Environmental magneto-gradiometric marine survey in high anthropic noisy area

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Abstract

We describe the magneto-gradiometric survey performed in the "Mar Piccolo" of Taranto, Italy in May 2005 for environmental aims. This region, being a noisy harbour environment, provides a challenging test for magnetic methods. To reduce the spurious noise signals, both of temporal and spatial origin, we used two Geometrics G880 caesium magnetometers towed in transverse gradient configuration. We show how in shallow waters this gradiometric configuration allows one to distinguish the anomalies due to small metallic bodies near the seafloor from the induced noise due to anthropic contribution and geomagnetic field variations. A direct visual inspection confirmed that the peculiarities highlighted in the gradient anomaly map were due to abandoned metallic objects founded on the seafloor.

Keywords: environmental reclamation, anthropic noise, magneto-gradiometric survey

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I. INTRODUCTION

The coastal areas, and in particular the harbour zones, are habitat with peculiar characteristics whose delicate equilibrium is the result of the interaction of multiple factors that can easy be modified and compromised by the anthropic installations. The creation of infrastructures and the harbour traffic give frequent examples of destabilization; consequently the actions of the mankind to the safeguard of this delicate field are more and more numerous. Reclamation and reorganization are the departure point in order to reconstitute an adequate environmental sustainability, and they can be realized by actions in order to eliminate the pollution sources and the polluting substances or at least to reduce the actual concentration in the various environmental scenarios. The first phase of a reclamation process and environmental restoration is the classification, quantification and localization of the waste, abandoned or deposit in uncontrolled way.

Within this contest, we performed a magnetic survey in may 2005 in the “Mare Piccolo” of Taranto, Italy. The “Mar Piccolo” is a half-closed river basin of approximately 20 Km squares subdivided by two capes in two smaller basins, one of which is in communication with the “Mar Grande” and therefore it is connected to the Ionian sea, through two channels. The second instead is inner and has a narrow marine circulation. The maximum depth is respectively 13 m for one basin and 9 m for the other. The “Mare Piccolo” is surrounded by the city of Taranto, which is a great environmental hazard industrial area and, being seriously compromise in all environmental sectors, it’s considered a ”site of national interest for reclamation actions” [Parlamento Italiano 1998, Ministero dell’ambiente e tutela del territorio 2001].

A large amount of of metallic objects can be found in a harbour area: barrels lost during naval operation or intentionally abandoned, chains, and even last war weapons. Thus a first useful investigation is a magnetic survey of the area, which can identify their magnetic signal and help to locate their position in order to the reclamation of the site. The magnetic survey can reveal not only metallic objects on the seabed, but it can also identify targets below it: this turns out very important to the localization if they were buried in the mud and thus hidden to a visual inspection.

In the present work we describe the magnetic gradiometric survey in the Taranto harbour which was performed in May 2005 in order to detect magnetic targets deployed on the seabed or buried some meters below it. The selected area is characterized by high magnetic noise, while the survey aimed to find small metallic objects on the seafloor at a depth between some to 15-20 m; thus the main task of the survey is to distinguish small magnetic anomalies among the anthropic magnetic induced noise typically present in commercial harbour area. The choice was thus to set up a gradiometric magnetic survey in the area under investigation: the relative difference between the two sensors may reduce dramatically the effect of spurious signals coming from temporal variations or other far anomalies of anthropic origin which vanish at the scale of few meters.

In the following sections we describe the planning procedure for a survey of this kind and the magneto-gradiometric configuration, then we analyze the Taranto specific case and discuss results obtained with the post processing of the gradiometric data.

