HIGH RESOLUTION MARINE MAGNETIC SURVEY OFF BURGAS HARBOR, AIMING TO IDENTIFY UXO TARGETS ON THE SEABED

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Summary
Over 400,000 shells of different calibers were dumped in Burgas Bay after the end of WWI. The operation under the coordination of the British forces was completed without the dumping areas to be clearly mentioned and mapped, allowing us today to assume that they can be anywhere in Burgas Bay. During the expansion of Burgas Harbor carried out between 2001 and 2006, a great deal of ammunition, originating from both WWI and WWII, was discovered and recovered by the dredging operations. In the near future, the port authorities intends to initiate new dredging activities within a 90,000 sq. m surface as part of the next harbor expansion and need that area to be scanned for items such as UXO, wrecks, pipes, anchors and other metal objects dumped on the sea floor, that could disturb and even endanger the dredging.

A high-resolution marine magnetometric mapping carried out in August 2016 by a team comprising both Romanian and Bulgarian specialists entirely covered the area of interest and was able, in a magnetic environment dominated by huge variations of the total geomagnetic field due to geological sources, to highlight the presence of over 75 potential target areas (Dimitriu at al., 2016a), where UXO-type items, possibly dumped or lost ferrous objects, accumulations of ammunition, etc. could be found on the seabed of shallowly buried in sediments.

Geological Setting

The area investigated covers a small part of the offshore prolongation of Srednogorie Unit, whose key feature (Zagorchev et al., 2009) is the massive presence of the Late Cretaceous volcanism and synchronous granitic intrusions, ranging in composition from ultrabasic to acid, which was interpreted as an island-arc / back-arc system. The thickness of the Upper Cretaceous volcano-sedimentary formation exceeds 4 km. Very important too, for the interpretation of the magnetometric data is the presence of massive Paleozoic granite bodies within the Precambrian high-grade metamorphic rocks, which constitute the crystalline basement of the region.

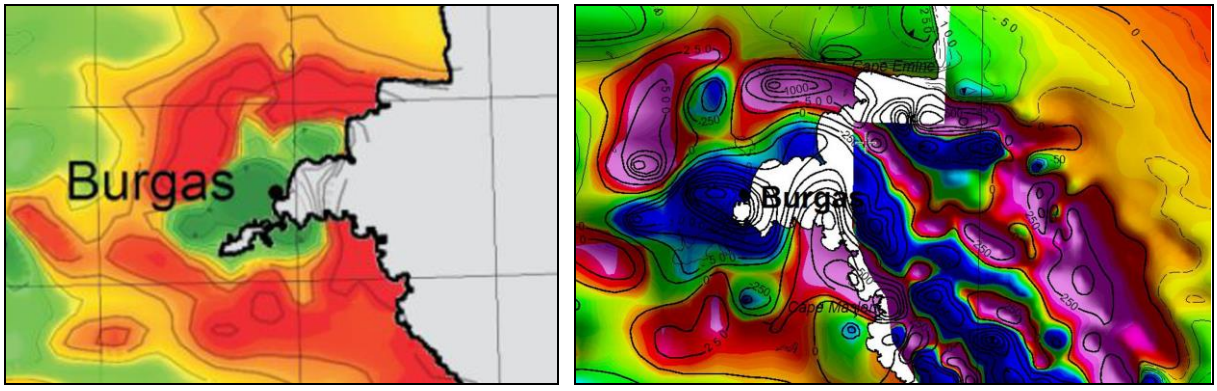

Fig. 1 Regional morphology of the geomagnetic field in Burgas area (left, fragment from Trifonova et al., 2012) and the adjacent offshore (right, fragment modified from Dimitriu et al., 2016b)

The presence of very intense (over 17,000 nT) and extended, regional magnetic anomalies in Burgas area, caused by the presence of magmatic rocks in depth, is well depicted (Fig. 1) onshore by Trifonova et al. (2012) and offshore by Dimitriu et al. (2016b). Also important for the interpretation of the magnetometric data is the presence in the bay area of the "black sands", which have high contents of titanomagnetite minerals (Hrischev et al., 1979), resulted from the physical decomposition of outcropping magmatic rocks. These black sands are visible on the beaches of Burgas, but were also found on the seabed. Their presence makes the interpretation of the geophysical data even much more complicated.

