Archaeometric Researches and Applications for Gallic Economy

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Project ANR (National Agency for Research) CELTECOPHYS

1- Geophysical Methods of Prospections: ARP©, AMP

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Within the framework of the project CELTECOPHYS (ANR), we chose to develop a space approach for the craftsmen workshops which reflect the technological dynamism of this period at the end of the Iron Age and of which we want to specify the nature.
The purpose is to be able to answer to the increasing requests of many extensive surveys in France like abroad, at low prices and for surfaces where surveys cannot be done manually. The stakes are thus important as well on the level of the application of theoretical research undertaken in the laboratories, as of the inevitable need to test these new tools with archaeologists over varied and difficult field conditions, with specific problems to the Protohistory.

Applications of geophysical techniques

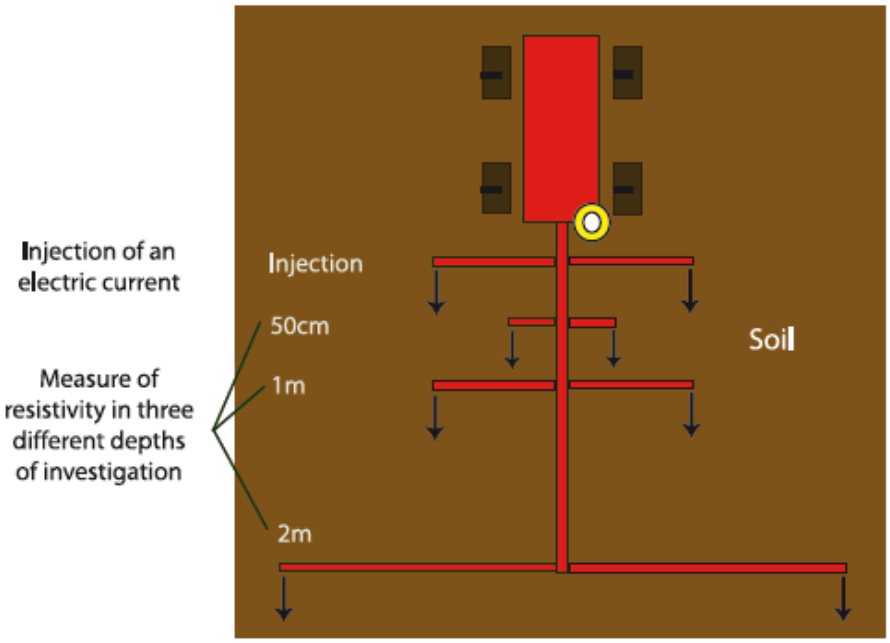
Evaluation of archaeological potential in Rescue Archaeology in France is generally done by spot observations like trenches and field walking. This last method can be very successful but only if archaeological artefacts are near the surface and if the land has been ploughed recently.
Geophysical techniques can be planned in advance and have the advantage that the entire surface can be scanned. Compared to manual survey, the gain in terms of time of operation in the field was estimated to 20 at minimum. Since the first year where ARP surveys begun for Archaeology (2004) and 49 ha surveyed, the increase of the area surveyed every year is of 50 %.

The ARP© System

Electrical resistivity is a well known parameter in geophysics. Pedologists usually use its inverse, electrical conductivity, to characterize soil salinity, soil solution mineralization or aquifer waters. A soil resistivity highlights its ability to inhibit the flow of an electrical current. Measured in Ohm.m, resistivity varies with soil texture, water content, clay content, depth and substratum nature. Resistivity values are obtained from injected current intensity, differences in potential and probes configuration (the latter defining the investigated soil volume).
Using the ARP© technology, it is easy to map quickly and efficiently the soil with a very high spatial resolution. In the field, with only one go, it is possible to obtain simultaneously three different resistivity maps corresponding to three different depths of investigation (usually from 0 to 50 cm, 0 to 1 and 0 to 2 m), but also the Digital Elevation Model (DEM) of the area being mapped. The 3 maps provide complementary information. Their analysis leads to the description of the weathered zone variability along the 3 axis, thus allowing defining soil units.

The AMP System

In a general way, the magnetic method is recognized to be most capable to reveal the presence of archaeological filled structures and ferrous objects. The general principle of the magnetic survey is relatively simple since it consists of the measurement of the earth magnetic field and more particularly variations of the field generated by the buried structures (measurement in nanotesla, nT). The magnetic method can thus be described as passive geophysical method since it consists in measuring a field of natural origin contrary to the electric method for example.



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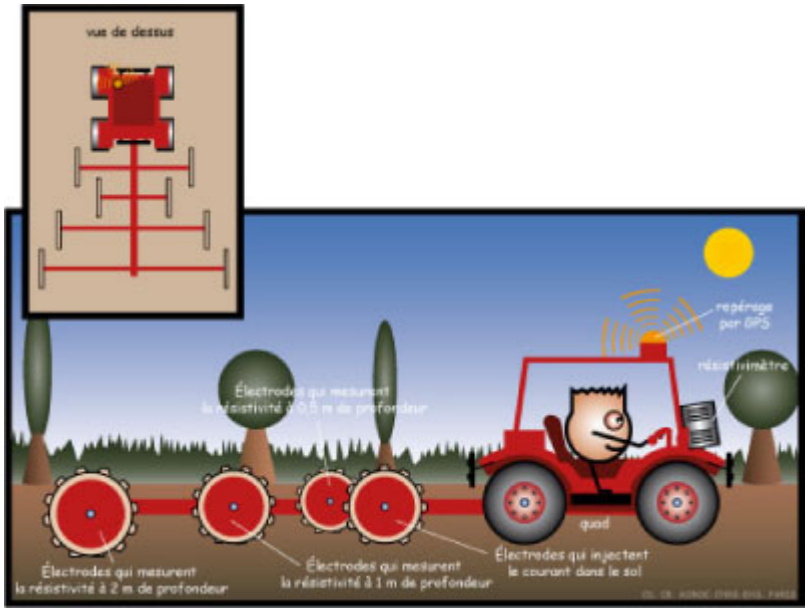

