Factors Control of Gold Mineralization and Associated Ore Metals, Um Rus Area, Central Eastern Desert, Egypt

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Abstract: Geological studies and mineralogical investigation reveal that gold mineralization and associated ore metals are essentially associated with smoky quartz and wall rock alteration zones, whereas kaolinitization, sericitization, vermiculitization and carbonatization are present as by-products of alteration processes. The studies reveal also that the base metal sulfides associated with gold mineralization are represented by pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, pyrrhotite, bornit, covellite, and marcasite, as well as oxides such as magnetite, hematite and hydroxides such as goethite. Gold is commonly present as fine minute specks scattered within some sulfides such as pyrite and chalcopyrite and hydroxides such as goethite. However, in quartz veins is obtained along the microfractures. In the alteration zones, it is relatively more abundant in the highly ferruginted rocks. Paragenetic sequence of gold and associated ore metals suggests three different stages. These are pyrite and magnetite stage, followed by pyrite and arsenopyrite stage, and marcasite, hematite and goethite stage. Actually, the second stage of pyrite-arsenopyrite stage represents the most common one of gold mineralization.
[I. Abu El-Leil, S. M. Sakr, L. M. Abd El-Salam, H. M. Azzam, and R. M. El-Wardany **Factors Control of Gold Mineralization and Associated Ore Metals, Um Rus Area, Central Eastern Desert, Egypt.** *J Am Sci* 2016;12(7):110-125]. ISSN 1545-1003 (print); ISSN 2375-7264 (online). http://www.jofamericanscience.org. 12. doi:10.7537/marsjas120716.12.

Keyword: Um Rus, Gold mineralization, Paragenesis sequence

Introduction

Um Rus is situated in the Central Eastern Desert (CED), between latitudes 25º 26′ 30" - 25º 29′ 30" N and longitudes 34º 32′ 30" - 34º 35′ 15" E. It covers an area about 137 km2 (Fig. 1). It is area is characterized by low to moderate topographic reliefs. The main topographic feature is Gabal Um Rus (262 m height). The area is traversed by Wadi Mubarak, Wadi Abu Dob, Wadi Magal, Wadi Um Barak and Wadi Kadabora El Hamra.

The area had been studied by Amin (1955), Kabesh et al. (1967), Hilmy et. al. (1968), Salem, et al. (1981), Kamel, et al. (1983), El-Mahallawy (1984) Sabet and Bondonosov (1984), Osman and Dardir (1986), El-Dosuky et al. (1987),Kamel et al. (1992), Harraz and EL-Dahhar (1993), Sabet and Azzaz (1993), Harraz and EL-Dahhar (1994), El-Mezayen and Abu El Leil(1996), Harraz, (2002), Amer et. al. (2012), and others.

Geology

The study area comprises different rock units related to island arc assemblage and late to post orogenic stage, that have been arranged from older to younger according to the following:-

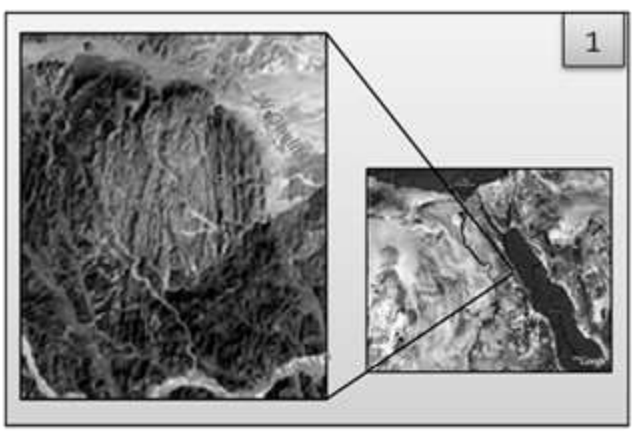
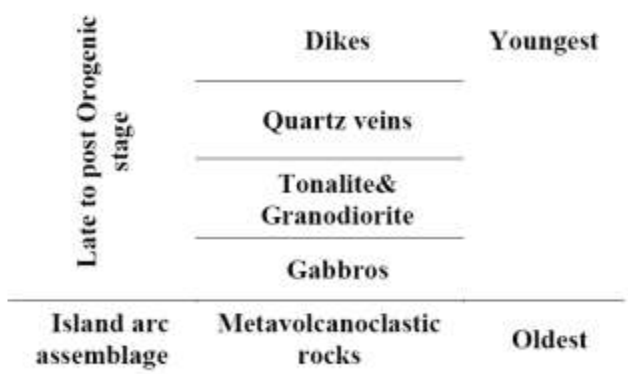


Fig. (1): Location map of Um Rus area.



Gabbros:-

The investigated gabbros have been mapped as younger fresh gabbro (Abu Ela, 1991, El-Mahallawy, 1984, Abu El-Ela, 1991, El-Mahallawy, 1984, El-Mezayen et.al 1996, Tolba, 2007). they form a semi-circular body intruded by tonalite and granodiorite pluton of Gabal Um Rus. The gabbros of Um Rus area have relatively moderate relief occurring as dark green with violet tint, medium to coarse grained rocks (Fig. 4). They show pronounced primary banding, with succession of melanocratic olivine gabbro and gabbro norite band, alternated with leucocratic gabbro bands of troctolite, anorthosite and altered gabbro. Moreover at the western side, particular along the contact with tonalite and granodiorite, the hybrided gabbro is obtained probably due to action of hydrothermal fluids accompanied by the tonalite and granodiorite interaction (Fig. 5). Diverse composition of hybrid rocks had been pointed out by Amin, (1955).

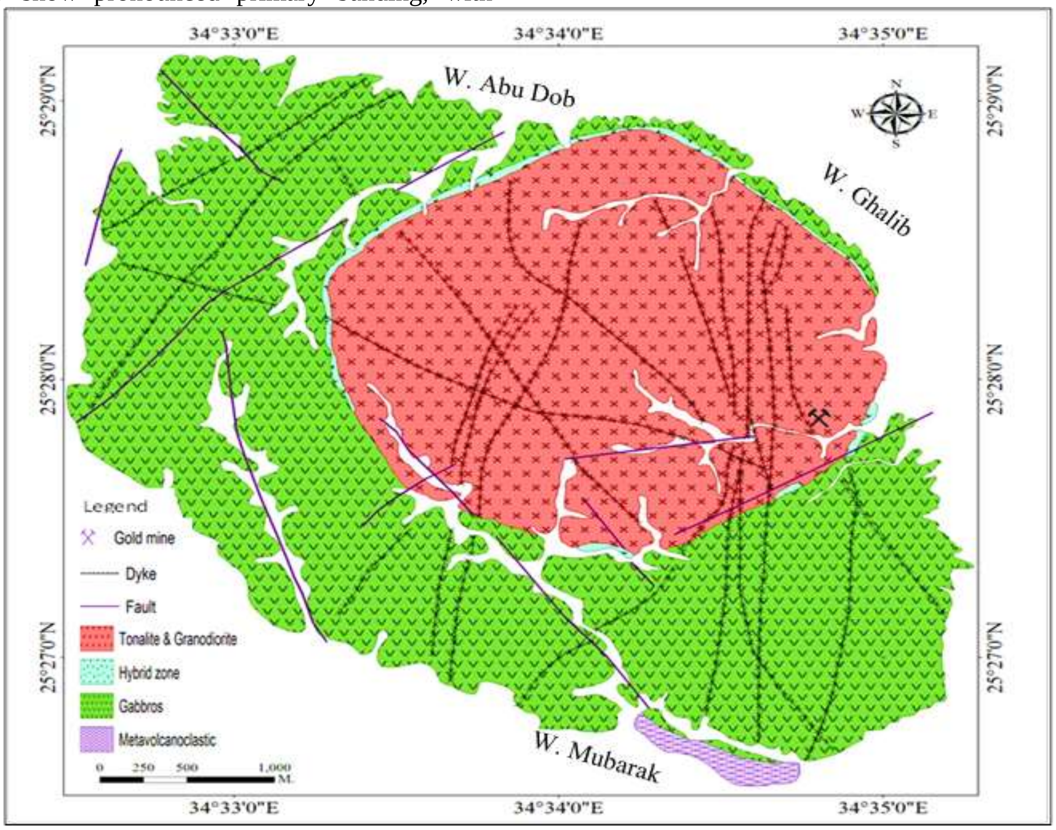


Fig. (2): Geologic map of Um Rus area (modified after Abu zeid et.al, 1985).

Tonalite and granodiorite:-

Tonalite and granodiorite rocks of Um Rus pluton form an oval-like body, intruding the surrounded gabbros situated between Wadi Abu Dob and Wadi Mubarak (Fig. 2). The pluton was described as Um Rus pluton and referred to as gray granite (El-Mahallawy, 1984). The pluton in the vicinity of the gold mine (Fig. 6) is traversed by some mineralized quartz veins. In some parts particular along the contact gabbros, the tonalite-granodiorite rocks are associated with some xenoliths of the surrounding country rocks (fig. 7).The Um Rus gold mine is located at the south-eastern part of Um Rus pluton, where cupola-like bodies of tonalite-granodiorite intrude the gabbros and a hybrid zone of them has been produced.

Wall rock alteration:-

Um Rus pluton had been affected by action of hydrothermal solution, particular along the southern parts forming up wall rock alteration zone varying from few meters to about 300m in thickness . The alteration processes are represented often by kaolinitization (Fig. 8), sericitization (Fig. 9), vermculitization (Fig. 10), and carbonatization (Fig. 11).