II. PLANNING OF THE SURVEY

Once the target nature of the investigation has been identified it is necessary to plan an efficient cover of the surveying area through a mesh, most possible regular, made by a series of parallels lines and a series of orthogonal tie lines. The survey geometry, in terms of line spacing, and the sampling rate is chosen in order to be able to detect the expected anomalies. In real field operation the planning is finally chosen as a compromise between the precision in the target localization wanted, the size of metallic detectable targets and the available shipping time. In the measurements of marine magnetism applied to ambient contexts, and therefore in high definition, the quantities that must be acquired, besides the intensity of the magnetic field, are a much possible careful value of the positioning of the vessel and the relative positioning of the measure apparatus [Caratori et al. 2006]. The "Istituto Idrografico della Marina" (IIM) supplied all the marine logistic needed to perform the present survey, in particular vessels and magnetometers; thus the needed positioning accuracy is guaranteed by the use of the differential global positioning system (DGPS) which is currently installed on-board of IIM vessels. It is also of critical importance a good knowledge of the depth in the measurement point. In the conventional surveys the presence of a "coherent" reference station (Magnetic Base Station) is of fundamental importance; it is placed in proximity of the survey area, and it is useful both to carry out the monitoring of Earth geomagnetic field and to isolate the spatial variations from the temporal ones.

Anyway, also in a gradiometric survey the base station data are useful to study correletions of the natural variations with the detected anomalies and eventually to decide to reject or accept them after a further analysis. Particular attention must be paid in order to use a low magnetic signature ship, to use high sensitivity magnetometers, to perform high precision positioning of the measurement point and to take care of the temporal variations.

III. CASE STUDY

In the framework of the collaboration activities between the Istituto Idrografico della Marina and the Istituto Nazionale di Geofisica e Vulcanologia (INGV) formalized inside the Coordinamento Nazionale per la Geofisica Marina (CONAGEM), a magnetic survey took place in the "Piccolo Mare" of Taranto, Italy during May 2005. Its goal was to obtain useful information on the location of handmade with magnetic signature, in order to their removal for the environmental reclamation of the site. The survey offered the possibility to carry out a particularly meaningful test for the application of magnetic procedures to typically environmental issues. It must be stressed here that extreme conditions for the magnetic survey have been found in the area: they were due to the remarkable presence of anthropic noise caused by the high number of ships and harbour infrastructures. It was however possible to carry out an enough meaningful survey thanks to the availability of a gradiometric device made by two caesium magnetometer (Geometrics G-880 model) in transverse configuration. The use of high sensibility device in the gradiometric configuration concured in fact to a better identification of the different targets which were present in the surveying area and that could not be easily detected by conventional techniques of acquisition and processing. In fact, in such a noisy area, even the use of a reference base station cannot be sufficient to completely highlight the searched spatial anomalies among the anthropic noise and the temporal variations.

A magnetic-gradiometer is made by two sensors which acquire two total magnetic field values in two separate spatial points; the difference between the two magnetic values divided by the distance between sensors is a good approximation for the component of the magnetic gradient along the direction parallel to sensor separation. This approximation makes sense assuring that the distance from the source of anomalies is much greater than the separation between the two sensors: the condition is satisfied in our case. The gradiometric device was towed by an glass reinforced plastic (GPR) hydrographic boat by means of rubber dinghy spoiled by all magnetic signature devices at a distance of 20 m.; such a distance represents a good compromise among the requirement to minimize the effects of noise generated by the ship and its equipment, the need to limit the positioning errors due to lee-way effects of the towing of and the constrain to maintain the heading of the two sensors as much as possible equal. The particular solution to accommodate the two sensors immediately under the hull of the rubber dinghy was due to the difficult maneuverability in emergency of the boat and of the towing.

Contextually to the magnetic survey a detailed bathymetry was acquired (fig.1) through a multi-beam device: the accurate positioning of the carrier was guaranteed by a GPS differential system. Once all the reference geometric parameters are known, the positioning of the magnetic sensor device was obtained by interpolation during the acquisition process. Close to the survey area a magnetic base station was placed to monitor the Earth geomagnetic field in order to guarantee that the relief was carried out in quite magnetic days. Due to the geometry of the area, to the requirements for navigability during an emergency and to respect of the available working time, the relief was planed with East-West profiles with interline of approximately 20 m. Furthermore twelve ties have been executed with variable interline separation in order to refine the evidences of magnetic signatures found during the making of the lines. The whole area of survey is defined by a quadrilateral whose vortexes are N40° 28' 31.7'', E17° 14' 11.3'', N40° 28' 52.3'', E17° 14' 11.1'', N40° 28' 51.0'' E17° 16' 05.6'', N40° 28' 28.27'' E17° 16' 04.75'': it extends to approximately 1.7 Km squares and it was covered by approximately 65 km of shipping (fig. 1). During the survey all the present surface objects in the measure area (buoys, catenaries, ships, etc.) have been punctually taken into account in order to isolate their signal during the processing step. By mean of a GPS cinematic relief the coastal line and the profile of harbour structures have been delineated too. The direct avaibility of the gradient signal (along North South direction in making the East-West lines) makes it possible to quickly produce a map of gradient magnetic anomalies in the area, without the necessity to proceed to complex processing of data. The gradient signal is not affected by the temporal variations of the geomagnetic field and the noise due to anthropic activities is strongly suppressed: thus the gradient signal may give direct information of anomalies in the area. After a quick treatment of the acquired data, which can be really made during on-field operations, some anomalies have been highlighted, meaningful for size and intensities and some location were visited by scuba divers which performed a visual inspection: the corresponding cataloging is reported in tab.I.

