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ORIGINAL ARTICLE

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# The effectiveness of marine magnetic surveying for mapping the location of anthropogenic objects in the Baltic Sea

## Skuteczność morskich badań magnetycznych w mapowaniu lokalizacji obiektów antropogenicznych na obszarze Morza Bałtyckiego

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**Abstract:** The aim of the paper is to present the use of marine magnetic surveying for mapping the location of anthropogenic objects on or buried in the seabed. The main purpose of collecting magnetic data is to detect local sources of increased magnetic field intensity, and to indicate the presence of ferromagnetic objects in the investigated area. The work contains the results of research carried out in the Baltic Sea area by the Maritime Institute in Gdansk. Hydromagnetic surveys are implemented mainly in the framework of pre-investment studies to inventory objects in the sea bottom, which can hinder the construction of subsea installations or affect the technological process of construction. Based on the interpretation of measurement results, the occurrence of anthropogenic objects, such as wrecks, linear objects (e. g. gas pipelines, cables, trawl wires), or munitions, can be determined.

**Keywords:** Marine Magnetometer, Magnetic Anomalies, Baltic Sea

**Streszczenie:** Celem pracy jest przedstawienie użyteczności badań magnetycznych do mapowania obiektów pochodzenia antropogenicznego na dnie morskim lub znajdujących się pod warstwą osadów. Głównym celem gromadzenia danych magnetycznych jest wykrywanie miejscowych źródeł o zwiększonej intensywności pola magnetycznego oraz wskazywanie obecności obiektów ferromagnetycznych w badanym obszarze. Praca zawiera wyniki badań prowadzonych w rejonie Morza Bałtyckiego przez Instytut Morski w Gdańsku. Badania hydromagnetyczne są realizowane głównie w ramach badań przedinwestycyjnych w celu inwentaryzacji obiektów na dnie morza, które mogą utrudnić budowę instalacji podmorskich lub wpływać na technologiczny proces budowy. Na podstawie interpretacji wyników pomiarów można określić występowanie obiektów antropogenicznych takich jak: wraki, obiekty liniowe (np. gazociągi, kable, trały) lub obiekty militarne

**Słowa kluczowe:** magnetometr morski, anomalie magnetyczne, Morze Bałtyckie

## Introduction

Objects on the seabed may have a negative impact on the environment (e.g., causing a contamination of sediments), be a threat to human life (e.g., un-exploded ordnance, shells, bombs), or be dangerous for shipping (objects at a depth of less than 18 meters). Targets can also destroy fishing trawls (e.g., iron wrecks) or hinder the construction of subsea installations (e.g., old linear structures, hydro-technical constructions). The search for targets, performed near large metropolitan ports, usually is associated with the work aimed at restoring the recreational function of an investigated region. Here, the degree of littering of the sea bottom depends on the intensity of the economic activity (e.g., sailing, fishing, exploitation).

The most common anthropogenic objects that can be detected on the seabed with usage of the hydromagnetic method because of their magnetic properties are:

- objects of military origin (e.g., mines, bombs, torpedoes),
- objects that result from maritime disasters (e.g., wrecks, containers),
- abandoned fishing appliances (e.g., fishing nets hooked on obstacles or broken in the storm)

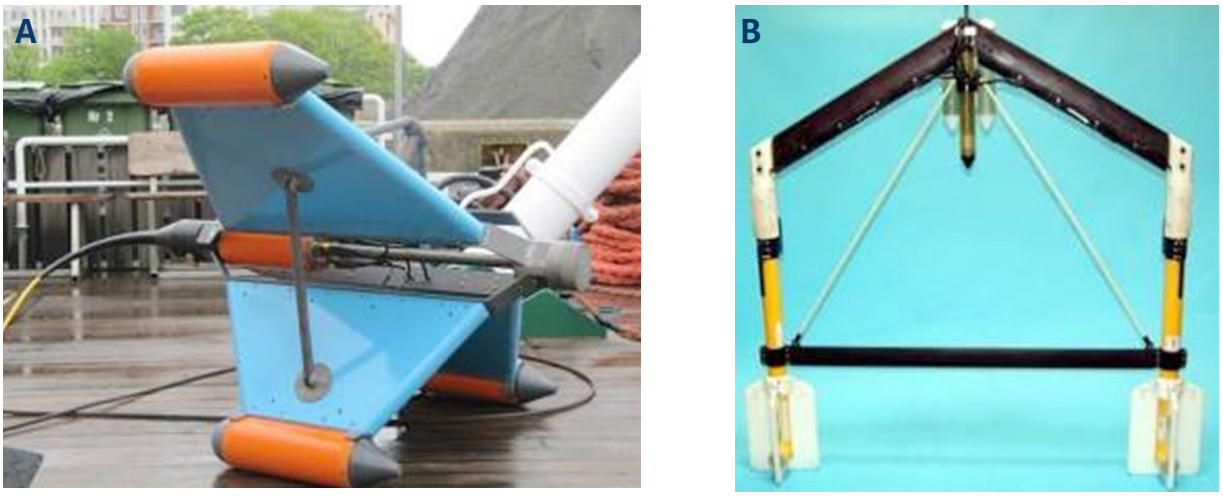


**Fig. 1.** a) Magnetometr SeaQuest by MarineMagnetics (Canada)(fot. W. Konieczny); b) Magnetometr by Geometrics (USA) (source: www.geometrics.com)

- lost anchors and towing devices (e.g., anchors, chains)
- lost measuring systems
- old undersea cable installations and pipelines,
- destroyed fish farming equipment
- devices left after exploration and exploitation of mineral deposits (e.g., parts of the drilling probes).

