unlikely to have occurred very long before the formation of the examined layers of calcareous mud [found beneath the peat]. In any case, by the beginning of the Hallstatt period, the Old Rhine near Maudach had already been abandoned by the river and left to silt up."

Critics of the Rufiniana harbor hypothesis may now argue that a Rhine loop that had dried up since the early Iron Age could not have been particularly attractive as a Roman boat harbor. To address this, one must first ask to what extent it is permissible to use a single pollen sampling site—without having investigated the broader geological and geomorphological context—to speak for the entire Maudacher Old Rhine loop (the Maudacher Bruch). With regard to the question of the Roman Rufiniana harbor, this conclusion by the authors becomes particularly questionable when considering the map in Fig. 60. Here it becomes very clear that, given a process as complex as the silting up of the Rhine and the shifting of Old Rhine branches over centuries and millennia, the conclusion drawn from an excavation find at a single site is being extrapolated very far. Partial silting with peat formation in the area of the excavation may indeed have occurred for a time at the beginning of the Hallstatt period, without anything changing in the area of the old loop more than 2 km away. It should not be forgotten that partial silting did not necessarily persist for the next 1,000 years, but that the side arms could also have been flooded again. Today, the subsidence rate in the Upper Rhine Valley Graben is 1–2 mm/year, and extrapolated backward, this would amount to up to 2 m of subsidence over 1,000 years between the Early Iron Age and the construction of a Roman port, resulting in the disappearance of all previously existing areas of siltation. An argument against a Rufiniana port at today's Maudacher Bruch, if it is put forward, therefore has no basis.



Fig. 60. The Maudacher Bruch, the location of the presumed Roman boat harbor (rectangle), and the approximate location of the excavation site with pollen dating (triangle). The distance as the crow flies is over 2 km.

The discussion must also include the construction of the Floßbach canal—which had apparently fallen into oblivion among historians and archaeologists but is described in the latest local chronicle of the municipality of Mutterstadt [2017]—which in the 18th century cut off the tributaries of the Lachgraben, Marlach, and Stechgraben from the Rhine of that time far upstream of Mutterstadt and today functions as a stream with an artificial source (Fig. 22). The stream courses reconstructed today were of vital importance for the Roman vici located there and for the large settlement expanding into Rufiniana, which served as a major transportation hub.

When conducting Rufiniana research, it is essential to consider the invaluable contribution of the Digital Elevation Model (DEM) in its DGM 1 format, which features a 1 m × 1 m grid resolution and a vertical resolution of 20 cm, with interpolations in the datasets and maps down to less than 1 m and less than 20 cm. Data processing and visualization options—such as topographic maps at any selectable scale with precise profile measurements, spatial 3D representations, and shaded reliefs—now enable previously unimagined insights, which are increasingly being utilized in archaeology but, curiously, are rarely applied in geology and engineering geology.

The situation is similar in geophysics. While engineering and geological firms still largely ignore these methods in favor of drilling, at least high-resolution geomagnetic surveys are routinely used in archaeology, and geoelectric resistivity measurements with grounded electrodes are employed from time to time. The method used here in the Rufiniana case— pulse electromagnetics , which operates very rapidly, continuously, and with high digital resolution , with far-reaching

The potential for adapting methods to specific research conditions has also been largely overlooked in archaeology. This applies equally to ground-penetrating radar, which, although increasingly used in archaeology, is often employed by users who lack in-depth knowledge of data processing and interpretation, resulting in findings that frequently remain unsatisfactory.

The ground-penetrating radar results in our Rufiniana project—after their significance had previously been tested only in a pilot phase for selected research questions—have already led to the described, far-reaching findings (harbor site, expansion of the settlement, possible small fort at the intersection, possible well galleries)—which strongly support the notion of a significant Roman site at Rufiniana near Mutterstadt.

6 Conclusions

The objective stated at the beginning of this paper—to provide evidence and documentation, based on Metzger's (2019) recent research, for the location of the Roman town of Rufiniana near Mutterstadt, as mentioned by Ptolemy—has been achieved. The strip targeted by Metzger, roughly 4 km long and several hundred meters wide, between the Wasserwerk Vicus in the north and the area of the silted-up Hessesee in the south, yields results from the Digital Terrain Model (DTM 1) and geophysical measurements using three complementary methods, which are interpreted in line with the Rufiniana hypothesis. Key to the acceptance of the hypothesis are geophysical evidence of extensive anthropogenic structures in the harbor area hypothesized by Metzger, as well as human-made structures beneath the road junction precisely located using DGM 1, which could indicate the site of a small surveillance fort, and indications of a potentially more extensive water supply system for a larger settlement. Although not yet explored with geophysical measurements, but clearly emerging structurally in DGM 1, an extension, if not a concentration, of the presumed Rufiniana to the north of the previously favored area and there in the western extension is not considered out of the question. Together with the previous historical and archaeological research by Metzger (2019), the new investigations support the notion of Rufiniana as a large settlement and an important Roman land/water transportation hub that was integrated into a supraregional and (from today's perspective) transnational transportation network.