Quartz Veins:-

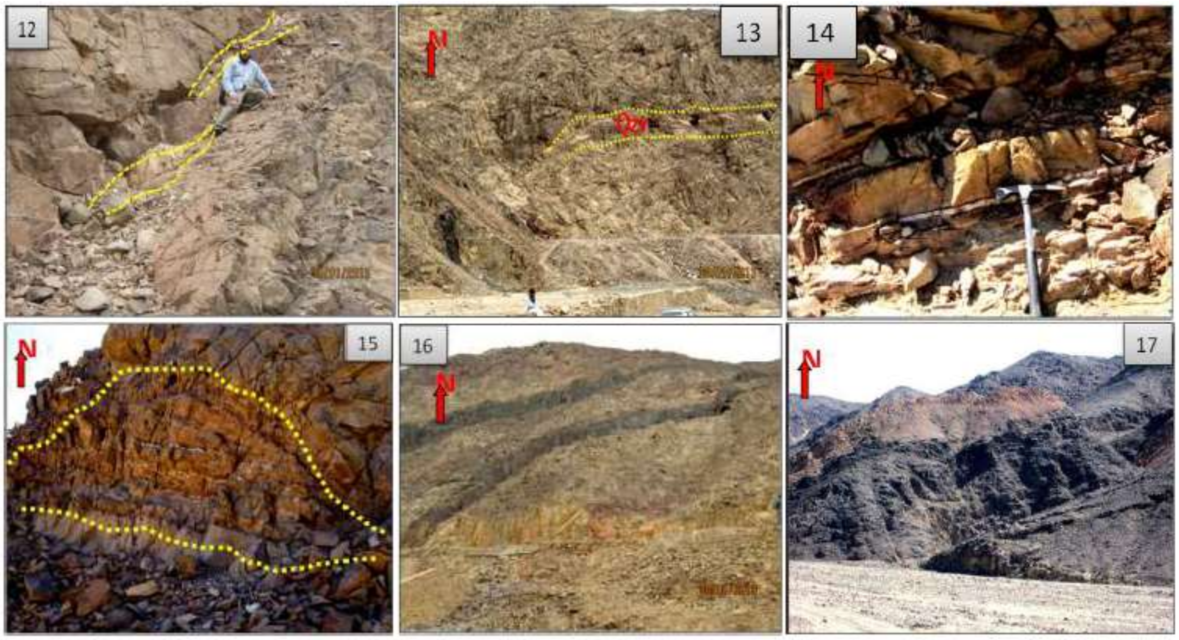
Quartz veins extend through over an area about 9 Km^2 of the tonalite and granodiorite at the contact with the gabbros. They occur as milky-white and smoky veins and veinlets, sometimes of rosy color and mainly of straight trends, rarely of curved and discontinuous streaks (Fig. 12&13). The main recognized trends of Au mineralized quartz veins are NE-SW, NEE-SWW and ENE-WSW (Fig. 14), while the barren ones have mainly NW-SE trend (Fig. 15). Sometimes, they form discontinuous lenticular bodies, often with parallel arrangement, and rarely do they occur as curved sheared, banded and brecciated mineralized zone. Field studies indiecate that, the milky quartz veins had been formed before the smoky ones, however the early milky quartz veins are interested by some intermediate and acidic dikes, while the smoky quartz veins had been formed later.

Fig.(3):General view of the highly weathered

Fig. (4):General view of gabbros of relatively

Figs:- (5):Hybrid contact zone(Hy,z) of gabbros (Gb), tonalite and granodiorite rocks (T&Gd) close to Um Rus gold mine. (6): Adite of Um Rus gold mine (adm) in tonalite and granodiorite rocks (T&Gd). (7): Xenoliths (Xe) of older country rocks associated with Tonalite and granodiorite rocks (T&Gd).

Figs:- (8): Kaolinitization of tonalite and granodiorite rocks in the alteration zone . (9): Sericitization of tonalite and granodiorite rocks in the alteration. (10): Vermculitization of tonalite and granodiorite rocks in the alteration zone. (11): Carbonatization of tonalite and granodiorite rocks in the alteration zone.



Figs:- (12): NE-SW quartz veins cutting the tonalites and granodiorite rocks nearby Um Rus gold mine. (13) NEE-SWW discontinuous quartz veins cutting the tonalites and granodiorite rocks nearby Um Rus gold mine. (14) ENE-WSW discontinuous quartz veinlets cutting the tonalites and granodiorite rocks nearby Um Rus gold mine. (15) NW-SE barren quartz veinlets cutting the tonalites and granodiorite rocks nearby Um Rus gold mine. (16) Two NE-SW parallel basic dikes cutting throughout the tonalite and granodiorite rocks. (17) NE-SW acidic dikes cutting throughout the gabbros.

Dikes:-

Large amounts of parallel to sub-parallel dikes traverse the area. They are varying from (30 cm) to (10 m) in thicknesses. They have nearly N-S, NE-SW and NW-SE trends. The majorities are vertical represented by acidic(Fig. 16), intermediate, and basic dikes (Fig. 17). Field observations indicate that the intermediate and acidic dikes are the oldest, while the basic dikes are the youngest. The intermediate dikes are mainly andesite, the acidic dikes are rhyodacite and the basic dikes are mainly basalt.

Petrography

The petrography of the exposed rocks units in the study area, whereas (60) thin sections were examined to verify the minerals composition.

1-Island arc assemblage:-

The island arc assemblage is represented by high schistose rocks of metavolcanoclastic origin, that have the composition of rhyolite crystal tuff, which comprising essentially of quartz and feldspar porphyroblastic crystals embedded in fine grained groundmass of the same composition. Quartz occurs as porphyroblastic crystals showing often wavy extinction. Sometimes it occurs as oriented aggregates of banded like shape. The feldspar crystals are represented by fine plagioclase and orthoclase crystals highly altered into sericite and clay minerals. Iron oxides are also observed of considerable content (Figs. 18&19).

2- Late to post orogenic stage:

The late to post orogenic rocks are represented by gabbros, tonalite, granodiorite, quartz veins and dikes.

2-1- Gabbros:-

Most of the study gabbros exhibit ophitic and poikilitic texture with subordinate granular texture. However, the layered gabbro may show a pronounced tendency of primary segregation of alternating feldspar and mafic bands. The investigated gabbros are represented essentially by olivine gabbro, gabbro-norite, troctolite and anorthosite.

2-1-a-Olivine gabbro:-

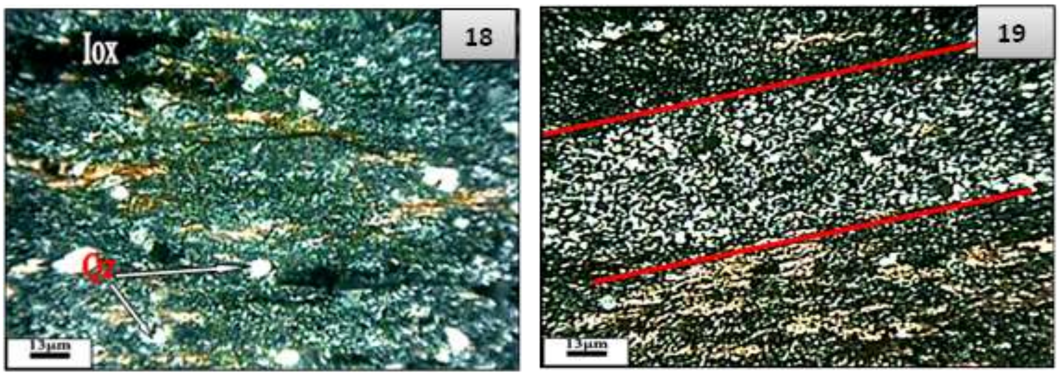
The olivine gabbro is medium to course grained rock composed essentially of plagioclase, olivine and pyroxene (Fig. 20). Sericite and iron oxides are the main secondary minerals. It exhibits mainly equigranular texture with subordinate cumulate texture and ophitic texture (Fig. 20).

Plagioclase is mainly labradorite represented by subhedral and euhedral crystals. Sometimes, it is partially altered to sericite.

Olivine is recorded with noticeable amount as subhedral and anhedral crystals showing often perfect Y-cracks in most cases. It is usually altered to iron oxides particular along cracks and prephyries. Sometime olivine fine crystals are enclosed within the plagioclase crystals (Fig. 20).

Pyroxene is mainly represented by augite and hypersthene, they enclose some plagioclase crystals to show well developed ophitic texture (Fig. 20). Both of augite and hypersthene are altered to iron oxides with variable content.

Sericite and clay minerals are the main secondary minerals, occurring as very fine aggregates due to the alteration of plagioclase scattering overall the mineral constituents. Iron oxides are the main accessories represented by brown and black grains, associating often with the mafic minerals (Fig. 20).



Figs :- (18): Photomicrograph of metavolcanoclastic rock of rhyolitic composition showing quartz (Qz), plagioclase, and iron oxides (Iox) porphyroblastic crystals(C.N.). (19) Photomicrograph of quartz banded like shape in Metavolcanoclastic (C.N.).

