High spatial resolution magnetic survey on the Neolithic site of Le Pontet (Charente-Maritime, France): presentation of the method and associated processing

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High spatial resolution magnetic survey on the Neolithic site of Le Pontet (Charente-Maritime, France): presentation of the method and associated processing

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***Abstract* – This paper focus on an original magnetic survey with a high spatial resolution used to map the Neolithic site of Le Pontet at Saint-Nazaire-sur-Charente (Charente-Maritime, France). The protocol involves to use a motorized total station to locate each magnetic data measured by a G-858 magnetometer.**

The data processing enables to enhance the magnetic map and to obtain a final error of location of a few centimetre. The accurate localization of measurements by the total station permits to understand the magnetic intensity variations between two consecutive profiles in slope (variation of the height of the sensors during the uphill and the downhill). The using of the topographic data of the total station will enable to correct the variation of magnetic intensity induced by the relief.

The results of the magnetic survey allow to bring out several causewayed enclosures, pits and postholes. The archaeology excavations will be positioned on the basis of magnetic survey.

I. INTRODUCTION

The Neolithic site of Le Pontet at Saint-Nazaire-sur-Charente (Charente-Maritime, France) is located near the estuary of the River Charente and close to the city of Rochefort (Fig.1). It was identified by aerial photographs showing the presence of four subparallel and discontinuous ditches. Their morphology and material found on the surface indicate that they correspond to the late Neolithic period.

The site is established on limestone cliff bordering a small valley leading to River Charente. A multidisciplinary study is being conducted in this wetland so as to establish the palaeo-environmental context associated to the Holocene Neolithic settlement.

The study takes place in a collective research program on the “Dynamics of occupation and exploitation of the salt in the “charentais” gulfs, from the Neolithic to the Iron Age”. This research program, using new methodologies of survey, aims to characterize the salt worker sites. In this contribution, we will focus mainly on the magnetic survey which is particularly adapted to the study of Neolithic causewayed enclosure sites, as It was shown for other sites on the region [1], [2] or further [3]–[6].

A first campaign of magnetic survey was carried out in August 2014 on a surface of about 1ha by using a FEREX gradiometer (Foerster Institüt). This instrument has four fluxgate sensors, spaced 0.5m apart. Their sensitivity is about 0.3nT/m. The aims were to map ditches to obtain a more precise shape, to discover non-identified structures on the photograph. The map of the gradient of the vertical component of the magnetic field was acquire with a spatial resolution of 0.5x0.1m (20 points/m²). It gives good results, largely complementary to aerial photographs (Fig.1).

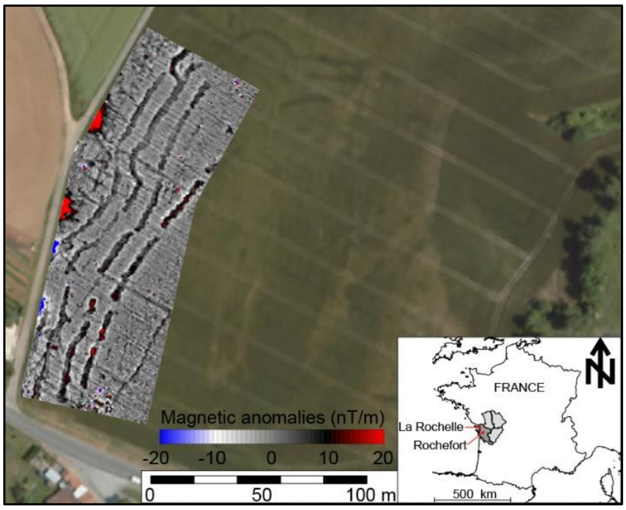

Fig. 1. Map of magnetic anomalies obtained using FEREX gradiometer and placed on an aerial photograph (BD ORTHO® 2006, IGN©) of the site of Le Pontet (near to Rochefort).