## Hydromagnetic survey

Hydromagnetic measurements are measurements of the total intensity of the Earth's magnetic field carried out at sea. The measured value of the Earth's magnetic field (T) depends on the place and time of measurement, associated with periodic and aperiodic changes in the natural magnetic field of the Earth. The observed magnetic field of the Earth has a complex structure. At any point in space, it will be the vector sum of the dipole field, the continental field, the external field, the anomalous field (which is the sum of the regional anomalous field plus the local anomalous field), and the interference field (Grabowska 2012). Instrument self-noise, communication errors between the instrument and the recording system, and noise induced by waves impact recorded values of the magnetic field in hydromagnetic. The interference field may also be an effect of noise from electrical sources, vessels, or cables.

A hydromagnetic survey enables detection of anthropogenic objects on the sea bottom, which are ferromagnets. The magnetic field induced around ferromagnetic objects by the Earth's magnetic field generates magnetic anomalies.

The paper shows results of a hydromagnetic survey, carried out with magnetometers: SeaQuest by Marine Magnetics company (fig. 1a) and G882 by Geometrics company (fig. 1b). Devices are property of Maritime Institute in Gdansk.

Magnetometer surveys are usually used with other marine geophysical survey techniques, such as side scan sonar, multibeam echosounder, subbottom profiler or ROV (Remotely operated underwater vehicle).

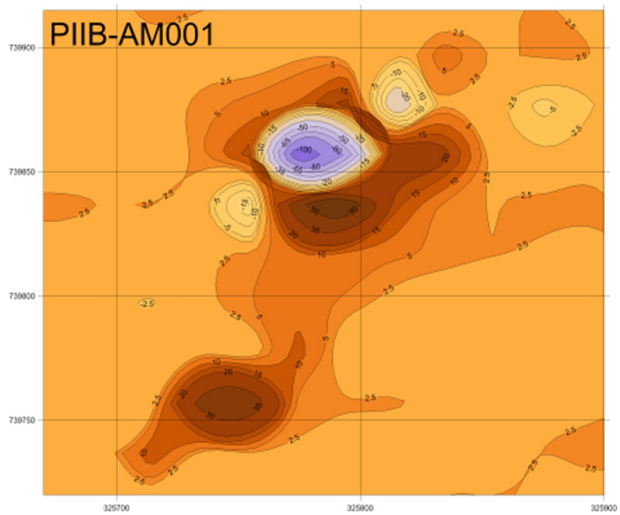


**Fig. 2.** Map of the magnetic anomalies showing the anomaly PIIB-AM001

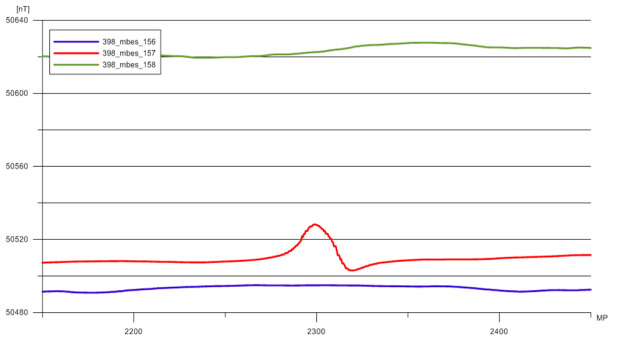


**Fig. 3.** Modules of the total magnetic field recorded on the three adjacent survey profiles at the site of the anomaly PIIB-AM001

## Methodology

The nature and natural conditions of the study area are the main factors affecting the used methodology of collecting magnetic data. Constant and adequate distance from the seabed to the

