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Petrological and mineralogical characterization of Wadi Ghadir pegmatite, southern Eastern Desert, Egypt.

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ABSTRACT

Wadi Ghadir pegmatite bodies are represented by two bodies (large and small), which crossed by latitude 24°48'28.83"N and longitude 34°52'38.43"E, and latitude 24°48'25.75"N and longitude 34°52'46.65"E respectively. They are hosted by monzogranites. They consist of a) wall zone in the form of thin and discontinuous, b) the intermediate zone is mainly composed of K-feldspars. It shows sharp contact with wall zone and gradational contact with core zone and c) quartz core which encloses isolated flakes of muscovite. The separated heavy minerals are magnetite, garnet, zircon, rutile, monazite, uranothorite and gold element (i.e. NYF-type). The presence of garnets could be attributed either to the assimilation from country rocks or to crystallization from volatile-rich magma. Gold is restricted to the associated quartz-veins; this may refer to relation of gold to the monzogranites. Fluid inclusions are mainly represented by primary two-phases and two generations secondary inclusions. The early fluid generation is higher in temperature and salinity relative to the late one. The calculated conditions of trapping at temperature 360 ^{o}C, and pressure up to 2585 bars for the early generation, and 170 ^{o}C, 139^{o}C for the late. The trapping conditions for immiscible fluids that of H_2O - and CO_2-rich inclusions are temperatures range (170 – 400 °C) and pressures (900-2000 bars). As a result of investigation of chemical composition for K-feldspar samples and performed physical parameters tests, the studied pegmatites fit well of wall rather than floor ceramic tiles. Wadi Ghadir NYF-pegmatites are interpreted as deriving from mantle-sourced anorogenic granitic magmas with peralkaline singnature.

1. Introduction

The pegmatite term means any holocrystalline, very coarse-grained rocks of bright color, which is composed of intergrowth of quartz and K-feldspars with or without mica and tend to be enriched in normally rare elements e.g. Li, Be, Ta, Nb, Rare-Earth Elements (REE), U and Th (Clark & Steigeler, 2000).Cameron et al. (1949) described three lithologic and structural units found in many pegmatites, which are: 1) zones or a successive shell, complete or incomplete, reflect to varying degrees the shape structure of the pegmatite body, 2) fractures filling, that fill fractures in previously consolidated pegmatite, 3) replacement bodies that are formed primarily by replacement of pre-existing pegmatite. These zones have been divided in the following manner from the margin to the center: a) border zone, b) wall zone, c) intermediate zone and d) core.

Satterly (1957) divided the pegmatites into simple and complex; however, the simple bodies are subdivided into unzoned and zoned. Ginsburg (1984) established a scheme of four formations of pegmatites based on mineralogical or textural features and related to depth of emplacement, which are: abyssal, muscovite, rare-element, and miarolitic. The pegmatites can be classified according to their Na_2O and K_2O concentration ratios into primitive (alkali-poor), intermediate, and evolved (alkali-rich) (Jolliff et al., 1992). Černy (1991) classified pegmatite into four classes, which are: a) abyssal, which was formed from high to low pressure, b) muscovite, which formed at high pressure, lower temperature, c) rare-Element, which was formed at low temperature and pressure, and d) miarolitic or shallow level pegmatite. According to their composition Rare-Element Class is subdivided into LCT and NYF types; LCT mean rich in Li, Cs, and Ta and NYF mean rich in Nb, Y, and F. Wise (1999) related the pegmatites to either post-tectonic to anorogenic plutons formed in continental or oceanic rift zones. Martin and De Vito (2005) proposed that NYF pegmatites are formed in extensional or anorogenic, whereas LCT pegmatites are generated in compressional or orogenic tectonic settings.

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Mixed NYF and LCT are formed as a result of contamination, either at the magmatic or post-magmatic stage.