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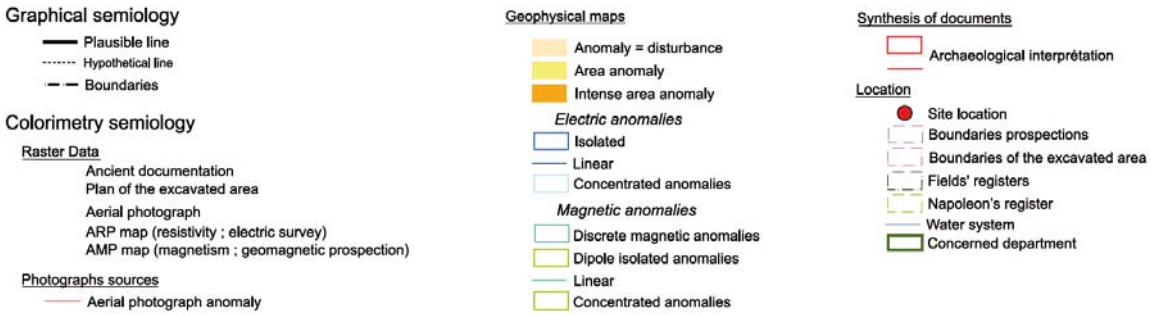

Legend used by the ANR CELTECOPHYS

2- An area of the Gallic *oppidum* of Gondole (Le Cendre, Puy-de-Dôme, France) revealed by magnetic survey : extrapolation from excavation data.

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This geophysical survey has been financed partly by the program ANR CELTECOPHYS and partly by the SRA Auvergne (Ministère de la Culture).

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Topic
History and evolution of the urban subsoil

Sites and their landscapes

Key words: magnetic survey, aerial survey, *oppidum*, craft working features, cut features

The Gallic *oppidum* of Gondole (Le Cendre, France) has been subject to a variety of archaeological surveys since the year 2000. Mechanical trenching and aerial photography show that the site occupies an area of 70 hectares. The proto-urban layout of the site has been revealed by a limited area of excavation (3500 m²) and some of the better quality aerial photographs. As part of the ANR Celtecophys project a magnetic survey was conducted by GEOCARTA (AMP system). The survey covered an area of 3.5 hectares and included the area previously excavated.

Despite the unfavourable geological context (alluvial deposits with basaltic pebbles) several anomalies that could be interpreted as archaeological features were identified. The comparison between the magnetic survey of the previously excavated features and the adjacent area enabled the elaboration of a magnetic anomaly referential.

Based on the information gathered on the excavated area we noted that :

- cellars are easily identifiable with a distinctive signal difference depending on the depth of the features : the shallower constructions give off a weak signal and show up on plans as uniform grey patches that are quite difficult to pick out ; the deeper cellars give off a much stronger signal with a strong bipolarisation ;
- the pottery kilns, theoretically very magnetic, show up as loud isolated anomalies. The surface survey and the excavation results for these features are perfectly correlated and even show up the internal organisation of each kiln with the furnaces towards the West and the associated pits towards the East. The bronze working pit shows up as a white strip (negative) ;
- the more isolated features, pits, wells... are more or less visible on the magnetic survey and are generally represented by less noise.

On the magnetic survey the majority of the previously excavated features are clearly visible. The cellars, palisade trenches and kilns are easily identifiable and their localisation is conforming to the plan of the excavation. The pits and wells are not as easily identifiable and the stone track way is not perceptible on the surface survey.
Some of the linear anomalies that do show on the magnetic survey are not archaeological features and could well be modern plough marks.

Using the 2005-2008 excavation results we have proposed to interpret the results obtained from the magnetic survey of the surrounding area. We insist on the fact that these interpretations remain hypothetical and are based on the observations obtained from recently refilled excavated features. We cannot be certain that features refilled 2000 years ago would give off the same magnetic signal.

About 30 magnetic anomalies picked up by the surface survey with strong dipolar contrasts are very similar to the signals recorded over the previously excavated cellars and 17 other readings seem to match the pottery kilns. The presence of five possible kilns shows up just next to a previously excavated well. At the time of excavation this well contained a large amount of finds almost all of which were badly fired ceramics and elements of burnt liner clay. A further 40 weaker anomalies seem to be likely to be wells and other smaller features.

The aerial survey carried out in 2008 is partly in adequacy with the two other surveys. About 20 features are visible in the same places on the plans compiles. It seems more than likely that these two survey methods are complementary. If we addition the aerial and magnetic anomalies we can identify 50 large features that are probably cellars and a further 80 smaller features. The number of probable unexcavated features is roughly the same as the density estimation made based on the excavation results.

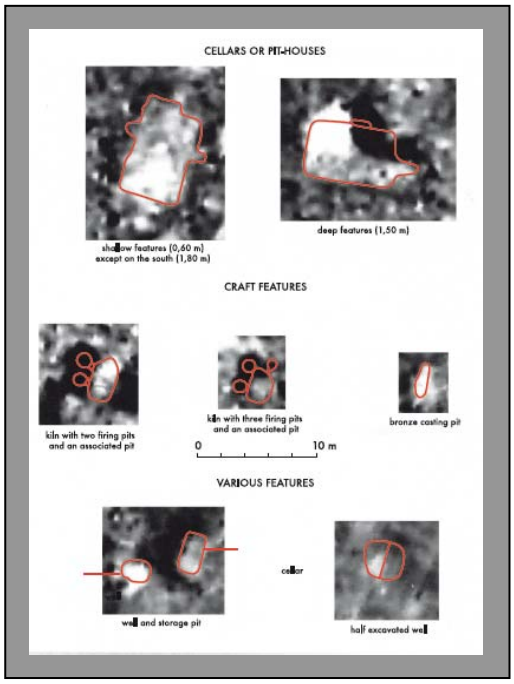
To sum up, both surface survey methods are complementary and show an organized layout of archaeological features. The cross-referencing of surface surveys with recently excavated areas has enabled us to interpret signals that normally would have been classed as insignificant. In the near future we plan to check the results obtained from the surface surveys by mechanical excavation.

Location of the excavation and of the area.
Subject of the magnetic survey (Geoportail).