Method

The area of interest, which was covered by the high resolution, total magnetic field measurements, is located in Burgas Bay, close to the southernmost dock of the harbor (Fig. 2). The measurements (10 readings/second) were carried out with a Geometrics G-882, total field marine magnetometer that was operated onboard a 9 m long engine boat. A temporary geomagnetic base station was deployed and operated near Kraymorie, a village located southwardly of the city of Burgas, by a Geometrics G-856 meter during the marine measurements. Onboard the research engine boat a single beam, dual frequency digital hydrographic system, as well as a data acquisition and navigation control system were also installed.

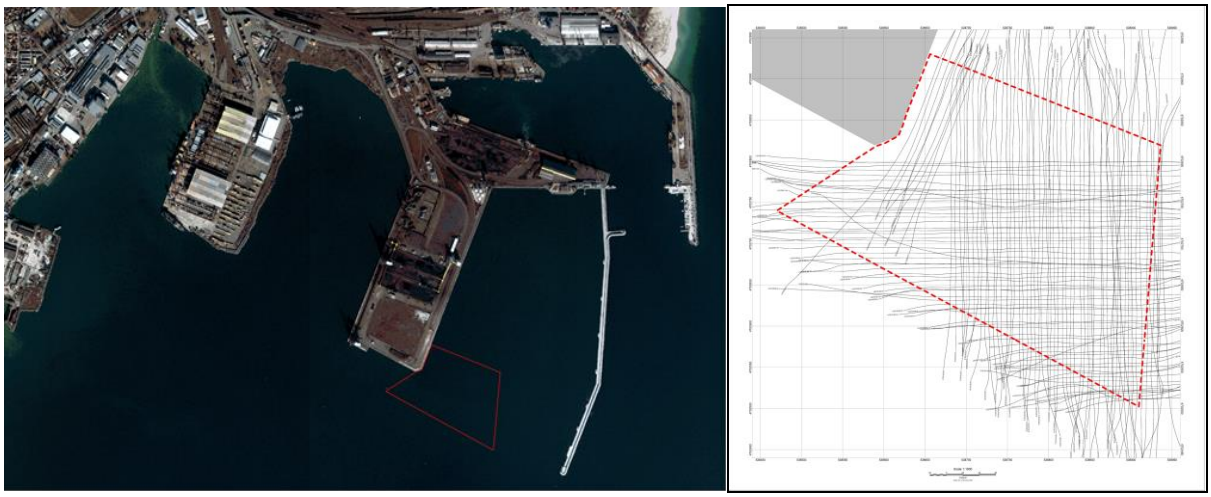

Fig. 2 On the left is the satellite view (from www.earthexplorer.usgs.gov) of Burgas Harbor. The red polygon represents the survey area. On the right is the network of geophysical lines that covered the area of interest

The E-W width of the survey area is ranging from 300 m on north to 500 m on the southern limit. On N-S direction, the extension of the survey area is around 275 m. The high-resolution magnetometric lines finally covered an area of around 100,210 sq. m. The total length of the geophysical lines, planned and measured 5 m apart one from the other, is 84.7km. Over 232,000 readings of the total geomagnetic field, acquired on the study area, were validated, imported, processed and visualized within a dedicated database open within the georeferenced environment offered by the *Oasis montaj*^{TM} software.