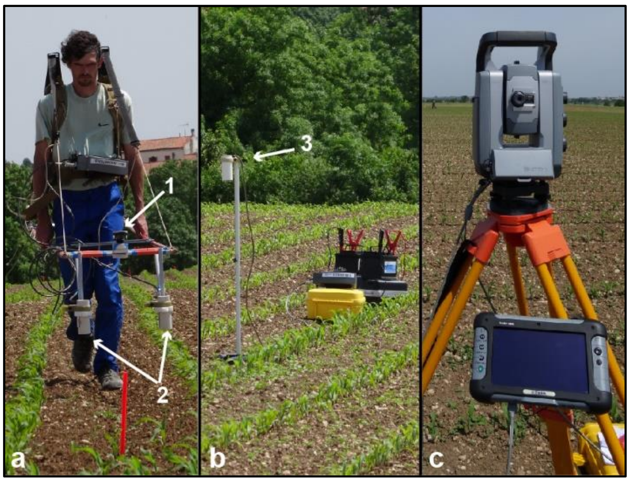

Fig. 2. a: G-858 magnetometer (Geometrics) with two caesium vapour sensors, horizontally spaced 0.39m apart (2). Glass prism reflective placed between the two sensors (1). b: G-858 magnetometer disposed in base-station (3). c: motorised total station (S8, Trimble).

However, the micro-relief doesn't enable to keep a constant walking sped during the acquisition of each profile. This generate a zig-zag effect, sometimes about 1m, particulary visible on the ditches. Furthermore, the gradiometer doesn't enable to detect smaller structures such as postholes due to a low sensitivity. To overcome at these problems, another protocol was employed with a higher spatial resolution and a better sensitivity.

II. THE PROTOCOL, MEDOTHOLOGY AND TREATMENTS

A. *Presentation of the protocol*

The protocol involved to measure the variations of the total magnetic field using a G-858 magnetometer (Geometrics) with two caesium vapour sensors horizontally spaced 0.39m apart (Fig. 2a). The sensitivity of the sensors is about 0.1nT [7]. Total magnetic field values were corrected of diurnal variation using another G-858 magnetometer disposed in base-station and far from any magnetic pollution (Fig. 2b). The G-858 magnetometer recorded 10 measures per second, both for the mobile sensors and for the base-station.

The location of each datapoint (tridimensional reference) was done by a motorized total station (S8, Trimble) with an error of few millimeters (Fig. 2a). A glass prism reflective is placed between the two sensors and reflects the laser beam transmitted by the total station (Fig. 2c). The total station operated at 20Hz (20 measures per second).

With this protocol, the mobile magnetometer was in base-station mode and it recorded only time and total field intensity but no location (The later were acquired only by the total station which recorded the time too). For this survey, the operator was following the field corn rows as prospecting lines (black crosses, Fig. 3).

So, the motorized total station and the G-858 magnetometer operated independently of one other. Data from magnetic measurements and positions were saved in two files with for common variable the time. To combine to each measuring point with one position, a phase, so called "synchronization", is carried out at the beginning of survey. The principle is to correlate a magnetic signal with a displacement. To do this correlation, a back and forth movement of the sensors is performed in the direction of a magnet. The G-858 magnetometer records the amplitude variation of the magnetic signal and the total station records the movement [8].

B. *Assembly between magnetic data and location data*

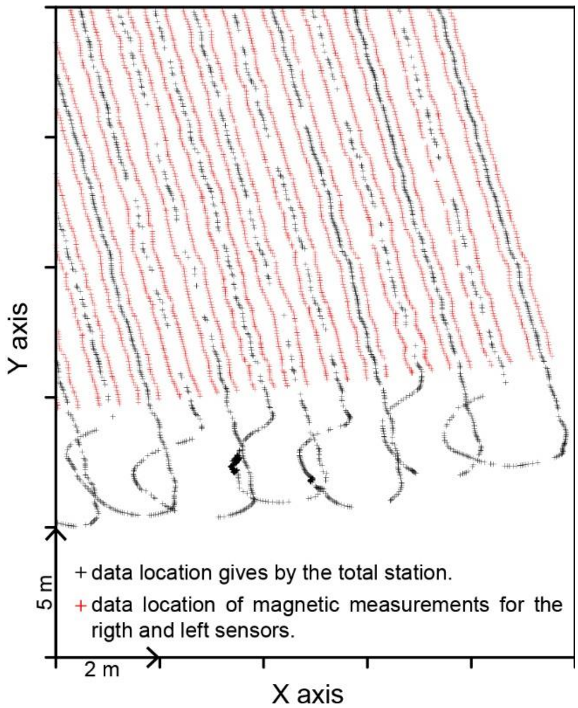

Fig. 3. Data locations of prism (black crosses) and of magnetic measurements for the right and left sensors (red crosses). The circular path corresponds to the profile changes. The spaces with no location values on a profile corresponds to a zone where the total station lost the glass prism. However, the position of magnetic measurements was interpolated from the nearest points. The resolution was about 30 points per m².