2-1-b-Gabbro-norite:-

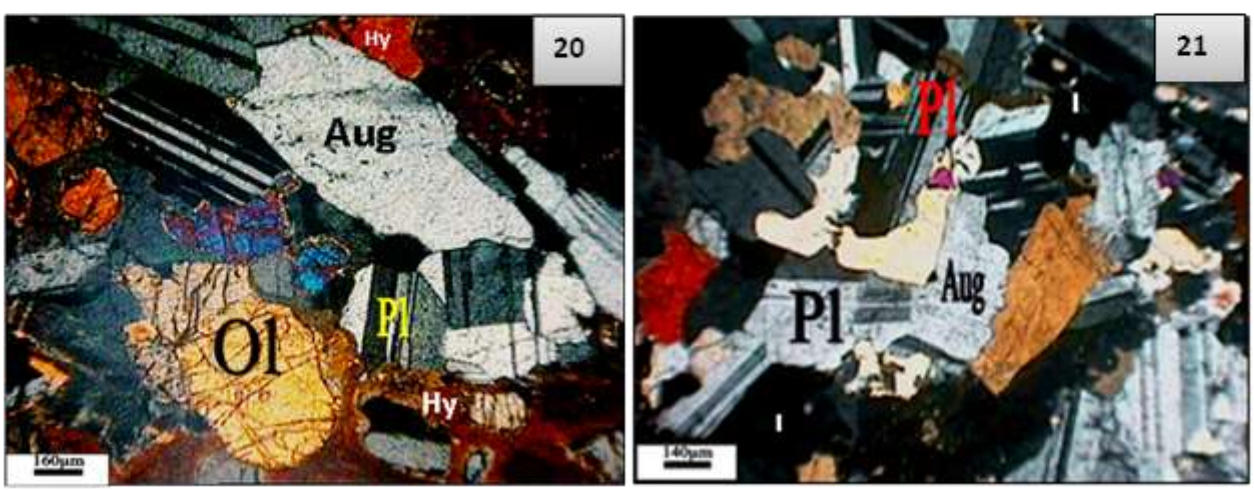
Gabbro-norite exhibits mainly the granular texture, it is composed mainly of plagioclase, augite and olivine, in addition to sericite and iron oxides as secondary minerals (Fig. 21).

Plagioclase is mainly labradorite and bytownite of albite and pericline twinnings occurring as elongated prismatic subhedral crystals. Sometime, the plagioclase crystals include some short prismatic augite crystals, as well as they are altered to sericite with partially masking of their twinnings.

Augite is represented by subhedral crystals, displaying distinctive tow set of cleavages at right angle (~90^{o}). It is partially altered to iron oxides particular along cleavages forming aschillar texture, as well as it encloses some plagioclase crystals to form ophitic texture.

Olivine is represented by anhedral cracked crystals, sometimes it is enclosed within augite and plagioclase. Olivine is slightly altered to iron oxides.

Opaque minerals and iron oxides are occasionally appeared as fine black aggregates along the cleavages, cracks, and boundaries of olivine and pyroxene minerals (Figs. 21).



Figs :-(20): Photomicrograph showing lamellar twinning_of plagioclase (Pl), olivine (Ol) characterized by Y-cracks, augite (Aug), and hypersthene (Hy) crystals with equigranular texture and subordinate ophitic texture.in olivine gabbro (C.N.). (21): Photomicrograph showing ophitic and sub-ophitic texture, plagioclase (Pl), augite (Aug), in gabbro-norite (C.N.).

2-1-c-Troctolite:-

This type of gabbro consists mainly of plagioclase, olivine, and augite as essential minerals and iron oxides as accessory minerals (Fig. 22). It often displays equigranular texture with subordinate ophitic, subophitic, and poikilitic.

Plagioclase is represented by subhedral and euhedral crystals. It is twinned to albite, albite-carlsbad and pericline laws and partially altered to sericite (Figs. 23). Sometimes, it is setted within augite to show ophitic texture and within olivine to show poikilitic texture.

Olivine is represented by less anhedral to subhedral crystals coarse grained characterized often by Y-cracks and. Sometimes, it includes some plagioclase and iron oxide as well as it is partly surrounded by augite. Also it is partly altered to iron oxides.

Pyroxene is represented by relatively minor amounts of augite. It is represented by subhedral to anhedral colorless crystals, sometimes has reddish brown and pale brown pleochroism (Fig. 22). It encloses plagioclase crystals, exhibiting subordinate ophitic and subophitic textures.

Iron oxides are represented by deep black grains scattering over the plagioclase, the olivine and the pyroxene minerals, as well as along cracks, and crystal boundaries (Fig. 22).

2-1-d- Anorthosite:-

The anorthosite is leucocratic rock. It exhibits granular texture, composed mainly of plagioclase that reaches up to (92%) of the rock composition, in addition to minor amount of augite and hornblende. The secondary minerals are chlorite, sericite, the accessory minerals are iron oxides and quartz.

Plagioclase is mainly labradorite. It occurs as medium subhedral to euhedral prismatic and tabular crystals, with clear lamellar twinning and sometimes with carlsbad-albite twinning and zonation. It is often partially altered to sericite, as well as it encloses some fine mafic minerals forming subordinate poikilitic texture (Figs. 23).

Hornblende occurs as medium subhedral crystals, with clear two sets of cleavage and sometimes with simple twinning, partially or completely altered to chlorite.

Augite is represented by minor amount of prismatic crystals partially or completely altered to chlorite (Figs. 23).

Chlorite and sericite occur as secondary minerals distributed along cleavage planes and edges of the hornblende and the plagioclase (Figs. 23). Iron oxides occur as black grains scattering over the rock mineral constituents. Quartz occurs as accessory mineral is represented by fine anhedral crystals, showing often wavy extinction (Fig. 24).

2-1-e-Altered gabbro: -

The altered gabbro is composed mainly of altered plagioclase and augite. Sericite and chlorite are the main secondary minerals. Iron oxides are the main accessory minerals.

Plagioclase is represented by labradorite and bytownite occurring as subhedral and euhedral prismatic to tabular, medium to fine crystals. It is highly altered to sericite with often masked twinning, however the less altered crystals display lamellar twinning prismatic crystals, often altered to chlorite and iron oxides.

Biotite occurs as fine flaky crystals, partially or completely altered to chlorite, and iron oxides particular within cores and their rims.

Chlorite represents the main secondary minerals occurring along cleavage planes and edges of biotite and augite.

Iron oxides are represented by black aggregates scattering over the rock constituents. Sericite aggregates are also recorded as alteration products of plagioclase (Figs. 25).

2-2-Tonalite and granodiorite:-

Both tonalite and granodiorite are associated with each other forming the main body of Um Rus pluton.

2-2-a Tonalite:-

Tonalite is medium grained rock exhibiting often granitic texture, with subordinate poikilitic texture. It is composed essentially of plagioclase, quartz, biotite and hornblende. Chlorite, sericite, and epidote occur as secondary minerals, iron oxides as accessory minerals.

Plagioclase is represented by oligoclase and occurs as euhedral and subhedral crystals showing often lamellar twinning (Fig. 26). It occasionally encloses some fine grains of mafic minerals. It is often partially or completely altered to sericite and epidote.

Quartz occurs as anhedral, subangular to subrounded cracked crystals. It shows wavy extinction in most cases (Figs. 26).

Biotite occurs as subhedral and anhedral flaky crystals. It is often altered to chlorite and epidote, as well as it is associated with iron oxides (Figs. 26).

Hornblende is represented by anhedral and subhedral crystals, showing often two set of cleavages and rarely with simple twining (Fig. 26), it is partially or completely altered to chlorite and iron oxides (Fig. 26).

Epidote occurs as secondary mineral, associating often with plagioclase, hornblende and biotite with characterized high interference color.

Chlorite is the secondary mineral occurring predominantly along cleavage planes and edges of hornblende and biotite (Fig. 27). Iron oxides are represented by black grains scattering over the main rock constituents.

2-2-b- Granodiorite:-

Granodiorite is composed essentially of plagioclase, quartz, perthite, biotite and hornblende, exhibiting often granitic texture with subordinate poikilitic texture and perthitic texture.

plagioclase is represented mainly by oligoclase. It occurs usually as subhedral and euhedral crystals, partially and completely altered to sericite(Fig. 28).

Perthite is mainly microcline perthite represented by vein and patchy types. It is fractured and slightly sericitized. Moreover it has lot of opaque minutes often iron oxides (Fig. 28).

Quartz occurs as coarse anhedral grains, often deformed and observed with wavy extinction (Fig. 28). It encloses some oligoclase and hornblende crystals to indicate that it had been crystallized after them.

Hornblende occurs as subhedral, tabular and prismatic crystals, partially altered to chlorite. It hosts some iron oxides (Fig. 28).

Biotite is represented by reddish brown and green flaky and tabular crystals. It is partially or completely altered to chlorite and host iron oxides (Fig. 28).

Chlorite occurs as secondary products after biotite and hornblende. Usually, it is associated with iron oxides (Figs. 28). However sericite is also present as secondary products of plagioclase scattering within the granodiorite rock minerals (Fig. 28).