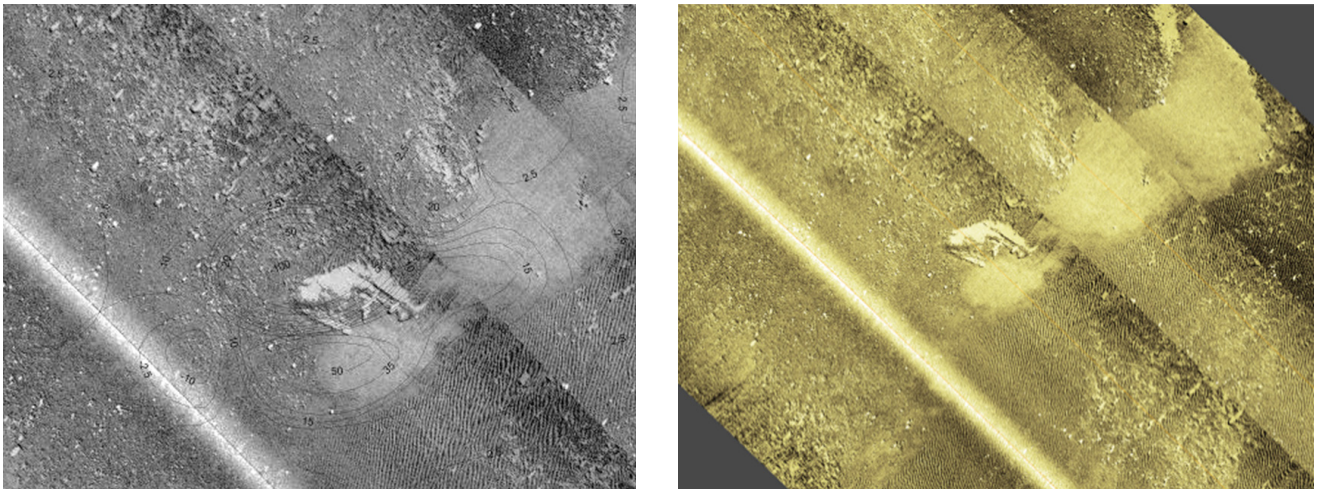

**Fig. 4.** Side scan sonar image of the shipwreck in detected magnetic anomaly PIIB-AM001 (Gulf of Koszalin)

magnetometer, adequate runline spacing, constant layback (the distance from the towfish to the boat), high sampling rate, and constant speed of the boat are significant for a correctly carried out measurement..

The most effective methodology, which allows for detection of the greatest number of objects, is to tow the magnetometer towfish as close to the seabed as possible and to use small runline spacing. In practice, these conditions cannot always be fulfilled. The danger of hitting the seabed with the magnetometer means an adequate distance between the seabed and the towfish must be maintained. This distance will depend on the nature of the seabed (the variable bathymetry, diverse surface relief), the prevailing sea conditions, and the skills of the operator. The expected target size determines the distance between runlines. Smaller targets will only be detected at or near the runlines, while between the runlines, only much larger targets can be noticed. A compromise must be reached between the minimum acceptable detection mass against how long the survey will take to complete. It is worth mentioning, the denser the runline spacing, the higher the survey costs are.

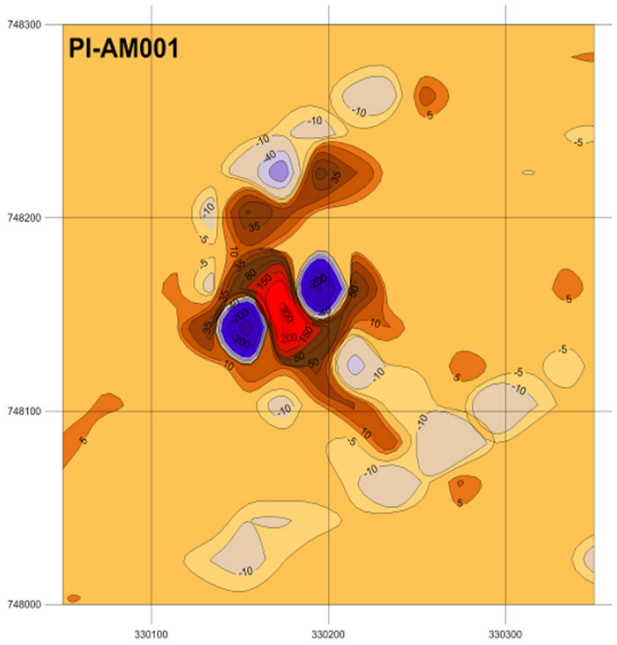


**Fig. 5.** Map of magnetic anomalies showing the anomaly PI-AM001(Gulf of Koszalin)

## Results

Hydromagnetic surveys are implemented mainly to inventory objects in the sea bottom. Magnetometers can detect defections in the earth's magnetic field caused by various ferrous objects. The most common ones have an anthropogenic origin. Rarely, natural objects (e.g., ridges, strong bathymetry) cause anomalies. The interpretation of collected data gives possibility to determine the occurrence of anthropogenic objects, such as wrecks, linear objects (pipelines, cables, ropes), or military facilities (explosives, UXO – Unexploded Ordnance).

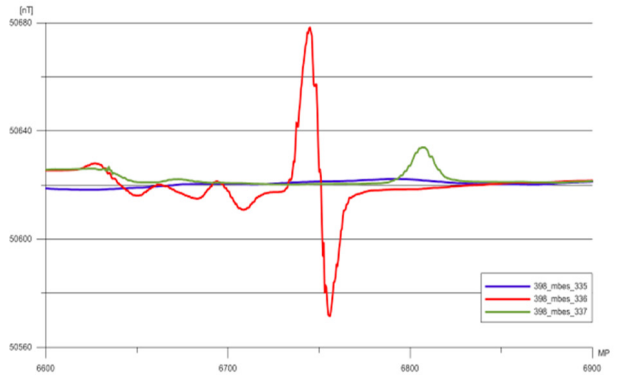


**Fig. 6.** Charts of magnetic field intensity recorded by the measuring device in three adjoining measuring profiles at the site of the anomaly PI-AM001(Gulf of Koszalin)

## Wrecks

Wrecks are large-sized targets, over 2 meters. Mostly, these objects are the remains of sunken vessels, but it is also common to

