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Gold Mineralization

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Introduction

Gold (Au) is a transition metal between Ag and Rg in the chemical series of the Periodic Table. Its atomic number is 79, and atomic mass 196.96655 (2) g/mol, and has only one stable isotope number 197. The gold isotype 198Au (half-life 2.7 days) is used in some cancer treatments. The metal has been known and prized as an object of beauty and for its unique properties of chemical stability,
Electrical conductivity, malleability and ductility (trivalent and univalent) since
Mankind's earliest awakenings. As a standard of value against which to appraise
The costs of labor, goods, currency and national economy, it has been the standard of many currencies since the world's first coinage in Lydia between
643 and 630 BC. The name for gold is derived from the historic English word
`Geolo', for yellow and the chemical symbol for gold Au, from the Latin name
For gold `aurum' (glowing dawn). Gold has a long history of use in society so it is no surprise that measurements of gold involve old and somewhat obscure units. Gold is always traded in Troy ounces. Take note: a Troy ounce is not the same as other ounces.

1 Troy Ounce = 31.1 grams because gold is so soft it is often alloyed with other metals in order to improve its durability. Commonly it is mixed with copper, platinum or nickel. Gold alloys are rated using the 24 point carat system. 24 carat gold is pure (100% Au w/w), 18-carat gold is 75% gold by weight and 12-carat gold is 50% gold by weight. The carat system is also applied to Platinum. Just be careful though. This system refers to gold content by weight. Sometimes people assume a given purity to mean the amount by volume. With gold being such a dense material 50% gold by weight does not mean 50% gold by volume! Bullion dealers sometimes quote gold purity using ‘fineness’. 4 nines fineness or 9999 fineness is simply another way of saying 99.99% gold! 4 nines gold is effectively 24 carat gold.

Golden numbers:

1. The Atomic Number of gold is 79. The mass number of the only stable isotope is 197.
2. Gold has 4 synthetic isotopes. Au-195, Au-196, Au-198 and Au-199.

3. Gold is a rare element but it is sometimes concentrated into ore deposits by geological processes. Modern mining and metallurgical techniques have allowed ores with as little as 2 grams per ton of gold to be mined profitably.

4. An exploration company discovers two ore bodies that could both be mined by open-cut methods. OB1 has an average gold concentration of 7 grams per ton and an estimated ore-rock reserve of 75 million tones. OB2 has an average gold concentration of 2.5 grams per ton and estimated ore-rock reserve of 200 million tones. OB1 has 100 million tons of overburden that will cost 10% of the gold reserve to remove. OB2 has 45 million tons of overburden that will cost 5% of the gold reserve to remove.

The company only has a permit to open one mine.

5. Gold is very ductile. Some claim that a troy ounce of gold can be drawn out into a wire 60km long. Assuming the wire has a constant circular cross-section.

6. Gold is very malleable. Gold can be beaten into a thin sheet and used to guild the surface of objects, even food. It is said that one troy ounce of gold can be beaten into a sheet that covers 9m2.

Assuming the sheet is of even thickness and exactly 3m square.

7. A gold prospector walks into a precious metal dealer in Perth with a bag full of her gold panning. On average the panning are 95% gold by weight.

Chapter 1:

General Gold Information:

Chemical Formula:	Au
Composition:	Molecular Weight = 196.97 gm
	Gold 100.00 % Au
Empirical Formula:	
Environment:	Quartz veins and alluvial deposits.
IMA Status:	Valid Species (Pre-IMA) Prehistoric
Name Origin:	Anglo Saxon, of uncertain origin.
Synonym:	Electrum - Ag Alloy

Gold Image:

Images:

Gold Silver

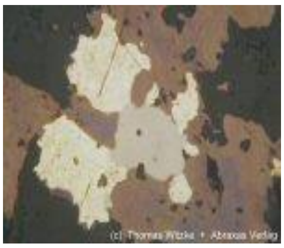
Comments: Very well crystallized Electrum (Silver rich gold) on quartz.

Images:

Gold

Comments: Well crystallized bright metallic

Images:



Gold Isomertieite Arsenopalladinite Bornite

Comments: Light grayish grain of intimately intergrown Isomertieite and arsenopalladinite (in the Section (from microprobe analysis) in Reflected light.

Images:

Gold Petzite

Comments: Dark, stubby petzite crystals with native gold On Quartz.

Images:

Gold

Comments: Two skeletal octahedral crystals of gold.

Physical properties of gold:

Cleavage:	None
Color:	Yellow, Pale yellow, Orange, Yellow white, Reddish white.
Density:	16 - 19.3, Average = 17.64
Diaphaniety:	Opaque
Fracture:	Hackly - Jagged, torn surfaces, (e.g. fractured metals).
Habit:	Arborescent - "Tree like" growths of branched systems (e.g. silver).
Habit:	Granular - Generally occurs as anhedral to subhedral crystals in matrix.
Habit:	Platy - Sheet forms (e.g. micas).
Hardness:	2.5-3 - Finger Nail-Calcite
Luminescence:	None.
Luster:	Metallic
Magnetism:	Nonmagnetic
Streak:	yellow

Chemical properties of gold :

Atomic number	79
Atomic mass	196.9655 $g.mol^{-1}$
Electronegativity according to Pauling	2.4
Density	19.3 $g.cm^{-3}$ at 20°C
Melting point	1062 °C
Boiling point	2000 °C
Vanderwaals radius	0.144 nm

Ionic radius	0.137 nm (+1)
Isotopes	7
Electronic shell	[Xe] $4f^{14}$ $5d^{10}$ $6s^{1}$
Energy of first ionization	888 $kJ.mol^{-1}$
Energy of second ionization	1974.6 $kJ.mol^{-1}$
Standard potential	+1,68 V (Au^{+}/ Au)
Discovered	c.a. 3000 BC

Optical Properties of Gold:

RL Color: Gold-yellow when pure, silver white to copper-red when impure, blue and green in transmitted light.

Reflectivity

Standardized Intensity (100%) Reflection Spectra of Gold in Air

λ	R	% Reflectivity 0 50 100	∑ R(λ)
400 nm	24.90		
420 nm	26.50		
440 nm	28.10		
460 nm	31.60		
480 nm	39.00		
500 nm	49.50		
520 nm	57.80		
540 nm	63.40		
560 nm	67.80		
580 nm	71.00		
600 nm	73.80		
620 nm	76.10		
640 nm	78.20		
660 nm	80.10		
680 nm	81.90		
700 nm	83.60		

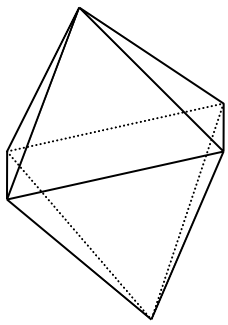
Calculated Relative Intensity Colors of Gold in Air

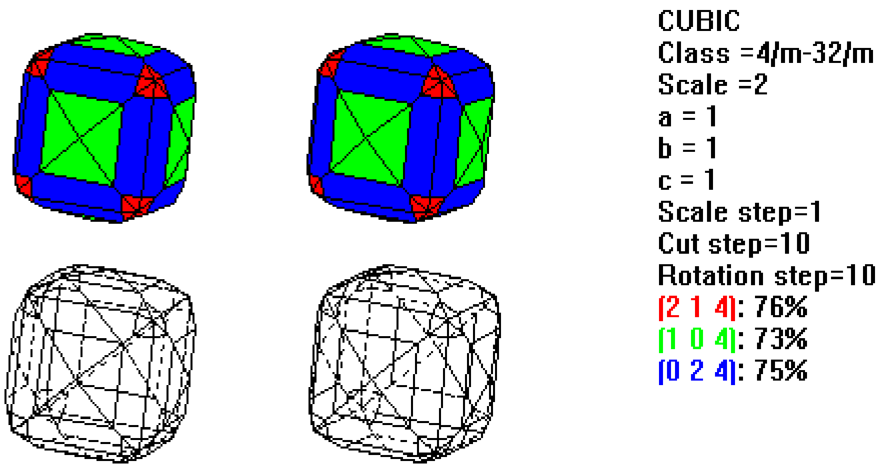
Relative Intensity	0%	0%	0%	0%	100%	120%	50%	80%	10%	40%	270,	280,

Calculated Properties of Gold:

Electron Density:	**□$_{electron}$=15.5 gm/cc** note: □$_{Gold}$ =19.3 gm/cc.
Fermion Index	Fermion Index = 0 Boson Index = 1
Photoelectric:	**PE$_{Gold}$ =1,695.89** barns/electron **U=PE$_{Gold}$ x □$_{electron}$=26228.24** barns/cc.
Radioactivity:	**GRapi = 0** (Gamma Ray American Petroleum Institute Units) Gold is **Not Radioactive**

Gold Crystallography:

Cell Dimensions:	a = 4.0786, Z = 4; V = 67.85 Den(Calc)= 19.28
Crystal System:	**Isometric - Hexoctahedral** H-M Symbol (4/m 3 2/m) Space Group: F m3m
X Ray Diffraction:	By Intensity(I/I_o)**: 2.355(1), 2.039(0.52), 1.23(0.36),**
Forms:	
Crystal Structure:	



Gold Classification:

Dana Class:	**1.1.1.1** (1)Native Elements
	(1.1)with metallic elements other than the platinum group
	(1.1.1)Gold group
	1.1.1.1 Gold Au F m3m 4/m 3 2/m
	1.1.1.2 Silver Ag F m3m 4/m 3 2/m
	1.1.1.3 Copper Cu F m3m 4/m 3 2/m
	1.1.1.4 Lead Pb F m3m 4/m 3 2/m
	1.1.1.5 Aluminum Al F m3m,P m3m 4/m 3 2/m

Strunz Class:	**I/A.01-40** I - Elements
	I/A - Metallic and intermetallic compounds, Carbides, Nitrides, Phosphides and Silicides
	I/A.01 - Series Copper, Silver and Gold
	I/A.01-10 Copper Cu F m3m 4/m 3 2/m
	I/A.01-15 Allabogdanite! (Fe,Ni)2P P nma 2/m 2/m

	2/m
	I/A.01-20 Silver Ag F m3m 4/m 3 2/m
	I/A.01-40 Gold Au F m3m 4/m 3 2/m
	I/A.01-50 Auricupride Cu3Au P m3m 4/m 3 2/m
	I/A.01-60 Tetra-auricupride AuCu P 4/mmm 4/m 2/m 2/m
	I/A.01-65 Bogdanovite (Au,Te,Pb)3(Cu,Fe) P m3m 4/m 3 2/m
	I/A.01-68 Hunchunite! (Au,Ag)2Pb F d3m 4/m 3 2/m
	I/A.01-70 Anyuiite Au(Pb,Sb)2 I 4/mcm 4/m 2/m 2/m

***Occurrences of Gold*:**

Geological Setting:

1) Primary hydrothermal veins.

2) Volcanic.

3) Alluvial**.**

Association:

Pyrite, chalcopyrite, arsenopyrite, pyrrhotite, sylvanite, krennerite, calaverite, altaite, tetradymite, scheelite, ankerite, tourmaline, quartz.

Abundance of Gold:

- **Earth's Crust**/p.p.m.: 0.0011
- **Seawater**/p.p.m.: 0.00001
- **Atmosphere**/p.p.m.: N/A
- **Sun** (Relative to H=1E^{12}): 5.6

The Many Uses of Gold:

1-Jewelry: The Primary Use of Gold.

2- Financial Gold - Coinage, Bullion, Currency Backing.

3- Electronics.

4- Computers.

5- Dentistry.
6- Aerospace.
7- Awards and Symbols of Status.
8- Glassmaking.
9- Industry.
10-Nano Technology.
11-Fuel cells.
12- Medical Uses.