Results and discussion

The map of the magnetic anomaly corresponding to the study area (Fig. 3, left) illustrates, as it was expected, very large and rapid variations (over 1,250 nT) of the total geomagnetic field over a relatively very small surface. Thus, only of the map surface, over less than 300 m the intensity of the magnetic fields increases from -770 nT to over 230 nT, which is impressive. Still, despite the very rapid increasing gradient, the presence of several local magnetic anomalies is visible. The survey area is located on the flank of an extended negative magnetic

anomaly, which probably covers an important surface of Burgas Bay (Fig. 1) and is bordered toward NE by a positive and less extended magnetic anomaly developed toward the city. The sources of these anomalies are probably represented by magmatic bodies belonging to Srednogorie Unit.

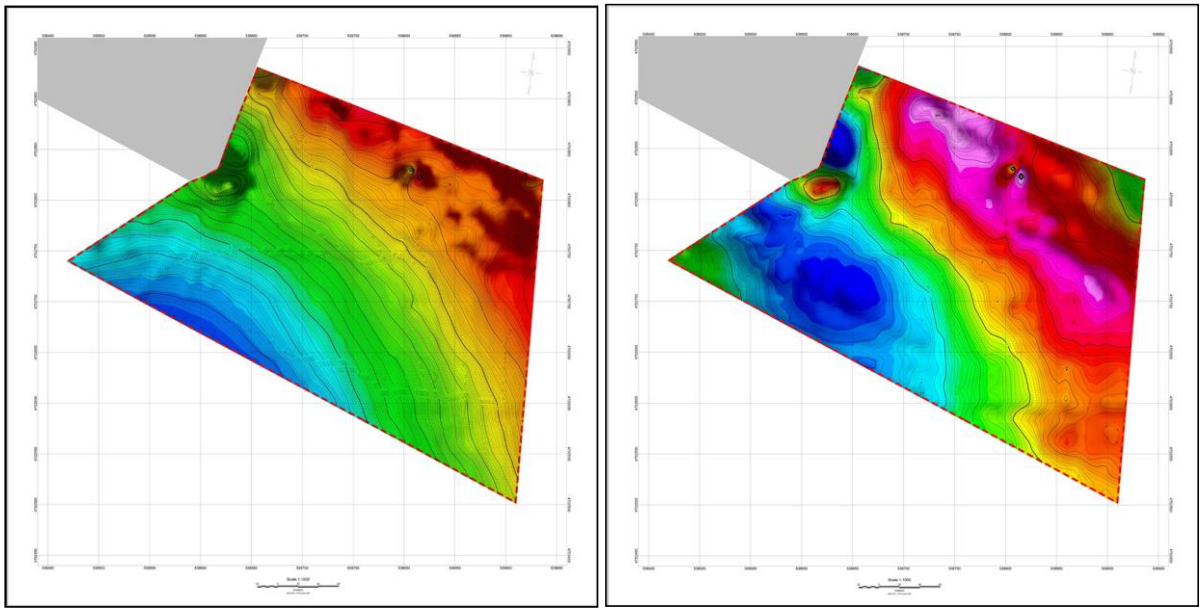

Fig.3 Maps of the magnetic anomaly (left) and of the local magnetic anomaly (right) of the study area

In order to eliminate from the magnetic anomaly map the effect due to the deep and remote sources, an analytical separation of local and regional magnetic effects was made. The result of this operation (Fig. 3, right) illustrates the detailed morphology of the local magnetic anomaly, free of the regional magnetic effect. The new resulted map illustrates the disappearance of the intense, increasing toward NE, troublesome gradient, which is now replaced by two relatively local magnetic anomalies, incompletely mapped on the survey area. Thus, a negative magnetic anomaly, heading NW-SE, with amplitudes of -200 nT is now obvious in the SW of the survey area. It is bordered to NE by a positive magnetic anomaly, also heading NW-SE, whose amplitude locally exceeds 140 to 200 nT. On the background of these relatively broad wavelength anomalies, several others, which could be due to local sources, some of them definitely of anthropic origin, randomly distributed or aligned along 2-3 lineaments, become visible. The maps in Fig. 3 also highlight the presence near the dock of several local magnetic anomalies, which could be due to the large pile of steel pipelines sections stored on the dock surface, just near the investigated area.