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Member of the Palatinate Association, Mutterstadt chapter; former managing director of the Mutterstadt municipal administration; and currently in charge of the Mutterstadt Archives. He has taken on the commercial, organizational, and promotional aspects of the Rufiniana research. We would also like to thank Ms. Monika Eisenbarth, director of the Schlarb Library in Bad Dürkheim, for her local knowledge and the “treasure” of old maps from the library, both of which she contributed to the Rufiniana research. Through his hikes, Manfred Schell has made a significant contribution to our understanding of the section of the Roman road between Lambertskreuz and Frankensteiner Stich/Friedensforst-Alsenborn. We also extend our heartfelt thanks to him. Without the extensive contribution of our ground-penetrating radar specialist Jens Possekel during the fieldwork and the complex data processing, as well as without the tireless efforts of Till Ernstson in conducting further measurements, the results presented here would not have been possible.

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APPENDIX

(1) Stoneley waves in ground-penetrating radar measurements over boreholes, well shafts, or other vertical material interfaces.

A Stoneley wave is a boundary wave (or interfacial wave) that typically propagates along a solid-solid interface. When found at a fluid-solid interface, it is also referred to as a Scholte wave. The wave is of maximum intensity at the interface and decreases exponentially away from it (partially translated from Wikipedia).

While Stoneley and Scholte waves play a well-known role in seismology, their observation and application have received little attention to date. A very nice description with an informative animation titled "Guided GPR Waves" can be found on this website

<https://www.leibniz-liag.de/en/research/methods/electromagnetic-methods/ground-penetrating-radar/guided-gpr-waves.html>, and the following text has been taken from that page with translation:

In a unique and innovative way, GPR (ground-penetrating radar) is used in combination with a waveguide in a borehole to obtain high-resolution water content distributions. The idea behind this method lies in the use of guided electromagnetic waves that travel vertically along the waveguide and are reflected at its lower end. By knowing the depth of the waveguide, velocities can be calculated for each depth interval and converted into water content using petrophysical relationships.

In the case of our ground-penetrating radar measurements, these characteristic interface waves were observed, and inspired by the animation, the following small sketch was created (Fig. A1_1).

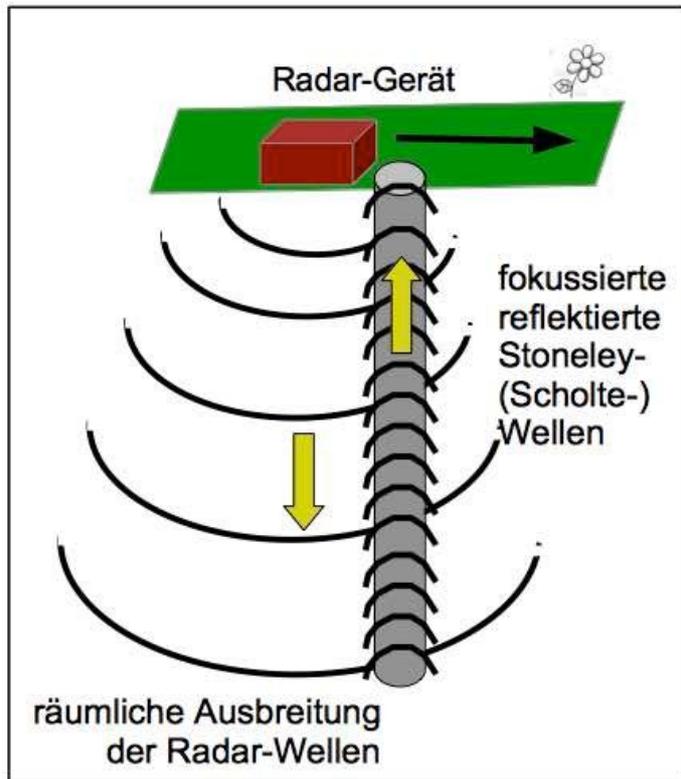


Fig. A1_1. Principle of the formation of ground-penetrating radar interface waves, which are also observed here in the Rufiniana project.