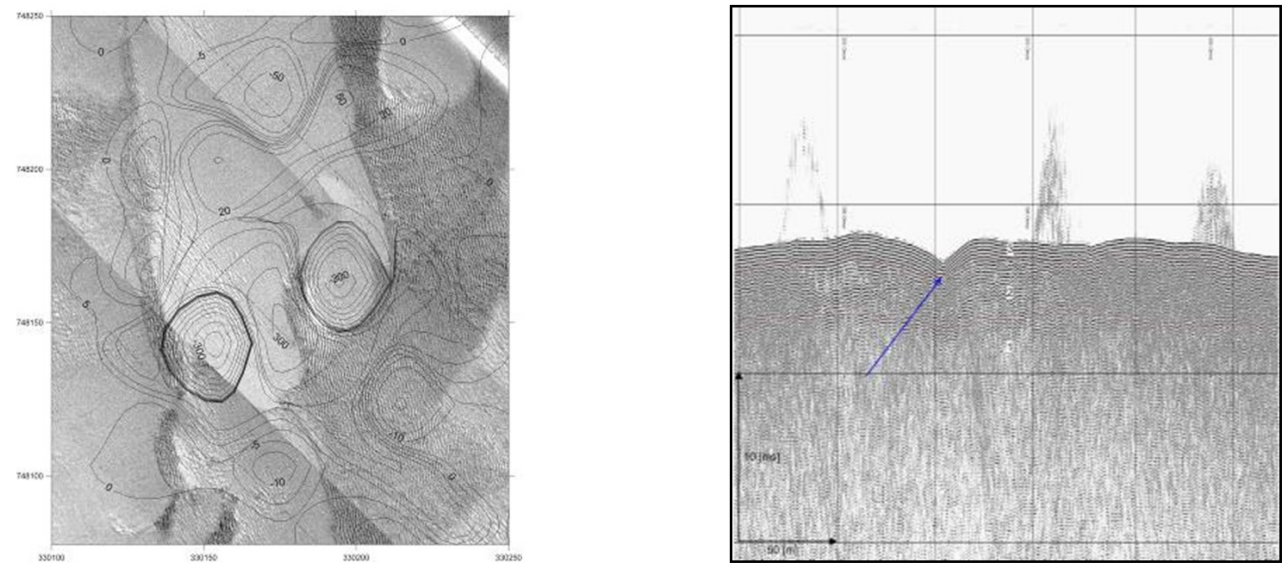

**Fig. 7.** Side scan sonar image of the sea bottom combined with the values of magnetic field anomalies (a) and seismic profile (b) at the site of the anomaly P1-AM001 (Gulf of Koszalin)

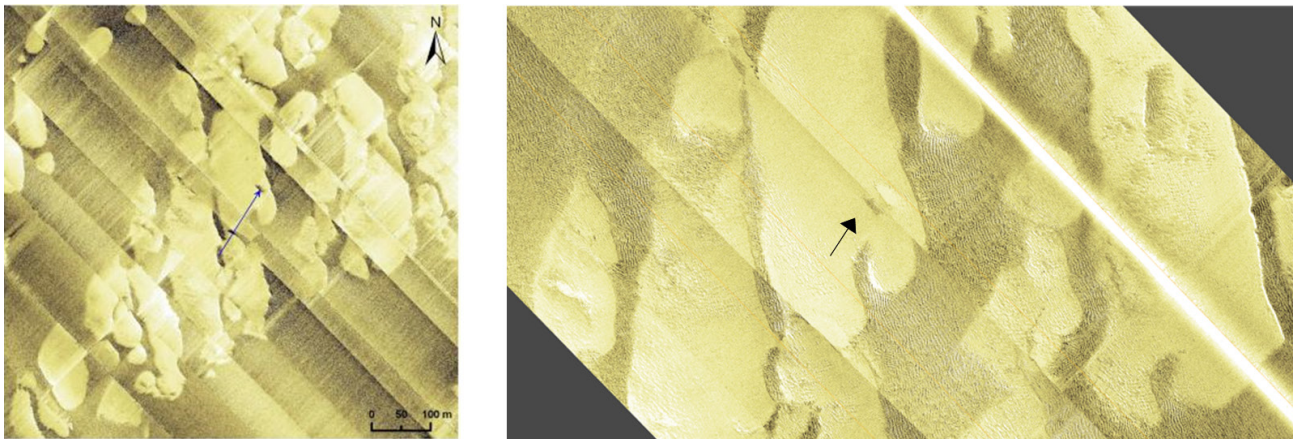


**Fig. 8.** Side scan sonar image of the site of the anomaly PI-AM001(Gulf of Koszalin)

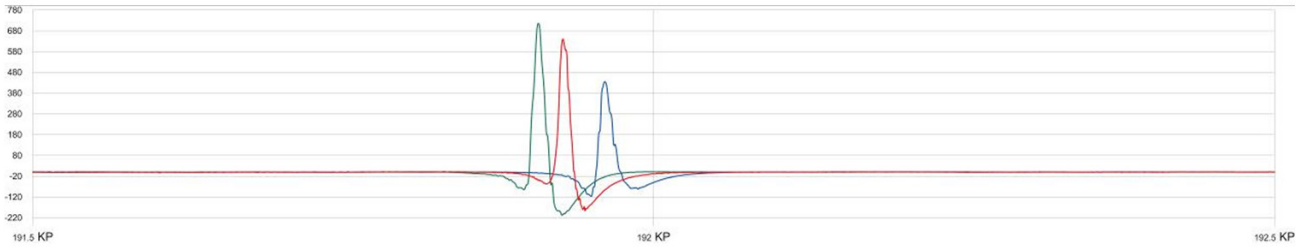


**Fig. 9.** Chart of magnetic field intensity recorded in three adjoining measuring profiles at the site of detected anomalies (Baltic Sea)

