The use of ASTER data and geochemical analyses for the exploration of gold at Samut area, South Eastern Desert of Egypt

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Abstract

The present study investigates the use of ASTER and geochemical data in the exploration of new gold occurrences in altered granodiorite rocks at Samut area in the South Eastern Desert of Egypt. The mapping approach developed and applied in this study integrates image ASTER and field data sets to produce a map showing the alteration zones within granitoid rocks in the Samut area. Due to the differences in hydrothermal mineral components as well as their intensities and influences on the surrounding rocks, various alteration processes have been occurred within the host granodioritic rocks. Such alteration processes include sericitization, chloritization, silicification, and ferrugination, resulted from the chemical interaction between the host rock minerals and mineral bearing ascending solutions. Each alteration process is characterized by significant minerals. The sericite and altered plagioclase characterize the sericitization process, whereas biotite, muscovite, chlorite, and hornblende minerals are associated with chloritization. However, silicification process is manifested by the quartz veins and fractured quartz grains. The ferrugination process is characterized by the transformation of magnetite to hematite and goethite. The chemical analyses of the unaltered granodiorites yielded Au content between 0.01 and 1.61 ppm, while in the altered granodiorite; Au content is around 0.02 to 14.79 ppm. The presence of gold in the unaltered and altered granodiorite even in a low percentage, but in huge tonnages gives an importance and makes the study area worthy of gold exploration and possible exploitation and hence international propagation. The Samut district is made up of intermediate to acidic metavolcanics intruded by a hornblende granodioritic pluton and cut by acidic dykes and quartz veins and veinlets. The associated hydrothermal activity with the plutonic intrusion led to the occurrence of promising alteration zones for gold in the granodiorite.

Keywords Samut district · ASTER data · Alteration zones · Gold exploration

Introduction

Gold in the Samut gold mine in the southern part of Eastern Desert occurred in quartz veins cutting through granodiorite, and with extensive mining of these quartz veins since the Pharaonic and Roman times, new sites for gold mining need to be identified either in the alteration zones developed in the granodiorites. This fact was the motivation of the present

study to pinpoint these alterations for exploring gold therein. As well as, Samut area is easily accessible and suitable for gold mineralization due to the presence of worthy rocks for gold prospecting. It is located in the South Eastern Desert of Egypt between latitudes 24° 45' to 24° 50' N and longitudes 33° 50' to 34° 00' E, covers about 70 km² (Fig. 1).

The gold deposits in the Eastern Desert occur as a result of syngenetic and epigenetic processes. In the syngenetic metamorphic model, the gold-bearing fluids may be either circulating seawater (Fripp 1976) or metamorphic water (Kerrick and Fryer 1979). The epigenetic hydrothermal Au-bearing quartz veins in the Egyptian basement are believed to be genetically related to magmatic events (e.g., Pohl 1988). Pseudo-hydrothermal processes due to convective cell circulating fluids through fractures are also suggested by Takla et al. (1989, 1990). Furthermore, Almond et al. (1984) and Hassaan and El Mezayen (1995) suggested the derivation of the ore fluids by metamorphism during ophiolite and/or island

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Fig. 1 Location map and general view of the Samut area in the Eastern Desert of Egypt

arc tectonic stages. This is consistent with Boyle (1979) who proposed a greenschist metamorphogenic model for the origin of gold (Helba et al. 2001). Botros (2004) envisaged a combined metamorphic-magmatic origin for these fluids. The gold occurrences and distributions in the Eastern Desert are tectonically controlled by wrench faults and shear zones (Helmy et al. 2004). In this study, integrated tools of remote sensing and field work were applied to get qualified and promoted results. The use of remote sensing techniques provides detailed mineralogical information and help in mineral mapping and lithological discrimination (Rowan et al. 1977; Goetz et al. 1983; Boardman et al. 1995; Kruse et al. 2003; Zoheir and Lehmann 2011; Pour and Hashim 2012). Zhang et al. (2007) processed ASTER data for extracting the lithology and mineral information that help in detecting alteration zones and characteristic minerals for gold exploration in the south Chocolate

Mountains (California). Salem and Soliman (2015) used ASTER data in the identification of alteration zones in the metavolcanics for gold prospecting at the eastern end of Wadi Allaqi, S. Eastern Desert, Egypt.