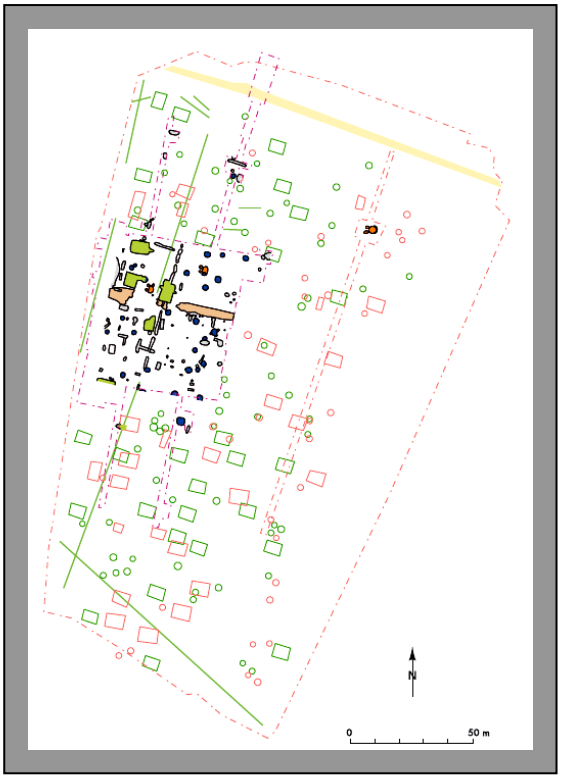
Ovens of potter: two laboratories of cooking associated with only one pit workshop.

Cellar comprising a staircase and a ground arranged (preserved depth : 1,35m).

CELTECOPHYS



Magnetic anomalies referential based on the previously excavated features.



Comparison between magnetic survey results and aerial survey results.

3- Magnetic survey of the *oppidum* of Herisson (Allier, France)

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Topic
Sites and their landscapes

Key words: magnetic survey, *oppidum*

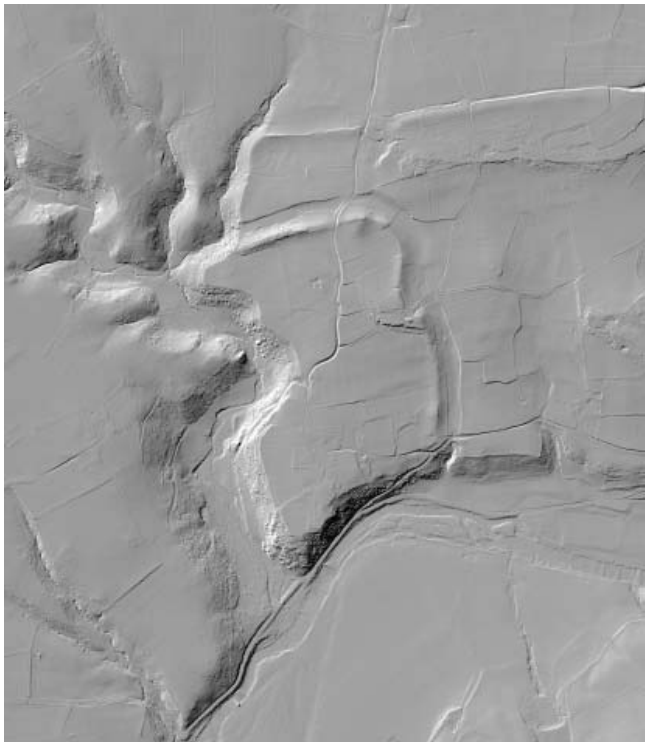
The roman fortification of Herisson is located inside the modern region called "Bourbonnais" and has the particularity to be at the crossing of three important Gallic tribes territories: Arvernes, Bituriges and Eduens.

Between the Allier and the Cher, this *oppidum* is located in a woodland area which corresponds to the south east border of the Bituriges territory.

With its two concentric enclosures delimitating a total area of 73 ha, this Gallic *oppidum* was scanned by Lidar in 2004.
In 1569, Nicolas de Nicolaï said that from the antic city of Corde it was possible to see "the ruins [...] the streets and the stones pathways [...]". In the nineteenth century, Louis Batissier described the existence of large pathways covered by large, flat and juxtaposed stones. In 1988, part of a large pathway was discovered by amateurs. In 2003, during the archaeological excavation over the rampart and specifically over the remains of the monumental entrance which gives access to the Gallic city, a new portion of the stoned pathway dating from the beginning of the first century B.C. was discovered.

Within the French ANR project Celtecophys, a magnetic survey using the AMP system developed by GEOCARTA was undertaken in order to detect and map the old stoned pathways and also the internal structure of the city. Three hectares were covered. Despite a bedrock made of a sandstone with iron oxides, the magnetic response of the soil is low (dynamic range of the map between –2 and 2 nT/m) and favourable for an archaeological magnetic detection. The magnetic map shows clearly two orthogonal streets and some buildings. No clear large stone pathway was found and a resistivity survey will be undertaken in order to check if these pathways are detectable or not.

Oppidum of Hérisson (orthophotography from Géoportail), administrative limits and localization of the surveyed area.



DTM obtained by Lidar over the *oppidum* of Herisson.

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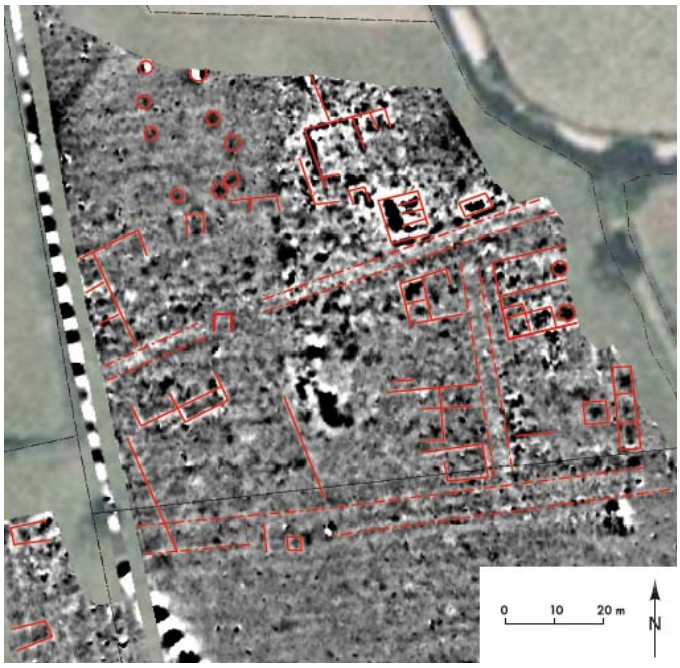
Magnetic prospection (scale =-4 to 4 nT/m) :
orthography (Géoportail), administrative
limits and anomalies



Zoom of the Northern anomalies, synthesis of the documents : layouts corresponding to the administrative limits are observable, while other anomalies let predict the existence of an urban screen and many buildings.

Vestiges of the *Oppidum* of Hérisson.

Zenith photography of the excavations.

4- Batilly-en-Gâtinais (Loiret), a rural aristocratic Settlement.