Medical uses of Gold Compounds:

Gold, in a variety of forms, has been used in medicine throughout the history of civilization. In the twentieth century gold complexes were introduced for the treatment for rheumatoid arthritis, culminating in the introduction of the oral drug Auranofin in 1985. The clinical use and mechanism of action of gold drugs is reviewed here, including recent discoveries on the effect of gold drugs on geneexpression.The searchfor new medical usesof gold is described,focusing on the anticancer and antimicrobial properties of gold compounds. Some of uses of gold as:
Anticancer activity of gold compounds, Antimicobial actmty of gold compounds, gold – protein interaction.

Health effects of gold:

Effects of exposure: Inhalation: May cause irritation if exposure is prolonged or excessive. Ingestion: No adverse effects expected. Skin: May cause irritation and allergic reaction. Eye: May cause irritation. Gold is used to cure rheumatoid arthritis, under a treatment called *Chrysoteraphy.* It is prescribed when treatment with non-steroid anti-inflammatory drugs is failing to give relief.

Environmental effects of gold:

Gold has not been evaluated for its ecotoxicity. However, the biodegradation of gold under aerobic conditions is expected to be very poor and there is no evidence to suggest it creates ecological problems when released into the environment. Since gold is insoluble, it is believed to have minimal bioaccumulation and bioavailability characteristics.

Origin of Gold Deposit Found?

The radioactive decay of metal specks inside South African gold nuggets may have helped an international team of scientists determine the origin of the world's largest gold deposit. The discovery, described in a recent issue of the journal Science, not only sheds light on Earth's early geology, but promises to help future gold prospecting as well.

"If we can find another one of these giant deposits, that's at least a half-trillion dollar in today's prices, if not twice that," said research leader Jason Kirk, a geochemist at the University of Arizona in Tucson.

Nearly 40 percent of all gold mined during recorded history has come in the past 120 years from "the Rand"—the Witwatersrand Basin in South Africa. Scientists estimate roughly one-third of the world's gold resources still lie unmined in the nine million acres of this ancient lake or sea bed, whose name means "ridge of white waters" in Afrikaans.

The origin of these rich deposits has proven controversial. Two theories prevailed, Kirk explained. The placer model says the gold is older than surrounding rock, having washed into the basin from rivers and streams from surrounding mountains and highlands, much as the gold deposits in California that triggered the gold rush there did. The hydrothermal model, on the other hand, says the hot spring fluids deposited the gold inside the rocks.

To resolve the controversy, Kirk and colleagues in Australia and Britain decided to determine the age of the gold itself. If the gold is older than the rocks in which it is found, then the rocks must have built up around the gold, bolstering the placer model. If the gold is younger than the rocks that means it must have seeped in with fluids, supporting the hydrothermal model. "Gold is never pure. It always has something in it," Kirk said.

Gold Deposits in the Mantle and Crust:

Present theory is that gold and other heavy elements would have been evenly spread in the forming Earth. However, the percent of gold present in interstellar matter is extremely minute. As the core melted, gold would amalgamate along with iron

And nickel. The silicates floated above the core and formed the mantle which extends from a few miles below the present surface to about 2,000 miles down. It is composed of iron and magnesium silicates called Olivine with minor amounts of other impurities like gold. The surface of the planet is called the crust and is about

20 miles thick under the continents. Below the oceans, the crust is much thinner or completely absent. The crust differs from the mantle in that the rocks are made up of the elements sodium, magnesium, aluminum, and calcium.

Gold is present in the crust and mantle in very low concentration. Tests on California granite show an average of 0.103 parts per million, which works out to 0.003 ounces per ton. T.K. Rose, in his book, "The Metallurgy of Gold," cites a number of assays on rock samples taken from locations remote from known gold deposits. The values range from 0.03 ounces to 0.003 ounces of gold per ton.

High grade lode gold sites which have been worked in the past are the result of hydrothermal concentration or organic deposition.

Hydrothermal concentration is the leaching of deep mantle rock by water from the surface of the planet. Under the ocean, those geysers found during the last few years are evidence of this process continuing into the present time. Seawater seeps down into the mantle where it is heated and makes contact with the olivine rock. This rock contains small amounts of gold, manganese, and cobalt and larger quantities of iron and sulfur. These are leached from the rock and the heated seawater begins to rise until it finds a vent where it returns to the sea and deposits the sulfides of these metals as it cools. The process is the same on land; and many of the world's gold deposits were created from this process. The hydrothermal solutions at work on land are evident at Yellowstone National park where "Old Faithful" spews its lode of mineral-rich water on the hour, and hundreds of hot springs and mud holes smell of the sulfur-rich mineral they are bringing to the surface.

Organic deposition is similar to the carbon recovery from leach solutions which is used so much today. Ocean water contains gold in varying amounts; but the average is something like 120 to 130 tons to the cubic mile of sea water. If this solution is passed through previous rock or gravels containing organic matter, some of the gold will be deposited on the carbonaceous material. The gold reefs of South Africa were probably derived from this process. T. K. Rose theorizes in his book that much of the gold deposited in sedimentary rocks was by the process of adsorption on carbonaceous material.

Chapter 2

Gold mineralogy:

Natural resources of elemental gold are mainly contained in the mineral gold (plus 85%Au) and in seawater. The oceans contain a major resource of gold in solution but individual estimates are variable, depending upon the location of samples, which appear to range in gold content from as low as 0.1 to as high as 2.0 ppb by weight. Emery and Schlee (1963) note gold grades in the top 10m of sediments in the Atlantis 2 Deep between 5 and 10 ppm. However, attempts to recover gold from seawater on a commercial scale have so far failed, mainly because of the large quantities of water involved; ion exchange appears to offer the present best avenue for research. Salt, bromine and magnesia are recovered from seawater on a large scale hence the oceans must be regarded as a potential gold source of major proportions. Element associations are broadly classified on the basis of their affinities for metals, sulphides, silicates or gas phases, and are referred to in Table 1.1 as sidero-phile, chalcophile, lithophile and atmophile respectively (from Goldschmidt,1922). Basically a siderophile element, gold has some characteristics that relate it to chalcophile group elements. The general ubiquity of gold is

Table 1.2 Common element associations in some different deposit types (McQueer 1997)

Element association	Deposit type
Au-As-Sb (CO_2-Si)	Mesothermal. slate-hosted quartz-gold veins (e.g. Bendigo, Central Victoria).
Au-As-W-Ag-Sb-Te-±Cu-Pb-Mo (CO_2-S)	Archaean greenstone-hosted lode gold deposits (e.g. Kalgoorlie, Eastern Goldfields WA).
Ag-Au-As-Sb-Te±Hg-Mn (S-Si)	Epithermal gold-silver veins in volcanic host rocks (e.g. Golden Cross, NZ, Gidginburg, NSW).
Au-As-Hg-Fe±Sb-Te Tl (Si-S)	Carlin-type disseminated pyrite-arsenopyrite gold-bearing systems.
Sb-Au (Si-S)	Quartz-stibnite veins in metasediments (e.g. Costerfield, Vic., Hillgrove NSW).
Au-Fe-As-Cu±Zn (S-Si)	Quartz-sulfide veins containing Au associated with pyrite and arsenopyrite.
Hg-Cu-Au-S±As-Bi-Co	Associated with ultrabasic rocks.
Cu-U-Au-Ag-REE (S-F)	Hydrothermal hematitic breccia complexes (e.g. Olympic Dam, SA).
Pb-Zn-Ag±Cd-Cu (S)	Structurally controlled lead-silver veins and hydrothermal replacement bodies (Northhampton WA).
Fe-Pb-Zn-Cu-Ag±Hg-Sb-Au (S)	Stratabound volcanic-hosted massive sulfide deposits (e.g. Woodlawn, NSW, Roseberry, Que River, Tas.).
Fe-Pb-Zn-Ag, Mn-Ba-Tl±Cu-As-Sb (S)	Shale-hosted stratiform lead-zinc deposits (e.g. McArthur River, NT).
Fe-Pb-Zn-Ag-Cu (S) Fe-Cu-Au±Pb-Zn (S)	Turbidite-hosted sulfide vein systems (e.g. Cobar deposits, NSW).

Element association	Deposit type
Fe-Cu-Au±Ag-Bi-Mo Te (S) Fe-Mo (S)	Porphyry copper-gold and porphyry molybdenum deposits in subvolcanic acid to intermediate rocks (e.g. North Parkes, NSW, Climax, Co.).
Cu-Au-Bi (S) Fe-Cu-Pb-Zn-Ag W-Mo±Cu-Pb-Zn-Bi-As	Proximal contact replacement skarns (e.g. Browns Creek, NSW, Mt Biggendon, Qld, Old Cadia, NSW, King Island, Tas.).
Fe-Sn±As-Cu-Zn (O-S-F)	Replacement tin skarns in carbonate units (e.g. Mt Bischoff, Renison, Tas.).
Cu-Pb-Zn-W-S	Sulfides and scheelite occurring within sediments and volcanic rocks.
Fe-Ni-Cu-Co-PGE (S)	Nickel-copper sulfide deposits in mafic/ultramafic rocks (e.g. komatiite-hosted deposits, Kambalda WA, Sudbury, Canada).
Ni-Co±Mn (Si-O)	Ni laterites on ultramafic rocks (e.g. Greenvale, Qld, New Caledonia).
Cr-PGE-Ni-Cu (S-O)	Chromite lenses in layered ultrabasic rocks (e.g. Merensky Reef, S. Africa).
Fe-Ti-V (O)	Magnetite bands in layered mafic bodies and anorthosites (e.g. Bushveld Complex, S. Africa).
REE-Zr (CO_2-P)-Nb-Ta-Cu	Carbonatite deposits (e.g. Mt Weld, WA, Palabora, S. Africa).
Cu-U-V±Se-As-Mo-Pb	Redox front uranium deposits in terrestrial sediments (e.g. Lake Frome deposits, S. Africa).
U-V (K)	Calcrete uranium deposits (e.g. Yeelirrie, WA).
U-Au-Cu±Zn-Sn-Pb-Bi, Pt-Pd	Stratabound and structurally controlled uranium-gold deposits in carbonaceous sediments (e.g. Alligator River, NT).
Sn-W-As-B±Pb-Zn-Cu (O-S)	Porphyry style tin deposits (e.g. Ardlethan, NSW).
Sn-W-Mo-Cu-Pb-Zn-Au (F-B-Si-S)	Zoned vein systems in and around granites (e.g. Zeehan, Tas., Emmaville, NSW).
Ta-Nb-Sn-Li-Be (Si)	Pegmatites and complex veins associated with granites.
Al±Nb-Ti-Ga (O)	Bauxite deposits.

Demonstrated in Table 1.2, which shows common element associations in a range of ore deposit types.

Gold geochemistry:

Two important aspects of the aqueous geochemistry of gold are its chemistry And the particular properties of the matrix solution (e.g. acidity, pH and Oxidation potential, EH). Salinity can arise from various processes including rock

Weathering and dissolution of previously deposited halite, evaporation, sea water And aerosol deposition of seawater. Acidity, which is usually measured as pH And factors such as pH, Eh, and salinity have major effects on the speciation and Solubility of gold. Eh (electrical conductivity) values less than 200 mV indicate Reducing solutions, which tend to be rich in reduced species such as Fe^{2+}. Or SH^-. Values higher than 500mV indicate oxidizing solutions, which generally Contain high concentrations of oxidized species e.g., $UO2^{2+}$. Or $AuCl4^-$. The oxidation of pyrite and other sulphide minerals plays an important role in the generation of hydrogen ions (acidity) during weathering. Particular complexing anions and/or solution processes are required to enable ground water mobility and the various complexes to become important under different chemical conditions as specific complexes are thio-complexes, halide complexes and organic complexes.