The aim of the present study is to explore gold in the granodiorite and alteration zones at Samut area. A combination of remote sensing, field geology, and analytical techniques was prepared and applied to discriminate zones of promising alterations and assessment of the gold contents within the granodioritic rocks and hosted alterations.

Geological setting

The Geology of Samut area was reported by Hume (1937) as hornblende granite closely approximating to a syenite. Azzaz

Fig. 2 Geological map of Samut area (modified after EGSMA 1996, unpublished)

Fig. 3 ASTER FCC image bands 7, 5, and 3 in RGB showing the general geological and structural features at Samut area

et al. (1981) mentioned that the Samut area comprises diorite, quartz diorite, pink granite cut by granitic dykes, and felsite porphyries and dolerite sheets. Jakubiak (1988) mapped the present area as diorite and quartz diorite with subordinate granodiorite cross cut by quartz veins. Egyptian Geological Survey and Mining Authority (EGSMA) map (1996, unpublished) illustrated the geology of Samut area as Precambrian calc-alkaline metamorphosed intermediate-acidic volcanics associated with related pyroclastics of volcanic tuffs and breccias of andesite-dacite composition intruded by hornblende granodiorite plutons. Acidic dykes, granitic

sheets, and quartz veins and veinlets cut through the granodiorite and the volcanic rocks. These are probably associated with mineral bearing hydrothermal solution led to the formation of mineral bearing alteration zones in the granodiorites. Phanerozoic Nubian sandstones are unconformably overlying the metavolcanics in the western parts of the study area (Fig. 2). Described this area as an island arc metasedimentary matrix (meta-andesite, schist, and volcanoclastic clastic metasedimentary rocks) intruded by late to post-magmatic intrusions of granodiorite rocks which are crosscutting by granodiorite dykes and quartz veins.

Fig. 4 ASTER band ratio image (5/7, 5/1, 4) in RGB differentiated the alteration zones (yellowish greenish red) from the granodiorite rocks (blue) at Samut area

Fig. 5 ASTER band ratio (4/5) mapped the alteration zones (yellowish red and off-whitish creamy colors) in the granodiorites at Samut area

Methodology

ASTER data and geologic observations supported by mineralogical and geochemical analyses were integrated and used to finalize and conclude the results of this study.

Remote sensing data

ASTER data (free level IB ASTER VNIR & SWIR data Granule ID: ASTL1B 0403150819140808041013)—

acquired on March 15, 2008—were digitally pre-processed for georeferencing, atmospheric, and radiometric corrections by ENVI 4.7 and Arc GIS10 through conversion of the data to real-world coordinates on the area maps to improve the quality of the raw data. The pre-processed data were prepared for image processing by ENVI 4.7 software to provide the lithological discrimination and detect the alteration zones and characteristic minerals. Different image processing approaches such as false color composite (FCC) and band ratios have been used to extract the aimed information on the geology and

Fig. 6 Band math $\{(b7 + b9)/b8\}$ displayed kaolinite, sericite, chlorite, and epidote minerals occurring as mottled yellow and reddish yellow colors

Fig. 7 Band math $(b5 + b7)/b6$ revealed the clay minerals

mineralogy of the study area. FCC bands (7, 5, 3) in red, green, and blue (RGB) were used to give a color composite demonstrates the geological and structural features that may control the gold occurrences in the target area.

The band ratios transformation in RGB were used for identification of alteration zones, (Di Tommaso and Rubinstein 2007; Aboelkhair et al. 2010; Salem et al. 2013, 2016). The spectral data for rocks and minerals of the USGS spectral library (<http://www.speclab.cr.usgs.gov>) was used to evaluate and correlate the ASTER image spectral signatures considering the identified mineral composition of the different rocks in the study area.

Field geology and rock sampling

Geological fieldwork was undertaken to verify the ASTER interpretation considering the EGSMA (Wadi Ghadir map 1996, unpublished) and topographic sheets of Dungash district. Representative samples (GPS controlled) were collected from the granodiorite and altered granodiorite for the mineral and chemical analyses.