3-Wall rock alteration zones:-

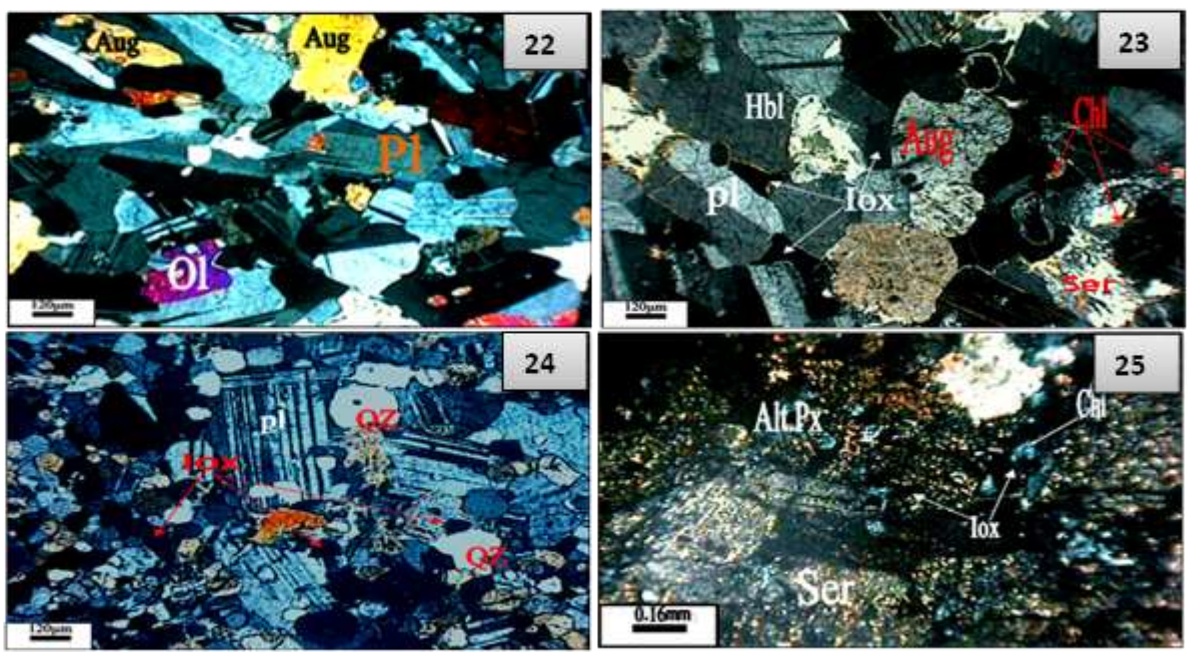
The wall rock alteration zones are represented by kaolinitization, sericitization, vermiculitization and carbonatiztion. They occur as by-products due to alteration of tonalite and granodiorite particular along the quartz veins. Microscopic studies and XRD analyses reveal that the main altered rocks are mainly subjected to kaolinitization, sericitization, vermiculitization and carbonatiztion processes.

3-1- Kaolinitization:-

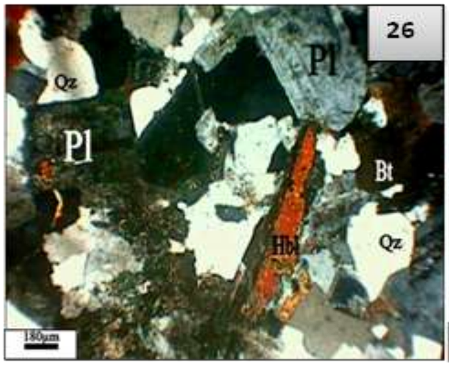
Two types of argillic alteration can be distinguished of the development of one or more clay minerals including alunite, kaolinite, illite and /or montmorillonite (Boyle, 1979, Bonham, 1988, Barger and Herely, 1989, Amer et, al, 2012) that occurred due to leaching of bases alkalis and calcium from all aluminous phases such as feldspars and micas. XRD analysis depicts that the kaolinitization processes had been done due to alteration of feldspar and mica, producing sericite, kaolinite and albite minerals (Figs. 29&31).

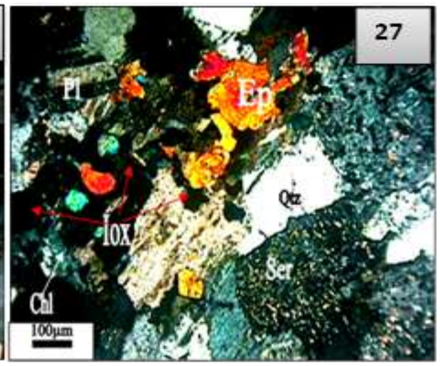
3-2-Sericitization:-

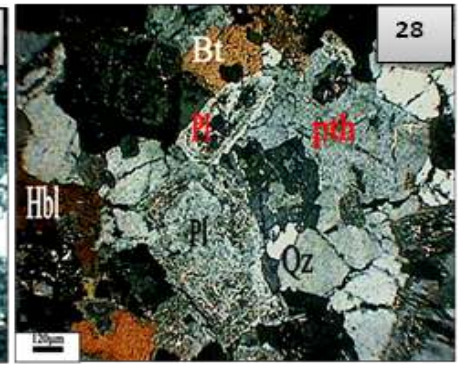
Sericitization involves the development of sericite as a result of the hydration of feldspar or from the rearrangement of K, Al and SiO_2 within the intensively altered wall rock (Boyle, 1979). The dominant sericite (fine muscovite) is often associated with feldspar, quartz and pyrite as recorded by X-ray chart to indicate that the feldspars and micas may be transformed to sericite, with secondary quartz as by-product or secondary mineral (Fig. 30&32).



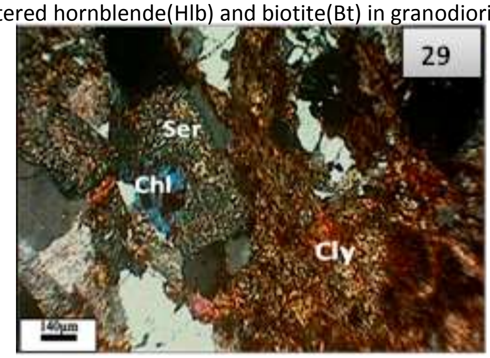
Figs:- (22): Photomicrograph showing plagioclase crystals (Pl) twinned albite, albite-carlsbad and pericline laws, olivine (Ol), and augite(aug) in troctolite (C.N.). (23): Photomicrograph showing plagioclase (Pl) partly altered to sericite (Ser), minore amount of hornblende (Hbl) partaly altered to chlorite (Chl) , and augite(Aug) in anorthosite (C.N.). (24): Photomicrograph showing plagioclase (Pl), quartz (Qz) as accessory mineral and iron oxides scattered the rock constituents in anorthosite (C.N.). (25): Photomicrograph showing augite (Alt.Px) altered to chlorite (Chl) and iron oxides (Iox) and plagioclase (Alt.Pl) highly altered to sericite (Ser) in the altered gabbro (C.N.).

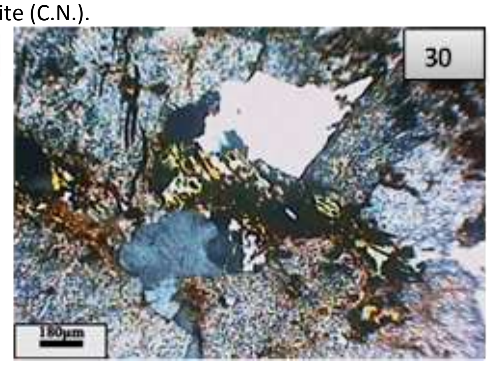




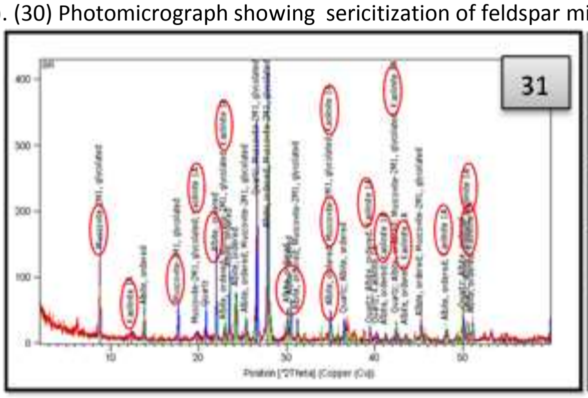


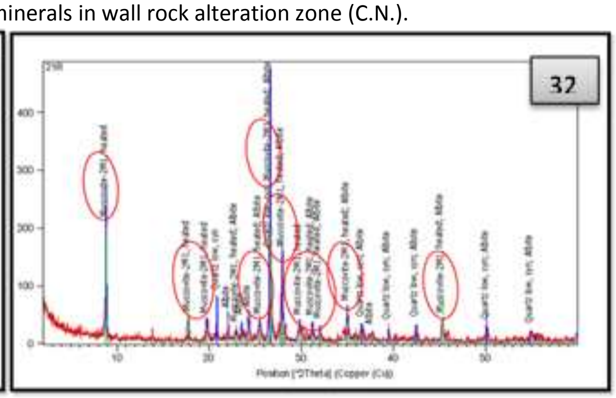
Figs:- (26): Photomicrograph showing plagioclase partly altered to sericite (Pl), deformed quartz with wavy extinction (Qz), hornblende(Hbl) shows simple twinning, and altered and biotite(Bt) in tonalite (C.N.).(27): Photomicrograph showing epidote (Ep) after hornblende and plagioclase, some grains of iron oxides (Iox) and chlorite(Chl) in tonalite (C.N.). (28): Photomicrograph showing plagioclase crystal(Pl) altered to sericite with secondary zonation, microcline perthite(pth) are mainly vein type, deformed quartz (Qz), altered hornblende(Hlb) and biotite(Bt) in granodiorite (C.N.).





Figs:- (29) Photomicrograph showing clay (Cly), sericite (Ser) and chlorite of kaolinitization processes in wall rock alteration zone (C.N.). (30) Photomicrograph showing sericitization of feldspar minerals in wall rock alteration zone (C.N.).





Figs:- (31): X-ray diffraction chart of kaolinitization processes in the wall alteration zone . (32): X-ray diffraction chart of sericitization process (fine muscovite) in wall rock alteration zone.

3-3-Vermiculitization:-

Microscope studies indicate that vermiculite is highly connected with biotite and chlorites hydrothermal alteration often with a change in their Fe: Mg ratio. The development of secondary chlorite (Fig. 33), may result from the alteration of mafic minerals already present in the country rocks. XRD shows that the vermiculitization is usually associated with quartz (Fig. 35).