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Topic
Landscape evolution
Sites and their landscapes

Key words: Iron Age, magnetic survey, rural settlement, aristocracy, magnetic survey

The site of “Pierriers’ at Batilly-en-Gatinais (France) is a rural settlement of the end of the Gallic period. It was formerly known by aerial photographs (Dominique Chesnoy) taken at the beginning of the year 2000. The first archaeological work was undertaken as a diagnostic (Trial trenches by René Chemin from INRAP in 2005) during the construction of A19 motorway. Then an archaeological excavation took place between July 2006 and March 2007 under the direction of Sophie Liegard (INRAP, site I & 1-2). In parallel to these excavations, Terra NovA (now GEOCARTA sa.) undertook magnetic surveys to the North and South of the main enclosure within the ANR Celtecophys project.

The archaeological excavations carried out by S. Liegard made it possible to propose a first interpretation of this site. This site is a rural settlement whose aristocratic origin is now doubtless, dating from the end of the Gallic period.

The site is composed of a rectangular enclosure of 150 by 120 m, delimited by a 6.5 m broad ditch for a depth of 3.5 m. This enclosure is characterized by a regular subdivision of space in four bands of about thirty meters broad, marked by palisades covered by painted cob. The passage between each of these bands was done via a tower-porch resting on 12 posts. The entrance of this main enclosure was done by a monumental tower-porch with 4 known phases of construction. Several buildings were excavated, all of them having complex plans. They, for the majority, are built on posts and are installed in a trench of foundation.

This enclosure is lying at the extremity of a bigger one which dimensions are at least 370 m over a width of 250 m. At the forefront, a vast esplanade of 170 x 150 m is surrounded with several buildings for storage or linked to craftwork. At the rear of this second enclosure, 5 burial places (in sitting position) were found, traces of several other burial places were also found by magnetic surveys to the North of the diggings.

François Malrain, in his work on the Gallic peasants, proposes a hierarchy of the rural settlements. This site corresponds to the highest category :

- An organisation of space divided in 2 clearly defined sectors as the *pars urbana* (central enclosure) and the *pars rustica*, with buildings surrounding the esplanade.

- A clear symmetry of the whole site, with a regular space organisation.

- The presence of several - probably at least twelve- burial places (in sitting position) which indicated a cultual area.

- The presence of floral decorations over the walls covered by cob, probably over the buildings and over the palisades. One of the colours corresponds to Egyptian blue and may be considered as a Mediterranean importation.

- Important fraction of imported material, with an NMI of more than 400 amphoras.

- Presence of armament.

- Discovery of a small bronze figurine which represents a bird of pray, and whose quality depicts the aristocratic sphere.

These high quality artefacts are remarquable despite the absence of structures like pits and silos. The trench by itself was only excavated over a distance of 150 m out of 540 m (28% of overall length).

This site was occupied between the middle of the 2nd century and the middle of the first century B.C. (LT D1 and LT D2a). A reoccupying of the site is attested at the Augustan Period. What happens between is not clear and it is not sure that a continuation of the occupation exists.

The rescue archaeological excavation could study a small half of the 10 ha of this site (surface estimated inside the enclosure). Only excavations over the whole area could give a full image of this aristocratic settlement. With a site of such dimensions, it is clear that excavations could not be made randomly, but has to rely on a global understanding of the whole site. This knowledge comes from aerial photos and magnetic surveys. It is then possible to choose the sectors for excavation according to the archaeological questions and to the adaptation of the possible means : excavation of a necropolis does not require the same means as excavation of a trench 7 m wide!

This reflexion prevails for the 2008 archaeological campaign conducted by the University F. Rabelais (Tours). The choice of the place of excavation was made inside the main enclosure, near the already excavated area, using aerial photos and magnetic surveys. For this zone, we had at our disposal a geomagnetic prospection carried out by the company Terra Nova in 2007, and an air photographer. These two documents showed the continuity of the palisades, already highlighted previously and a large building, whose post holes were visible as well on the geomagnetic prospection as on air photography.

Batilly-en-Gâtinais is thus a good example of the use of combined surveying techniques for understanding a site whose dimensions implies multi-year research programs of excavations.

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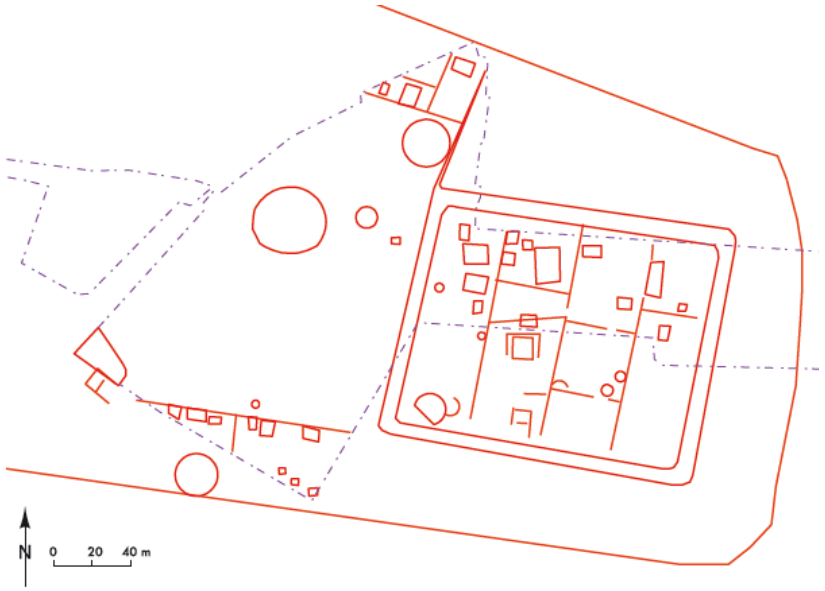
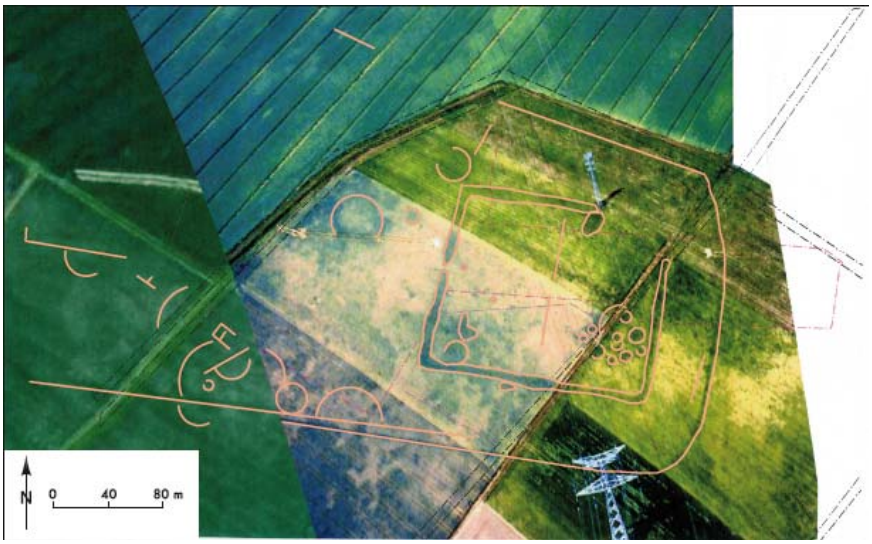


Administrative limits, site of the excavated zone and magnetic map :
Synthesis of the various data and proposals of restitutions starting from the anomalies.