Analytical methods

The mineralogical investigations were conducted on polished and thin sections of the selected samples using Nikon research microscope in the Geology Department, Cairo University, to define the ore and altered minerals associated with the gold.

The available chemical analyses (atomic absorption and fire assay), performed by Mica-Star Company in OMAC

Laboratories Ltd. Ireland, were interpreted to chemically characterize the alteration zones and the assessment of the gold content in the granodiorite as well as in alteration zones. The major elements were analyzed by the atomic absorption method whereas the minor elements were obtained by fire assay for the gold, and by the atomic absorption for the associated elements. The detection limit of the analyzed trace elements is as follows (all in ppm): Ag > 0.5, As > 5, Au > 0.01, Ba < 2, Be < 1, Cd > 1, Ce > 2, Co > 1, Cr > 2, Cu > 2, Li > 2, Mo > 1, Nb > 5, Ni > 1, Pb > 3, Rb > 50, Sb > 5, Sc > 1, Se > 10, Sn > 5, Sr > 2, Ta > 2, Te > 5, Th > 5, Tl > 5.

Results and interpretations

The application of ASTER data in the field mapping and mineral investigation lead to recognizing, differentiating, and interpreting the targeted altered zones widespread in the granodiorites at Samut area.

ASTER data interpretations

FCC

The FCC image bands (7, 5, 3) could differentiate between the metavolcanics in the east (deep brown), plutonic rocks in the central part (pale bluish brown), and Nubia sandstone in the west (yellowish brown color). Also, it displays a good drainage pattern and regional geological, structural, and lineament

Fig. 8 Small shaft in the first zone of old working to follow the quartz vein for gold exploitation. (After Ahmed 2012)

Fig. 9 The second zone of the old working for gold exploitation, south of the main quartz vein. (After Ahmed 2012)

features, e.g., faults, shearing, and major folding at Samut area (Fig. 3).

Band ratios

Based on the examination of the spectral signatures (i.e., distinctive absorption features and high reflectance values) along the electromagnetic spectrum as generated from the analysis of ASTER datasets over Dungash-Samut area, we used image rationing technique to emphasize and quantify these spectral differences in alteration zones. Specifically, we constructed the ratio images by summing the bands representing the shoulders of absorption features as a numerator, and the band located nearest the absorption feature as a denominator.

ASTER band ratios (5/7, 5/1, 4) in RGB helped in differentiating the altered zones in the granodiorite rocks. In this image, the proper granodiorite appears as blue color, the altered granodiorite in the south (around Samut gold mine)

Fig. 10 Altered granodiorite at Samut gold mine area

shows mixed blue and brown colors, while the intensively altered granodiorites near and along the contact with the metavolcanics display yellowish greenish red color (Fig. 4). The band ratios (4/5) of ASTER data helped in recognizing detailed discontinuous alteration zones clearly present in the north, east, and west of Samut gold mine; these appear as yellowish red and off-whitish creamy colors (Fig. 5). The detected alteration zones are characterized by significantly altered minerals. The following ASTER band ratios were used for identifying these altered minerals:

Fig. 11 Field photograph showing the intensively altered granodiorites with a clearly developed fault surface marked by quartz and carbonates in the NW of Samut mine area. (After Ahmed 2012)

Fig. 12 Field photograph of quartz veins and veinlets cutting granitic rocks with early formed quartz veins brecciated along the newly formed shear plane

1. Band math $\{(B7 + B9)/B8\}$ reflected the sericite, kaolinite, chlorite, and epidote minerals and appeared as yellowish white color (Fig. 6).
2. Band math $\{(b5 + b7)/b6\}$ displayed the clay minerals as whitish creamy and yellowish red colors (Fig. 7).

Field geology

The field work in Samut area and Samut old mine defined and located the alteration zones that were detected by the remote sensing interpretation in the granodiorite.