-Thio-complexes:

Sulphur forms a number of species with varying oxidation states from ÿ2 to .6. Depending upon the concentration of reduced sulphur, the most important species for gold mobilizations appear to be (from lowest to highest oxidation-state):

· Hydrogen sulphide (SH^-)

· Solid sulphur, which does not mobilize gold

· Thiosulphate ($S_2O_3^{2-}$).

· Sulphite ($SO3^{2-}$).

· Sulphate ($SO4^{2-}$), which does not complex gold.

The most important sulphur species for Au mobilization appear to be hydrogen Sulphide and thiosulphate.

-Halide complexes:

The dissolution of Au chloride (AuCl2) requires highly acid, saline and oxidizing Conditions:

$$2Au_{(S)} + 4Cl^- + ½O2 + 2H^+ \leftrightarrow 2AuCl_2^- + H2O .$$

-Organic complexes:

Organic/biologically based complexes important for the mobility of Au in soils include cyanide complexes, organic complexes, and colloidal gold and biological effects.

-Cyanide complexes:

Organic complexes capable of mobility of Au in soil profiles include cyanide Complex Au $(CN)_2^-$. A highly organic horizon can contain high levels of cyanide And produce Au mobility.

-Colloidal gold:

Gold readily forms molecular aggregations up to 5 _m in size (colloids or sols) And such chemical species have been known for centuries. Where stabilized by Organic matter.

Gold grain morphology:

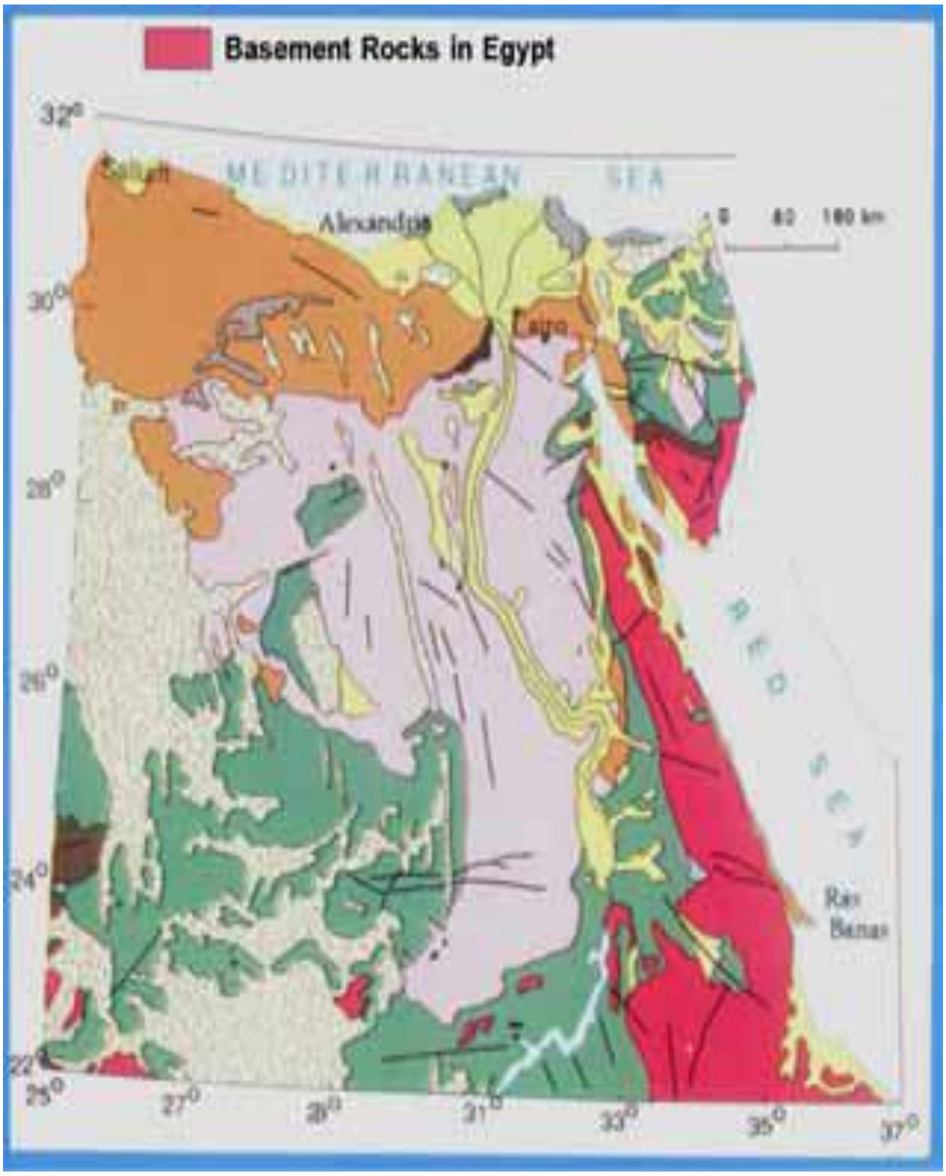
The morphology of a grain of gold is inherited from its primary state and to a Large extent, irregularities of gold grains in source rocks predetermine grain Morphology in an alluvial setting. Gold is one of the last minerals to crystallize Out under hydrothermal conditions of deposition and thus tends to fill cracks and Spaces between other minerals with which it comes into contact. The gold grains Are moulded by the geometry of the opening into aggregates of irregular shape And size and commonly contain inclusions of quartz and other rock forming Minerals.

Source of gold	Type of gold	Morphology of colours	Size mm	Remarks
Gold from bedrock source	Hypogene (primary ores)	Xenomorphic angular, equant elongate, and laminar segregations. Hypidiomorphic crystallites glistening facets and dendritic intergrowths.	0.1–200	Coarse grains rare.
	Supergene (zones of oxidation)	Lumpy, spongy, with pimply pitted surface. Excrescences and projections of irregular shapes, octahedral crystallites and their intergrowths.	0.1–1000 up to 2000 and more	Fine grains retained.
Placer gold	Of hypogene origin	Flaky, drop-like, laminar wire-like, sometimes small crystallites with glistening or shagreen surface. Frequent impressions or crystals of hypogene minerals.	250–1000 dominant	Fine grains dispersed or agglomerated.
	Oxidation zones	Equant, thickly laminate with relicts of lumpy or spongy structure rarely incomplete crystalline shape; surface pimply pitted shagreen lustre uneven.	200–500 dominant up to 2000–3000 rarely nuggets	
	Hydrogenic	Dendrites, 'corals', aggregates and intergrowth of grains drop-like sinters with uneven lustre and rough surface.		Precipitation of fines from above.

Chapter 3

GOLD IN EGYPT

More than 120 ancient gold deposits and occurrences are located in the Precambrian basement rocks of the Eastern Desert of Egypt which considered as a gold metallogenic province. Within the Eastern Desert the gold mineralization displays high clustering in the central and southern parts rather than the northern part. The Eastern Desert of Egypt has been considered the main target for gold exploration and exploitation.



Gold Production:

Gold production in Egypt started as early as pre-dynastic times (~ 4000 B.C.) and continued up to the fifth century A.D., from the fifth century A.D up to the 19 th Century there were little sporadic gold exploitation from the southern part of the Eastern Desert. The ancient gold mining was confined to the gold-bearing quartz Veins without any attention to the associated alteration zones. There are no records of the quantity of gold that had produced during that period.

During 20th Century:

By the beginning of the year 1902 systematic gold production was established marked by documentation of the quantity of the exploited gold. This period of gold production continued until the year of 1927 with cumulative production of about 2750 kg. Of fine gold. Between 1927-1934 the gold production was nearly stopped due to definite technical reasons concerning the depth of the ores, the raising water table in the shafts and poor communications. The period between (1932-1958) represents a new stage of gold exploitation in Egypt, during which a quantity of 4200 kg. Of gold was produced from a number of deposits such as Sukari, Umm Ud, Hangaliya, Umm Rus, Barramiya, El Sid, Umm Garaiat, and others. The gold content of the exploited deposits ranges from 11 to 30 gm. /t and the total production from 1902 to 1958 was about 7 tons of pure gold. By the end of 1958, gold production was stopped due to nationalization of Naser period, and also due to the lack of technology and capitals for mining investment.

Gold Distribution in Egypt

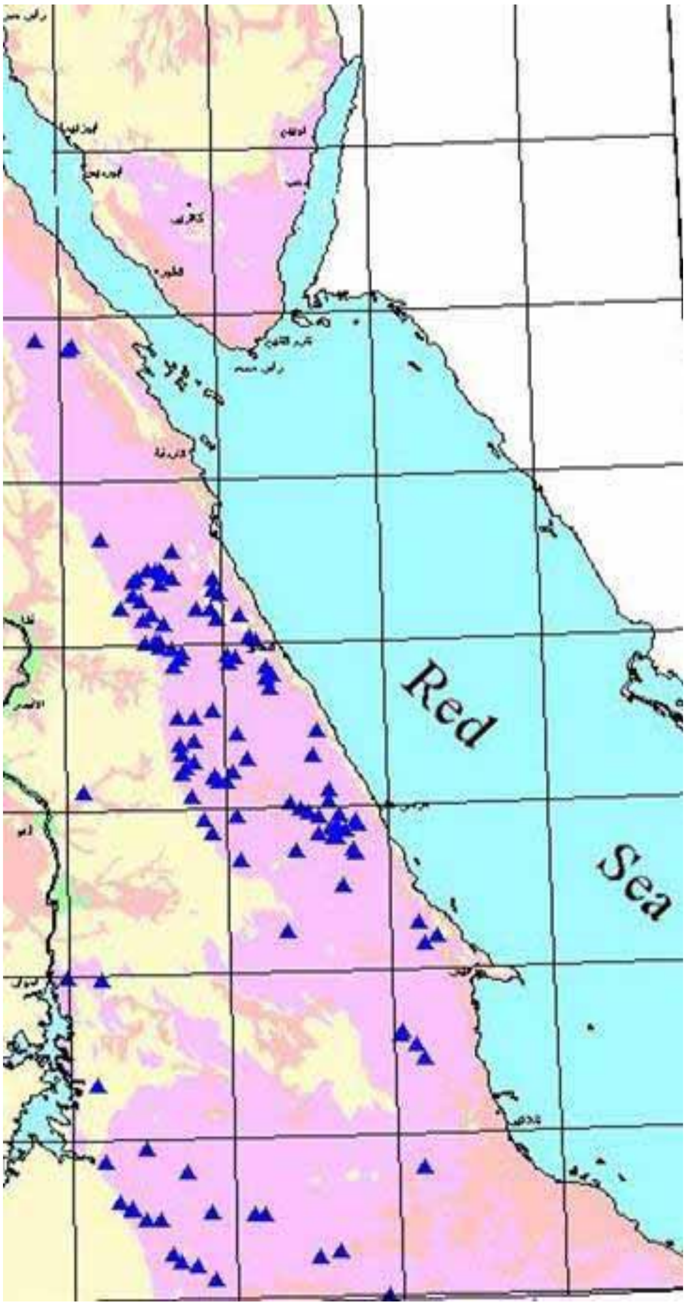
1- Northwestern group:

Includes, Umm Mongul, Umm Balad
And Wadi Dib gold deposits.

2- Northern group:

Includes, Fatira, Abu Marawat, Semna,
Gabal Semna, Abu Qurahish, Kab Amiri,
Sagi, Gidami, Hamama, Erediya, Abu Had,
Atalla, El Rabshi, Um Esh, Hammamat,

Umm Had, El Sid, umm Selimat, Hammuda, El Nur, Kareim, Kab El Abyad, Tarafawi, Sherm El Bahari, and Zeidon gold deposits.



