Int J Appl Earth Obs Geoinformation 73 (2018) 682–696

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

An integrated approach for mapping mineral resources in the Eastern Desert of Egypt

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ARTICLE INFO

Keywords:
Remote sensing
GIS
Mineral resources
Alteration zones

ABSTRACT

Observations of the Earth from space either by satellites or aircrafts are significant approaches for mineral exploration, because of their capability of revealing hydrothermal alteration minerals and sensing the surface/subsurface fracture/fault zones. A study area that is situated in the Pan-African belt of Egypt is tested for targeting potential area of mineral resources involved the hydrothermal system using satellite imagery combined with aeromagnetic, geochemical and field data. Extracted alteration layers using ASTER data and major structures (fault/fracture zones) from DEM, ALOS/PALSAR and aeromagnetic data were prepared and integrated using Knowledge-driven technique in multicriteria-decision making tools for producing mineral prospect map. The results revealed five predictive areas of expected mineral occurrences ranging from excellent to very low. Spectral analysis using ASTER data allowed defining the key-hydrothermal minerals which revealed three successive zones of alterations e.g., argillic, phyllic and propylitic. Plausible areas of minerals fitting to the ore body representing the center of the extensive alterations. Field, geochemical, and ore microscopic investigations validated the results of integrated data. Field data revealed that the mineralization zones extend along NNE-SSW thrust trend that later modified by NW-SE, N-S and NE-SW strike slip faults. Hydrothermal processes related to later magmatic stages probably were responsible for destruction and remobilization of the primary minerals of the host metavolcanics. Microscopic examination revealed that Fe-Cu-*Zn*-Pb sulfide minerals are associated with auriferous quartz veins. Plausible areas of prospective interest for possible mineralization also were characterized using geochemical analysis. This study successfully displays the key role of integration approach for exploring mineral resources in arid regions.

1. Introduction

The sensors onboard land observation satellites and aircrafts presented spectral and geometric information. Sensing technique from space has been applied in many disciplines e.g., lithology, structures, and changes of landscapes at different spatial resolutions since few decades. It also provided valuable tools for geological investigations and exploring mineral resources (Sabins, 1997, 1999; Abrams et al., 1983; Sultan et al., 1986, 1987; Abdelkareem and El-Baz, 2017). Since the advent of remotely sensing data, advanced techniques have been applied for exploring mineral resources. This technique detects area of a probable mineral resources and discriminating the new prospects prior to detailed and costly ground investigations (Bedell, 2001; Bedini, 2011; Rowan and Mars, 2003; Mars and Rowan, 2006). Two prominent factors were considered to conduct mineral exploration using remote sensing techniques, include (1) identification of hydrothermally altered rocks, and (2) delineating fractures/ fault zones (Sabins, 1999) that represent the conduits for fluids.

Several studies involved the optical Landsat data for mineral exploration (Rowan et al., 1974; Abrams et al., 1983; Goetz et al., 1983; Sultan et al., 1986, 1987; Abdelsalam et al., 1995; Kenea, 1997; Sabins, 1997, 1999; Zhang Tingbin et al., 2016). In the last few decades, considerable advances in image processing techniques allowed visualizing and interpreting the remotely sensing data. Such improvements achieve their most consideration by characterizing the key hydrothermal alteration minerals that proven the exact location of hydrothermal deposits (Abdelkareem and El-Baz, 2017). Advances in imaging systems and the advent of Advanced Spaceborne Thermal Emission and Reflection (ASTER) data allowed characterizing specific indices in mineral alterations (kaolinite, allunite, muscovite, illite, epidote and chlorite)

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https://doi.org/10.1016/j.jag.2018.07.005
Received 14 February 2018; Received in revised form 3 July 2018; Accepted 3 July 2018
0303-2434/

that define several alteration zones of hydrothermal activities (e.g., Rokos et al., 2000; Drury, 2001; Gabr et al., 2010; Cudahy, 2012). Applying such technique is significant for potential mineral exploration, for reducing the degree of risk to investment in the mining sectors and for identifying the mineralization zones.

Airborne and satellite remote sensing data have been employed for sensing geologic units and hydrothermal alteration in many mining districts around the world (Crósta et al., 1998; Carrino et al., 2018). Detecting areas of high mineral resources is a challenge point in regions of difficult accessibility. Geologic maps still generic to extract valuable information that allowed stackholders to invest. This cause a problem, that these maps are not effective in promoting various stackholders to take actions in selecting areas of the potential mineralization. At present, exploration techniques are reinforced by a wide array of advanced data processing and integrated approaches, using the spatial analysis technique of Geographic Information System (GIS) software packages. This allows spatially displaying and combining the evidential layers and visualization zones of mineral potentials.

The method of combining data in a GIS also allowed prospecting and predicting optimum new mineralized areas in fast approach (Abdelkareem and El-Baz, 2017, forthcoming article). In the past, conventional tools based on using manual tools weren't appropriate and accurate because of distortion and inaccurate results. At present, innovation processes that uses updated technologies and innovative approaches of geo-information's allowed detecting the optimum area of mineral potentials (Harris et al., 2001; Carranza, 2008; Carranza et al., 2015). Since the beginning of the GIS techniques various datasets were combined and integrated to identify efficiently new mineralized zones. Knowledge-driven technique in multicriteria-decision was applied to generate predictive map (Carranza, 2008; Compos et al., 2017). Such approach Knowledge-driven data combination techniques uses scored binary evidential maps. Seven evidential maps were integrated. Each map assigned a weight, W*e*, representing the grade of abundances. Moreover, each vector (v) forming an evidential map (e) given a score, (Pve). Therefore, the obtained predictive integrated as a weighted average (S), by the subsequent equation (Carranza, 2008):

$$S = \frac{\Sigma_e^n (P_{ve})(W_e)}{\Sigma_e^n W_e} \quad (1)$$

The plausible area of mineral resources represents the vector intersections areas of the combined map. Vectors were categorized from 1 to 4 (see Fig. 7) as the numeric number 1 represent a low possibility for locating mineral resources; however, numeric number 4 refers to the higher possibilities.