The synchronization phase enables to find the time difference between the two instruments to match the times. A position data is assigned to a magnetic data using the two nearest location points. This two points are determined by comparison between the time of the location data (total station) and the time of the magnetic data (G-858 magnetometer). There is an anterior point (time of the location data is inferior to time of the magnetic data) and a posterior point. The positioning is dependent to the ratio of the time difference between the magnetic data and the anterior point on the time difference between the posterior and anterior point. So, the coordinates of magnetic data is calculated by a linear interpolation from the anterior point and this ratio.

However, the coordinates of magnetic data do not consider the arrangement of the sensors. The calculated coordinates correspond to the prism position when the magnetic measurement has been recorded (middle between the two sensors). Indeed, the sensors are perpendicular to the operator-prism axe and spaced at 0.195m of both sides of the prism (Fig. 2). A translation and a rotation permit to calculate the coordinates of each magnetic data of the two sensors (Fig. 3).

C. *Correction and enhancement processing*

Several processing are used to correct some bad locations and outlier magnetic data. This treatments are done with a MatLab routine.

The set of location data presents a few outlier points. A point is identified as outlier when its location is not in the trend of neighbouring points. The trend is characterized by the ratio of the sum of the distance between the controlled point and the two neighbouring points (anterior and posterior positions) and the distance between the two neighboring points only. This ratio is near to one when the three points are aligned and higher to one, when they are not aligned. Location data are considered as outlier when this relation is higher to two.

Several treatments are applied to magnetic measurement to remove the outlier data and to enhance the magnetic map. Data processing on the magnetic measurements is done by three exclusion criteria to remove outlier values and are made independently of the location data. The first involves deleting the values higher to a threshold. The second processing involves comparing the values of the left and right sensors for the same measurement. If the difference between the two sensors is very important and one of the value of the two sensors is very lower or greater to the median of magnetic data. This value is considered as outlier. The third processing involves removing the outlier values by examining if it follows the tendency of the neighbouring values.

During the survey, different magnetic sources pollute the measurements as metallic masses in movement such as cars, airplane and others. With this protocol, when a metallic masse approaches, the magnetic recording continue but the operator stop the walk. Thus, after the synchronization, measurements that have recorded this magnetic perturbations are removed by identifying the distance between two consecutive points that are close to zero.

To keep only surfaces with a high density of data, magnetic measurements are removed at the ends of the surveyed areas (Fig. 3).

This basic processing enhances the quality of the magnetic map. Finally, location data and the magnetic measurements are georeferenced with reference points localized by the total station. The final error of localization is a few centimetre.