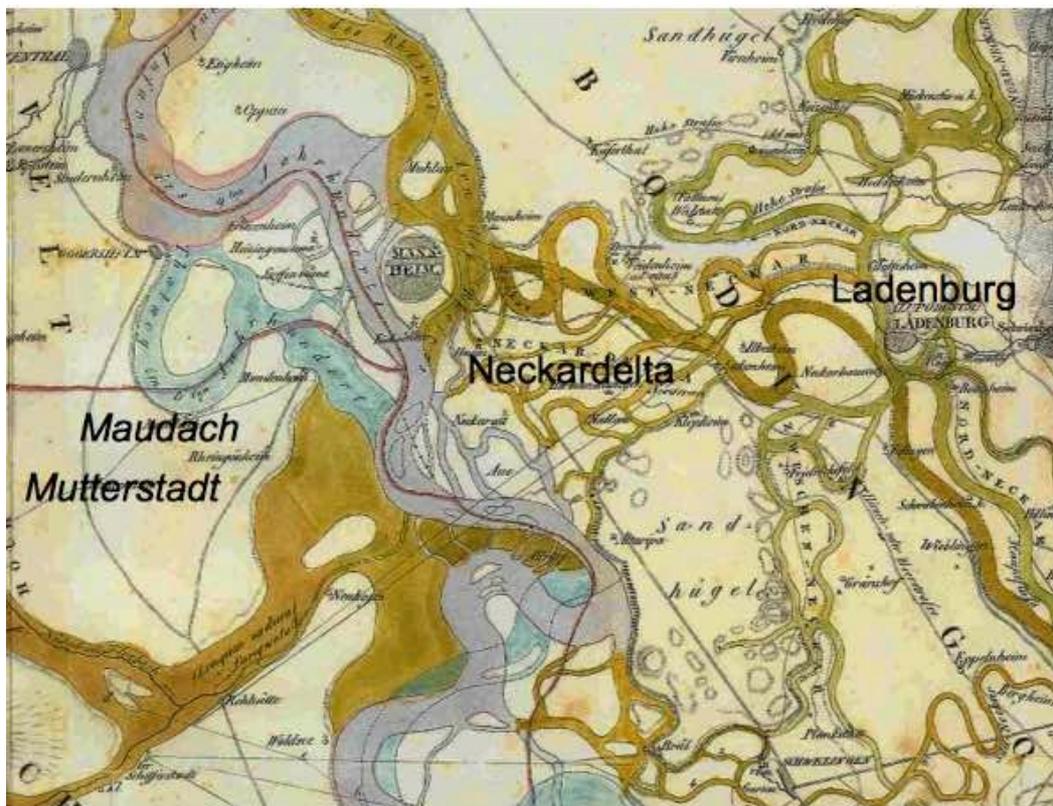
(2) Regarding a possible Roman well site near Maudach:

What is striking is the arrangement of the "structures," which reveals absolutely no systematic pattern. As for Roman constructions, the description of the water-seeking practices for wells, as described by Albrecht (2014) with a quotation from "VITRUV, De architectura – On Architecture, Darmstadt 1991, VIII 1, 1–7," might serve as a reference: "... observing certain rules almost always leads to success. Accordingly, one must lie face down on the ground before sunrise and observe the soil with one's chin propped up. Where vapors rise, water is to be found. Furthermore, observations of the soil and plant growth must be made: water occurs only in certain types of soil. For example, the supply is low in loamy and loose, coarse-grained gravel soils, and the taste is not exactly the best either. Certain plants can only grow well where there is sufficient underground water. Indicators of this are rushes, willow, alder, privet, reeds, ivy, and similar plants. However, these should not be located in depressions, as water accumulates more easily there and can thus distort the picture. To confirm these observations, further investigations must be carried out: A pit is dug at the desired location, into which, at sunset, a copper or lead basin or bowl—coated with oil on the inside—is placed upside down;

Next, cover the pit with reeds or leaves. If water droplets and condensation are found in the vessel the following day, then there is water at that spot. If the same procedure is followed using an unfired clay vessel, the vessel will be damp if the spot contains water and may even crumble due to this moisture. If you place a bundle of wool in the pit and water can be squeezed out of it the following day, this also indicates that the spot contains water. If you place a covered lamp filled with oil at this spot and, the following day, it has not burned out but is itself damp and still shows traces of oil and wick, then the spot contains water. Even if one builds a fire at the spot and the heated and charred soil gives rise to a misty vapor, water will be found there."

Given this, it should come as no surprise that the Roman fountains at Maudach on Römerstraße appear, from our perspective, to have been placed at random, whatever their intended purpose or users may have been.

(3) Various river courses over the centuries in the greater Mannheim area on a map from 1850



Detail from the "Charte des alten Flußlaufes im Ober-Rhein-Thal. First sheet. Published by BRAUN in Karlsruhe, 1850." Presumably the basis for the map in Fig. 28.