Aerial photography of an excavated building.



Aerial photo of the rural settlement of Batilly-en-Gâtinais, Loiret.
(Geoportail and photography by D. Chesnoy in 2000) and observable anomalies.

Photography (D. Chesnoy), administrative limits, vestiges excavated and simplified interpretation superimposed on magnetic map (Terra Nova 2007; scale: -1.5 to 1.5 nT/m) :

- An organisation of space divided in 2 clearly defined sectors as the *pars urbana* (central enclosure) and the *pars rustica*, with buildings surrounding the esplanade.
- A clear symmetry of the whole site, with a regular space organisation.
- The presence of several - probably at least twelve - burial places (in sitting position) which indicated a cultual area.

5- Roullée, a Gallo-Roman villa in an iron extracting area. Contribution of geophysical surveys and confrontation with old diggings plans

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This geophysical survey has been financed partly by the program ANR CELTECOPHYS, partly by the Conseil Général de la Sarthe.

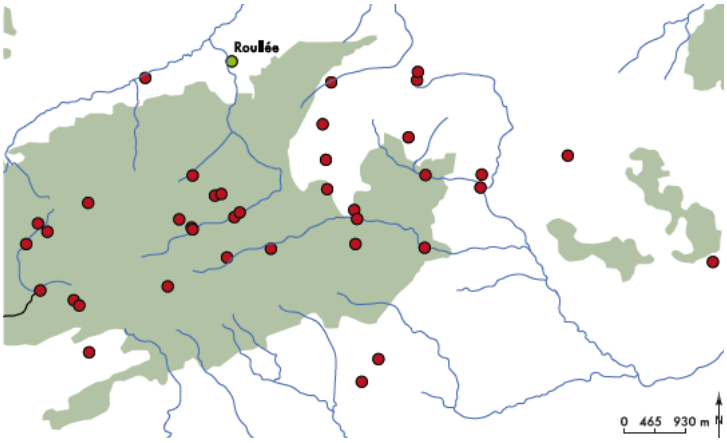
Topic
Sites and their landscapes
Landscape evolution

Key words : magnetic survey, resistivity survey, iron metallurgy, *balneum*, roman settlement

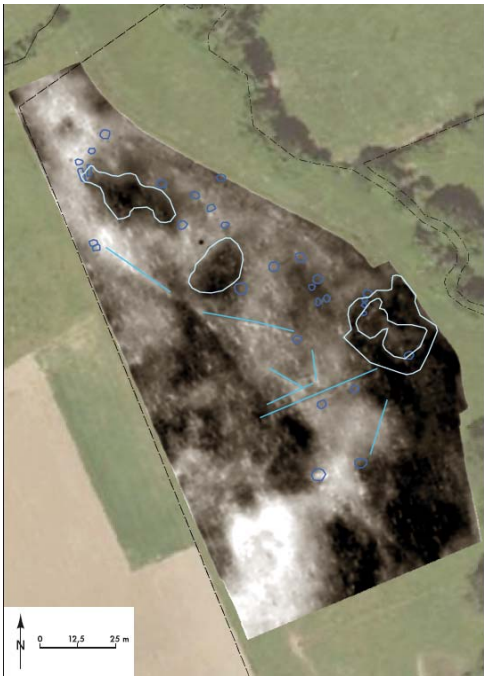
Even if there is no clear evidence yet between the settlement of the archaeological site of "Roullée" (Sarthe area, France) with the known iron activity in the nearby forest, one can only emphasize the proximity of this site with the largest iron slag concentration at the roman time, around the Sillée Forest. In fact, it is not the first time one finds a *balneum* or a more or less luxurious settlement, in the vicinity of a complete set of iron reduction sites or even above the top of an iron heap. The site of "Roullée" could fit into this small series of establishment, sometimes with refined architecture, found over or near iron-making centres. The presence of both a mosaic (the only known in the city of Cenomani) and a hypocaust painted plaster certifies the luxuriousness of its inhabitants. The area of Sillée situated over the Armorican Massif primary acid bedrock is not in favour of good arable land and meadows are found nearly everywhere. The exploitation of iron could be proposed as an explanation for the apparent opulence of Roullée.

The first difficulty was to identify the remains identified in the nineteenth century and then to appreciate the size and organization of the settlement. For this, a geophysical survey (electric and magnetic one) was completed with the new towed systems ARP(c) (resistivity) and AMP (magnetics, ANR project). Geophysical maps, both magnetics and resistivity, show clearly the presence of at least three buildings among which one can recognize the building formerly drawn by E. Hucher in 1844 thanks to its dimensions and to its plan (building 3. 4 and 5). At first sight, the buildings on the plan are separated. They do not seem connected by walls, but are oriented in the same way. This arrangement does not correspond to the common plan of an agricultural installation. Moreover, inside the buildings, the presence of several high magnetic anomalies may indicate the presence of fired structures. Some of the anomalies of smaller dimensions could correspond to graves or to metallic ‘furniture’ deposits associated with the necropolis established later on the site.