use this term in relation to sunken cars and other machines. The majority of wrecks have iron construction, as from 19th century, steel had become the principal material used in ship construction. In addition, vessels made of wood can be detected during marine magnetic survey due to the presence of iron machinery. Wrecks cause significant deflection in the Earth's magnetic field and are often characterized by complex, distinct anomalies.

The following text presents examples of magnetic anomalies in the Baltic Sea area related to the presence of wrecks. Magnetic anomalies PIIB-AM001 (fig. 2) and PI-AM001 (fig. 5) were recorded in the „Gulf of Koszalin" during the research carried out by the Maritime Institute commissioned by BALTEX Energy and Offshore Industries in Gdańsk in 2012. The aim of the work was to inventory the test area for large-sized objects of anthropogenic origin that could affect the technological process of aggregate. Runlines were spaced at 50 m.

Fig. 2 is a detailed picture of magnetic anomaly PIIB-AM001 recorded in the Gulf of Koszalin. The value of the anomaly am-

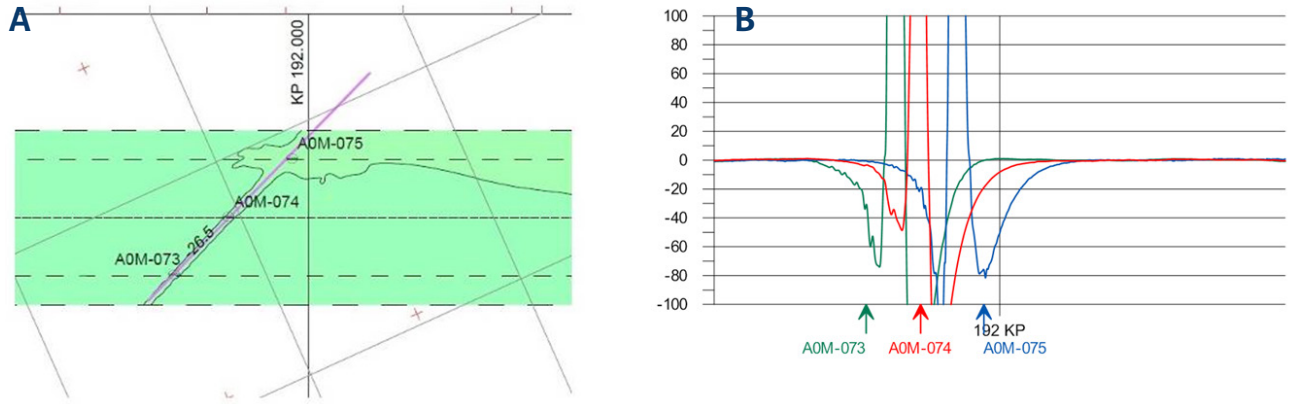


**Fig. 10.** A bathymetric map with marked magnetic field anomalies location (a) and charts of this anomalies (b) at the site of North Stream gas pipeline

plitude (100 nT) indicates presence of a ferromagnetic object. The graph (fig. 3) presents raw data of the values of total field intensity recorded on 3 adjacent survey profiles. On the red coloured profile, a clear magnetic anomaly of the amplitude value of 20 nT is visible. The shape of the graph indicates a relatively close distance between the measuring device and object while recording the signal.

Fig. 3. Modules of the total magnetic field recorded on the three adjacent survey profiles at the site of the anomaly PIIB-AM001

The illustrations (fig. 4) show side scan sonar images of the sea bottom in the area of detected magnetic anomaly PIIB-AM001. In the picture (on the left side with the superimposed contour lines of the magnetic field anomalies' values), a shipwreck is noticeable. The relatively low values of magnetic anomaly and the large size of the object indicates usage of wooden elements in the construction of the wreck.

Fig. 5 is a detailed picture of magnetic anomaly PI-AM001 recorded in the Gulf of Koszalin. The value of the anomaly amplitude indicates presence of a ferromagnetic object.

The graph below (fig. 6) presents the raw magnetic data recorded on 3 adjacent survey profiles. A higher magnetic field was recorded on two adjacent survey profiles. The amplitude value of 130 nT is visible on the red profile. The shape of the graph indicates a relatively close distance between the measuring device and object during the signal recording. On the green survey profile, a clear magnetic anomaly of the value of 13 nT is visible. The detailed distribution of the magnetic field for the anomaly indicates a relatively large object placed between the survey profiles.