3- Central group:

Includes, Umm Rus, Sigdit, Talat Gadalla, Abu Mutwaad, Daghbag, El Hisinat. Bokari, Umm Salatit, Abu Dabbab, Abu Qaria, Umm Salatit, Umm Selim, Barramiya, Dungash, Samut, Umm Hugab, Urf El Fahid, Atud, Sukari, Umm Tundeba, Hangalia, Kurdeman, Sabahiya, UmmUd, Allawi, Lewewi, Dweig, and Hamash old deposits.

4- Southeastern group:

Includes , Umm Eliga, Betan, Qurga, Rayan, Hutit and Umm kalib gold deposits.

5- Southwestern group:

includes ,Hariari, Umm Ashira, Nekib, Haimur, Nile Valley “Block E” , Umm Garaiat, Marahik, Atshani, Murra, Filat, Seiga-1, Seiga- II, Umm Shashoba, Abu Fass, Umm Tuyur; Betam gold deposits.

6- Other occurrences:

Include, Wadi Geli, Qulan, Kab El Rayan, Sheialik, Abu Rahaya, Kurtunos, El Hudi, Korbiai, & Romit.

Chapter 4

Gold Mineralization

The gold mineralization in the Eastern Desert is reflected in the following types:

1-Vein type:
Most of the Eastern Desert gold mineralization is confined to gold-bearing quartz Veins of various dimensions and directions. In the most cases gold occurs in a free
State within these veins (El Sid gold deposit).

2- Dyke type:
In few cases the gold mineralization is confined to sheared and hydrothermally altered dykes mostly of felsites porphyry type. The mineralization is confined to gold-bearing quartz vein lets and silicified- pyritized zones scattered through the whole mass of the dyke (Fatiri gold deposit).

3- Alteration zones type:
The mineralization is confined to gold-bearing alteration zones associated with Auriferous quartz veins system sited in brittle-ductile shear zones. The gold Concentration depends on the nature and intensity of the alteration and type of country rock (Barramiya, Dungash and Samut gold deposits).

4-Gold-sulphides type:
Gold and silver mineralization was also recorded in association with gossonized Polymetallic sulphides mineralization confined to sheared acidic-intermediate Metavolcanics (Abu Marawat gold deposit).

5-Gold-bearing BIF type:
Epigenetic gold mineralization is recorded recently in association with the banded iron formation (BIF) of the central Eastern Desert (W. Karim) and also in the SW part of the Western Desert (Owinat BIF).

6-Placer type:
Small scale gold mineralization was also detected in some alluvial deposits in the Eastern Desert. It is found scattered in the whole thickness of the alluvial, not Concentrated near the bedrocks.

Episodes of Gold Mineralization

There are different views dealing with the genesis and development stages of gold mineralization in Egypt. Early researchers related gold mineralization in Egypt to the hydrothermal processes that accompanied the emplacement of the dioritic intrusions of Pre-Cambrian age. Others assumed that gold mineralization is of multi-staged nature and it was related to the intrusion of the Gattarian granites. Four episodes of gold mineralization including pre-organic, syngenetic to late organic, Riphean- Lower Paleozoic and Mesozoic-Cenozoic (Sabet et al 1976). **Recent investigations revealed that** the Eastern Desert of Egypt is considered to be a gold metallogenic province since it comprises more than 120 gold deposits and occurrences enclosed in the Precambrian Pan-African basement rocks. There are three major gold mineralization phases were recognized in the Eastern Desert of Egypt. The earlier phase is reflected in gold-bearing quartz veins confined to brittle ductile shear zones genetically related to the island arcs accretion tectonics. Auriferous veins are mostly enclosed in volcano-sedimentary sequences of the accreted terrains. In most cases the mineralized veins are accompanied by gold bearing wall rock alteration zones of alteration pattern comprises silicification, Sulphidization and carbonatization. The earlier gold mineralization was attributed to auriferous metamorphic fluids developed in association with the island arcs accretionary tectonics. The earlier gold mineralization phase is mainly concentrated at the southern part of the Eastern Desert of Egypt (e.g. Wadi Allaqi gold district). The mineralization is clearly predate the emplacement of the postaccretion younger granites-gabbros association (El Shimi 1996). The second gold mineralization phase is reflected in gold-bearing quartz and carbonate veins developed along shear and tensional fractures related to the back arc basin closure tectonics in the central Eastern Desert (e.g. Barramiya-Umm Samra- Dungash – El Sid and W. Karim gold deposits). The third gold mineralization phase is reflected in gold and copper -bearing quartz veins associated with barite veins and gossanes. The mineralization is confined to shear and tensional fractures system developed in Dokhan volcanics and their granitic equivalents intrusions in the northern part of the Eastern Desert of Egypt. The mineralization may relate to the emplacement of younger granitic intrusions and the last E-W continental collision tectonics affected on the area at the end of the Arabo-Nubian Shield crustal evolution (Umm Balad gold deposit).

New targets for gold mineralization in the Eastern Desert

Within the basement rocks of the Eastern Desert of Egypt there are **several** geologic environments and a number of specific areas appear to be promising for hosting significant gold mineralization as following:

-Volcanogenic-massive sulphide deposits:
The Eastern Desert hosts few volcanogenic massive sulphide deposits. The most Significant one is that of Umm Samuki area at the south of the Eastern Desert. This type of deposit contains significant concentrations of gold as has been recorded in many parts of the world.

- Banded Iron Formation (BIF) deposits:
The Banded Iron Formation (BIF) deposits in the central Eastern Desert represent new target for hosting **g**old mineralization. These deposits proved to be gold mineralized ones where the BIF at Wadi Karim and Umm Nar are invaded by gold-bearing quartz-carbonate vein lets. The Archean BIF in the SW- of the

Western Desert of Egypt preserved also to be gold mineralized one. Accordingly, more attention should be directed to this type of deposits.

- Alteration zones and gossanes:

Regional and local silicified and sulphidized alteration zones and gossanes located along shear and tensional fractures may represent a new target for hosting gold mineralization in the Eastern Desert. These targets can be easily detected using remote sensing technique.

A new classification of the gold deposits of Egypt

1-Introduction:

The Eastern Desert of Egypt is well known as a gold-mining area since ancient times and more than 90 gold deposits and occurrences are spread over the whole area covered by the basement rocks of Precambrian age.

2-Overview of the basement geology:

The Precambrian basement complex of Egypt comprises about 10% of the total area of the country. It is exposed mainly in the Eastern Desert along the Red Sea, and sporadic ones located in the Western Desert at Gebel Oweinat. A considerable part also covers the southern portion of Sinai (Fig. 2). In the Eastern Desert, the basement rocks extend as a belt parallel to the Red Sea coast for a distance of about 800 km.

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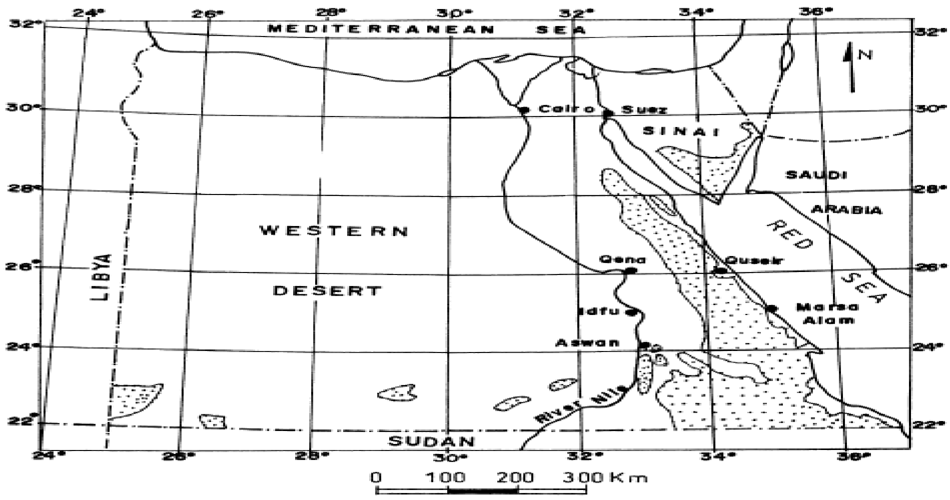


Fig. 2. Distribution of basement outcrops in Egypt. Younger sedimentary formations. Precambrian basement rocks.

The basement rocks of the Eastern Desert of Egypt constitute the Nubian Shield that formed a contiguous part of the Arabian shield in the Arabian Peninsula before the opening of the Red Sea. It is generally accepted that the basement of the Nubian Shield was cratonized during the Pan-African orogeny around 570 Ma ago **(El Gaby et al., 1988)**. The term ''Pan-African'' was introduced by **Kennedy (1964)** to define an ''important and widespread tectonic and thermal event'' which affected the African continent during the Late Precambrian and Early Paleozoic, some 500F100 Ma ago.

3-Classification of gold deposits:

According to the previously mentioned tectonic–magmatic evolution of the Nubian shield, a threefold classification of gold deposits in Egypt is offered. These are:

1. Stratabound deposits.
2. Non-stratabound deposits
3. Placer deposits.

1. Stratabound gold deposits:

These deposits are hosted in island arc volcanic and volcaniclastic rocks that are equivalent to younger metavolcanics (YMV) of Stern (1981), Shadli metavolcanics (El Ramly, 1972) and ophiolitic mélange (Shackleton et al., 1980; Ries et al., 1983). Volcanic rocks are represented mainly by basalts, basaltic Andesitic and dacites. The volcaniclastic rocks, which accumulated in intra-arc basins are frequently intercalated with Banded Iron Formation (BIF) of Algoma type particularly in the central part of the Eastern desert and associated further to the south with massive sulphide deposits similar in many respects to the massive sulphide deposits of the Canadian shield (Hussein et al., 1977).
Stratabound gold deposits are classified into three main types:

1.1. Gold-bearing Algoma-type banded iron formation (BIF):

-BIF in the Eastern Desert occurs as well defined stratigraphic unit within the Pan-African layered volcanic and volcaniclastic rocks. At present, it is well established that BIF in the Eastern Desert resembles those found in Achaean and younger volcanic assemblages and belongs to the class of Algoma-type deposits which are related in time and space to volcanic activity (Sims and James, 1984; Botros, 1995a; Khalil, 2001).

-The majority of BIF in the Eastern Desert belong to the oxide facies where hematite and magnetite occur in bands alternating with silica-rich bands. However, carbonate and sulphide facies are also encountered in some localities (Aly et al., 1992; El Gaby et al., 1994).

-Recently, gold mineralization associated with oxide facies of BIF at Abu Marawat gold prospect (Botros, 1991, 1995a) and Um Nar area (Dardir and Elshimi, 1992) was recorded. In this study, Abu Marawat BIF is taken as an example for gold-bearing oxide facies in Algoma-type BIF. At Abu Marawat area, BIF is located the upper parts of Abu Marawat mountain as sharply defined horizon within volcano-sedimentary succession.

-The genesis of the auriferous BIF in Abu Marawat gold prospect was attributed to interaction between volcanically derived fluids (hot brines) and seawater. The hot brines were capable of leaching iron, silica, gold and other associated elements from basaltic andesites and basalts of tholeiitic affinity that characterized

The early stage of the island arc volcanicity (immature arc). When these brines mixed with seawater, auriferous BIF was deposited as chemical sediments (Botros, 1991).

Fig. 7. Photo showing a boulder of BIF with rhythmic alternation of iron oxide-rich bands (dark) and silica-rich bands (light), Abu Marawat area (from Botros, 1991).