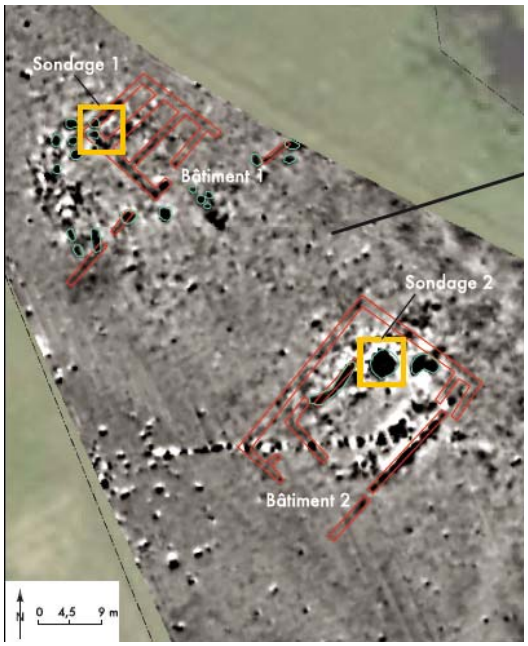
Diggings will be implemented according to the geophysical prospecting during summer 2009. They will focus on the Northeast corner of the newly identified two buildings. Building 2 with a significant magnetic anomaly may correspond to a home cooking oven, a fireplace or a craftsman forging. Several punctual anomalies should also be checked in order to establish a typology which will make it possible to go further in the interpretation of the survey. These diggings will also allow us to qualify better the nature of this settlement and to characterize the chronology and the preservation of the site.



Localization of the largest iron slag concentrations located in the Sillée Forest.

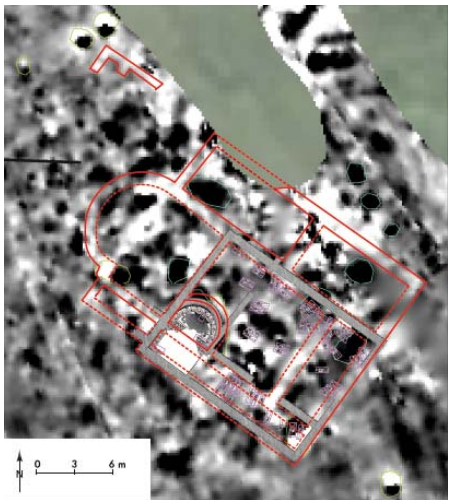


Electric prospection on the site of Roullée (channel 2 ; scale : 56 to 410 ohm/m) : orthophotography (Géoportail), administrative limits and anomalies.



Zoom on the Northern anomalies, synthesis of the documents : building 1, building 2, strong specific anomalies and localization of the surveys carried out in August 2009.

Magnetic prospection on the site of Roull (scale –9 to 9 nT/m) : orthophotography (administrative limits and anomalies.



Zoom on the southern anomalies:
- Building 3, strong specific anomalies; each black, grey or white square is function of the signal's density (25 cm^2).
- Ancient document's geocoding of the villa with mosaics and tombs' localization (E. Hucher, 1844).

6- Contribution of a large scale geophysical survey to analysis of the evolution of the Western boundary of Allonnes (Sarthe)

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Topic
Sites and their landscapes

Key words : aerial survey

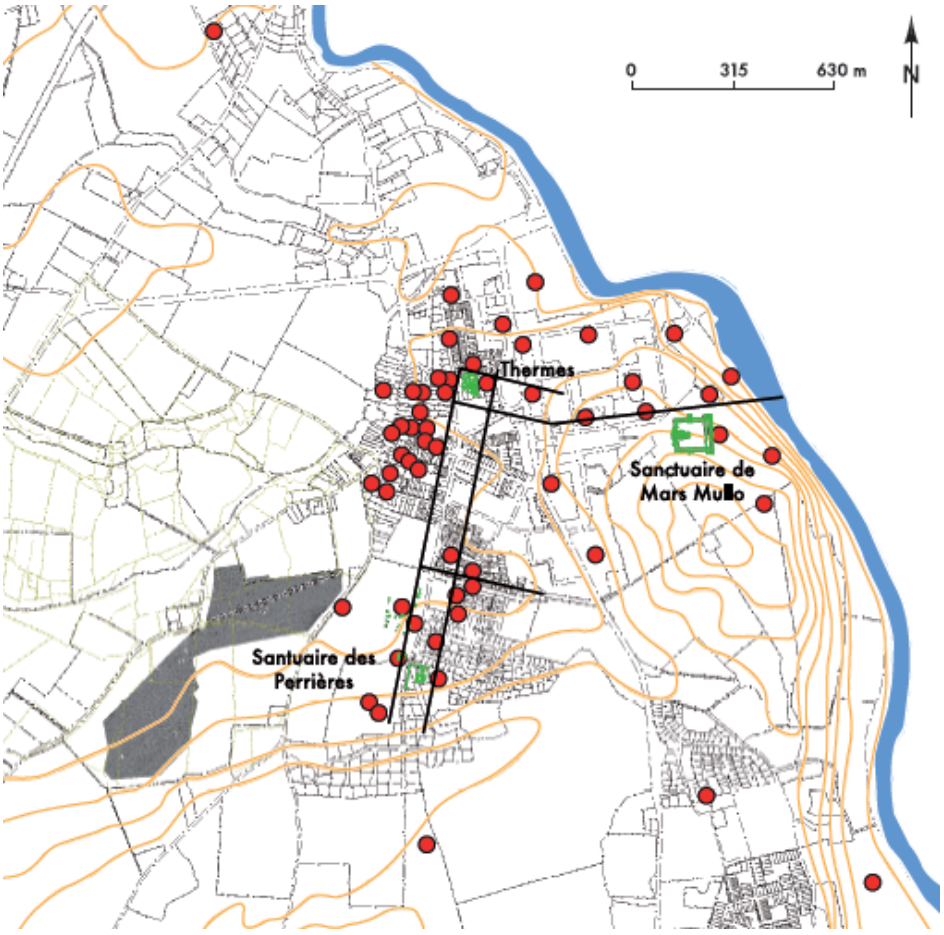
How is it possible to understand the anthropogenic evolution of the landscapes? A. Levy, in his book about urban morphology, states that "the concept of the layout's morphology covers how these layouts are distributed in the space of the city according to the various stages of urban growths and their expansion procedures".
Thus, the urban binomial (couple) networks/ frames perfectly explain the construction process of the town's composition. The mappings of Allonnes' urban composition demonstrate the importance of this morphological reading. Indeed, it is striking to see how successive waves can be oversimplified in this way. From the ancient city to the contemporary one, several phases of the urbanization remain legible. The expansion projects of the modern town to the West have focused our attention in this still agricultural area. "La ZAC de la Buissonnière" is part of the area threatened by the growth of the town.

Examination of aerial photographs shows several enclosures in these plots. INRAP's archaeological trial trenches, on the other side of the road, have identified a Roman necropolis. Is this route part of an ancient track or not? Does the Roman necropolis continue further to the West? Have we reached the limits of the Western Roman city? What was the nature of the occupation of this area before and after the Roman Period?