The illustrations (fig. 7) show side scan sonar and seismic images of the sea bottom in the area of detected magnetic anomaly PI-AM001. In the picture on the left side (fig. 7a), with the superimposed contour lines of the magnetic field anomalies, no target is noticeable. Additional verification and analysis of a seismic profile taken in the place of the magnetic anomaly confirms the presence of the object (fig. 7b).


**Fig. 11.** Side Scan Sonar image at the site of North Stream gas pipeline

In the side scan sonar images (fig. 8), where the magnetic field anomaly has occurred, the target (probably wreck) was marked. It is possible the object or a part of it is under a layer of sediment. It was possible to find the wreck only on the basis of hydromagnetic data, which indicated a likely place of the target's position.

## Linear objects

Among the linear objects that can be recognized on the sea bottom, there are cables, pipes, ropes, and anchor chains. These targets are difficult to identify on the basis of side scan sonar images or bathymetric maps. The most effective method of searching for linear objects is the hydromagnetic method. The following text presents examples of such objects detected using this method. Magnetic anomalies (fig. 9) were registered during the survey carried out by the Maritime Institute in Gdansk commissioned by the operator of the Gas Industry GAZ-SYSTEM S.A. in 2011. The aim of the work was to examine the route of the underwater gas pipeline and to indicate locations of potential anthropogenic objects (wrecks, pipelines, cables) that can affect the planned investment. The project scope was to connect the underwater gas systems of Poland and Denmark. Runlines were spaced at 50 m. The results presented in the graph below (fig. 9.) indicate presence of a linear object. Strong anomalies are an effect of the North Stream gas pipeline, which crosses the route of the planned investment.

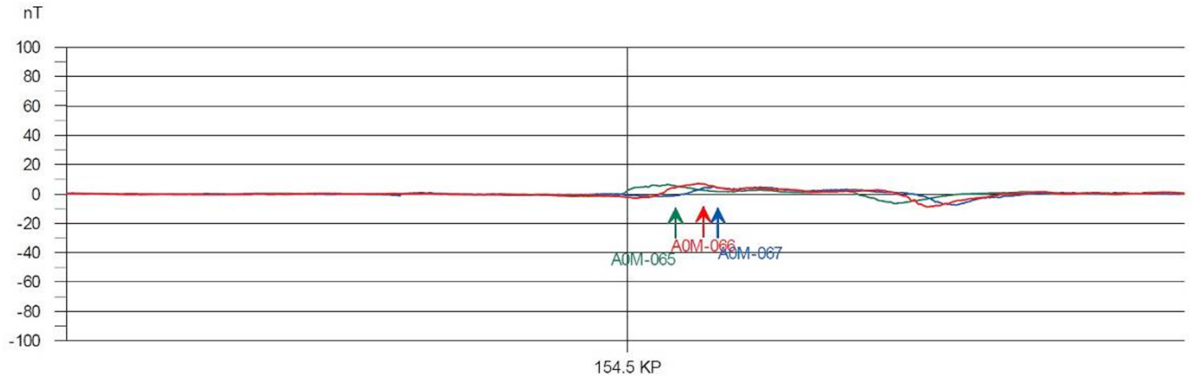


**Fig. 12.** Charts of magnetic field intensity recorded by the measuring device in three adjoining measuring profiles (Baltic Sea)

Fig. 10 a presents the bathymetric map with marked runlines, the location of the detected anomalies, and the location of the North Stream gas pipeline.

Fig. 11. shows side scan sonar mosaic, where the North Stream gas pipeline is visible.

The following hydromagnetic studies were carried out on the planned route of a submarine pipeline construction in the Baltic Sea area. During the survey, magnetic anomalies were detected on three adjacent runlines. The values of the observed magnetic anomalies (positive and negative) are approx. 10 nT. The distribution of magnetic anomalies along the measurement profiles (fig. 12) indicates a linear object of small size that crosses the route of the planned investment.