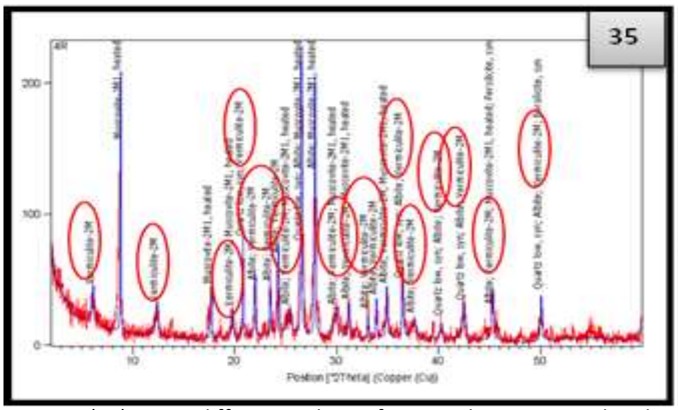
3-4-Carbonatiztion:-

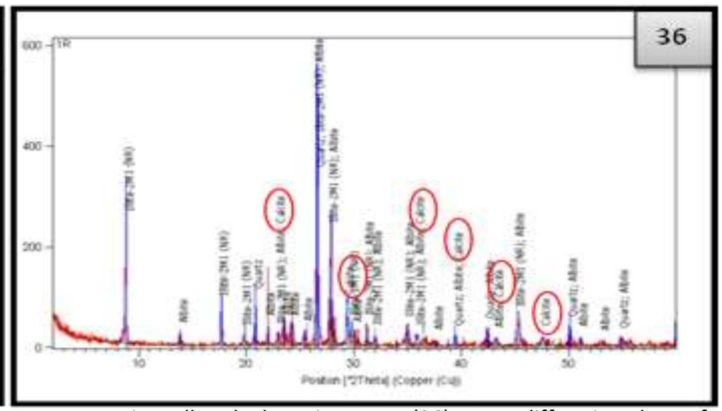
Carbonatization involves the introduced carbonate minerals due to alteration. Microscopic investigation despite that the carbonate minerals occur mainly as irregular aggregates mainly represented by calcite (Fig. 34). XRD analysis shows that the carbonatization is represented by calcite associated mainly with albite and quartz (Fig. 36).

4-Quartz veins:-

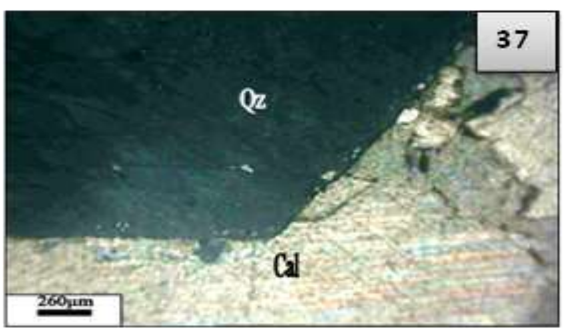
The quartz veins are composed essentially of quartz grains associated with biotite and hornblende, as well as sericite, chlorite, iron oxides, and pyrite. Quartz occurs as brecciated interlocked crystals, often with sutured edges and wavy extinction. It is usually cemented by chalcedony and associated with some calcite crystals (Fig. 37). Sericite and chlorite occur as fine aggregation associating with opaques minerals and iron oxides. Biotite and hornblende are less common, usually altered to iron oxides (Fig. 38). Opaque minerals are represented by coarse aggregates of pyrite.

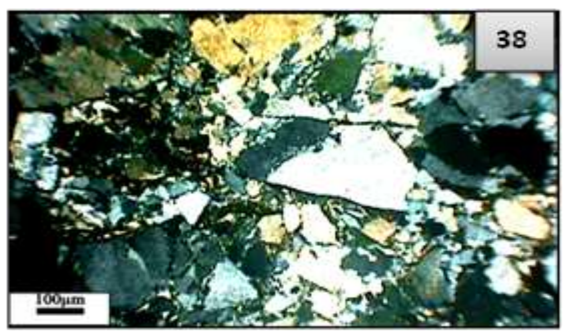
Figs:- (33): Photomicrograph showing vermiculitization of mafic minerals (biotite) in wall rock alteration zone (C.N.). (34): Photomicrograph showing calcite (Cal) associated with quartz (Qz) in wall roc alteration zone (C.N.).



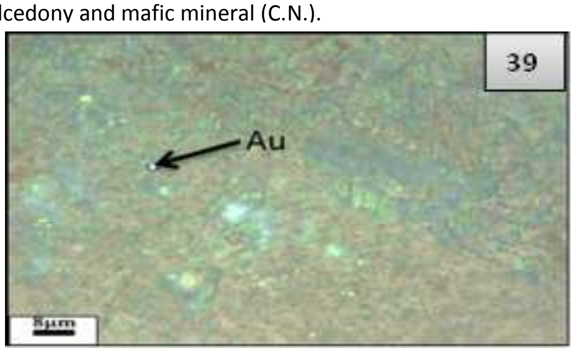


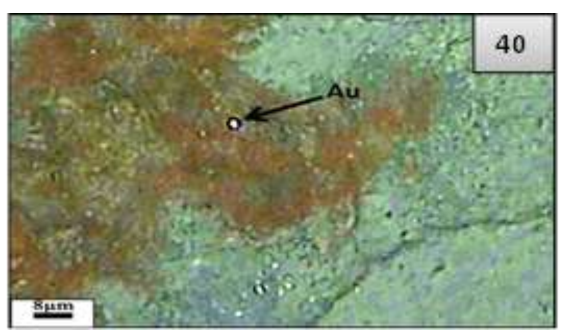
Figs:- (35): X-ray diffraction chart of vermiculite associated with some quartz in wall rock alteration zone. (36): X-ray diffraction chart of calcite associated with quartz and albite in wall roc alteration zone.





Figs:- (37): Photomicrograph of quartz(Qz) associated with calcite(Cal). (38): Photomicrograph of brecciated quartz vein cemented by chalcedony and mafic mineral (C.N.).





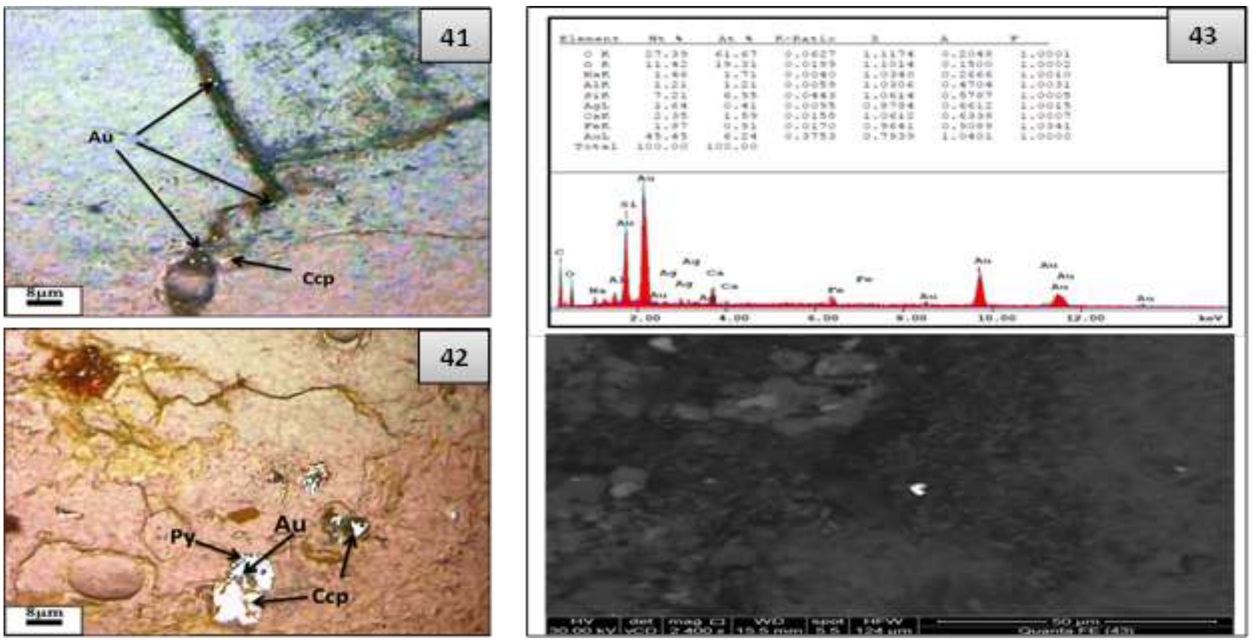
Figs:- (39): Photomicrograph showing Au grains associated within quartz veins. (40): Photomicrograph showing Au grains associated within altered zone of tonalite-granodiorite.

Ore Mineralogy

For the auriferous quartz veins and the altered rocks of Um Rus area, Au has been examined using reflected light for the polished sections, to show ore paragenesis. Some ore minerals have been subjected also to EDX analysis in Central Laboratory of the Egyptian Mineral Resources Authority (EMRA) using scanning electronic microscope. The studies reveal that the associated minerals with gold are the base metals sulfides, represented by pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, pyrrhotite, bornit, covellite, and marcasite with addition to magnetite, hematite and goethite. The following are full descriptions of these minerals.

1-Gold:-

Gold occurs often as small bright and golden yellow skeletal, sheaf like and irregular grains up to (0.9µm) particularly in the quartz veins and altered tonalite and granodiorite (Fig. 39&40). Gold is also present as fine minute specks scattered within some sulfides such as pyrite and chalcopyrite (Figs. 41) and hydroxides such as goethite. In quartz veins particular the smoky quartz, gold is obtained along the microfractures (Fig. 42), however in the alteration zones, it is noticed that the mineral is relatively more abundant in the highly ferruginted rocks. EDX analysis reveals that some minor contents of elements other than Au have often reported, but these often present in impurities represented by C (27.39%), O (11.42%), and Si (7%), in addition to Na, Al, Ca, Fe and Ag (7.5%). However, the content of Au reaches to (45.45%), (Fig.43).



Figs:- (41): Photomicrograph showing Au grains associated within pyrite (Py) and chalcopyrite (Ccp), in quartz veins. (42): Photomicrograph showing Au grains associated with chalcopyrite (Ccp) within microfractures, in the smoky quartz veins. (43): EDX and BSE image of Au.