Samut prospect

The Samut prospect is developed in an area underlain by acidic metavolcanic and pyroclastic sequence intruded by a granodioritic pluton cut by granitic dykes and quartz veins. The Samut mine is confined to the granodiorite intrusions, situated in the middle and upper reaches of Wadi Samut and its tributaries in the southern periphery of the granitic plutons. At Samut mine area, the most comprehensively investigated

Fig. 13 Photomicrographs illustrate different features of the altered granodiorites. **a** Hornblende (Hb) altered to uraltite (Ur) and chlorite (Chl), altered plagioclase (Alt. plag), quartz grains (Qz), and extensive sericitization around fractures. **b** Sericitization and silicification around fractures with quartz and chlorite in the intensively altered granodiorites. **c** Magnetite grain (Mag) being martitized “oxidized” and altered to goethite, with possible tiny specks of gold in reflected light. **d** Pyrite cluster and possibly tiny specks of gold (Au) in altered granodiorites

zones of the old working for gold mineralization are sets of continuous quartz veins and altered brittle shear zones. These occur around latitudes $24^{\circ} 50' 41''$ – $24^{\circ} 51' 20''$ N and longitudes $33^{\circ} 54' 38''$ – $33^{\circ} 55' 00''$ E in the granitic rock at NNE-

SSW trend. The first zone (Fig. 8) extends 400 m in length and 20–30 m in width with gold contents range between 0.005 and 1.55 g/t. The second zone (Fig. 9) lies directly at the south of the first one by 100 m extending in sub-longitudinal trend

Fig. 14 Photomicrographs shows the quartz invading in the granodiorites. **a** Early formed quartz veins being brecciated along a newly formed shear plane. **b** Mineralized quartz veinlet traversing older quartz vein with the development of secondary quartz. **c** Gold Speck “shiny yellow,” within the young quartz veinlet cutting across old quartz veins in reflected light

Table 1 Atomic absorption analysis of major elements of the granodiorites in Samut area

	Al%	Ca%	Fe%	K%	Mg%	Mn%	Na%	P%	S%	Ti%
1	7.88	2.53	3.36	2.80	0.85	0.06	2.95	0.103	0.02	0.56
2	7.89	3.32	5.39	2.15	1.52	0.08	2.97	0.205	0.01	0.92
3	7.66	2.23	3.59	3.14	0.91	0.06	2.67	0.113	0.01	0.61
4	7.60	2.08	2.93	2.83	0.67	0.05	2.91	0.081	<0.01	0.47
5	7.61	1.97	2.99	2.38	0.84	0.05	2.99	0.076	0.01	0.46
6	7.98	3.04	3.68	3.45	1.15	0.06	2.44	0.115	0.01	0.67
7	8.17	3.70	4.88	2.10	1.70	0.08	2.85	0.163	<0.01	0.88
8	8.10	3.11	4.85	2.21	1.49	0.08	3.18	0.171	0.01	0.86
9	8.06	2.26	4.64	2.22	1.39	0.07	3.22	0.162	0.03	0.84
10	8.08	2.63	5.04	2.30	1.74	0.08	3.26	0.167	0.01	0.84
11	7.87	3.06	4.63	2.49	1.37	0.08	3.05	0.157	<0.01	0.78
12	7.83	2.89	4.86	2.31	1.53	0.08	3.12	0.167	<0.01	0.82
13	7.90	2.70	4.92	2.39	1.46	0.08	3.39	0.169	<0.01	0.86
14	8.21	2.74	4.90	2.56	1.55	0.08	3.24	0.163	<0.01	0.86
15	8.33	5.66	4.63	2.20	1.32	0.07	2.68	0.153	0.01	0.77
16	6.86	1.70	2.36	4.10	0.62	0.04	2.00	0.062	<0.01	0.37
17	7.96	2.95	4.98	2.49	1.52	0.08	3.27	0.162	<0.01	0.86
18	8.20	2.65	4.71	2.49	1.37	0.08	3.47	0.172	0.01	0.83
19	7.73	2.27	3.93	3.10	1.13	0.06	2.75	0.130	<0.01	0.68
20	8.26	3.49	4.47	2.64	1.41	0.07	3.04	0.155	<0.01	0.75

Table 2 Atomic absorption analysis of minor elements of the granodiorites in Samut area (ppm)