IV. DISCUSSION

The advantage of processing gradient data in comparison to magnetic signal is clear if one look at a single line profile as shown in fig. 2. This plot highlights how the magnetic profile shows anomalies which are not due to magnetic sources (see for instance the anomalies in the right part of the panel) but probably to natural or anthropic induced variation: the gradient signal is not affected by these noisy contributions. The gradiometric signal maps are plotted in fig.3 and fig.4: in fig.3 the gradiometric signal along north-south direction (measured making the east-west lines) is shown; in fig.4 the magnetic gradient along the east west direction (measured making the north south ties) is also shown. Due to ship time we do not have the possibility to cover the whole area with both direction (north-south and east-west), thus the east-west gradient component is evaluated only in a small zone of the whole area. The boxed area on the left in fig.3 shows the overlapping between the two relieves (lines and ties). In this boxed area it is also possible to compute the norm of the 3D analytical signal of the magnetic field [Nabighian 1972, Nabighian 1974, Nabighian 1984, Roest et al. 1992] defined as:

$$|A(x, y)| = \sqrt{\left(\frac{\partial M}{\partial x}\right)^2 + \left(\frac{\partial M}{\partial y}\right)^2 + \left(\frac{\partial M}{\partial z}\right)^2} \qquad (1)$$

where M is the total field anomaly, the positive direction x is toward East, the positive direction y is toward North and z is along the vertical. The corresponding map is shown in fig. 5. We want to stress here that these maps were not produced after post processing magnetic signal to numerically compute the gradient of the field, but rather they are directly measured. The only component which we are not able to measure in the present configuration is the vertical one ($\frac{\partial M}{\partial z}$) which is computed starting from the knowledge of the two horizontal gradient component as in [Nabighian 1984] in order to construct the analytical signal as defined in eq. 1. After the inspection of gradient map consisting anomalies are evidenced in correspondence of the coast line; they are mostly due to the signal induced by the ships and harbour structures with the exception of the point 6 that reveal a high intensity not compatible with the superficial evidences. The point 5, turns out to be in proximity of an under construction wharf and the opposite anomaly probably is due to a source that goes towards north and may be linked to such superficial evidence. In the north-east area there are small anomalies due to the presence of surface buoys with annexed chain identified during the survey. The other anomalies do not appear linked to any superficial evidence and therefore a further investigation with direct visual techniques was suggested. After immersions of authorized scuba divers in a selected set of locations the straight relations between the measured marks and the generating sources were pointed out: they are summarized in last column of tab. I.

As was pointed out by Nabighian [Nabighian 1984] the study of the analytic signal properties in a gradiometric survey can reveal further information on the magnetized sources. In the case of sharp and localized metallic target the analytic signal profile produced is of bell shape kind whose half width at half height is equal to the depth of the anomalous magnetic contrast. The shape is plotted in fig. 6 for the anomaly n. 3; the least square fit with a bell shape function indicate a depth of c.a. 13 m which is compatible with the object on the seabed found with the visual investigation (tab. I). This tecnique can thus be useful in searching objects that can result hidden to a visual inspection because they are buried in the seafloor mud; the accurate processing of analitycal signal data can reveal the depth were to search for those buried objects.