1.2. Gold bearing tuffaceous sediments:

Tuffaceous sediments, which are often banded, graded bedded and intercalated with BIF are usually gold bearing (Botros, 1993). This style of mineralization is localized in areas where volcanic and volcaniclastic rocks are intimately intercalated with each other. Botros (2002) believes that this style of gold mineralization in the Eastern desert of Egypt may represent a break or termination within the volcanic stratigraphy, and in areas occupied by island arc volcanic and volcaniclastic rocks, such breaks are confirmed by the occurrence of BIF which is also considered to be a chemical sediment precipitated during breaks of volcanic activity (Sims and James, 1984).

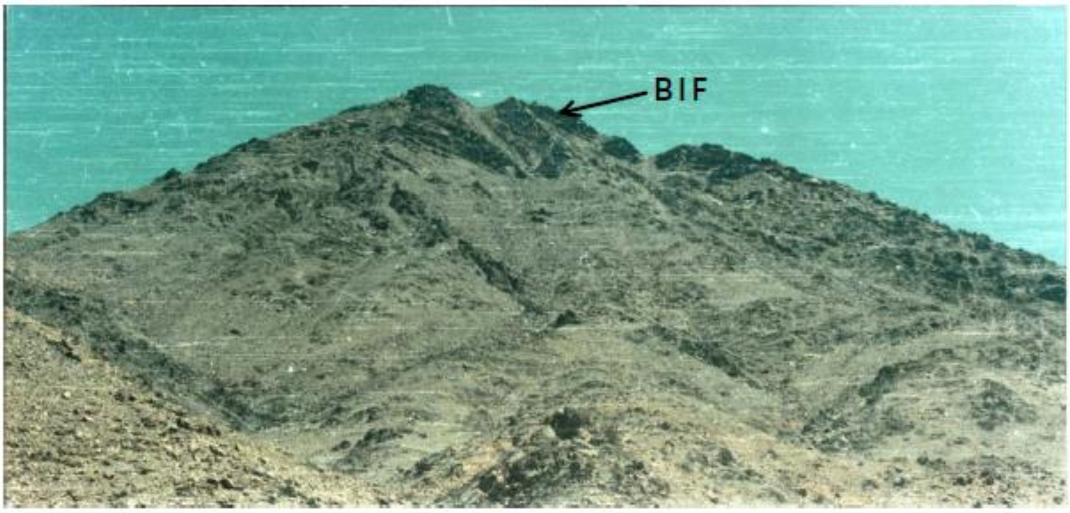


Fig. 9. Algoma-type Banded Iron Formation (BIF) occurring as sharply defined stratigraphic unit within the Pan-African layered basaltic andesites, basalts, tuffs and volcanogenic wackes, Abu Marawat area, Eastern Desert of Egypt.

Fig. 10. Close view of pillowed metabasalts at Abu Marawat area, Eastern Desert, Egypt.

1.3. Gold bearing volcanogenic massive sulphide Deposits:

-Volcanic hosted massive sulphide (VHMS) deposit in the Eastern Desert include Um Samuki, Helgit, Maakal, Darhib, Abu Gurdi, Egat and El Atshan. Some of these deposits (e.g. Darhib and El Atshan) have been identified as talc mines (Hussein, 1990). Most studies on VHMS deposits in Egypt are concentrated mainly on the Um Samuki deposit, which is the largest in the reserves and the best in ore grade.

-Um Samuki is a Zn–Cu–Pb sulphide deposit in a area of very rugged topography amidst the belt of island arc volcanic rocks. For that area, Searle et al. (1976) divided Shadli volcanic rocks (island-arc volcanic rocks) into the older Wadi Um Samuki volcanic rocks and a younger Hamamid assemblage. The Wadi Um Samuki volcanic rocks are a thick succession of submarine cyclic basic and acid volcanic with minor intercalated banded tuff and chert beds. The Abu Hamamid group includes two distinct cycles of volcanism. Each cycle starts with pillowed Basalt and terminates with thick beds of rhyolitic volcaniclastic rocks. Vent complexes are recorded in the area and are thought to be the centers of eruption For the acidic phase of the first volcanic cycle. The massive sulphide body is confined to the coarse acid pyroclastic rocks of the first cycle of Abu Hamamid Group (Searle et al., 1976). The body occurs along a specific stratigraphic horizon, which separates the brecciated rhyolite and vent facies on one hand, and the banded graded bedded tuffs on the other hand. The ore minerals of Um Samuki ore body are represented mainly by sphalerite, chalcopyrite, pyrite, marcasite and minor galena. Secondary minerals include covellite, bornite, marcasite and occasional neodigenite (Deyab, 1986). The upper contacts of the massive sulphide body at Um Samuki are sharp and well defined; while on the footwall side, an extensive pipe or funnel of alteration is present. Here, the alteration zone beneath the ore body at Um Samuki area is characterized by septechlorite and talc, associated with variable amounts of carbonates and tremolite (Rasmy et al., 1983). Two distinct spatial and mineralogical associations of gold mineralization could be identified in the volcanogenic massive sulphide deposits and their footwall alterations (the keel zone) in the Eastern Desert of Egypt (Botros, 2003):

(a) Gold–silver–zinc association:

Here gold grades are very low and silver is anomalous. This association occurs typically in the upper levels of the deposit where low-temperature sulphides are abundant. This association deposited in the initial stage of the massive sulphide body development where gold was transported as thio-complex Au (H_2S) with significant amounts of lead, zinc and silver, usually in the range 150–250 ºC.

(b)Gold–copper association:

This association typically occurs in the footwall rock alteration zone (the keel zone) and the lowest parts of the massive sulphide body. Silver is very low. Lead usually, but not always, accompanies gold in this association. This association deposited in the later stages where gold and copper were transported as chloride complexes, in relatively high-temperature fluids (>300 ºC) with low pH (< 4.5), low H_2S concentration, high salinity (greater than that of seawater) and moderate to high oxygen fugacity. Deposition took place due to decreasing of temperature and/or increasing pH conditions. The keel zones at Darhib, Abu Gurdi, El Atshan, Um Selimat, Nikhira and Egat talc mines represent this association.

2. Non-stratabound gold deposits:

These deposits are hosted in a wide range of rocks that were formed in different tectonic environments. Non-stratabound gold deposits are divided into vein type Mineralization, which has constituted the main target for gold in Egypt since Pharaonic times, and disseminated-type mineralization hosted in hydrothermally Altered rocks (alteration zones) which have recently been recognized as a new target for gold in Egypt. Mineralizing fluids of different sources are suggested for the formation of these deposits.

2.1. Vein-type mineralization:

This in turn is subdivided into:

(a) Vein-type mineralization hosted in metavolcano-sedimentary assemblage and/or the granitic rocks surrounding them:

This style of vein-type mineralization constituted the main target for gold since ancient times, where ancient Egyptians extracted gold from these veins in open-pit and underground workings. The style is confined to the metamorphosed island arc volcanic and volcaniclastic rocks and/or the older (syn-tectonic) granitic rocks surrounding them and is analogous to the vein-type gold deposits mentioned by Kochine and Bassuni (1968) and El Ramly et al. (1970). Vein-type gold deposits of this environment have been formed during the Pan-African orogeny (Botros, 2002a) synchronous with the regional metamorphism (green schist to amphibolite-facies) and attendant upon calc-alkaline I-type granites that are widely distributed in this environment. It seems that metamorphic grade is important because most auriferous quartz veins are hosted rocks which have been metamorphosed at conditions below the amphibolite-greenschist boundary (Botros, 1995b).

(b) Vein-type mineralization hosted in sheared ophiolitic ultramafic rocks: The vein-type mineralization hosted in the sheared ophiolitic serpentinites is Another style of vein-type mineralization connected with the Pan-African orogeny. In this style, linear zones of ophiolitic serpentinites show extreme alterations along thrusts and shear zones with the development of a range of talc, talc carbonate and reddish brown quartz-carbonate rock (listwaenite). Listwaenite is frequently mineralized with gold (Botros, 1991; Oweiss et al., 2001). The most characteristic feature of listwaenite is its relative resistance against weathering, If compared with the surrounding rocks; accordingly, it stands out forming prominent topographic ridges (Fig. 16). Examples for this style of mineralization in the Eastern Desert are encountered in Barramiya, El Sid and Hutite.

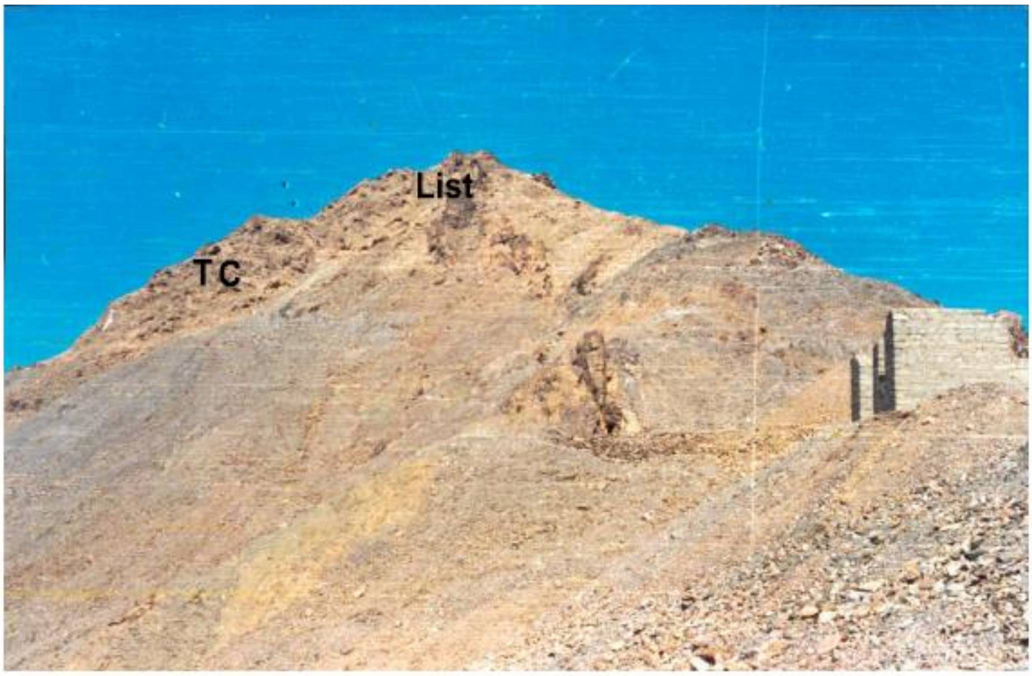


Fig. 16. Listwaenite (List.) ridge (site of old mining operations) surrounded by talc-carbonates (TC) on both sides. Barramiya gold mine. Eastern Desert of Egypt.

(c)Vein-type mineralization connected with porphyry copper deposits:

South Um Monqul prospect located in the Eastern Desert of Egypt is known as a district for gold mineralization. Rocks of the prospect are Upper Proterozoic in Age and include intrusive rocks with a porphyry phase among the intrusive that are spatially and temporally associated with volcanic rocks. These rock assemblages correlate most strongly with those of active continental margins. Country rocks of the prospect are hydrothermally altered and four main alteration Assemblages are recognized:

(1) Hydrothermal biotite (potassic).

(2) Quartz–sericite–pyrite (phyllic).

(3) Sericite–clay (phyllic–argillic).

(4) Chlorite–carbonates–epidote (propylitic) assemblage.