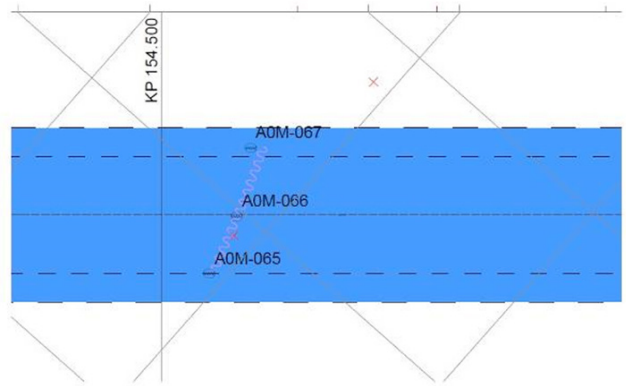


**Fig. 13.** A bathymetric map with marked magnetic field anomalies location (Baltic Sea)

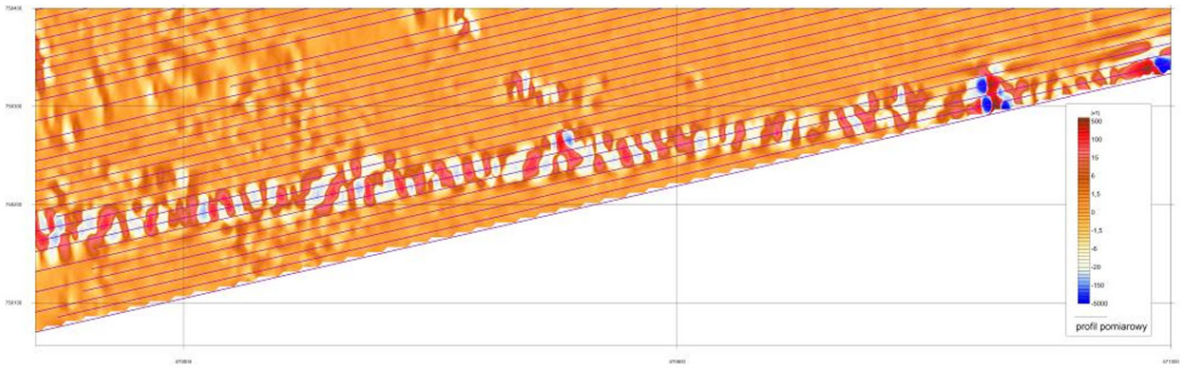


**Fig. 14.** Map of magnetic anomalies at the site of investigated area (Gulf of Gdańsk)

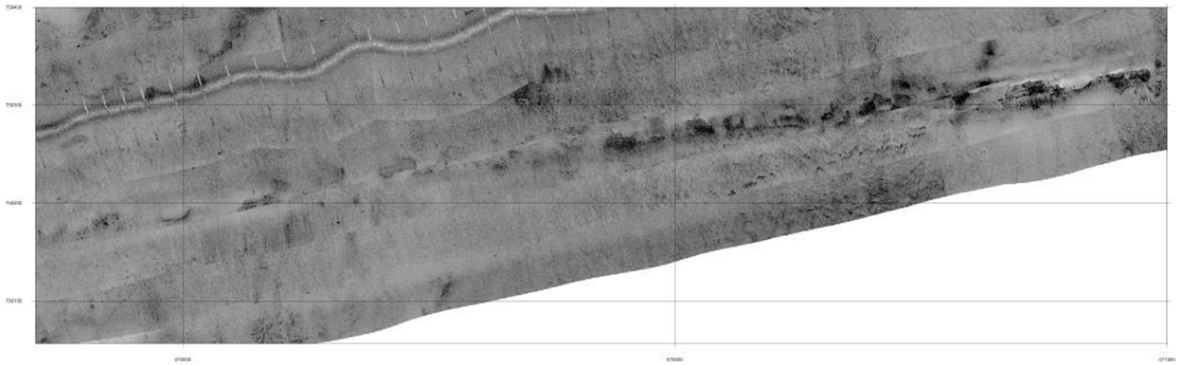

**Fig. 15.** Side scan sonar image of the investigated area (the Gulf of Gdańsk)

The bathymetric map (fig.13) has not confirmed an object in the area where the magnetic anomalies were registered. Only the comparison of data from the navigation map confirms a cable that crosses the route of the planned investment.

Fig. 14 presents a map of magnetic anomalies registered in the area of the Gulf of Gdańsk. The study was commissioned by the Polish Oil and Gas S.A. in 2014. The aim of the work was to investigate the marine environment in the area of planned investment, including the detection of anthropogenic objects. On the research area, the survey was carried out along runlines spaced at 10 m. On the resulting map, a strong magnetic anomaly with an elongated shape is visible. Distribution of the magnetic field indicates a linear object with ferromagnetic properties that is probably a linear underwater installation (e.g., pipe, pipeline) buried under a layer of sediment. The Side Scan Sonar image map of the seabed (fig.15) does not confirm any construction in the investigated area.

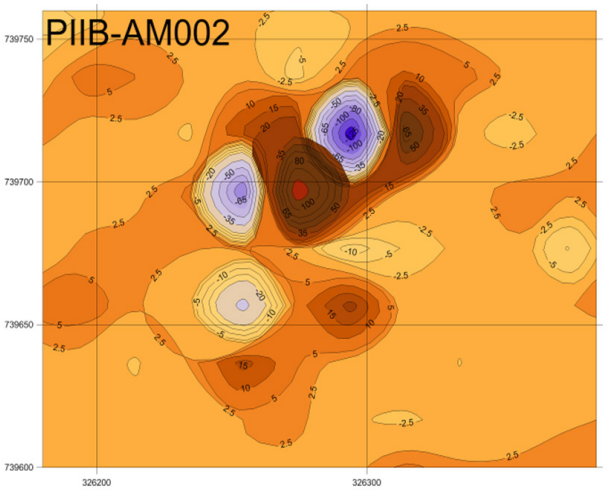


**Fig. 16.** Enlarged map of the magnetic anomalies showing the anomaly PIIB-AM002 (Gulf of Koszalin)

## Military objects

Among the military facilities found on the seabed are naval mines, bombs, unexploded ordnance. Fig. 16 presents an enlarged map of hydromagnetic anomalies registered during the survey carried out by Maritime Institute in Gdańsk in the "Gulf of Koszalin" area.