V. CONCLUSIONS

We demonstrated how a gradiometric configuration can be very useful to resolve magnetic anomalies in a high noisy anthropic area. We were able to clearly identify a large number of magnetic targets which were deployed or abandoned on the seabed, the number of identification being limited only by the available time. Although the results of the present survey turn out to be positive as a whole, the necessity of a dedicated structure was highlighted: a specific project for an optimal use in similar contexts must be defined which could guarantee a better stability for the towing system. In fact the towed rubber dinghy induced a sure tilt movement in the sensor device that generated the induction of additional high frequency noise. As a result of this experience and in reason of the use of the device for both environmental and archaeological survey, a suitable catamaran structure has been planned and implemented; later on this new structure was able to give more satisfactory results. Furthermore the total magnetic field is by definition a scalar physical quantity and its space derivative is a three-dimensional vector; the used gradiometer configuration is only able to measure the projection of the gradient along the direction of separation of the two sensors. In order to measure all the vectorial components and therefore the whole analytical signal at the same time, it would be necessary to acquired three axial independent measures using four sensors placed on an dedicated platform; this will ensure that the whole analytic signal could be measured simultaneously with a huge survey time saving. In this work we overcame the problem using only a couple of sensor but doing lines and ties and thus doubling the time necessary for the survey while still maintaining a compatible confidence level on data. Anyway the results here obtained clearly demonstrate that even measuring only two component of the magnetic gradient, we were able to extract good information for the localization of metallic target in a high noisy area such that of Taranto harbour.

[Parlamento Italiano 1998] Parlamento italiano, art.1, comma 4, legge n. 426/1998

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Table I: Relevant points and metallic object identified by visual inspection

Figure 1: Survey extension (lines and ties path in white) and the bathymetry. The Taranto harbour is located in the south east coast of Italy approximately in the middle of the box in the bottom right map.

Figure 2: Example of magnetic signal (bottom panel) and gradient signal (upper panel) along a line. The large anomaly on the left is due to some magnetic sources, while the anomalies on the right, which are present only on the magnetic signal and not in the gradient one, are probably due to anthropic noise.

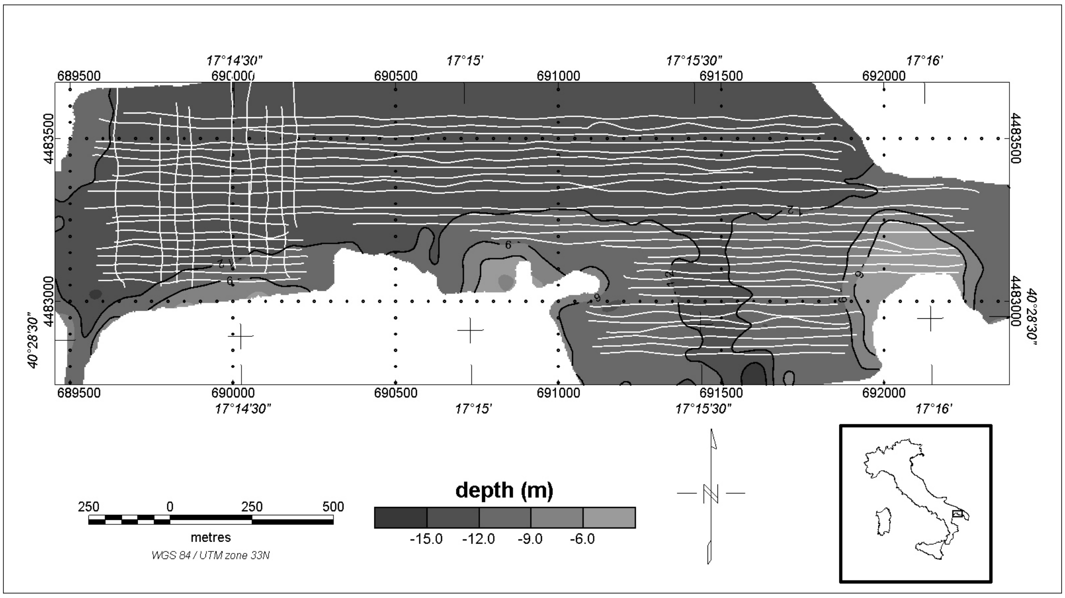
Figure 3: Magnetic gradient: the measured component along north-south direction; the circles identifies the actual object found on seabed and listened in tab. I. Inside the square box on the left the whole analytical magnetic signal was computed and it is plotted in fig.5.