2-Sulfides:-

2-1-Pyrite:-

Pyrite is the most dominant sulfide phase occurring with gold. It represents about (15%) of the total opaque minerals. It seems to be one of the early crystallize mineral, however, it is replaced by number of the other sulfides. The mineral has a yellowish white color. It is observed as fine to coarse euhedral crystals size from (0.1mm) to (4mm) showing often pentagonal, pyritohedrons and cubic forms (Fig. 44). Alteration of pyrite to goethite is commonly observed (Fig. 45). According to optical characteristics two types are distinguished, the normal pyrite and the As-rich pyrite which represents the most dominant and wide spread pyrite phase. Zoning is commonly observed in this phase. It is clear that the cataclastic cracks represent the path ways for the percolating hydrothermal solutions, and accelerated their effects. However, replacement of pyrite by goethite may strongly suggest hydrothermal effects (Ramdohr, 1980). Some gold grains are observed within the pyrite crystals (Figs. 44&47), however about (4 %) of the extracted gold in Um Rus gold mine was probably produced from pyrite (Abu Zeid, 1987). Under supergene conditions, pyrite is readily oxidized to goethite, and loses about (40 %) of its gold content (Osman, 1989). The pyrite crystals show varying degrees of oxidation. Ore microscopic studies revealed that oxidation may be partial, complete or multiple. Partially oxidized process is characterized by conversion of the pyrite rims into goethite as successive rhythms, separated by remarkable voids produced after replacement (Fig. 46). It is also noticed that reflectivity of the oxidized bands is of heterogeneous due to variation of oxidation. Moreover, the absent of siderite as an intermediate product may suggest high oxidation potential during the process (Garrels and Christ, 1965). The rhythmic texture of goethite indicates successive stages of conversion of pyrite to goethite, mainly controlled by the prevailing physicochemical conditions. The oxidation of pyrite in the shallower parts of the veins are incomplete, while the presented parts away from the ground and meteoric water are mostly unaffected. EDX analysis shows that the pure crystals have composition of Fe up to (43.03%) and S up to (51.21%), (Fig. 48).

2-2-Arsenopyrite:-

Arsenopyrite is the second abundant ore mineral of Um Rus area. It occurs as cloudy, idiomorphic prismatic and subhedral pseudo-bipyramid crystal form (Fig. 51). Other crystals have an elongated skeletal form (Fig. 49). They may attain large dimensions up (6 mm) length, and (2.5 mm) width. The mineral is of brightly reflecting, faint cleavage and lamellar twinnings. Arsenopyrite shows reflection pleochroism particular along its boundaries. Replacement is so frequent for arsenopyrite, the common replaced mineral is pyrite (Fig. 50). It is frequently observed intergrown with pyrite, and less with gold inclusions. Arsenopyrite is often characterized and identified by fracturing and cracks as well as replacement zonal texture. The fracturing and cracks may attribute to later deformational events. Moreover, arsenopyrite is characterized by oscillatory and growth texture reflecting the variation of As content, whereas the As content probably increases from the core to the rim of the zoned grains. Arsenopyrite is partially or completely altered to sphalerite (Fig. 54). EDX analysis despites that the arsenopyrite has of O up to (24%) Fe is up to (19.90%), C up to (19.03%), Ca up to (8.97) and (7,25%) for Al, Si, and K (Fig. 53).

2-3-Chalcopyrite:-

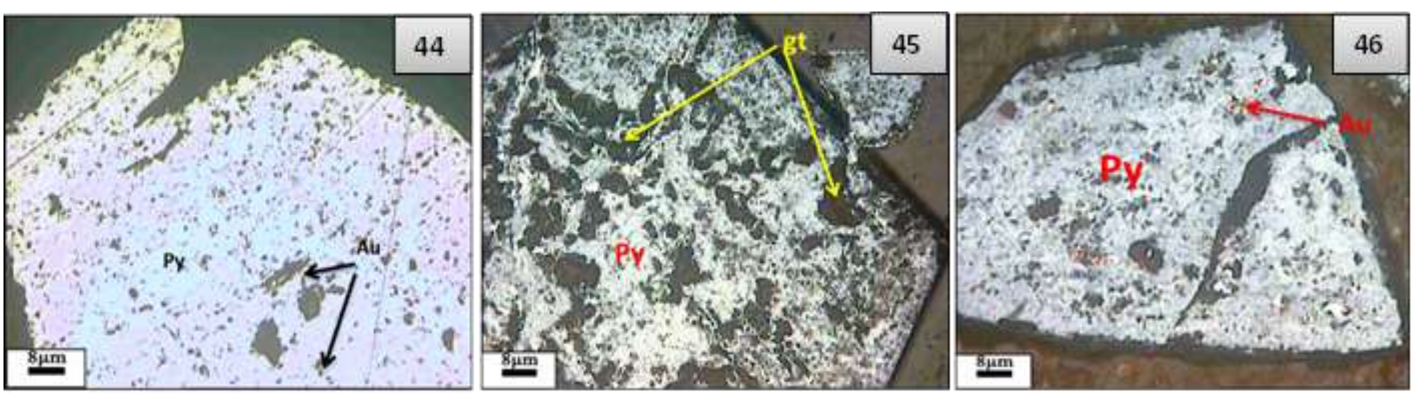
Chalcopyrite occurs either as disseminated irregular grains or as fine inclusions hosted within the coarse pyrite grains and other sulfide minerals (Figs. 51). It occurs with brass yellow color up to (0.6 mm) length and (0.3) mm width (Fig. 52). The mineral shows weak bireflectance without any internal reflections. Generally, the chalcopyrite is uncommon mineral in Um Rus gold bearing quartz veins as well as alteration zones.

2-4-Sphalerite:-

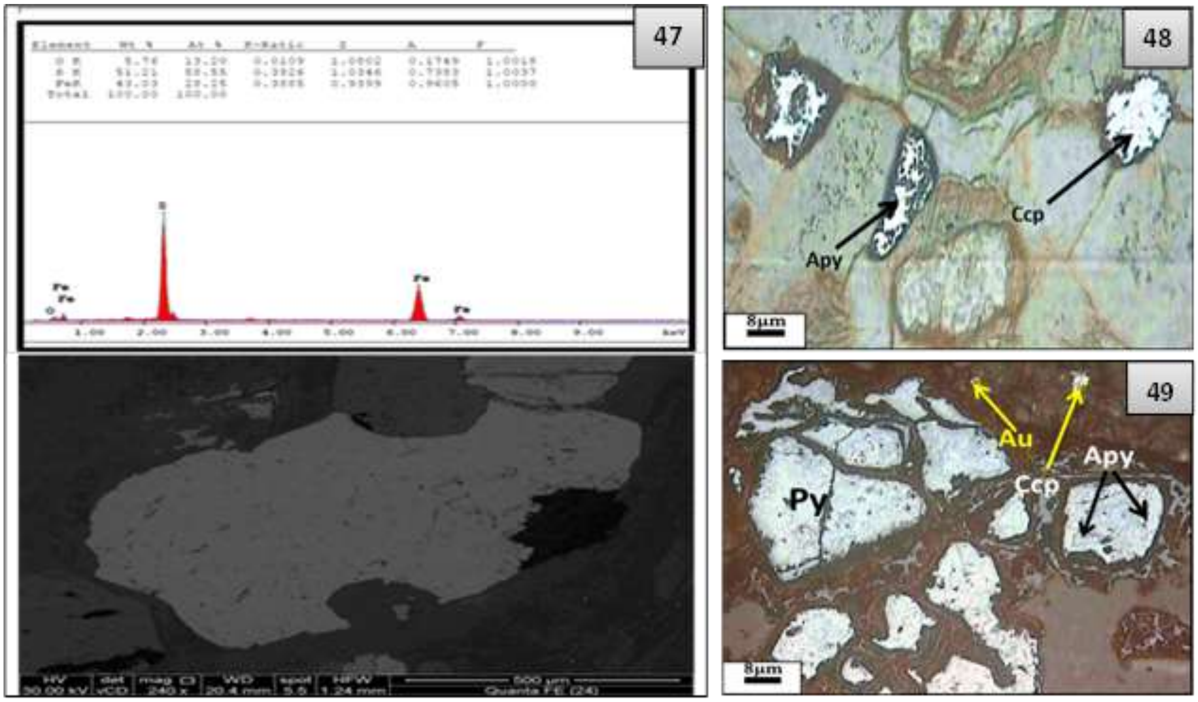
Sphalerite has dark gray color, with delicate faint blue, as well as brownish tint color and distinct internal reflection (Fig. 53), it occurs as isotropic crystal without any bireflectance, and lowest reflectivity among the common observed sulfide phases. Sphalerite occurs in different forms, either as coarse aggregates or as small isometric crystals as well as fine inclusions within the goethite. It may replace pyrite forming coarse grained crystals exhibiting distinct lamellar twining (Fig. 54). It is rarely replaced by the chalcopyrite and marcasite. It is observed that the investigated gold bearing quartz veins have an appreciable content of sphalerite rather than the alteration zones.