Pegmatites are widely distributed in the northern part in the Eastern Desert of Egypt and present throughout different types of country rocks (Fawzy et al., 2020). Most of the pegmatite bodies in Eastern Desert are usually associated with granitoid rocks (Fig.1a). On the other hand, a few pegmatite bodies are incorporated with mafic-ultramafic rocks. Furthermore, barren pegmatites are widely scattered and distributed, as mono-veins or dykes in various country rocks at various areas all over the Eastern Desert, whereas the zoned mineralized pegmatites bodies are rare. Pegmatites may be derived by differentiation of granitic system from a residual fluid. Pegmatites are varied in length, width, and direction. They are penetrated and/or invaded migmatite-gneiss, gneiss, granodiorite, tonalite, trondhjemite and alkali granites. Four pegmatites field can be recognized in the Egyptian Eastern Desert (Greenberg, 1981; Rashwan, 1991; Khaleal et al., 2022), namely:

1. Gattar –Wadi Hebal pegmatite field that located at the northern portion of the Eastem Desert. Mineralization such as molybdenum, REE, and fluorite-bearing pegmaties are observed at Gabal Gattar (Shalaby et al., 1999; El-Nahas, 1997) and Abu Zawal area (Helmy, 1999).

2. Wadi Bezah pegmatite field, which is located at the central portion of the Eastern Desert. The associated mineralizations of beryl, mica, Sn, Nb, Ta, REEs, and fluorite bearing pegmatites are observed at various areas (e.g., Nweibia, Abu-Dabba, Igla, Mueiha, Hamrit Waggat, and Wadi Bazih).

3. Migif-Hafafit pegmatite field that located between the central and southern portion of the Eastern Desert. Corundum, emerald/beryl, vermiculite, asbestos, mica, Nb-Ta and fluorite mineralizations are observed at various areas (e.g., Nugrus, Sikait, Zabara, Hafafit-Migif, Umm Kabo, Abu-Rasheid, and Abut Nimr).

4. Umm Rasein-Hamaany pegmatite field, which is located at Southern portion of the Eastern Desert. The associated mica and tourmaline mineralization of are observed at Umm Rasein, Umm Tayor, Wadi Umm Hebal area around sol Hamid shear zone and Garf.

Kamar (2015; 2021) described the pegmatites of Wadi Ghadir as simple zoned pockets and lenses, which are hosted by monzogranites. The zoned pegmatite bodies show gradational contacts with their host monzogranites, and they have the following zonal arrangement: wall, intermediate, and core zones.

The present work focuses on the detailed characterization of the zoned pegmatite bodies enclosed by granitic rocks in Wadi Ghadir area through petrography, mineralogy (i.e., separation and investigation their content of heavy minerals), fluid inclusion geochemical characteristics and physical testing. The present study aims to shed light on Wadi Ghadir pegmatite bodies in terms of mode of formation and their suitability for ceramic industry.

2. Analytical techniques

Eighty-five thin sections, representing the studied granites and pegmatite bodies, were petrographically studied in detail. The heavy minerals from Wadi El-Dob pegmatite body, the Scanning Electron Microscope (SEM) investigation and radiometric study were carried out at Nuclear Material Authority (NMA) Laboratories. The pegmatite samples were crushed to 60 mesh and the heavy mineral separation were carried out by heavy liquid separation using bromoform solution (Sp. Gr. 2.86 g/cm3). Magnetic fractionation using a Frantz Isodynamic Magnetic Separator (Model L-1) was used to fractionate heavy minerals according to their magnetic susceptibilities. Firstly, the magnetite was collected by a hand magnet coated with a plastic film, and then the magnetite free samples were subjected to the magnetic separation. The conditions of Frantz Isodynamic Magnetic Separator are transvers slope = 5, longitudinal slope = 20 and a set of 0.2, 0.5, 1.0, 1.5 magnetic and 1.5 non-magnetic current amperes. Each fraction obtained from the magnetic separation process was microscopically studied under binocular stereomicroscope. Semi-quantitative EDX chemical analyses of selected heavy minerals were carried out by Energy Dispersive X-ray (EDX) were carried out using SEM model (PHILIPS XL 30) attached with (EDX) unit was used. For the radiometric study, the measurements of the radioactive elements distribution and concentration were performed using the portable gamma-ray spectrometer Gs 512 instrument was used. Fluid inclusion petrography and microthermometric measurements has been carried out on doubly polished wafers 0.2-0.3mm thick using a Chaixmeca heating freezing stage (Poty et al., 1976) at the Geology Department, Assiute University. The stage was calibrated for temperatures between -100 and 400 ℃ using Merck chemical standards as well as according to the melting point of distilled water (0 ℃) and phase transition in natural pure CO_2 inclusions with triple point al (-56.6 ℃).