Figure 4: Magnetic gradient: the east-west component

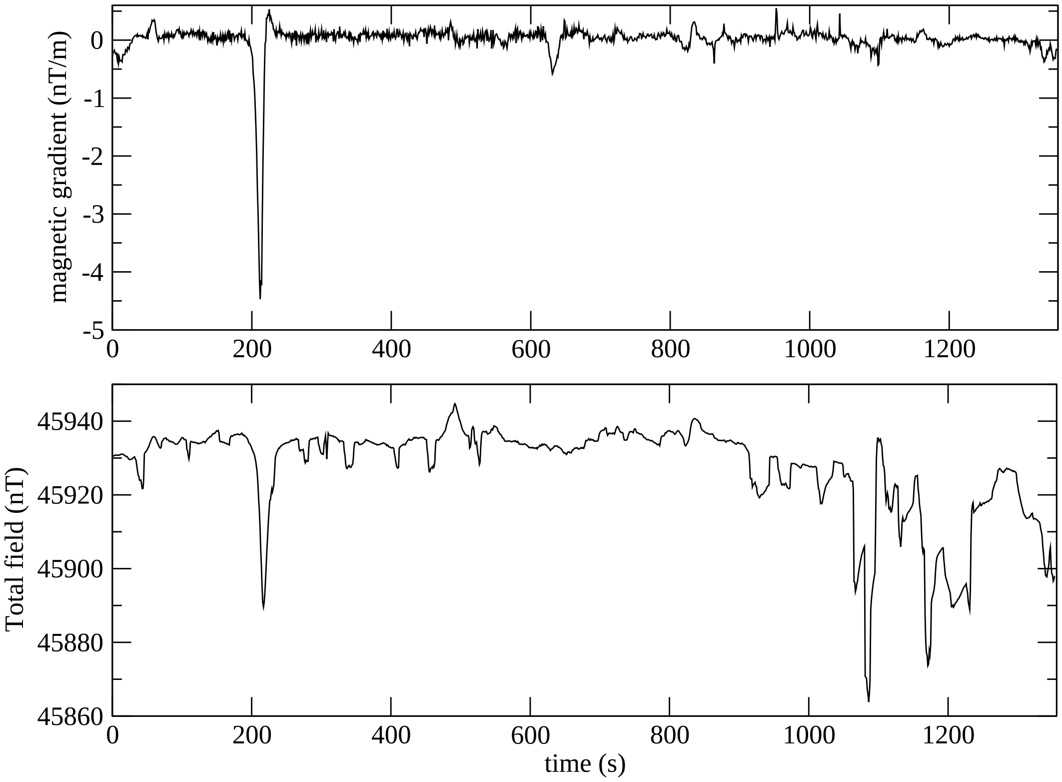
Figure 5: The 3D magnetic analytic signal norm calculated in the boxed area of fig. 3

Figure 6: The analytical signal least squared fit with a bell shape function in order to estimate the depth of the source of anomaly n. 3.