Combining these geophysical surveys with other sources such as photographs, aerial surveys, Géoportail (French topographical maps on line), Google imagery and fields'registers, we can analyse the evolution of administrative frames from Antiquity to present day, geocoding them all together, including the buildings on the outskirts of the city. Napoleon's register was georeferenced and vectorized and found to coincide precisely with linear anomalies in the magnetic survey. So it is possible to control the topographical accuracy of the Napoleonic register, and only some positions of frame borders need to be corrected. Two lands parcels predated the Napoleonic register. A wide double-ditch enclosure was found and can be followed both over the Google images and over the magnetic images. Further West, several enclosures are visible.

Following the geophysical prospection, a re-examination of aerial photographs, taken at different time of the year, provided additional information about the continuation of the structures in the adjacent plots. Many discrete magnetic anomalies are clearly visible; some of them are anthropogenic and will have to be checked by an archaeological excavation. Some may correspond to tombs. However we are outside of the Roman city. The shape of the enclosures is closer to medieval structures or even proto-historic ones.

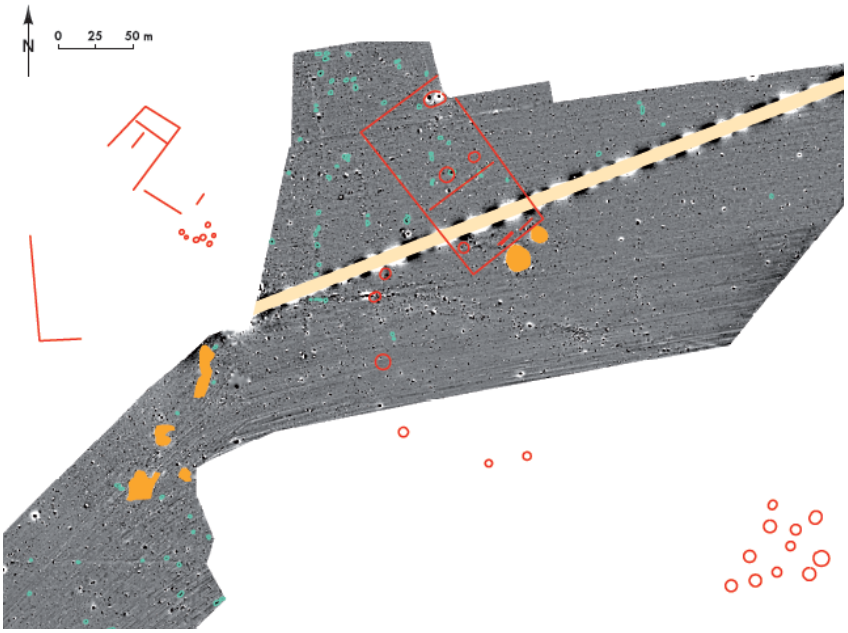
No surface artefacts have been found to help clarify the chronology. But, while uncertainties remain, it has nevertheless been possible without excavation to show that the area has been occupied since Antiquity, to precisely frame the borders and land units and to determinate the plans of some of the dwellings.



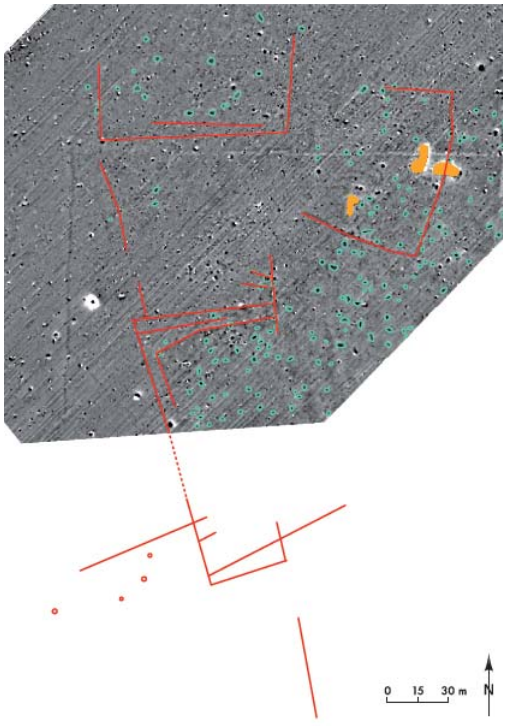
Nowadays Register, Napoleon's register, ancient monuments and ancient indices of occupation.
V.B. CAPRA

Orthographies of the extreme Southern limits of the city (IGN and Geoportail), nowadays register, Napoleon's register and anthropogenic anomalies (administrative – others).

Magnetic prospections over 17 ha in the South of the city and land registers (scale = +- 4 nT/ m) : the administrative layouts are perfectly visible. One observes a division of the central piece former to the Napoleon's register and a small shift between the administrative layout and the corresponding magnetic anomaly.



Zoom to the Northern anomalies, synthesis of the documents; double enclosure.



Zoom to the Southern anomalies, synthesis of the documents ; several enclosures and many specific anomalies.

7 - Automatic magnetic mapping of the *oppidum* of Nasium (Meuse).

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Topic
Methods and innovation
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Key words: Magnetic survey, *oppidum*, rural settlement, aristocracy

Abstract

The *oppidum* of Nasium (Boviolles, Meuse) is one of the most important Gallic fortifications in the East of Gallia. Since several years, this *oppidum* gains of PCR (Research Collective Program) "Nasium, from the *oppidum* to the Gallo-Roman town" with the financial support of Conseil General de Meuse Council and French Ministry of Culture. The presence of both a Gallic fortification (main occupation between 2nd and first century B.C.) followed by a Gallo-Roman town made this site important for understanding the process of urbanisation (Dechezleprêtre, Méniel, Bonaventure 2007 ; Dechezleprêtre 2008).

The surface of the *oppidum* – more than 60 ha – required the use of several surveying techniques like field walking, geophysics and archaeological trenches. The magnetic survey was undertaken over 40 ha (spacing between profiles 50 cm, acquisition frequency 50Hz). The surveys were done manually and the first trials of AMP (Automatic Magnetic Surveying using a quad-bike) were done with success in 2006 using the sensors from Foerster interfaced with a dGPS and home-made GIS software (Géocarta sa.). This system enabled the survey of more than 10 ha a day, whereas the manual surveys is less than 1 ha / day (including topography).