Sample no. Element ppm	Ag	Au	As	Ba	Co	Cu	Ni	Nb	Pb	Zn	Zr
1	0.5	0.01	<5	463	15	103	18	16	13	95	105
2	–	0.03	7	396	16	76	38	19	11	76	123
3	0.7	0.31	10	456	16	141	29	17	12	91	105
4	–	0.47	32	2941	13	196	36	16	11	68	181
5	–	1.46	60	1114	15	134	35	13	20	93	114
6	–	0.60	39	695	16	156	33	17	14	69	145
7	–	1.61	19	758	17	212	28	15	22	81	181
8	–	0.35	10	450	23	94	69	14	13	76	146
9	–	0.40	16	489	22	121	54	13	12	77	139
10	–	0.31	789	331	14	101	27	6	16	50	98
11	–	1.55	56	502	23	175	48	13	20	103	172
12	–	0.24	9	585	21	149	43	14	14	83	178
13	–	0.61	33	512	21	70	45	12	9	93	147
14	–	0.20	25	524	14	112	32	17	14	63	136
15	–	0.38	34	527	16	136	27	14	9	70	198
16	–	0.19	7	89	5	22	12	<5	5	19	42
17	–	0.04	10	568	23	162	45	15	14	80	220
18	–	0.21	8	538	23	162	43	15	17	82	187
19	–	0.23	7	724	19	166	33	15	14	82	147
20	–	0.56	94	660	16	138	35	17	24	78	161

along the main lode at 300 m length and 4 to 40 m in width giving gold contents between 0.002 and 0.6 g/t. The main vein crops out over a distance of 1100 m with 3-m width, stopped down at a depth of 60 m, the old workings are limited to a 500-m interval in its southern parts. There are numerous quartz veins that have the same trend parallel to the main vein with average thicknesses being 1.0 m in a sub-longitudinal trend 18° NNE and dip 65° eastward. Many quartz veinlets are distributed everywhere around the big quartz vein especially around the main lode in 0.5 to 3 cm widths and up to a few meters lengths.

Detected alteration zones

Altered granodiorites around Samut gold mine and intensively altered granodiorites near the contacts with the metavolcanics were differentiated and mapped in the host granodiorite rocks. These alterations were developed due to the hydrothermal activity that was associated with the crosscutting granitic dykes, quartz veins, and shear planes in the granodiorites. Neighboring Samut gold mine, the altered zones formed as patches and halos of yellowish brown color enriched in sericite and kaolinite, as well as pyrite and iron oxides, distributed everywhere near and around the dykes and fractures (Fig. 10). Along and near the contact zones with the metavolcanics, the shearing, fracturing, and faulting being severe suggesting zones of hydrothermal activity (Fig. 11). Therein, the granodiorites show intensively alteration forming continuous staining halos of variable sizes and shapes of yellowish brown colors enriched in clay minerals, pyrite, and carbonates. The quartz veins in the altered zones are of white and smoky types, trend $10\text{--}20^\circ$ and dip eastwards at angles averaging 65° . These veins are extended from 700 to 1300 m with average widths of 2 m, composed of massive and crystalline quartz as well as iron oxides and sulfides. Along the shear planes, the early formed quartz veins are brecciated and occasionally traversed by quartz veinlets up to a distance of 1 m away from the vein contacts in the granodiorite rocks (Fig. 12).

Petrography of granodiorites

The altered granodiorites are composed of quartz, plagioclase, biotite, and hornblende as major minerals; sericite and chlorite are the main alteration products. The hornblende is completely altered to chlorite. The wide distribution of micro-fractures and gliding is observed along plagioclase twin lamellae due to deformation, and intensive alteration of feldspars into sericite in the intensively altered granodiorites (Fig. 13a, b). The opaque minerals comprise sulfides and magnetite and are mainly affected by deformation and alteration. The magnetite is brecciated, corroded, and altered at grain boundaries and along cleavages to hematite, and then hydrated to goethite

Table 3 Atomic absorption analysis of major element contents of the analyzed alteration zone, Samut area