The chemical analyses of, granitic samples, wall and intermediate zones from the pegmatite body were carried out using X-Ray Fluorescence Analyses (XRF) for major elements using Origaku 3070 at Central Laboratories of Mineral Resources Authority, Cairo, Egypt. The physical testing of feldspars from pegmatite body, for the prepared green biscuit samples were carried out in the Laboratories of Arab Contractors Company.

3. Results

3.1. Geological background

Wadi Ghadir pegmatite bodies are located in the southern Eastern Desert. Wadi Ghadir lies at about 6 kilometers West Marsa Alam-Shalatien paved road at about 30 km South Marsa Allam city. The studied pegmatite bodies are represented by two small bodies, the larger lies at the intersection of latitude 24°48'28.83"N and longitude 34°52'38.43"E, while the smaller body is located at the intersection of latitude24°48'25.75"N and longitude 34°52'46.65"E (Fig.1a & b). Wadi Ghadir pegmatites are hosted by monzogranites. Monzogranites are medium to coarse-grained rock with pinkish color.

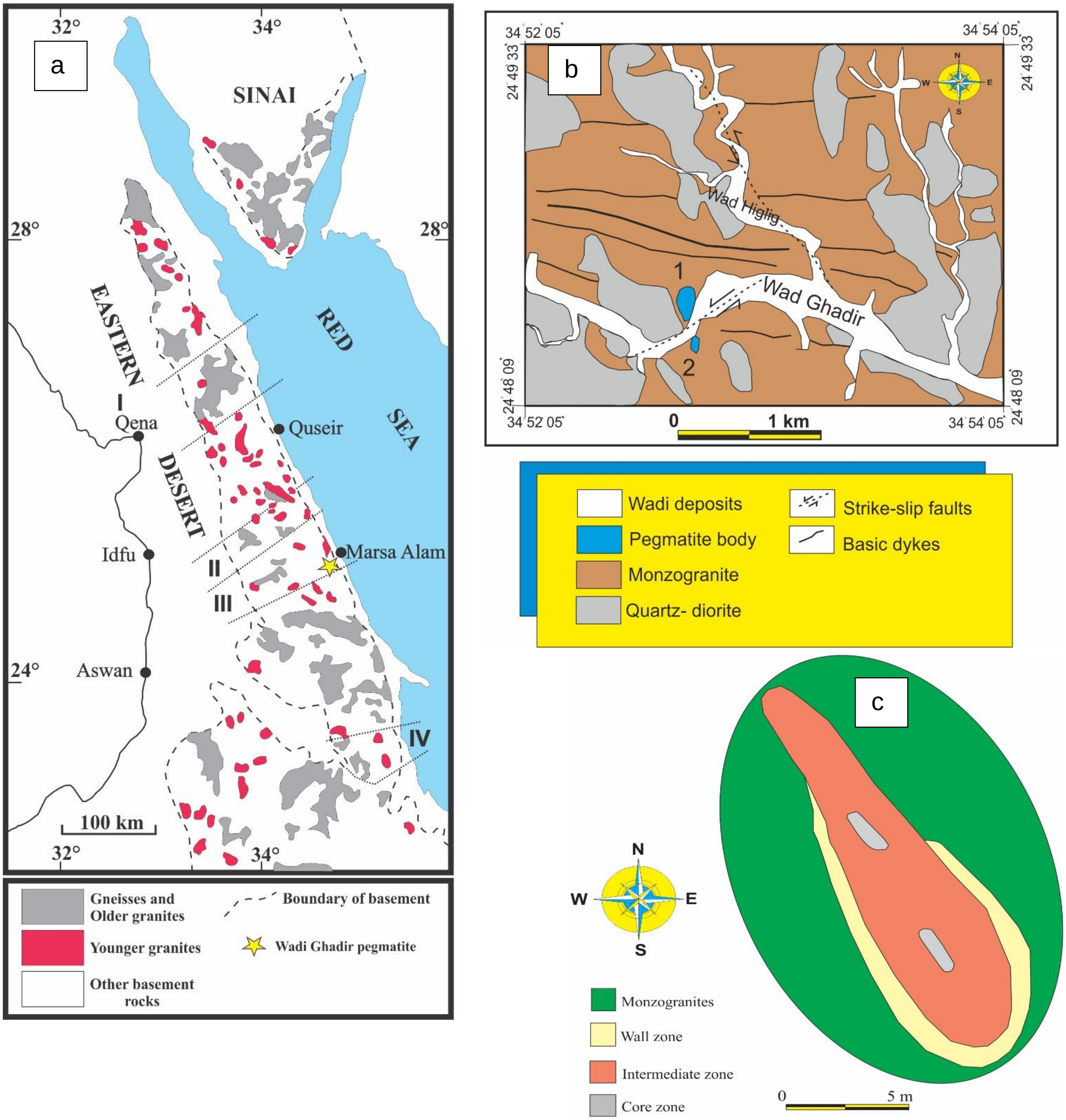


Fig. 1: a) Location map of Wadi Ghadir pegmatite body, I; II; III Northern Eastern Desert, Central Easter Desert and Southern Eastern Desert, respectively. b) Geologic map of Wadi Ghadir area (modified after Kamar et al., 2021) and c) Sketch of zoned pegmatite body of Wadi Ghadir area.

The present pegmatites range in size from a few centimeters to 20 m across and most of them are oval shape (Fig.1c). They occur as zoned pockets and zoned lenses. They show gradational contacts with host monzogranites (Fig.2a). However, sheets and dyke-like bodies of pegmatites are encountered in dolerite (Fig.2b). The zoned bodies are composed of K-feldspars and quartz (Plate 1a) as well as rarely biotite and muscovite. The K-feldspars /quartz ratio is variable (Plate 1b & c).