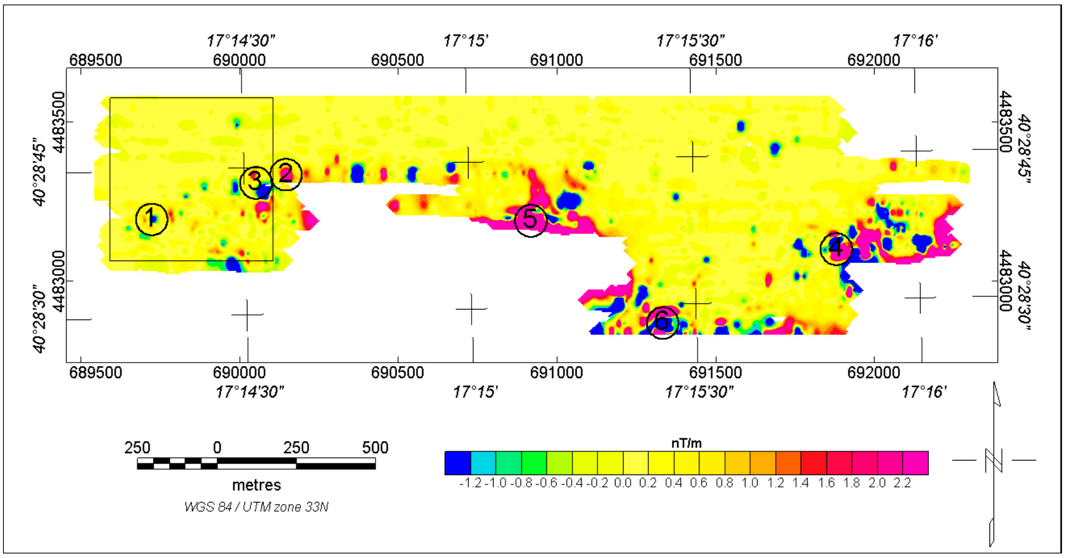
ID	LONG	LAT	Visual identification
1	17°14'17.3"	40°28'39.4"	Catenary
2	17°14'35.8"	40°28'43.8"	Iron filled tyre
3	17°14'31.3"	40°28'44.1"	One-armed anchor
4	17°15'48.9"	40°28'35.2"	Small metallic pieces
5	17°15'08.2"	40°28'38.9"	Iron
6	17°15'25.5"	40°28'28.1"	Iron



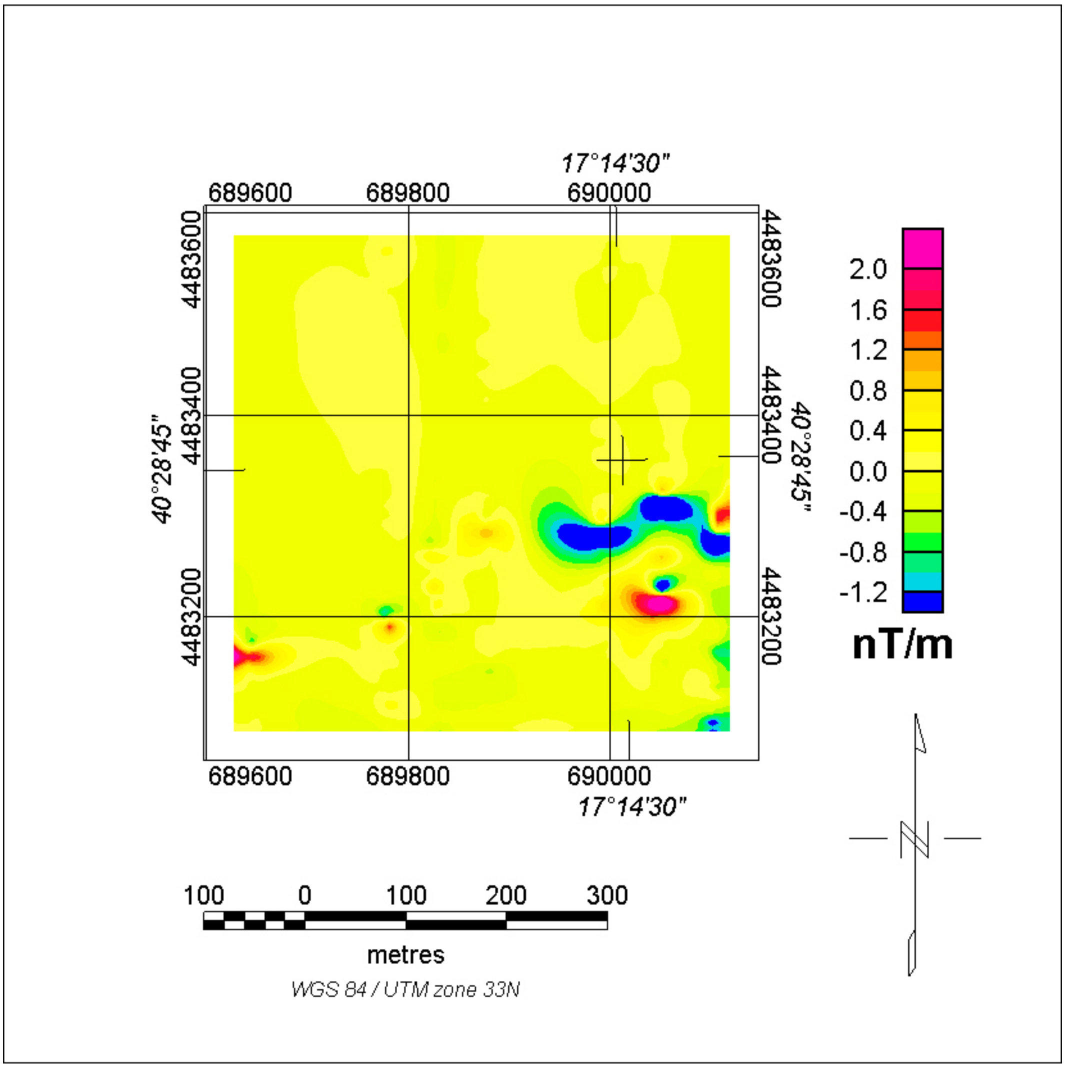
17°14'30"
17°15'
17°15'30"
17°16'
689500
690000
690500
691000
691500
692000
4483500
4483000
40°28'30"
depth (m)
-15.0
-12.0
-9.0
-6.0
250
0
250
500
metres
WGS 84 / UTM zone 33N