Sample no. Element %	Al%	Ca%	Fe%	K%	Mg%	Mn%	Na%	P%	S%	Ti%
1	5.00	0.74	5.10	1.53	1.28	0.290	0.16	0.188	0.03	3.953
2	4.23	1.03	2.51	1.18	0.58	0.393	1.00	0.054	0.02	4.739
3	2.28	0.18	1.55	0.72	0.23	0.124	0.45	0.034	<0.01	1.116
4	5.66	0.84	4.76	2.04	1.06	0.365	1.42	0.201	0.02	6.973
5	1.26	0.43	1.35	0.24	0.23	1.069	0.04	0.013	0.05	0.600
6	5.60	0.87	3.61	1.77	0.88	0.423	1.07	0.112	0.02	5.303
7	7.34	1.00	5.42	3.43	0.81	0.119	0.61	0.180	0.12	5.302
8	3.64	0.53	6.36	1.21	0.66	0.238	0.05	0.104	0.02	1.625
9	6.12	1.00	5.32	2.50	0.92	0.287	0.13	0.216	0.07	6.046
10	5.15	1.02	5.50	2.15	1.02	0.274	0.29	0.142	0.21	4.694
11	2.07	0.26	2.48	0.79	0.26	0.186	0.03	0.048	0.02	1.449
12	7.81	4.86	3.41	2.33	0.97	0.767	1.35	0.193	0.02	8.218
13	5.74	5.31	4.56	2.46	1.07	0.488	0.70	0.209	0.53	8.529
14	6.17	0.89	5.58	3.10	0.97	0.205	0.49	0.178	0.07	6.927
15	6.38	1.01	6.65	2.66	0.81	0.278	0.26	0.179	0.17	4.555
16	7.38	2.15	6.23	2.22	1.99	1.178	0.37	0.219	<0.01	8.005
17	1.50	0.33	2.07	0.44	0.23	0.169	0.03	0.040	0.04	1.410
18	4.73	0.71	3.93	1.37	1.38	0.429	0.79	0.113	0.02	4.292
19	6.93	0.71	5.83	1.12	2.21	0.555	2.16	0.164	<0.01	4.339
20	4.99	1.94	3.95	1.54	1.11	0.495	0.36	0.130	<0.01	4.644
21	4.51	0.71	3.58	1.48	0.65	0.468	0.17	0.124	0.01	5.242
22	4.60	1.79	4.08	1.32	1.28	0.419	0.79	0.129	0.02	3.974
23	4.80	0.85	4.40	1.47	1.22	0.404	0.57	0.171	0.02	5.391
24	1.45	0.80	1.70	0.42	0.45	0.368	0.03	0.048	0.01	1.464
25	7.72	1.21	6.54	2.31	1.33	0.552	0.11	0.262	<0.01	7.285
26	7.87	1.88	5.44	2.19	2.19	0.892	2.27	0.165	0.01	8.304
27	1.76	13.38	1.63	0.41	0.53	1.057	0.20	0.069	0.02	1.642
28	7.54	1.80	6.28	2.20	1.64	0.841	1.86	0.274	0.02	11.769
29	7.77	3.10	6.68	2.09	2.08	1.011	2.40	0.211	0.01	10.790
30	7.80	0.89	7.50	1.86	3.01	0.701	0.08	0.122	0.08	6.474
31	6.60	2.08	5.22	2.19	1.76	0.538	0.18	0.136	0.31	6.648
32	2.06	0.98	1.61	0.41	0.48	0.224	0.70	0.036	<0.01	3.135
33	7.89	3.87	5.64	2.15	2.24	0.940	2.61	0.191	<0.01	8.759
34	7.67	2.38	6.61	1.85	2.11	0.826	1.63	0.176	0.02	9.631
35	4.22	2.10	3.23	1.11	1.14	0.558	1.45	0.100	0.01	5.90
36	5.79	2.22	5.00	1.53	1.29	0.724	1.29	0.155	<0.01	7.904
37	4.93	2.15	3.64	1.21	1.13	0.562	1.58	0.123	0.30	6.164
38	5.39	1.24	3.57	1.94	1.29	0.614	0.22	0.092	0.04	3.015
39	5.13	6.17	3.96	0.99	1.31	0.840	1.54	0.101	0.01	4.693
40	8.76	1.75	5.50	4.00	0.59	0.278	0.06	0.301	<0.01	5.309

which associated with tiny specks of gold (Fig. 13c). The sulfides are mostly pyrite clusters or disseminated micro-crystalline, some of which could be pyrite or gold grains (Fig. 13d). Quartz veins cut the altered rock mass while the quartz veinlets were observed traversing older veins. The quartz in the early formed quartz veins is brecciated along

the newly formed shear planes (Fig. 14a). It occurs as euhedral to subhedral crystals showing wavy extinction due to strain effect. Secondary quartz is observed in the mineralized quartz veinlets which traverse older coarse-grained quartz veins (Fig. 14b) enclosing gold speck within the young quartz veinlets in the altered granodiorites (Fig. 14c).