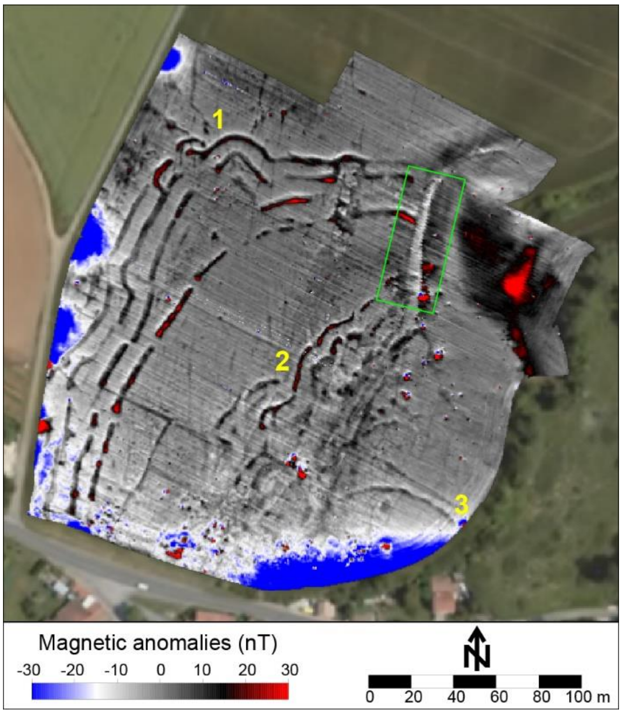

Fig. 4. Map of magnetic anomalies obtained using G-858 magnetometer. The prospected area, about 5ha, was mapped in four days. (1) external enclosure composed by four ditches ; (2) middle enclosure composed by two ditches ; (3) internal enclosure composed by one ditch. Green square shows the zig-zag effect induce by the relief (corresponding to a palaeo-cliff).

III. RESULTS OF THE MAGNETIC SURVEY

The results of the magnetic survey on the site of Le Pontet, illustrated by the Fig. 4, allow to bring out the causewayed enclosure visible on aerial photographs but also the presence of other ditches inside. The Neolithic site has a great enclosure of four discontinuous and subparallel ditches, then a second one enclosure inside and finally a third one enclosure composed by a unique ditch.

The first enclosure has a great entrance, on the north, with several small ditches which have an incurved shape and joining the external ditch. These extensions of ditches are called “pinces de crabe” (crab’s pincers) and mark enclosure entrances. The “pinces de crabe” are typical of the enclosures of west-central France [2]. In this entrance, several small punctual magnetic anomalies of low intensity could be interpreted as postholes as has been demonstrated on the Neolithic site of Chenommet (Charente, France) [2]. Internal ditches on the first enclosure show generally a greater intensity that external ditches and it may be induced by a different in filling ditches.

The second enclosure has two discontinuous and subparallel ditches and several “pinces de crabe”.

However, in the part of this enclosure, other structures are visible but their identification are difficult, probably ditches, postholes and pits. Future excavations will permit to recognize some of those structures.

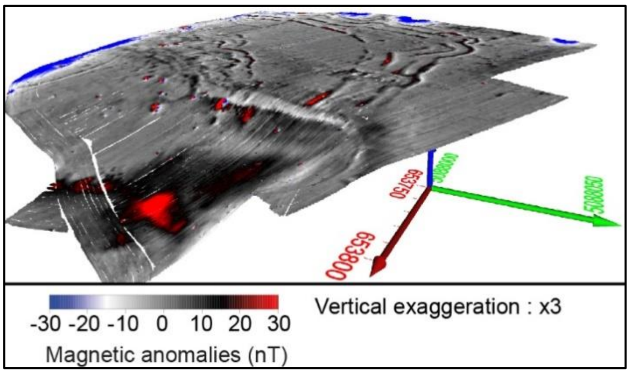

Fig. 5. Representation in three dimensions of the magnetic survey on the Neolithic site of Le Pontet. The topographic information correspond to the glass prism height and it is therefore elevated above the ground.

These two enclosures end on the palaeo-cliff (northeast) which characterized by a major slope failure, initiating the slope of the valley. This slope failure causes a zig-zag effect and prevents the good readability of the magnetic map on this zone.

The total station localizes each datapoint with a tridimensional reference, so the magnetic map can be shown in three dimensions, as illustrated in the Fig. 5 (the zig-zag effect and the slope failure are better identified). The topographic information from the total station will permit to correct the zig-zag effect (in progress).

IV. COMPARISON BETWEEN THE TWO MAGNETIC MAPS AND PROCESSING DATA

A. Comparison between the magnetic map obtained by the G-858 magnetometer and by the FEREX gradiometer

An accurate positioning of magnetic measurements of the G-858 magnetometer is made by the motorised total station. This, coupled with a high spatial resolution, permitted to obtain a map of magnetic anomalies. This protocol has different advantages as a better sensibility of the caesium vapour sensors in relation to the fluxgate sensors of the FEREX gradiometer [9]. On the Fig. 6, the magnetic anomalies of ditches, measured by the caesium magnetometer (Fig. 6a), present a wider range of intensity than the fluxgate gradiometer (Fig. 6b). The yellow arrows show a “pince de crabe” and ditch where the magnetic information are more detailed. In the yellow dotted boxes, two magnetic anomalies of low intensity of two older ditches are identified on the map right (Fig. 6b) but not visible on the other map or not clearly identifiable (Fig. 6a). Another advantage, it is a nearly absence of the zig-zag effect induced by the micro-relief which doesn’t enable to stay at a constant walk. Indeed, on the map obtained with the high spatial resolution protocol (Fig. 6b), the zig-zag effect is not visible compared with the map obtained with the FEREX gradiometer (Fig. 6a).