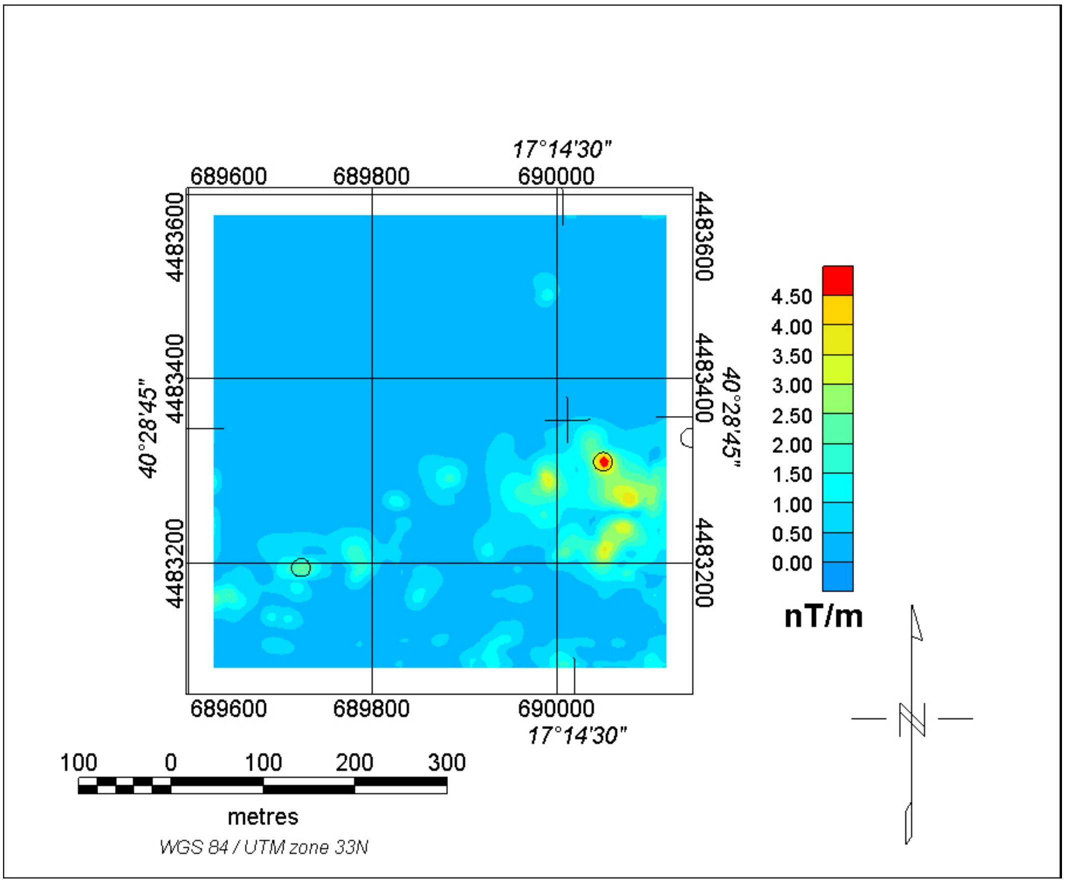
magnetic gradient (nT/m)
0
-1
-2
-3
-4
-5
0
200
400
600
800
1000
1200
Total field (nT)
45940
45920
45900
45880
45860
0
200
400
600
800
1000
1200
time (s)