(d) Vein-type mineralization localized at contacts between younger gabbros and granites:

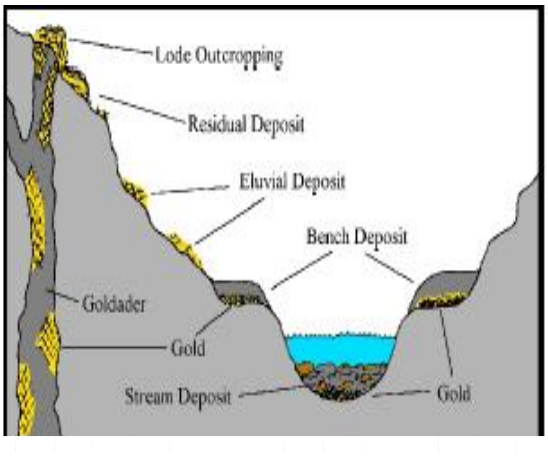
This style of vein-type mineralization is localized at the contacts between younger gabbros and granites. Younger gabbros (Basta and Takla, 1974) represent relatively small layered intrusive bodies comprising troctolites, Olivine gabbro, and hornblende gabbro and leuco gabbro. Generally speaking, younger gabbros are entirely unmetamorphosed and they represent intra plate magmatism that followed molasse-type sediments (Takla, 2002).

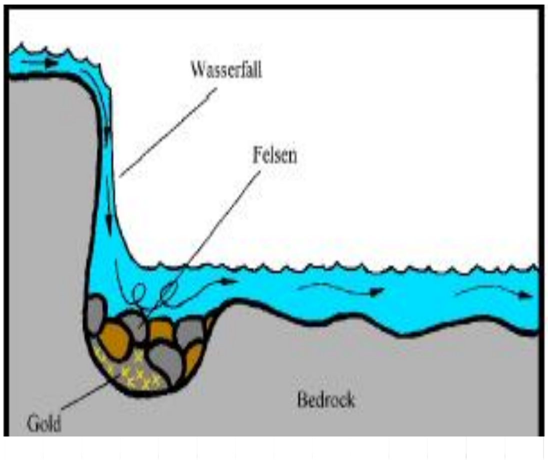
(f) Disseminated-type mineralization hosted in hydrothermally altered rocks (alteration zones):

Extensive rock alterations are a clearly visible characteristic feature of most Egyptian gold deposits and occurrences. The alterations occur either surrounding The auriferous quartz veins (Fig. 25) and/or structurally controlled by specific structural features, such as fractures shear surfaces. The most important types of wall rock alteration are sericitization, beresitization, silicification, sulphidation, Carbonatization, listwaenitization, chloritization and kaolinitization (Botros, 1993). Two main styles of alterations could be recognized in the Egyptian gold deposits (Botros, 2002). The first results during the liberation of gold from the source rocks, and is characterized by a widespread distribution and being spatially related to major structures. The second style, however, is related to the deposition of gold and is recognizable only within few meters of the auriferous quartz veins. The potentiality of each style is discussed and some applications of the concept are offered.

3. Placer deposits:

Most placer gold deposits accessible to ancient Egyptians were close to the auriferous quartz veins. The arid and hot climate that characterizes the Egyptian Deserts results in dominantly physical weathering. This is the most important factor responsible for the disintegration of potential source rocks by combination of thermal and mechanical weathering, working together over long periods of time. Two main categories of placer gold have formed in Egypt. These are modern placers and lithified placers (Botros, 1993). Modern placers are subdivided into alluvial placers and beach placers. The predominant accumulation of ore materials in a mechanically dispersed form in the wadis (dry water courses) of the Eastern Desert favours the collection of panned samples from the alluvial placers even where the alluvium contains considerable amounts of wind-blown sand (Bugrov, 1974). This method was successfully applied in Egypt while prospecting for gold in alluvial placers (Bugrov, 1974; Sabet et al., 1976 Botros, 1998; Abdel Rahman et al., 2001). Minor amounts of gold recorded in some Egyptian black beach sands (El Gemmizi, 1985) represent beach placers on the Mediterranean Sea. Conglomerate represents lithified placers. It occurs
At the base of the Upper Proterozoic molasse sediments of the Hammamat unit and/or the base of Upper Cretaceous Nubian Formation that overlies the more
Or less peneplained surface of the Precambrian basement rocks (Botros, 1993).





Chapter 5

Some gold areas in Egypt:

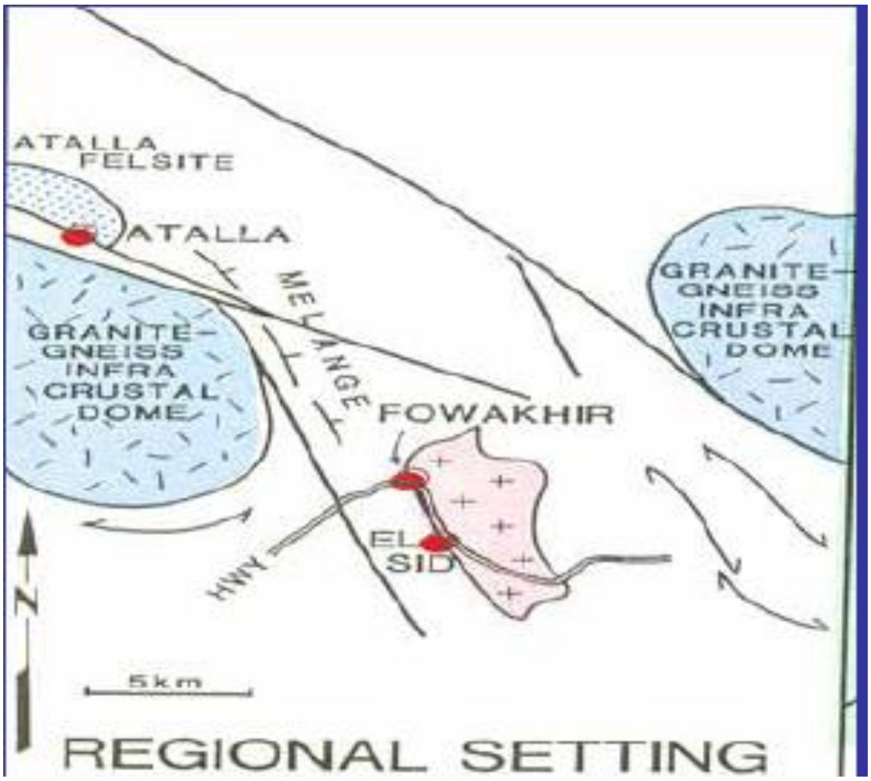
El Fawakhier Block

Location:

It is located at the southern part of the north Eastern Desert basement rocks to the north of Qussier - Qift tar road. It covering an area of 950 km2 at the intersection of Lat.25o 57`- 26o 15` N and Long. 33o 27 – 33o 44 E.

Geologic Setting & Mineralization:

El Fawakhier gold field area is a part of backarc basin volcano-sedimentary sequence associated with abducted ophiolitic bodies and regionally metamorphosed at green schist facies. The belt was intruded by post-tectonic Granitoids which host most of the gold mineralization's within that block (e.g. El Sid –Atalla gold deposits). Structurally, the block was deformed by two major tectonic events which provided dilation zones acted as channel ways and depositional loci for subsequently coming gold-bearing fluids. All the post-tectonic granitic stocks and their surroundings especially those of mafic-ultramafic rocks are highly recommended for gold exploration within that block. The gold mineralization is confined to gold-bearing quartz veins, silicified alteration zones and hydrothermally altered dykes confined to granitoid and metavolcanics rocks.



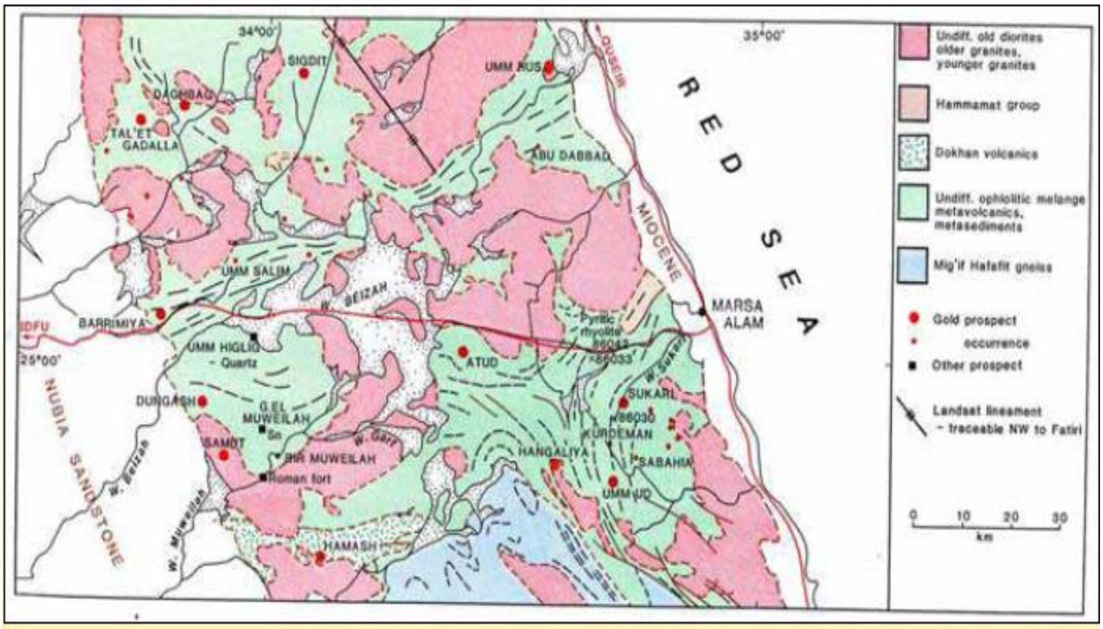
Barramiya Gold Block

Location:

It is located in the central Eastern Desert basement rocks, directly to the north of Idfu-Marsa Alam tar road. The block covering an area of about 1535 Km2 at the intersection of Lat.25 06 -25 21 N and Long.33 41 -34 12 E.

Geologic Setting & Mineralization:

Barramiya gold field block is a part of back-arc basin volcano-sedimentary sequence enclosing huge bodies of abducted ophiolitic rocks (serpentinites) and intruded by granites- gabbros association. The block hosts the second gold mineralization recognized in the Eastern Desert. The gold mineralization is reflecting in gold bearing quartz-carbonate veins hosted by the volcano-sedimentary sequence and granitoids. The mineralization is confined to brittle-ductile shear zones and tensional fractures developed in association with the back-arc basin closure tectonics, (e.g. Barramiya gold deposit-Umm Samra gold deposit).



Gold deposits and occurrences of Central Eastern Desert.

Oweinat Block

Location:

The block lies in the southwestern corner of the Western Desert of Egypt at lat. 22° 00' – 22° 20` N and long. 26° 00` – 26° 20` E. covering an area of 1245 km2.