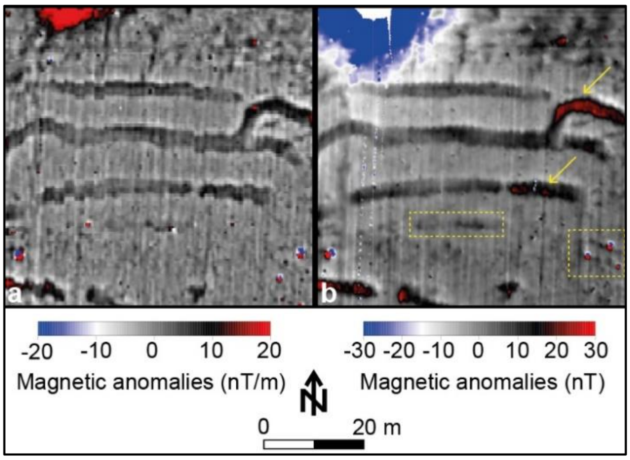

Fig. 6. Comparison between the magnetic maps obtain with the FEREX gradiometer composed by four fluxgate sensors (a) and with the G-858 magnetometer composed by two caesium vapour sensors (spaced horizontally) (b). The positioning of magnetic measurements of the G-858 magnetometer is carried out by the motorised total station.

The smallest structures are also more identifiable (probably as postholes) on the magnetic map with the high spatial resolution (Fig. 6b).

However, the FEREX gradiometer has four sensors, spaced 0.5m apart, and permits to obtain four profiles for one passage. So, for a same area, the latter is two time faster than the G-858 magnetometer. Furthermore, the magnetic gradient measurement is less disturbed by the magnetic masses than the total magnetic field measurement. Indeed, the magnetic disturbance of a magnetic masse, visible at the top the Fig. 6, is smaller on the magnetic gradient map (Fig. 6a) than the total field map (Fig. 6b).

B. Correction of the zig-zag effect induce by the topography

The micro-relief doesn’t enable to stay at a constant walking during the acquisition. This is the cause of the zig-zag effect on the magnetic map acquired with the FEREX gradiometer. The localization of each data magnetic point by the motorised total station doesn’t depend to the constant walking (Fig. 6). However, if the relief is very important, such as at the palaeo-cliff (visible on the Fig. 5), a zig-zag effect appears in the slope failure. This zig-zag effect is shown on the Fig. 7 which corresponds to an extract of the magnetic map with a high spatial resolution.

The slope failure corresponds to the zone characterized by negative magnetic anomaly with an elongated shape and surrounded by a positive magnetic anomaly of low intensity (Fig. 7). In the zone of the slope failure, the direction of the profiles during the survey is northwest southeast and a variation of intensity is visible between two profiles. Indeed, the positive anomaly surrounding the negative anomaly with the zig-zag effect present one profile with a magnetic anomaly of lower intensity compared to the following profile and inversely (generate an alternating of light and dark grey on the map (Fig. 7)).