2-5-Pyrrhotite:-

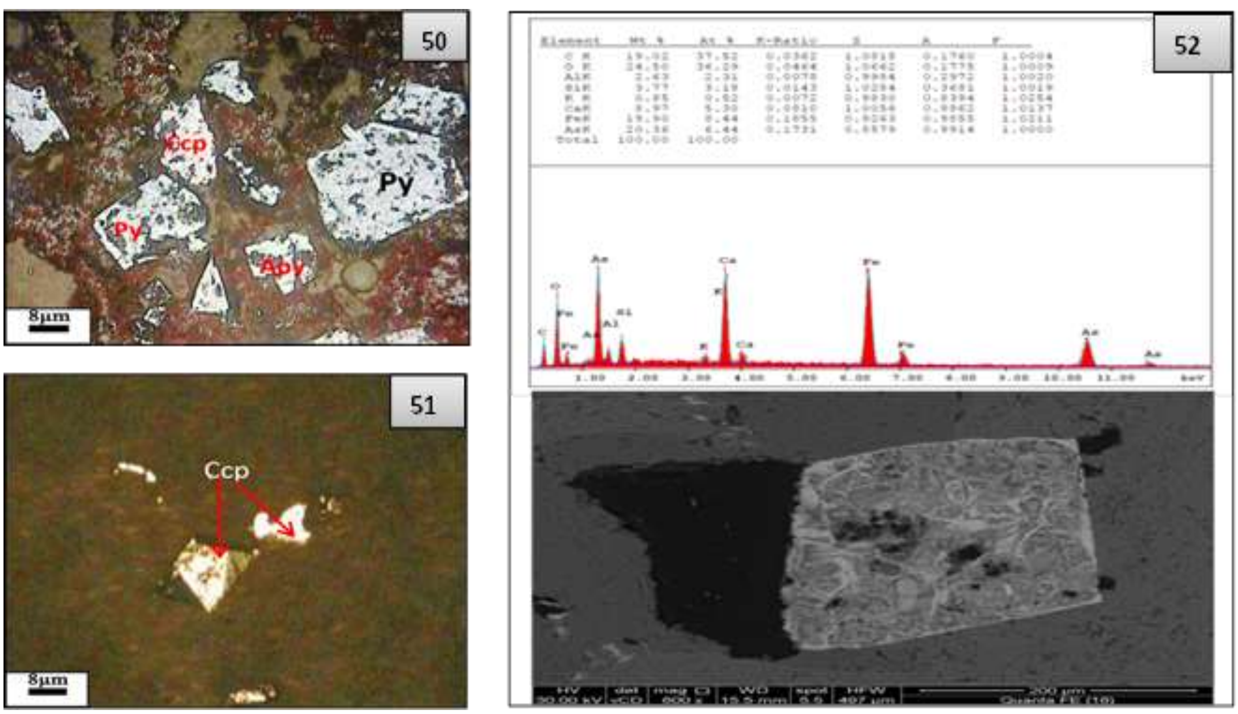
Pyrrhotite shows light brownish white color in the polished surfaces, with fairly high distinct bireflectance, particular along the grain boundaries (Fig. 55). Pyrrhotite crystals are present as tabular form usually present within the marcasite, bornite and goethite. This may indicate that the mineral was formed at the late stage of mineralization after pyrite and arsenopyrite.



Figs:- (44): Photomicrograph showing coarse cube of pyrite (Py) with includes some gold (Au) grains, in quartz veins. (45): Photomicrograph showing pyrite cube crystal (Py) slightly replaced by goethite (gt). (46): Photomicrograph showing deformation of As - pyrite (Py) and speck of gold (Au), associated with altered tonalite-granodiorite.



Figs:- (47): EDX analysis and BSE Showing pyrite crystal. (48): Photomicrograph showing irregular chalcopyrite crystal (Ccp) with brass yellow color and elongated arsenopyrite (Apy). (49): Photomicrograph shows cube of pyrite (Py) altered to goethite (gt) with gold (Au) inclusion, irregular grain of chalcopyrite (Ccp) and replaced zonal arsenopyrite (Apy).



Figs:- (50): Photomicrograph showing goethite (gt) pseudomorphs after of pyrite (Py), arsenopyrite (Apy) and irregular chalcopyrite (Ccp) crystal forms. (51): Photomicrograph showing chalcopyrite (Ccp) with brass yellow color. (52): EDX analysis and BSE Showing Arsenopyrite crystal.

2-6-Marcasite:-

Marcasite has pinkish tint color. It occurs as tabular and bipyramid small crystals. Marcasite exhibits strong bireflectance and violet gray anisotropism, without any internal reflections (Fig. 55). Lamellar twinning is the common and characteristic feature. The mineral is usually present along the fractures of the quartz veins and the groundmass of the altered rock zones. Small size crystals are commonly mistaken for pyrite (Fig. 56). Marcasite is usually intergrowth with pyrite and more readily oxidized in the oxidation zone.

2-7-Bornite:-

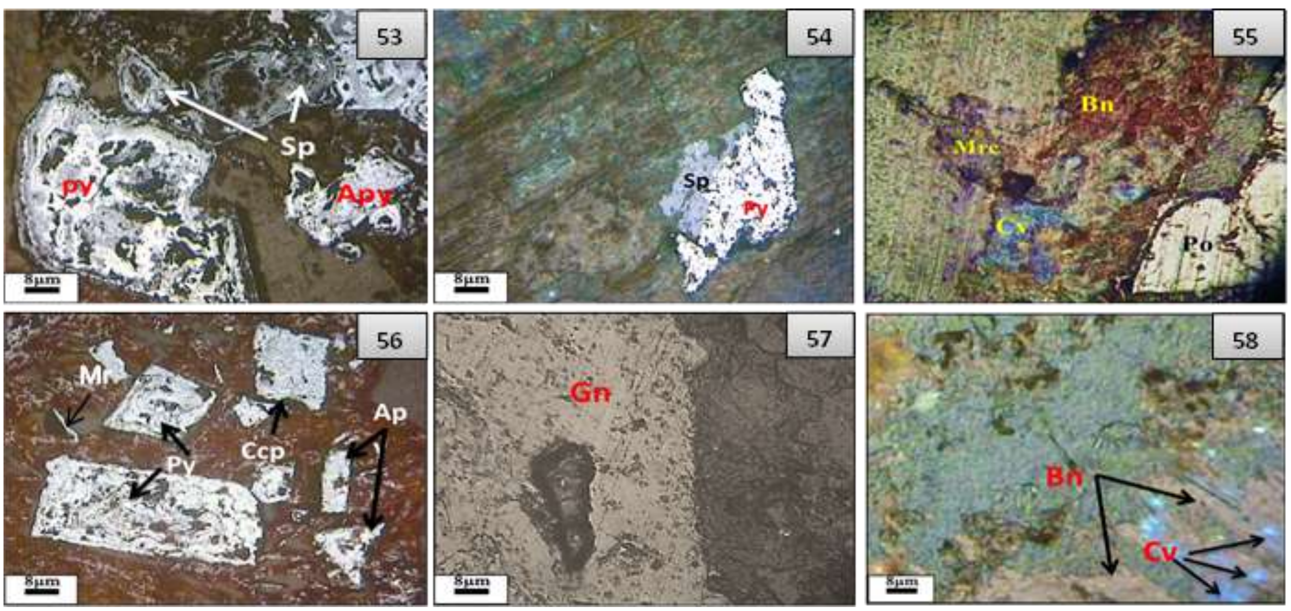
Bornite occurs as small irregular grains associated with covellite (Fig. 55). The mineral usually has light pinkish-brown color (Fig. 58). It is more common in the oxidation zone and rarely in the lower levels of the gold bearing quartz veins.

2-8-Galena:-

Galena occurs as anhedral and subhedral, pinkish tint color crystals with perfect triangular cleavage (Fig. 57). Galena sometimes replaces the pyrite and arsenopyrite. It also occurs as fine aggregates, however it increases in the size from the center of the ore body towards the outer zone of massive sulfide mineralization, then decreases again in the disseminated sulfides zone.

2-9-Covellite:-

Covellite occurs as aggregates with indigo-blue color. The mineral grains are usually small in size, showing sometimes one set of cleavage. Bireflectance is extremely high varying from light blue to deep blue and yet violet. The mineral is anisotropic without any internal reflections. Covellite is usually present as a secondary mineral in the oxidation zone and as alteration product of copper bearing chalcopyrite and bornite (Figs. 55&58), particularly in the recorded deeper levels of the gold mine. In this respect covellite forms an oriented intergrowth with bornite and bornite probably replaced by both mineral phases.



Figs:- (53) Photomicrograph showing arsenopyrite (Apy) completely altered to sphalerite (Sp) and pyrite (Py) to goethite. (54) Photomicrograph showing pyrite (Py) slightly replaced by sphalerite (Sp). (55) Photomicrograph showing covellite (Cv), bornite (Bn), pyrrhotite (Po) and marcasite (Mrc). (56) Photomicrograph showing pyrite (Py) with oscillation, arsenopyrite (Apy), chalcopyrite (Ccp) and marcasite (Mrc). (57) Photomicrograph showing triangle pits of galena (Gn) with characteristic triangle cleavage (ppl). (58) Photomicrograph showing covellite aggregates with indigo-blue color, and lamellar of bornite (Bn).