The graph below (fig. 17) presents the raw data of the values of magnetic induction recorded on 3 adjacent survey profiles. High values of the magnetic field registered during the survey indicate a ferromagnetic object in the investigated area. Anomalies were recorded on 2 adjacent runlines. On the red profile, the amplitude value is approx. 25 nT. The shape of the graph indicates a relatively close distance between the magnetometer and target during the signal recording. On the blue runline, an anomaly of the ap-

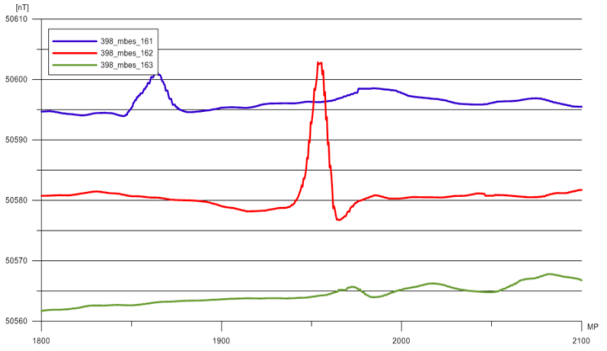


**Fig. 17.** Modules of the total vector of the Earth's magnetic field recorded on the three adjacent survey profiles at the site of the anomaly PIIB-AM002 (Gulf of Koszalin)

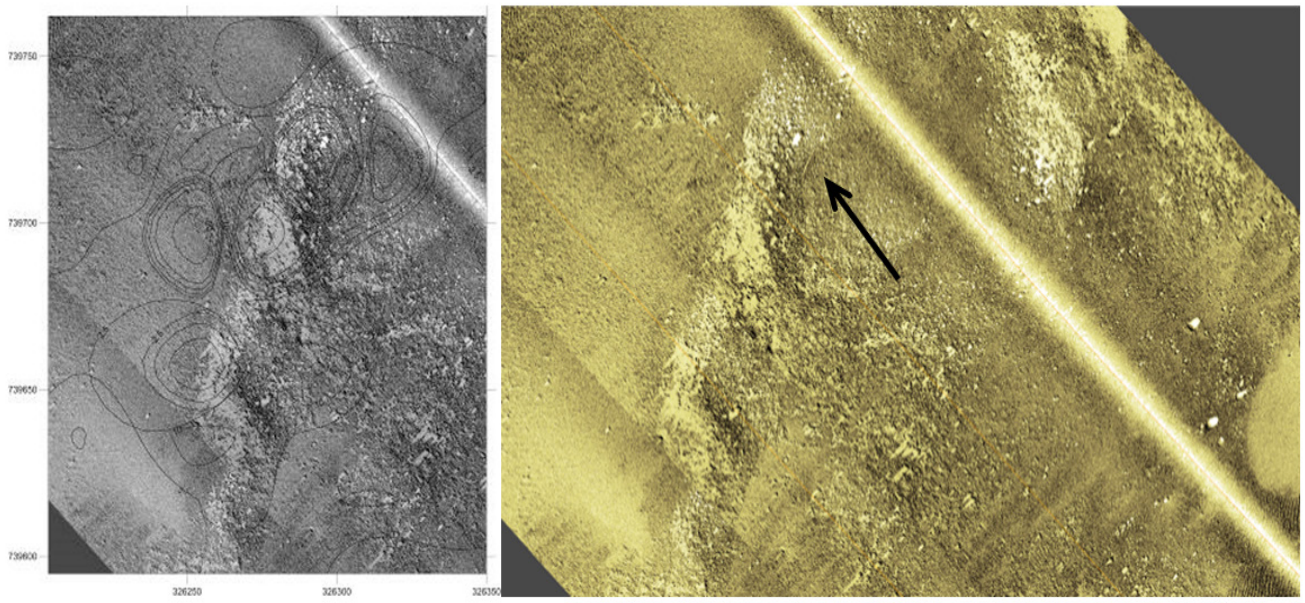


**Fig. 18.** Side scan sonar image of the sea bottom combined with the values of magnetic field anomalies PII-AM002 with marked military object (Gulf of Koszalin)

prox. value 5 nT is observed. Here, the magnetic field distribution indicates a ferromagnetic object between these profiles or two smaller targets near the corresponding runlines. Based on a comparison of the magnetometric data with the side scan sonar image map of the area where the anomaly PII-AM002 was detected (fig. 18), torpedoes on the sea bottom were found. Objects on the map in the form of bright spots are stones or other objects of anthropogenic origin.

## Conclusions

The presented results confirm the effectiveness of marine magnetic surveying for mapping anthropogenic objects on or buried in the seabed. The work presents examples of different ferromagnetic objects found during surveys and the shape of the magnetic anomalies they generate. Analysis of the magnetic anomalies map gives the possibility to recognize the type of target (point or linear object) or confirm its nature (material of construction). Magnetometer surveys are mostly carried out with other geophysical survey techniques to compare the data and define the observed object (e.g., in the side scan sonar map torpedoes can be mistaken as wooden bars). It is also possible to find ferromagnetic targets buried under a sediment layer. The maximum size of an iron object that can be detected is determined by the distance from the object to the magnetometer. The two main factors that affect this distance are the altitude of the device above the seabed (and target) and the distance between survey runlines. Smaller targets will only be detected at or near the run lines, while between the run lines, only much larger targets can be detected.

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