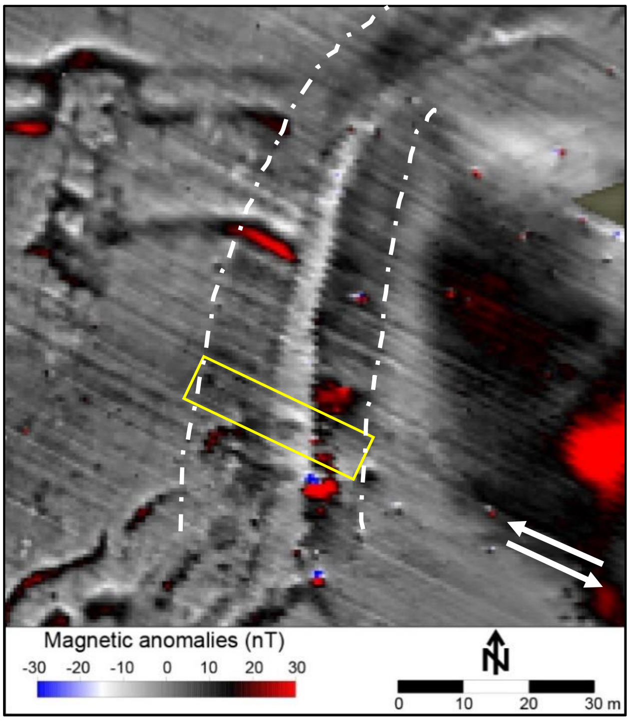

Fig. 7. Extract of magnetic anomaly map which present the zig-zag effect induces by the slope failure. The slope failure reveal the presence of a paleo-cliff. The two arrows marks the profile direction during the survey. The dotted lines indicate the zone with the zig-zag effect. The yellow rectangle shows the position of the magnetic and topographic profiles presented on the Fig. 8.

This zig-zag effect and this variation of magnetic anomaly intensity are induced by the height of sensors. The yellow rectangle on the Fig. 7 corresponds to the location of magnetic and topographic profiles shown on the Fig. 8. This figure presents two prospecting profiles with the magnetic data recorded by the G-858 magnetometer and the prism height data recorded by the total station. So, there is one profile during the uphill and one profile during the downhill of the slope.

The topographic reference for the comparison between the uphill and the downhill of the slope is a digital elevation model derived from the LiDAR data (Light Detection And Ranging) (Fig. 8, curve 1). The two prism height curves are represented by the curve 2 and 4 (Fig. 8). The downhill (2) and the uphill (4) present a small oscillation with a wave length around of 1m corresponds to the walk signal. This signal is induced by the oscillation of the glass prism when the operator walks along of the profile.

The two magnetic curves are represented by the line 3 (downhill) and 5 (uphill) (Fig. 8). The magnetic signal of the downhill (3) have a lower intensity than the magnetic signal of the uphill (5). There is a difference of few nT between both. This difference is induced by the height difference between the two prism height curves (Fig. 8, curves 2 and 4). Indeed, the uphill curve (4) is lower than the downhill (2). So, when the operator climbs the slope,