Exploration and exploitation of mineral deposits are necessary for many countries that rely on the utilization of their mineral resources to sustain their economics. The Egyptian Government intends to invest in what is called the “Golden Triangle” (GT) which covers a wide area (6000 sq km) between Qena, Safaga and Quseir cities (Fig. 1). The plan includes establishment of industrial, tourism, agricultural, and new urban zones through using the optimum natural resources in the region. Significantly, the study area “Abu Marwat” is located in the GT area. Such area represents an ancient gold mine that excavated by traditional methods since several centuries and need to explore by modern techniques.

Mineral exploration using field works only costs more than if we applying remote sensing reconnaissance befor the field investigations. Thus, the main target of the present research is to detect the potential areas of the probable mineral resources using integrated approaches of remote sensing and aeromagnetic data that quantitively assessed by applying GIS techniques and validated by field/lab data. To accomplish, this several objectives have been framed as follows: (a) construct a model to delineate hydrothermal alteration zones (HAZs); (b) understand the relationships between the fracture/fault zones and alteration zones and their impacts in defining mineral resources.

2. Study area

Abu Marwat area is situated in the northern section of the Central Eastern Desert (CED) of Egypt, about 400 km south-southeast of Cairo and 70 km from Safaga and 135 km from Qena. It extends between latitudes 26°27′ and 26° 32′ N, and longitudes 33° 36′ and 33° 42′ E (Fig. 1), covering about ~ 300 km^2. The nearest commercial airport is located at Hurghada and the nearest commercial railway is located at Qena. Moreover, Safaga city considers an important marina in the Red Sea coast of about 70 km from the present study.

The present study represents a part of the pan-African belt in the CED. The pan-African rocks covering Abu Marawat area comprises mainly of igneous and metamorphic rocks represented by dismembered ophiolitic rocks, volcanic/volcaniclastic suites of island-arc setting and calc-alkaline granitic rocks (Fig. 1c). The ultramafic rocks such as ophiolitic serpentinite and talc-carbonate are very limited in the area.

Abu Marawat area is mainly built-up by Neoproterozoic metavolcanics and associated metapyroclastics that were metamorphosed to greenschist facies (Botros, 2004; Fowler et al., 2006). The metavolcanics are intermediate to acidic rocks (e.g., El Mezayen et al., 1995; Mohamed et al., 2000; Osman, 2017) and characterize the predominant rock units occupying the area. The metavolcanics are classified into felsic and mafic varieties. They characterized by calc-alkaline affinity. These rocks encompass wide area and intruded by granitoids. Such associations were formed in subduction zone (El Shazly and El-Sayed, 2000; Asran et al., 2013). The granitic are voluminous syntectonic granodiorite-tonalite and post-tectonic potassic granites (Sims and James, 1984).

The occurrence of gold deposits were occurred as dyke-like and veinlets type associated with structural features (Hussein, 1990; Botros, 1990; Moharram et al., 1970; Martin, 1986; Zoheir and Akawy, 2010) cutting the metavolcanics. Such deposits are marked by alteration zone (Martin, 1986) as Gabr et al. (2010) characterized several zones using ASTER data.

3. Data used and methods

Remote sensing data represents by ASTER data will be used to delineate significant area of alteration zones and marked lithologic contacts. The aeromagnetic data will be used to extract subsurface fault/fracture zones that represent conductors for hydrothermal solutions. We also used geologic, geochemical and field data to constrain the results. The methods and approaches are summarized in Fig. 2.

3.1. Remote sensing data

ASTER satellite system was launched on board of the TERRA spacecraft in December 1999. It is a joint project of NASA and METI (Japan's Ministry of Economic Trade and Industry). ASTER cloud-free level 1B satellite data obtained on October 7, 2007 from United States Geological Survey (USGS) website. Level 1B data, the recorded radiance at the sensor (Wm-2sr-1μm-1), are processed from level 1 A by applying a radiometric processing. The image was referenced to the Universal Transverse Mercator (UTM) World Geodetic System 1984 (WGS84) zone 36 coordinate system. The six SWIR were resembled and stacked from 30 m to 15 m to retain the spatial feature of the VNIR-bands.

Since the arrival (2000) of the ASTER data, progresses have been made in field of mineral exploration. ASTER provided information about the mineral characteristics. Because of their adequate spectral, spatial and radiometric resolutions. They record information (14 channels) in the visible and near infrared (VNIR), shortwave length infrared (SWIR) and thermal infrared (TIR). Three channels characterized by 15 m spatial resolution in the VNIR section of the EM and six bands of 30 m spatial resolution in SWIR. Moreover, five bands of 90 m spatial resolution in the TIR region.

The VNIR channels of ASTER data such as bands 2, and 3 provide