The AMP system designed by Géocarta is made of a non-magnetic cart which can support up to 5 magnetic sensors, low-noise vertical fluxgate sensors, specifically designed by Bartington for this application, and electronic system for acquisition and filtering the analog output signals of the sensors, a dGPS for the acquisition in real-time (no post-processing) of the positioning data and finally of a software for real-time acquisition of these data. The software is part of a home-made GIS already used for the acquisition of continuous electrical data (ARP© system). The acquisition rate along the profile is at 80 Hz. Considering an average speed of acquisition of 4m / s, the sampling interval is 5 cm along the profiles. The distance between profiles is 2,5 m. At the same time, the output of the 5 sensors is displayed in real-time for quality check.

Processing of these data is standard : synchronisation of magnetic data and positioning data, removal of the mean value over each profile and for each sensor, 1D removal of outliers and 2D gridding by a spline function.

These geophysical maps prove that the entire surface was occupied and that specific high concentration areas exist. The magnetic anomalies recorded are several kinds : punctual, linear and diffuse ones. The most important is a linear anomaly which corresponds to a ditch from a total development of 1200 m, which does not make a strict partition of the plateau, but rather isolates the highest part of the *oppidum*. Other anomalies can also be seen and correspond to small ditches which limits dwelling ilots orientated along the different pathways which crosses this Gallic agglomeration. As for punctual anomalies, they correspond to caves, excavated workshops, extraction and rejection pits and wells. Archaelogical trenches have enabled to characterise the diffuse anomalies. They correspond mainly to soil levels with a high concentration in archaeological artefacts.

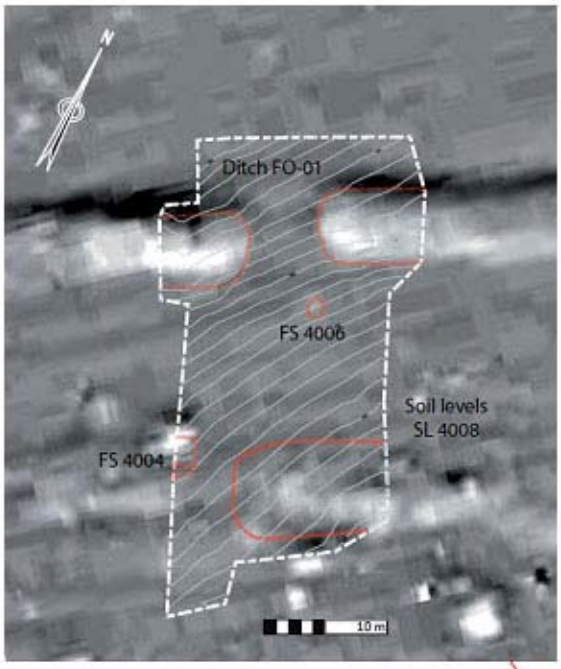
In conclusion, use of geophysical maps has brought information not only about the internal structuration of this site but also provide elements to apprehend the level of conservation of the vestiges.

References

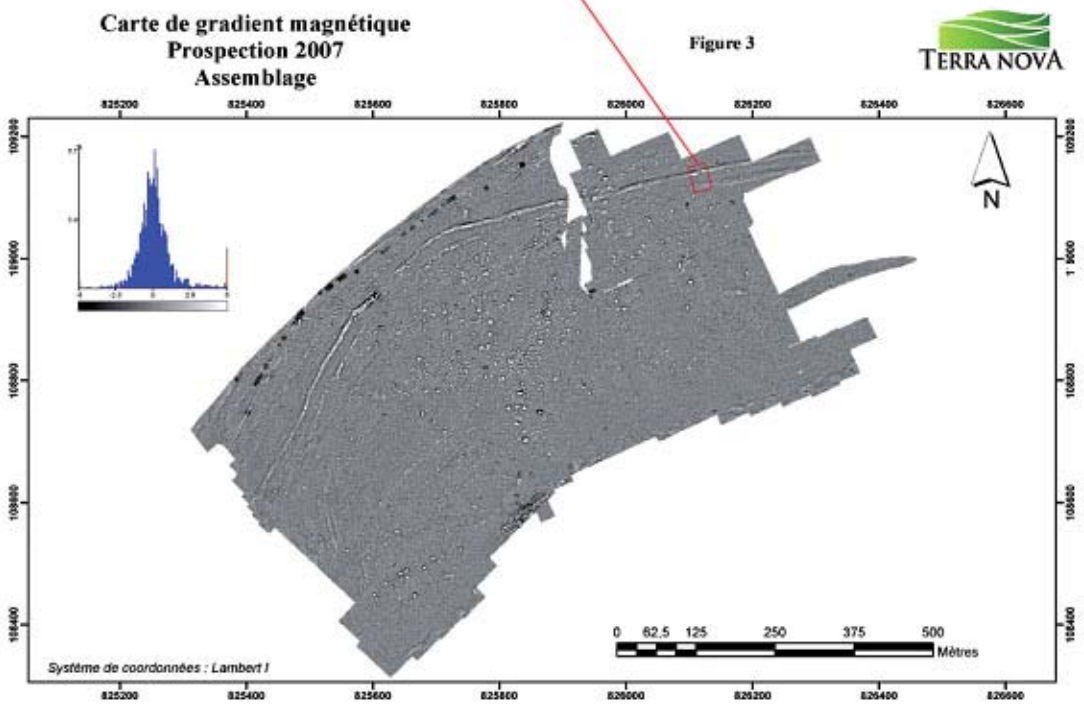
Thierry Dechezleprêtre, Patrice Méniel, Bertrand Bonaventure, « *L'oppidum de Nasium à Boviolles* (Meuse) : état de recherches actuelles », dans Ph. Barral, A. Daubigney, C. Dunning, G. Kaenel, M.-J. Roulière-Lambert éds., *L'Âge du Fer dans l'arc jurassien et ses marges. Dépôts, lieux sacrés et territorialité à l'Âge du Fer*. Actes du XXIXè colloque international de l'AFEAF (Bienne 5-8 mai 2005), Besançon : Presses Universitaires de Franche-Comté (Annales Littéraires), 2007, p. 45-54.

Thierry Dechezleprêtre, « L'urbanisation de l'Est de la Gaule : quelques réflexions à partir de recherches récentes sur l'oppidum de Boviolles (Meuse) ». Le Pays Lorrain, 2008, p. 119-123.

AMP System in the *oppidum* of Nasium.



Magnetic survey superposed with archaeological excavation (ditch in North and soil levels in South.



Magnetic survey of the site (Terra Nova 2007).