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Integrated magnetic, gravity, and GPR surveys to locate the probable source of hydrocarbon contamination in Sharm El-Sheikh area, south Sinai, Egypt

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ABSTRACT

Sharm El-Sheikh waters were suddenly hit by hydrocarbon spills which created a serious threat to the prosperous tourism industry in and around the city. Analysis of soil samples, water samples, and seabed samples collected in and around the contaminated bay area showed anomalous levels of hydrocarbons. An integrated geophysical investigation, using magnetic, gravity, and ground penetrating radar geophysical tools, was conducted in the headland overlooking the contaminated bay in order to delineate the possible subsurface source of contamination. The results of the geophysical investigations revealed three underground manmade reinforced concrete tanks and a complicated network of buried steel pipes in addition to other unidentified buried objects. The depths and dimensions of the discovered objects were determined. Geophysical investigations also revealed the presence of a north–south oblique slip fault running through the eastern part of the studied area. Excavations, conducted later on, confirmed the presence of one of the tanks delineated by the geophysical surveys.

1. Introduction

Sharm El-Sheikh City, a famous Egyptian resort on the Red Sea, is known for its fascinating beaches transparent water, and pristine reef life. The city also forms a cornerstone in the Egyptian tourism industry and attracts millions of national and international tourists every year. In 1999, Sharm El-Sheikh area was devastated by a sudden leakage of huge amounts of hydrocarbons into the sea. The spills were concentrated in and around Sharm El-Maya Bay and caused huge damage to the tourism activities in and around the contaminated area (Fig. 1). Although the spills were contained and instant remedial actions were taken, the source of the spills was not appropriately investigated and remains a controversial issue until today. Some studies, conducted immediately after the incident, concluded that the spill was caused by the inappropriate dismantling of an old power plant and its surface fuel storage tanks (Cairo University Report, 2001; Suez Canal University Report, 1999). This power plant was located on the shoe-shaped headland defining the southwestern border of the bay and was dismantled a few months before the spill incident. Other studies, however, suggested that oil contamination could be attributed to spilled crude oil, dumped oil wastes, and leaked fuel from boats (Khattab et al., 2006). Some researchers stated that the source of oil polluting the waters of the bay is buried under the southern headland and that the area is still under a threat from a persistent source of oil contamination (Morsy et al., 2010).

Although previous studies did not agree on the source of the pollution, they all agreed on the presence of high levels of hydrocarbon contamination in the area. Chemical analyses conducted on samples collected from the surface soil of the southern headland, and from the seawater and seabed sediments of Sharm El-Maya Bay showed anomalously high levels of hydrocarbon contamination (Khattab et al., 2006; Morsy et al., 2010).

The aim of the present study is to examine the hypothesis stating that the contamination source is buried under the southern headland and to identify the nature, location, and distribution of the sources of contamination in the area using appropriate geophysical tools such as magnetic, gravity, and ground penetrating radar techniques.

Magnetic techniques are efficient tools to investigate shallow artificial buried objects such as tanks, drums, and pipes and they are used frequently in environmental, engineering, and archaeological investigations (e.g. Jordanova et al., 2008; Mathe and Leveque, 2003; Simpson et al., 2009). The gravity method, however, is usually used as an assistant tool that is capable of differentiating between natural soil and buried manmade objects having different densities (e.g. Batayneh et al., 2007; El-Behiry and Hanafy, 2000; Hickey and McGrath, 2003). Ground Penetrating Radar (GPR) is the most commonly used technique in environmental and engineering investigations and has been increasingly used to successfully detect buried manmade objects in recent years (e.g. Allred and Redman, 2010; Peters et al., 1995; Porsani and Sauck, 2007; Zeng and McMechan, 1997).

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Fig. 1. Location map of the study area.

This study presents the experience of acquisition, processing, interpretation, and integration of magnetic, gravity, and GPR data collected to investigate the possible source of contamination in the Sharm El-Sheikh area.

2. Study area

Sharm El-Maya Bay is a relatively small bay located in the southern suburb of Sharm El-Sheikh City. The bay occupies an approximate area of 0.4 km^2 and has a 300-m-wide outlet to the northern Red Sea (Fig. 1). The bay is bounded by two headlands. The first headland is known as Ras Umm-Sidd and delimits the eastern margins of the bay. The other headland, where the present study is conducted, defines the western and the southern margins of the bay. It forms a shoe-shaped promontory projecting into the Red Sea and separates Sharm El-Maya Bay from the neighboring Sharm El-Sheikh Bay (Fig. 1). This headland ranges in height between 15 and 20 m above sea level and is composed of alternating beds of clastic sedimentary rocks and coralline limestone. The coast of the bay below is made of a narrow strip of sandy beach and submerged fringing coral reefs. Structurally, the study area lies in the intersection of the Gulf of Aqaba, Gulf of Suez, and the Red Sea that delineate the three most dominant structural directions in the region. The geophysical field survey was conducted in the northeastern corner of the southern headland whose surface is covered mainly by unconsolidated sediments.

3. Magnetic survey

The geophysical survey started with covering the entire area with magnetic measurements to detect any manmade buried objects with anomalous magnetization. The reason for conducting the magnetic survey method first is its capability to cover large areas in a short period of time and because hydrocarbon storage tanks are usually made of ferromagnetic materials. The magnetic data were collected over 140 stations covering the study area. At every station, measurements were conducted at two heights, 45 and 90 cm above the ground surface. Because of the presence of many surface sources of noise in the area, the station interval varied between 5 and 25 m based on ground surface conditions (Fig. 2). Base station measurements were regularly collected during the field survey. Horizontal and vertical controls of the field stations were obtained using differential GPS receivers. The differential GPS data processing resulted in position solutions with a standard deviation less than 1 m in the X, Y, and Z directions.

Because the study area is a small, perfectly flat-topped headland, no corrections for elevation changes were required. However, magnetic field measurements were corrected for diurnal variations using the repeated base station readings. The vertical magnetic gradient data were then calculated from both corrected and raw datasets. Both resulted in almost identical vertical magnetic gradient data. Vertical magnetic gradient data are useful in detecting buried underground shallow objects with magnetic characteristics (Breiner, 1973). The vertical magnetic gradient contour map, in nanotesla per meter (nT/m), is shown on Fig. 3.

Although magnetic data can be acquired and processed easily and rapidly, the interpretation of magnetic data is a difficult and complicated process. This difficulty arises from the many factors affecting the size, shape and amplitude of a magnetic anomaly. These factors include, among others, remnant magnetization with unknown direction, possible susceptibility anisotropy, and demagnetization effects. In the present survey, the above mentioned factors, in addition to the presence of several surface sources of noise, not only prevented taking measurements in some locations, but also affected the data quality and compromised the interpretation process. However, three pronounced anomalies with comparable characteristics could be seen on the vertical magnetic gradient map (Fig. 3). The first anomaly is located between $X=100$–150 m and $Y=40$–70 m, while the second anomaly lies between $X=150$–190 m and $Y=50$–80 m (Fig. 3). Both anomalies are almost identical dipolar anomalies with gradient values ranging between -80 and $+75$ nT/m. The distance between the centers of these two anomalies is about 40 m. The third anomaly lies about 120 m to the northeast of the second anomaly and is similar to the previously mentioned anomalies in size and shape. This anomaly is also dipolar with gradient values ranging between -85 and $+65$ nT/m. Each of these three anomalies starts in the northwest with a sharp peak of positive magnetic gradient values that changes suddenly into even sharper trough of negative gradient values in the southeast direction. Both peaks and troughs of the three anomalies are rounded to elliptical with their long axes pointing to almost the same northwest-southeast direction. Another