Mineralization:

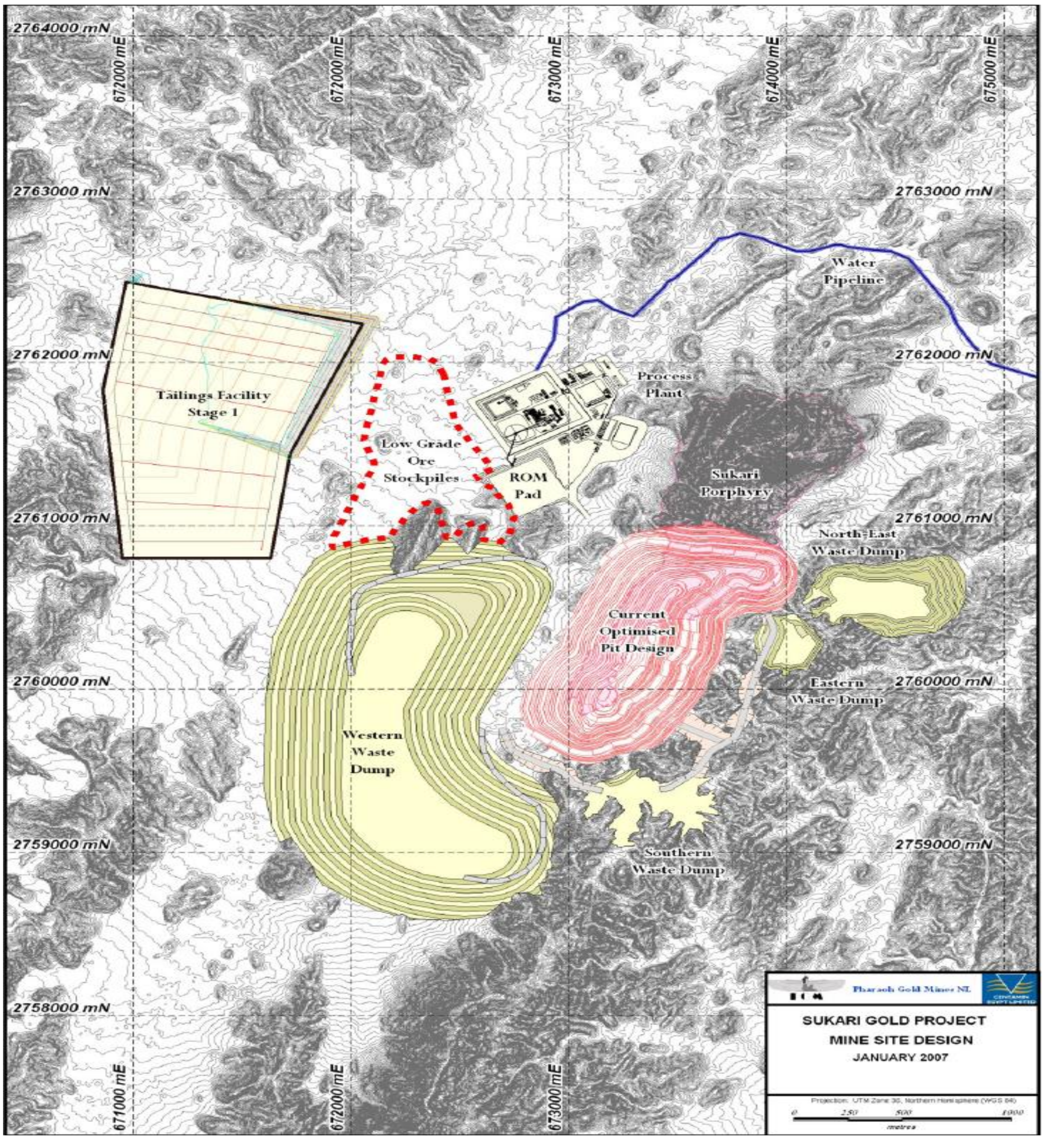
Gold mineralization was recorded in association with the banded iron formation (BIF) to the southwest of Gabal Kamel. The gold content ranges from 0.3 -23.6 g/t. Gold occurs as disseminated tiny grains within both silicates and iron oxides Minerals of the BIF. Gold grains are found disseminated in goethite, hematite, and magnetite with sulphides. The contents of the disseminated gold in the BIF are variable. Gold also occurs within the quartz veins that cross-cutting the basement rocks as well as the associated alteration zones in the country rocks.

SUKARI GOLD PROJECT

Project summary:

The Sukari gold mine is located 15 km west of the Red Sea in the southern central Eastern Desert of Egypt. The gold on this site was worked out by the Pharaohs and the Romans. Drilling is ongoing with nine rigs currently operating on site with the intention of concluding a feasibility study to a bankable standard for a 4 to 5 million tonne per annum processing plant.

Project design:



Geology of the Sukari gold mine area:

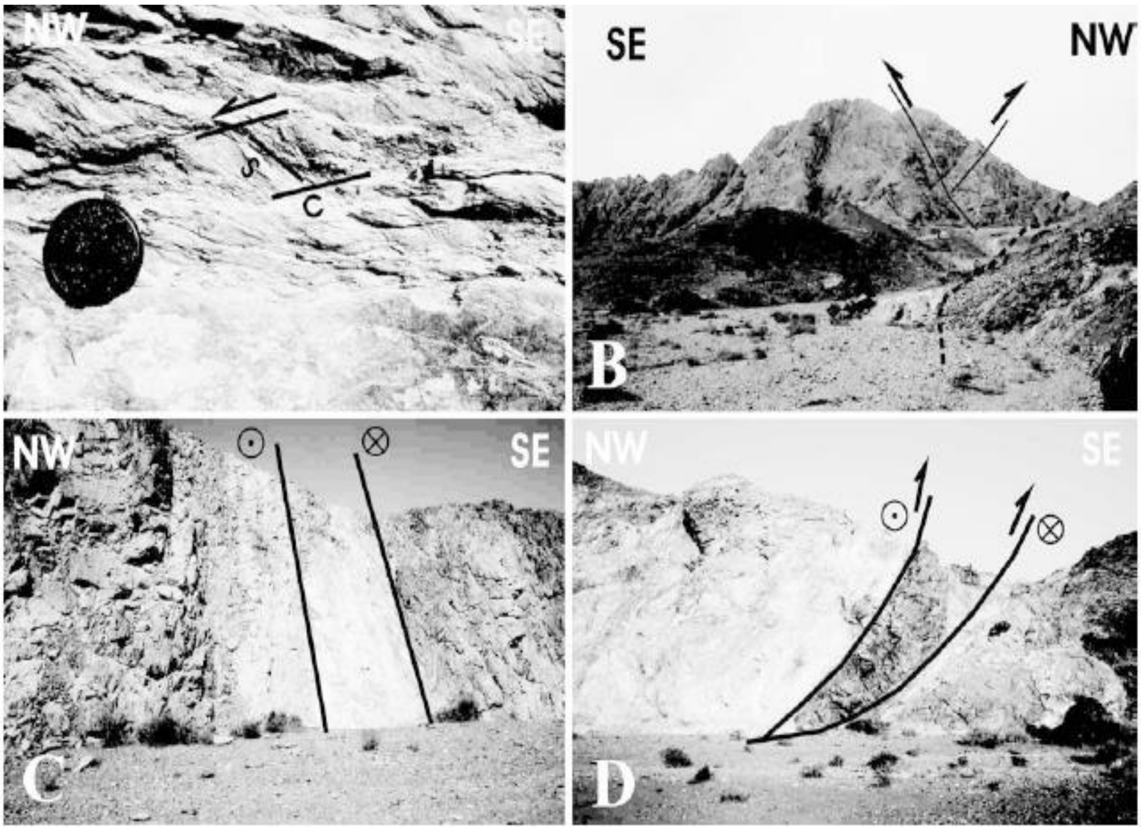
The Sukari gold mine is located approximately 15 km to the southwest of Marsa Alam, between the Red Sea coast and the Hafafit Gneiss Dome). The mine occurs within a Late Neoproterozoic granitoid (Arslan 1989; Harraz 1991) that intruded older volcanosedimentary successions and an ophiolitic assemblage, both known as Wadi Ghadir mélange (El Sharkawi and El Bayoumi 1979). The volcanosedimentary succession is composed of andesites, dacites, rhyodacites, tuffs and pyroclastics. Magmatic rocks are of calc-alkaline affinity (Akaad et al. 1995) and were formed in an island-arc setting (El Gaby et al. 1990). The dismembered ophiolitic succession is represented by a serpentinite at the base,

followed upwards by a metagabbro-diorite complex and sheeted dykes.
Metagabbro-diorite rocks and
Serpentinites form lenticular bodies (1–3 km2) as well as small bodies occur conformably scattered in the volcanosedimentary arc assemblage (Harraz 1991)
All rocks are weakly metamorphosed (lower green schist metamorphic facies), intensely sheared and transformed into various schist's along shear zones. Mineralized quartz veins and talc-carbonate vein lets are common. The Sukari granitoid is elongated in a NNE direction and bounded from west and east by two steep shear zones, covering an area of ca. 10 km2. The fresh rock is leucocratic, coarse-grained and pink in color. It has a heterogeneous mineralogical composition and ranges from monzogranite to granodiorite with dominant quartz, plagioclase and potash feldspars and less abundant biotite. The Sukari granitoid has a trondhjemitic affinity (Arslan 1989) and belongs to the ‘‘Younger Granite Suite’’ of Akaad and Nowier (1980). Harraz (1991) argued for a transitional tectonic environment
Between within-plate, volcanic-arc and syncollision granite fields. The age of the Sukari granitoid body is poorly constrained (630–580 Ma, Harraz 1991) but documents Late Pan-African magmatic activity in the area. In the vicinity of shear zones the granite is foliated, elsewhere, however, it has sharp intrusive contacts
Against the older rocks. Along those shear zones serpentinite and andesite is altered to listvenite rock (Khalaf and Oweiss 1993) that attains up to 70 m in thickness and extends for several kilometers. At the intersection of the two shear zones, where the gold mineralization is concentrated, the Sukari granite isalmost completely altered and transected by a large amount of quartz veins.

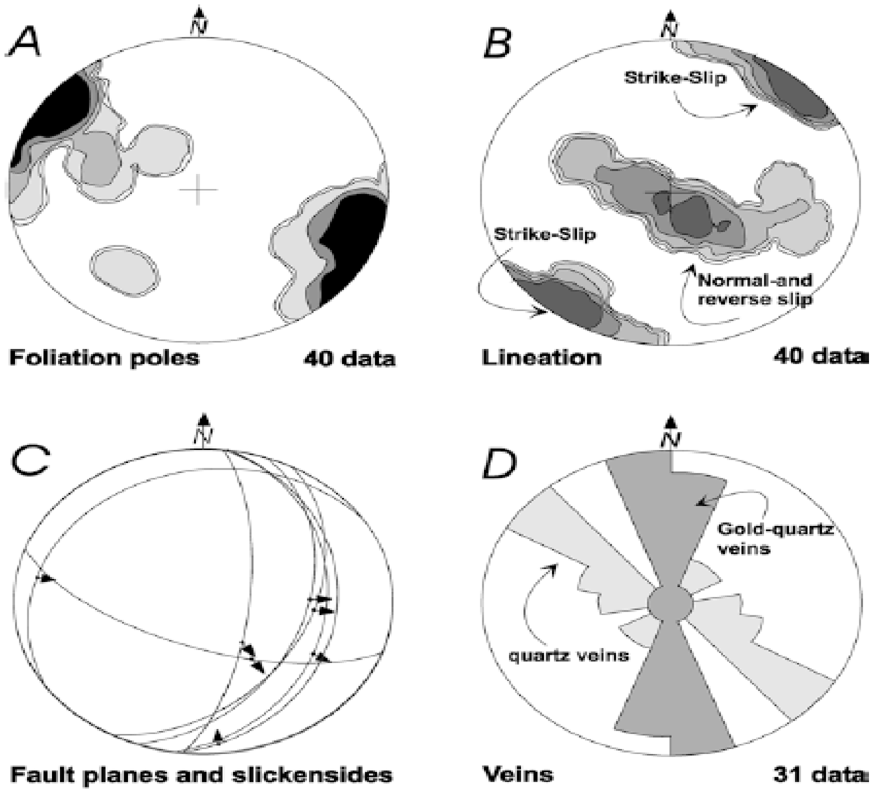
Structural setting of the Sukari area:

The structural study at Sukari focused on orientation, relative timing and kinematics of shear zones, faults and tension gashes. Gold-bearing vein systems with specific deformation increments and to provide the basis for the sampling. The area between Hafafit Dome and the Red Sea coast, which includes the Sukari mining district, displays an arc structure with NW–SE trend of main structural elements in the west and NE–SW trend close to the Red Sea (Fig. 2A). Three deformation increments are recognized in these areas that are responsible for the geometry of this domain:

1. Thrusting within the Pan-African Nappe assembly, in this area known as Wadi Ghadir mélange, was generally NW to W-directed Structures related to this event are south- to southeast-dipping thrusts and NW-trending shear zones. The contact between the Hafafit Gneiss Dome and the westerly adjacent Wadi Ghadir mélange sedimentary rocks of the Pan-African Nappes, previously interpreted as a thrust (Nugrus Thrust, Greiling et al. 1988) has been recognized as left-lateral ductile shear zone (Nugrus Fault, Fritz et al. 1996; Unzog and Kurz 2000; Makroum 2003). The NW-trending Nugrus Shear Zone represents a lateral ramp during northwestward displacement of Pan-African Nappes. Second-order sinistral shear Zones developed within the Wadi Ghadir mélange sedimentary rocks to the east of the Hafafit. The NEtrending thrust slices of Pan-African Nappes are Interpreted as frontal thrust fan (Makroum 2003). Close to the Sukari mine, the tectonic transport direction during thrusting is constrained from shallow to steeply southeast dipping shear planes and consistently NW-trending stretching lineation's associated with a widely spaced S-C fabrics (Fig. 3A). Although quartz veins developed in the course of this deformation increment, none of them is mineralized.