3- Oxides and hydroxides:-

3-1-Magnetite:-

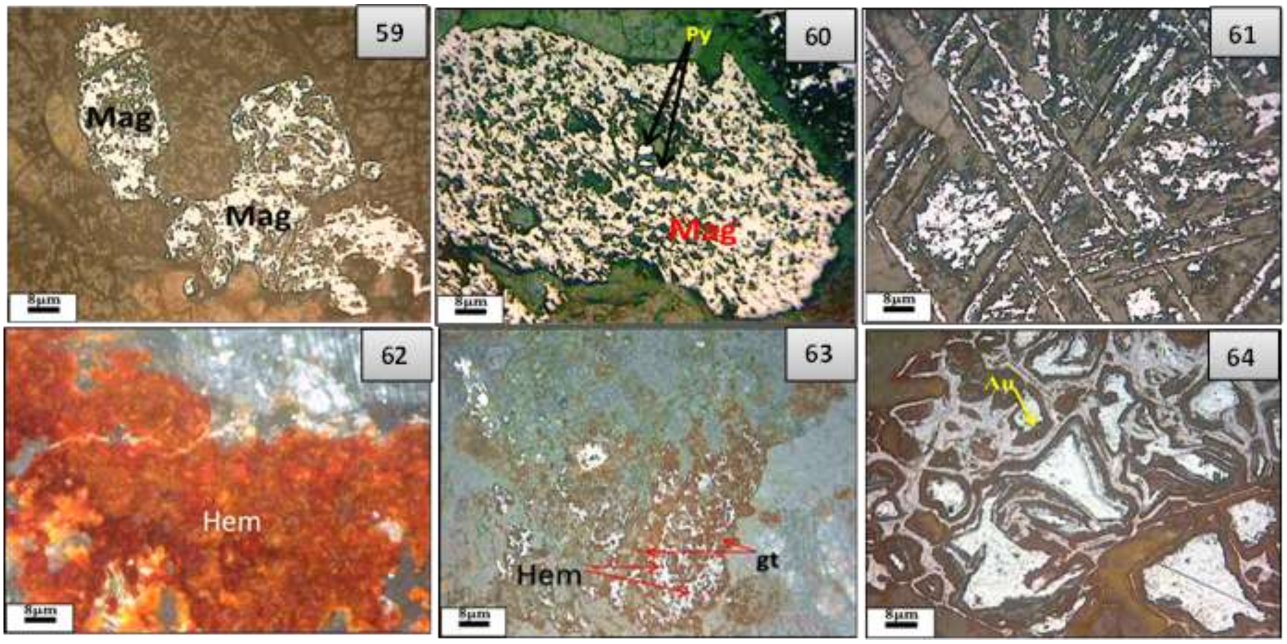
Magnetite represents about (~ 0.5%)of the whole rock volume. It occurs as medium and fine subhedral and euhedral gray cubes, sometimes with brownish tint color (Fig. 59). It encloses some pyrite grains (Fig. 60). Magnetite irregular patches and fine aggregates are also recorded scattering within the rock constituents. Regular martitization is obviously noticed especially at its peripheries. In this regular martitization, the octahedral planes are reacted producing triangular network lamellae of hematite (Fig. 61). It is important to mention that, this texture is regular as that produced by exsolution in which the hematite lamellae have uniform width.

3-2-Hematite:-

Hematite represents about (1%) of whole rocks volume. It occurs as grayish white, medium to fine aggregates with reddish brown in the internal reflection and unclear lamellar twinings (Fig 62). It commonly occurs as alteration product of magnetite (martitization) (Figs. 61). In the ex-solution intergrowths of the hematite lamellae are evenly distributed through the magnetite in blades of uniform size and patches along fractures. Hematite is slightly altered to goethite and/or iron rich oxy-hydroxides with clear colloform texture (Fig. 63).

3-3-Goethite:-

Goethite represents about (1%) to (2%) of the whole rock mineral constituents, of the upper levels of the gold mine. Goethite occurs mainly as coarse to fine, anhedral pseudomorphs crystals often after pyrite. The mineral has color varying from dull gray to bright gray and with a bluish tint. Goethite shows weak bireflectance and distinct anisotropism with brownish yellow or reddish brown internal reflections. The goethite pseudomorphs may attribute that it still retains the characteristic forms of pyrite. It sometimes shows colloform texture. It is also observed as irregular aggregates or patches after hematite or magnetite. Thin intersected veinlets of goethite sometimes occur in gangue minerals including some gold (Fig. 64).



Figs:- (59): Photomicrograph showing magnetite (Mag) with brownish gray tabular and octahedron shape. (60): Photomicrograph showing magnetite (Mag) crystal with brownish gray color enclosing some grains of pyrite (Py). (61): Photomicrograph showing martitization of magnetite as network lamellar of hematite. (62) Photomicrograph showing hematite (Hem) represented by gray white (plane polarized) and light and deep red in cross nickole. (63) Photomicrograph showing hematite (Hem) partially altered to goethite (gt). (64): Photomicrograph showing goethite(gt) pseudomorphs after pyrite (Py), associated with grains of gold.

4-Paragenesis sequence:-

Mineralogical studies reveal that the most of gold mineralization is rather related to the hydrothermal processes. Gold is observed associated with sulfides such as pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, bornite, marcasite and covellite, in addition to goethite and hematite, however both pyrite and arsenopyrite represent the most common minerals for gold mineralization. On the other hand, gold is nearly absent with magnetite occurrence. The investigation demonstrated three different stages of mineralization. These are pyrite and magnetite stage, followed by pyrite and arsenopyrite stage, and marcasite, hematite and goethite stage. The first stage of pyrite and magnetite is often is barren of any gold inclusions. In this stage magnetite occurs as isolated skeletal, euhedral and subhedral crystal, associated with coarse pyrite cubes up to (50µm). The second stage of pyrite-arsenopyrite represents the most common one of gold mineralization. This stage is often associated with other sulfide such as pyrrhotite, chalcopyrite, sphalerite, galena and bornite, most often due to alteration of pyrite. On the other hand, pyrite and arsenopyrite are defined mainly by subhedral and euhedral crystals, characterized by some concentric zones, defined by presence of gold inclusions. The third stage of marcasite and covellite is often associated with hematite and goethite. In this stage, gold is less common as compared with the second stage. Most often both hematite and goethite are due to alteration of pyrite and arsenopyrite at the later stage of hydrothermal alteration processes. The following figure comprises the main minerals associated with gold mineralization of the different three stages (Fig. 65).

Conclusion

Um Rus area represents one of the most common gold mineralized areas in the Central Eastern Desert of Egypt. The area comprises different rock units related to island arc assemblage and late to post orogenic stage, the island arc assemblage is mainly represented by highly schistose rhyolite crystal tuff, while the post to late orogenic stage comprises different types of gabbros (olivine gabbro, gabbro-norite, troctolite and anorthosite), tonalite and granodiorite that have been traversed often by some quartz vines and dikes.

Geologic studies and microscopic investigation reveal that, the gold and associated ore metals occur essentially with in the quartz veins and Wall rock alteration zone due to the interaction of the hydrothermal solutions accompanied often with the intrusion of the tonalite and granodiorite in to the gabbros. Two types of quartz veins have been distinguished, the milky and the smoky, whereas, the smoky quartz veins are considered as the gold mineralized varieties. On the other, the alteration processes are subjected to kaolinitization, sericitization, vermculitization and carbonatization. However the kaolinitization process is obtained often as by-products of feldspar and micas alteration, producing sericite, kaolinite and albite. Moreover, the vermculitization is highly connected with biotite and chlorite alteration. The carbonatization is represented mainly by calcite, often associated with albite and quartz.

Ore microscope studies of auriferous quartz veins and altered rocks may reveal that, the associated ore mineral of gold are the base metal sulfides represented by pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, pyrrhotite, bornit, covellite, and marcasite as well as hematite and goethite. Gold occurs often as small bright and golden yellow skeletal, sheaf like and irregular grains up to (0.9µm).

Paragenetic sequences of gold mineralization and associated ore metals suggest three stages. These are pyrite and magnetite stage, followed by pyrite and arsenopyrite stage, and marcasite, hematite and goethite stage. The first stage of pyrite and magnetite is often is barren of any gold mineralization, however, the second pyrite-arsenopyrite represents the most common gold mineralization stage. Occasionally, this stage is also associated with pyrrhotite, chalcopyrite, sphalerite, galena and bornite. The third stage of marcasite and covellite is often associated with hematite and goethite. In this stage, gold is less common as compared with the second stage.

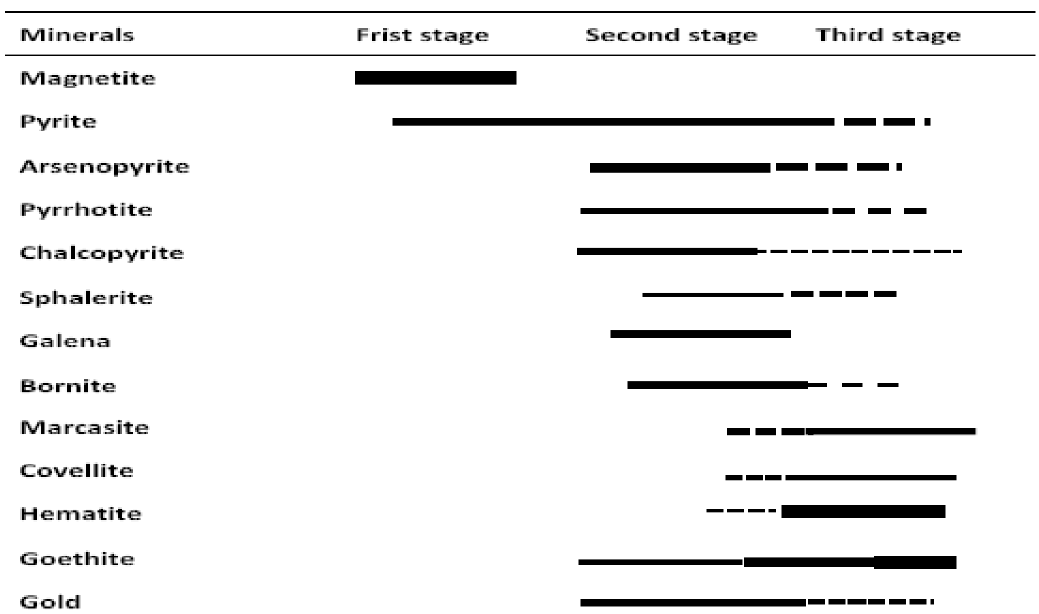


Fig. (65). Generalized paragenetic sequence of the constituents in mineralized veins and altered rocks at Um Rus area.

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7/3/2016