Table 4 Fire assay analysis for gold; and atomic absorption analysis of minor elements of the analyzed alteration zone samples, Samut area

Sample no. Element ppm	Ag	Au	As	Ba	Co	Cu	Ni	Nb	Pb	Zn	Zr
1	-	3.11	26	337	12	139	19	7	6	67	30
2	-	0.4	21	302	7	48	19	10	24	45	76
3	-	9.37	228	159	5	47	11	<5	23	33	40
4	-	0.76Z	195	458	15	217	24	14	47	112	82
5	-	0.02	9	281	5	34	18	<5	7	34	14
6	-	0.40	43	489	13	116	27	12	14	73	76
7	-	0.82	40	218	15	74	22	<5	6	87	72
8	1.7	7.58	11	1620	12	72	24	9	7	66	108
9	-	1.91	6	1796	12	78	23	8	6	76	100
10	2.0	12.45	54	252	5	177	12	<5	10	45	23
11	-	0.48	30	399	15	168	24	14	67	69	146
12	-	0.06	35	16,816	1	226	25	12	13	71	120
13	-	0.28	14	874	13	75	24	12	13	83	123
14	-	0.43	201	338	22	158	40	12	12	92	177
15	0.6	0.19	86	109	6	52	10	<5	8	46	26
16	0.6	2.27	111	550	11	84	27	8	8	47	96
17	-	0.04	233	358	19	139	40	10	8	80	153
18	-	0.10	8	563	20	107	42	13	12	117	191
19	-	0.19	7	89	5	22	12	<5	5	19	42
20	-	5.30	77	233	15	68	51	11	32	85	134
21	0.5	8.74	88	290	12	85	26	7	7	65	100
22	-	4.79	39	291	12	92	28	8	8	57	113
23	-	0.51	112	583	19	228	30	16	10	77	190
24	-	0.27	71	95	4	110	12	<5	18	19	45
25	-	0.14	8	557	22	144	42	15	11	92	167
26	-	0.01	<5	121	5	11	14	5	<3	24	48
27	-	0.02	8	518	21	103	55	14	11	79	187
28	-	0.02	53	419	23	90	54	14	10	83	165
29	-	0.20	724	370	18	92	39	11	10	66	136
30	-	0.02	21	302	12	60	26	10	16	51	102
31	-	0.16	122	33	2	13	7	<5	<3	10	6
32	-	0.01	14	145	6	43	15	<5	5	25	46
33	-	<0.01	53	343	17	98	37	8	9	56	107
34	-	0.02	16	45	7	31	23	6	12	47	26
35	-	0.02	117	197	13	84	22	8	8	55	52
36	0.5	0.73	15,349	674	15	266	18	8	10	52	195
37	0.6	2.16	9549	131	6	30	9	<5	11	19	53
38	-	0.12	351	96	2	8	6	<5	5	19	5
39	-	0.12	135	213	14	88	20	<5	6	54	46
40	0.6	14.79	130	9	1	5	4	<5	47	40	2

- not detected

Gold content in the granodiorites

The analyzed samples for major and minor elements of the granodiorites (Tables 1 and 2) revealed increasing in Al, Ca, Fe, K, and Na at the expense of Mg, Mn, P, S, and Ti suggesting a hornblende granodiorite composition of

dominance alkali feldspars (Table 1). The relative increase in Fe% may pertain to the leaching from the iron rich hydrothermal activity. In Table 2, the Au contents range around 0.01 and 1.61 ppm and found in a random relation with the associated elements of Ag, As, Ba, Ni, Pb, Co, and Cu.