2. The subsequent localized deformation is related to ongoing NNW- to N shortening and includes aconjugate set of steep NE-trending sinistral and NW trending dextral fault zones that evolved at brittle to ductile conditions. The NE-trending shear zones define the western and eastern margins of the Sukari granitoid locally developed, steeply southeast- and northwest-dipping reverse and normal faults are interpreted as negative and positive flower structures that developed during strike-slip faulting and accommodated variable displacement of individual Blocks Fabrics related to shear-zone formation include vertical, NE-trending Shear planes (Fig. 4A). Mineral-stretching lineations rom ductile fabrics within highly altered shear zones (e.g. quartz lineation rods, stretched minerals) document A combination of strike-slip (horizontal lineations in Fig. 4B) and vertical components of motion (vertical lineations in Fig. 4B) as typically observed in Flower structures. Associated shear-sense indicators form strike-slip zones (vein offset, S-C fabrics) and document sinistral sense of shear. Similar deformation Geometry with a combination of strike-slip and normal faults is also obtained from fault-plane and slickenside data (Fig. 4C) suggesting that this deformation geometry persisted at brittle conditions. Both, the Sukari granitoid and the highly altered host rocks are transected by several generations of quartz veins. The majority of gold quartz veins trend N–S and opened within the tensional segment during sinistral Shear (Fig. 4D). However, we emphasize that several stages of quartz vein formation are preserved; some early formed veins are folded and co-rotated during sinistral shear; late veins are straight and occupy high angles to the shear foliation.



3. Finally, discordant ENE-trending dikes and, on a large scale, the Wadi Igla molasse basin to the north of the arc document a late stage of approximately N–S extension. From structural data we conclude that:

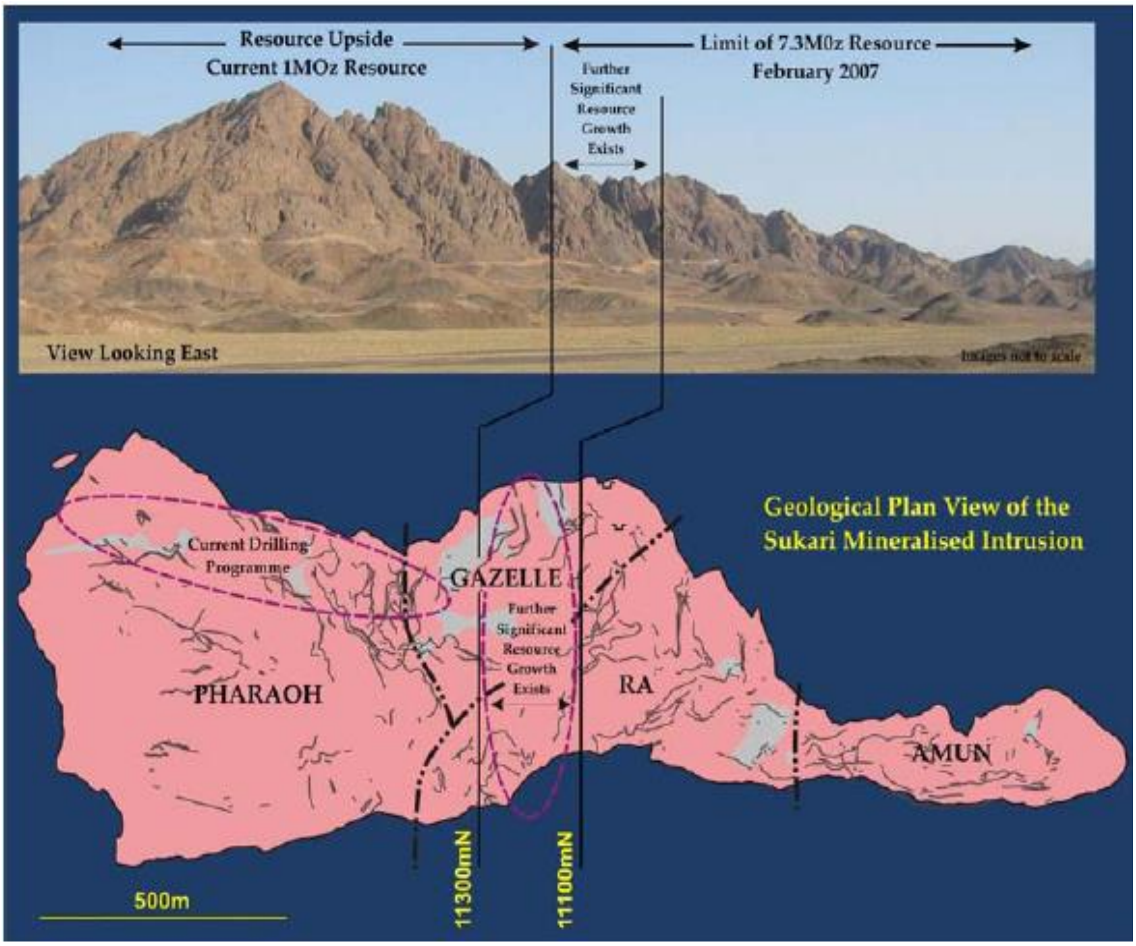
1- NW-directed thrusting and stacking of Pan-African Nappes predated gold mineralization, since neither gold quartz veins nor alteration zones are related to This tectonic event.

2- The sinistral strike-slip faults provided pathways for emplacement of the elongated Sukari pluton, which is entirely bordered by shear zones.

3- Intrusion together with shear-zone formation served enhanced fluid flow and alteration of pluton and host rocks. Alteration during sinistral shear deformation Formed mainly phyllosilicates that caused significant weakening of the host-rock rheology and ductile flow (e.g. Kolb et al. 2004).

4. Shear deformation persisted at brittle conditions and facilitated opening of tension gashes and precipitation of ore fluids. Time brackets for the deformation increments mentioned above include the ca. 585 Ma 40Ar/39Ar cooling ages from the Hafafit Dome that are interpreted to closely date the late activity of the Nugrus Fault System (Fritz et al. 2002). An upper age limit is given from the molasse sedimentation within the Wadi Igla Basin, which is considered to be of Late Neoproterozoic age (approximately 580 Ma, Rice et al. 1993).

Mineralization:

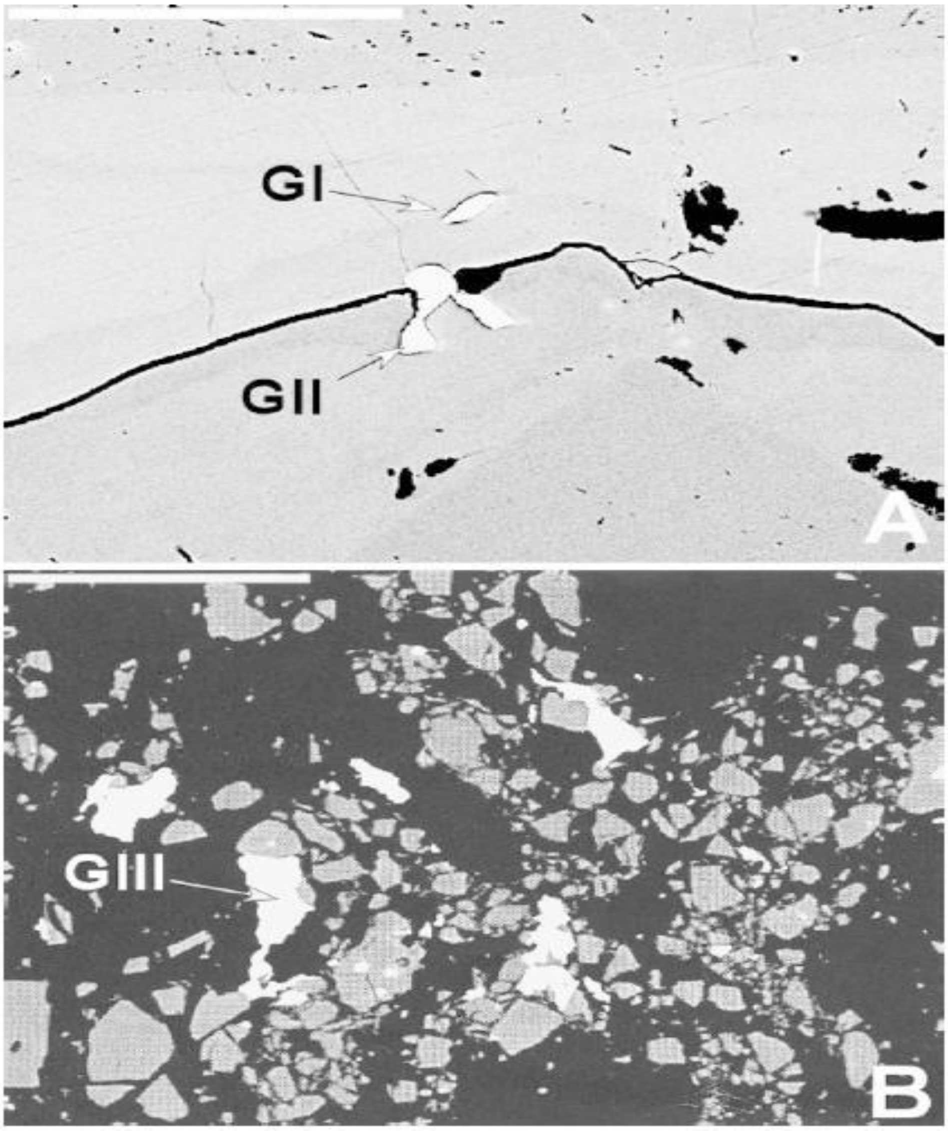


Gold occurs in two textural positions and three generations in quartz veins or vein lets:

(1) As inclusions in pyrite and arsenopyrite (GI and GII).

(2) As interstitial grains between pyrite and other sulfides (GIII).

Gold inclusions (2–20 lm) in pyrite are either located at the surfaces of As-rich zones (GI) as revealed by BSE images (Fig. 7A) or randomly distributed. Gold inclusions in arsenopyrite are randomly distributed or located along deformational cracks (GII, Fig. 7A). Interstitial gold grains (GIII, Fig. 7B) are usually associated with deformed pyrite and arsenopyrite in the deformed and sheared smoky quartz (type Q2). In this textural position, gold grains range from 2 to 80 lm and sometimes host small arsenopyrite and pyrite crystals. Electron microprobe analysis (Table 1) revealed that gold is always electrum (12–14 wt% silver). No systematic compositional difference between inclusion and interstitial gold were detected.


GI
GII
A
GIII
B

Reference:

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