The next steps we made in the data processing procedure aimed to better highlight the position of local magnetic anomalies due to small and scattered sources, which could be of anthropic origin. The analysis of the analytic signal carried out allowed us to identify and emphasize (Fig. 4) a large number of local magnetic sources located on the seabed, on the surface or buried in shallow sediments. The amplitude of these residual anomalies, which are present mainly in the northern part of the survey area, is ranging from a few nT to over 40 nT and their lateral extension may reach 15–20 m. The individual analysis of each marine magnetometer line allowed to pinpoint the possible locations of the sources for every local magnetic anomaly observed (grey dots on Fig. 4). Over 75 potential target areas which could host UXO-type objects have been noticed and indexed (Fig. 4, right) for further scuba diving inspection.

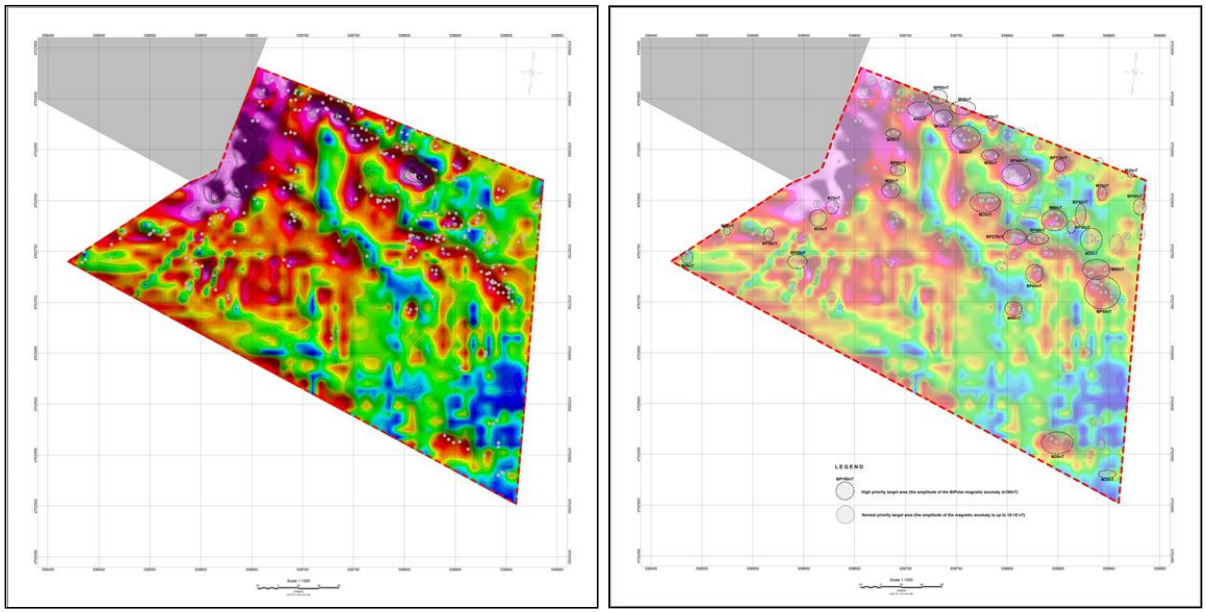

Fig. 4 Positions of local sources, highlighted by the analysis of magnetic analytic signal. Grey dots are interpreted positions of anomalous sources from the analysis of each marine magnetic line. Clusters of dots mark the locations of the target areas to be investigated by scuba divers

Other important observation regards the presumable burial depth of the potential UXO sources. Previous researches have shown that due to the waves and currents, which are very active in Burgas bay, soft to sandy sediments 1 to 4 m thick are likely to cover the UXO-type targets. Therefore, it's recommended the first 4-5 m of sediments to be dredged with a bucket dredger which is considered to be the safest tool in an area infested by UXO-type objects. Finally, in order to establish the origin for the magnetic anomalies found in each identified target area, prior to any dredging activity, a detailed and systematic scuba divers search, performed with high-resolution metal detectors, is recommended.

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