Gold content in the alteration zones in granodiorites

The results of 40 analyzed samples of the altered granodiorites for major and minor elements are shown (Tables 3 and 4). Al, Ca, Fe, K, and Na are increasing in amounts at the expense of Mg, Mn, P, S, and Ti, reflecting sericitization (Table 3). The depletion of Na in the alteration zones is mainly accompanied by an increasing in K depending on the degree of sericitization of the feldspars in the granodiorites. The fire assay of the gold and atomic absorption analysis of the associated elements in the altered samples is shown in Table 4. The gold contents range from 0.02 to 14.79 ppm. The associated elements show random relationship with the gold in these altered rocks.

Discussion

The ancient mining of Samut area was directed to the gold-bearing quartz veins cut in the granodiorite rocks, where the mining operations followed the mineralized quartz veins in the surfaces and also at depths. That mining activity had entirely exploited and consumed the gold from these quartz veins extensively. In the present study, the altered granodiorite rocks in Samut area were targeted for possible gold mineralization even with the low gold percentages in the alteration zones relative to those in the quartz veins, but with wide dominance and distributions of these alteration zones rather than the limited and rarely occurred quartz veins.

The gold deposits of Dungash-Samut district are of orogenic type and show metamorphic, structural, and mineralogical features occur along the shear zones crosscutting the granitic intrusions in the area (Groves et al. 1998, 2003). Botros (2004) assumed that the gold deposits at the Dungash-Samut area were not genetically related to the intrusion of the syntectonic or post-tectonic granites, instead developed in the late orogenic cycle in the Arabian Nubian Shield. Stated that the Dungash-Samut gold deposit is strongly controlled by brittle-ductile shear zones, whereas Zoheir et al. (2008) show that the precipitation of gold was triggered by reactions between the fluids in the shear zones and the country rock at temperatures of ~300° to 400 °C.

The influences of the granitic dykes, quartz veins and veinlets, shear planes, and faults reflect dominance of fractures and open spaces in the crosscutting granodioritic rocks. These fractures acted as venues for the circulating the hydrothermal fluids and mineral solutions to induce later static sericitization, chloritization, and even inducing silicification with the surrounding rocks, leaching and/or adding elements in the adjacent wall rocks developing of mineral rich alteration zones in the granodiorites. The source of silica is the quartz subjected to pressure solution generating silica. As a result of silica diffusing, later phase of veining has been created, forming

secondary mineralized quartz veins and veinlets cut the early formed veins.

The results of image processing of ASTER data complemented by the field geologic work enabled to discriminate and verify the alteration zones. The chemical analyses have proved the presence of gold in the alterations zones and in the unaltered granodioritic rocks.

The gold seems to occur as native gold specks in the altered granodiorites and within the second phase of silica veining unrelated to the pyritization process. In this respect, gold is expected to have been carried in solution with the silica in the second phase of silica veining which should be a target for gold exploration.

Conclusion

The results of ASTER data, field geology, and geochemical analyses helped in the detection of the hydrothermally altered zones with specific altered minerals as new targets for gold exploration in the granodiorite body in the Samut area. The applied tools yielded identical results, as the mapped alteration zones by the ASTER data processing have been verified and the same located in the field. Also, the petrographic study identified the altered minerals of sericite, chlorite, and clay minerals in rocks sampled in areas where the alterations zones were detected by the remote sensing interpretation. ASTER band ratio (4/5) is the best for detailed mapping of the alteration zones, band math $\{(b7 + b9)/b8\}$ is valid for detecting carbonate minerals, chlorite and epidote, while band math $(b5 + b7)/b6$ is the suitable one for illustrating sericite and clay minerals.

Gold mineralization at Samut area is associated with the sericitization, chloritization, and silicification processes developed as fracture fillings and easily recognized at surface exposures. The mineral composition of the alteration zones and country rocks obtained from the ASTER surface data and chemical analyses indicates that the Samut region is a promising target for gold mineralization because of the existence of extensive zones of intense alterations in the granodiorites. Using the VNIR and SWIR bands of the ASTER data is important for mineral exploration as they give highly accurate data that help in detecting limited and restricted areas of alteration zones as specified targets for mineral exploration saving time and costs.

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