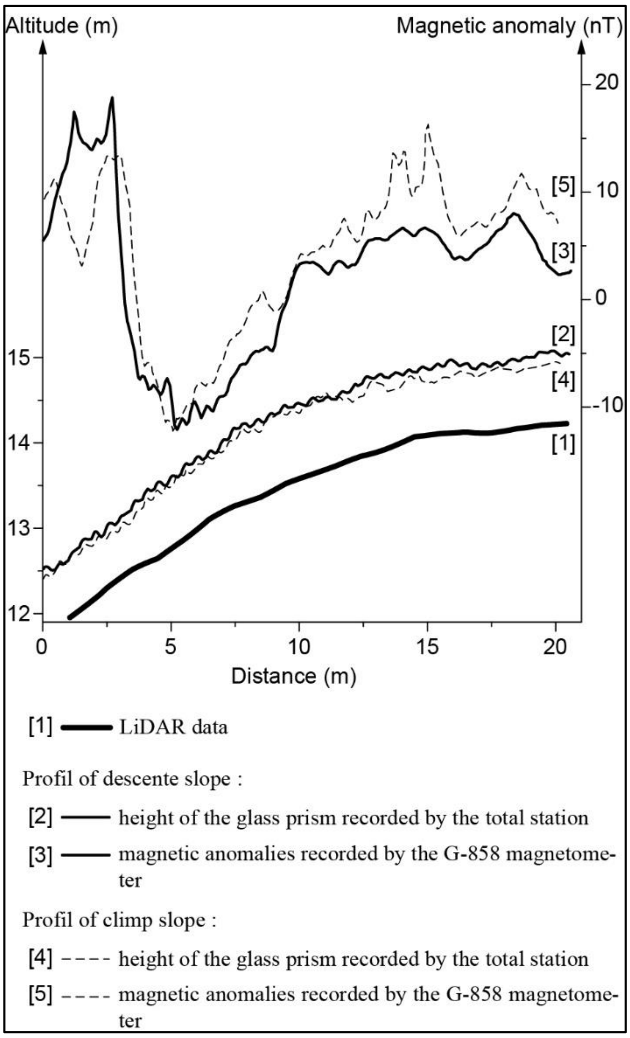

Fig. 8. Graph of the prism height data during the downhill (2) and the uphill (4) and also of the magnetic data during the downhill (3) and the uphill (5). The topographic reference for prism height data is a digital elevation model derive from the LiDAR data (1). These profiles correspond to the yellow rectangle on the Fig. 7.

the sensors are closer to the ground than when he descents the slope.

The slope failure corresponds to the zone with the highest deviation between prism height curves and magnetic signal curves (zone between 12 and 17m, Fig. 8). Thus, a magnetic alternating intensity is present between a climb profile and a descent profile. This induces an alternation of light grey and dark grey on the magnetic map and the zig-zag effect (Fig. 7).

This prism height variation comes from to the configuration of the device. The sensors are placed at the front of the operator. So, when he climbs the slope, the sensors are lowered relative to the default height of the sensors. As the magnetic intensity is dependent on the distance between the source and the sensor, the magnetic intensity is lower. This is inverse for the downhill. So, the zone between 12 and 17m corresponds to the profiles with the greatest height differences on the sensors and also corresponds to the greatest magnetic intensity differences (Fig. 8).

The height difference between the uphill and downhill of the profile is around 0.20m between 12 and 20m. This difference is around of few centimetres (maximum of 0.10m) between 0 and 12m. Each approach of the sensor to the soil corresponds to an increase of the magnetic intensity (Fig. 8).

The treatment prospect is the correction of the magnetic intensity difference between the downhill and uphill of the profiles. This correction is possible using the prism height supplied by the total station. So, a completed analysis of elevation data (prism height) is required to have a good understanding of the prism height variations. The magnetic data will be corrected of the height variations of the sensors, induced by the topography, by an upward continuation of the magnetic anomalies. This treatment will permit to correct the zig-zag effect induced by the topography.

However, there is also conceivable to apply this processing on all of the magnetic data. Indeed, to a lesser degree, the height of the sensors varies compared to the soil due to the micro-relief. By going further, the correction of walk signal could be envisaged and so removed the magnetic disturbances induced by the height variation of the sensors.

V. CONCLUSIONS

The results of magnetic survey on the site of Le Pontet allow to bring out the causewayed enclosure visible on aerial photographs (Fig. 1) but also the presence of other ditches inside (Fig. 4). The Neolithic site has a great enclosure of four discontinuous and subparallel ditches, then a second one enclosure inside and finally a third one enclosure composed by a unique ditch. This survey allows to detect many more specific anomalies of various sizes. This is perhaps identified as pits and postholes. The archaeology excavations will be positioned, in 2016, on the basis of surveys. It will improve the interpretations currently based only on geophysical data.

The FEREX gradiometer has a good resolution (20pts/m²) and is adapted for the cartography of archaeological structures as ditches, pits and hearths. For the same area, it is two times faster than the G-858 magnetometer. The FEREX has a good ratio between the magnetic map quality and the acquisition time. However, the positioning errors and its sensibility do not permit to detect the smaller structures as postholes. Thereby, the coupling between positioning data (total station) and the magnetic data obtained with the G-858 magnetometer permit to acquire a magnetic map to high spatial resolution (30pts/m²) and to detect the smaller structures. This protocol gives more accurate information on the magnetic anomalies associated to archaeological structures. Thus, this allows to excavate of the specific small areas without investing in a large excavation campaign.

The treatment of the variation in height between the ground and the sensors, induced by walking and topography, will increase the quality of the magnetic map. The use of a tridimensional positioning have advantages for correcting the signal intensity variations mainly related to the topography and operator.

To provide additional information for the interpretation of the magnetic map, other methods will be applied. Magnetic susceptibility measurements, electrical conductivity map and electrical resistivity tomography will enable to provide more information on the physical proprieties of the soil and archaeological structures.

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