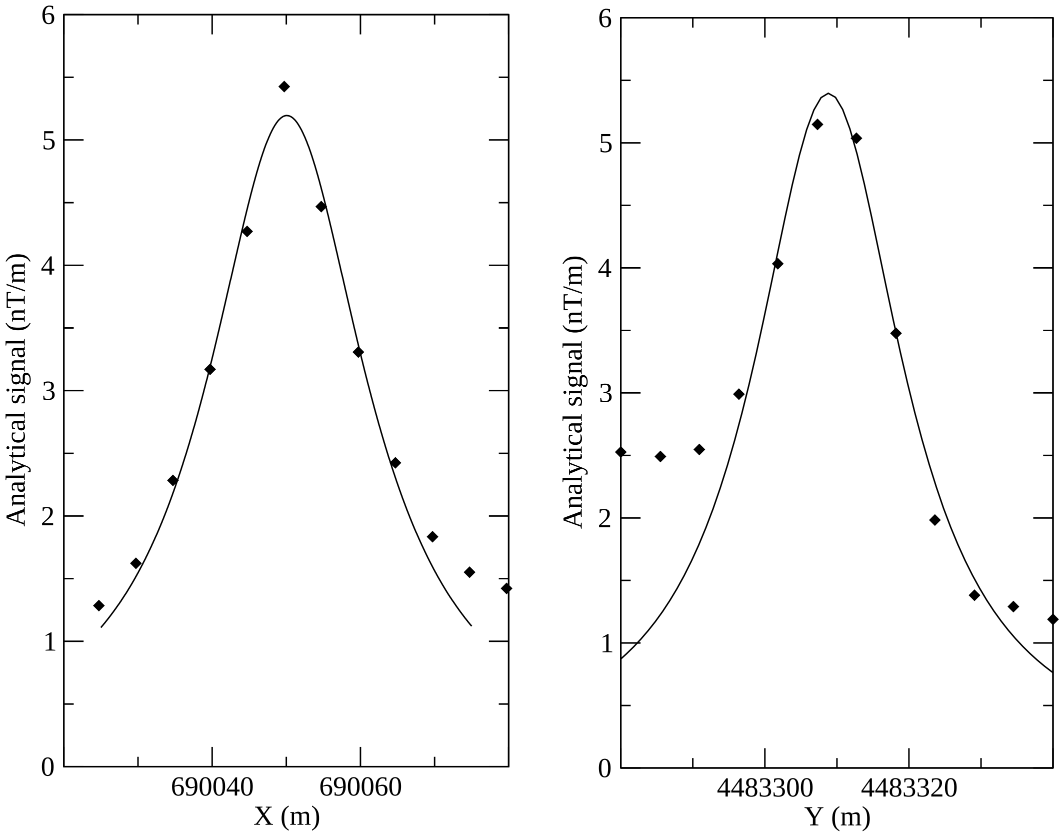


17°14'30"
17°15'
17°15'30"
17°16'
689500
690000
690500
691000
691500
692000
4483500
4483000
40°28'45"
40°28'30"
1
2
3
4
5
6
250
0
250
500
metres
WGS 84 / UTM zone 33N
nT/m
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2



17°14'30"
689600
689800
690000
4483600
4483400
4483200
40°28'45"
2.0
1.6
1.2
0.8
0.4
0.0
-0.4
-0.8
-1.2
nT/m
100
0
100
200
300
metres
WGS 84 / UTM zone 33N


17°14'30"
689600
689800
690000
4483600
4483400
4483200
40°28'45"
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
nT/m
100
0
100
200
300
metres
WGS 84 / UTM zone 33N



6
5
4
3
2
1
0
Analytical signal (nT/m)
690040
690060
X (m)
6
5
4
3
2
1
0
Analytical signal (nT/m)
4483300
4483320
Y (m)