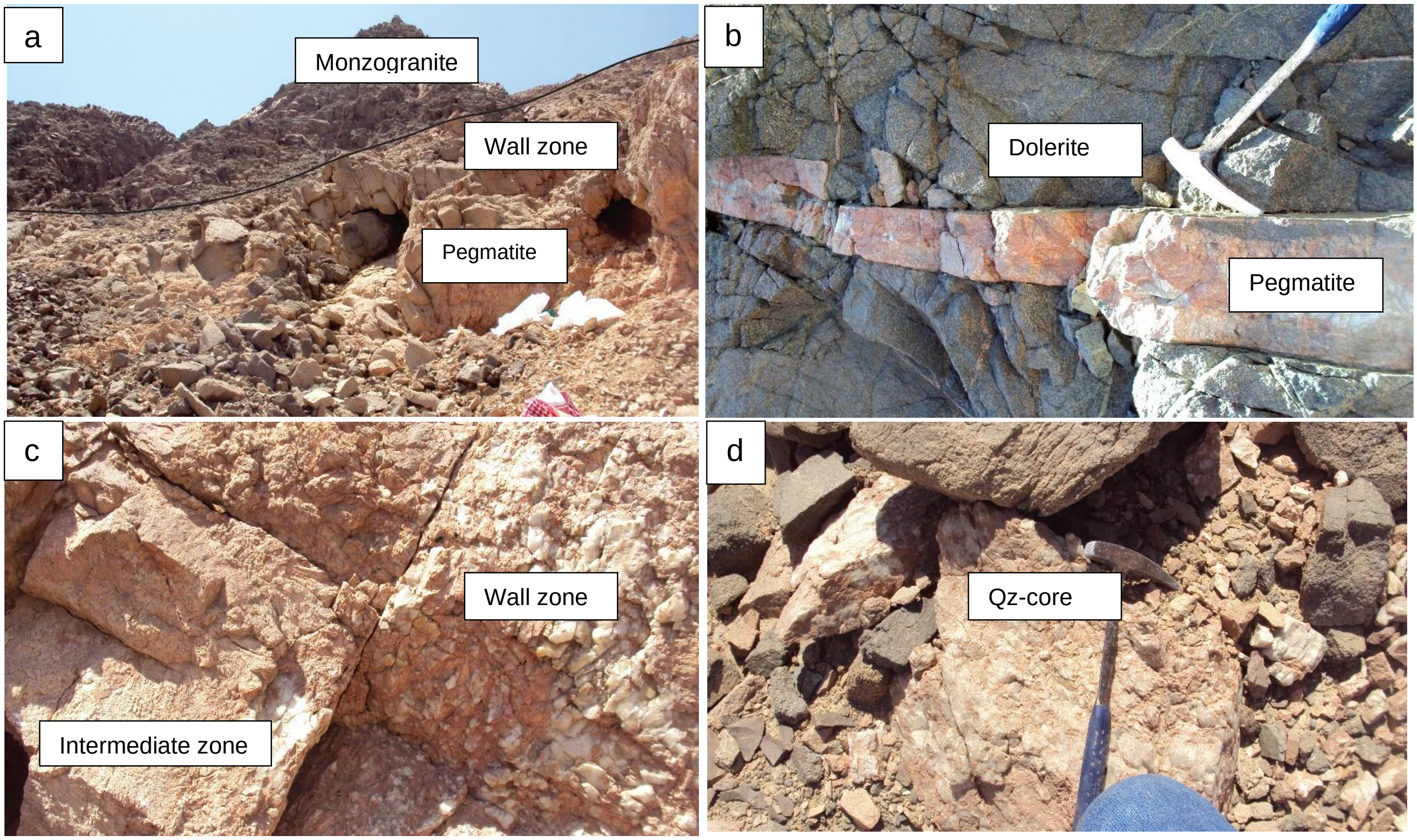


Fig. 2: Field photos from Wadi Ghadir area showing a**)** Contact between monzogranite and pegmatite body, b) Pegmatite vein cutting through dolerite dike, c) Contact between wall zone and intermediate zone, and d) Quartz in core zone.

Three different successive zones are identified in pegmatites of Wadi Ghadir as the following:

a) The outer zone (wall zone) represents a reaction zone between K-feldspars and the hosting rocks (Plate 1d; Fig.2c). This zone is usually thin and discontinuous.

b) The intermediate zone is composed of K-feldspars and usually represents the main constituent of the pegmatite body (Fig.2c). This zone forms sharp contact with core zone and gradational contact with wall zone. K-feldspar increases gradually towards the intermediate zone. Biotite and muscovite flakes are rarely distributed in the K-feldspars. The color of K-feldspars sometimes becomes brick-red due to ferrugination (Plate 1e).

c) The inner zone (core zone), which is composed of quartz (Fig.2d) and encloses isolated flakes of muscovite. Quartz appears rose in color, which could be attributed to iron oxides contamination during crystallization (Plate 1f). Several quartz-veins invading both monzogranite and pegmatite bodies.

3.2. Petrography

In Wadi Ghadir, the pegmatite bodies are hosted within monzogranites.

3.2.1. Monzogranites

Monzogranites have greyish pink color and show medium-grained hypidiomorphic texture. They are composed mainly of quartz, plagioclase, and K-feldspar. Chlorite and epidote are the secondary minerals, while the accessory minerals are biotite, zircon, monazite, apatite, sphene and iron oxides. Quartz occurs either as subhedral to anhedral crystals or as interstitial grains. Plagioclase occurs as euhedral to subhedral lamellar crystals. It exhibits albite, combined and pericline twinning. Pagioclase crystals show secondary zoning due to the alteration of their cores (Fig.3a). Myrmekitic intergrowths between plagioclase and quartz are common (Fig.3a).

K-feldspar occurs as subhedral crystals and is mainly represented by orthoclase perthite and microcline perthite (Fig.3b). Biotite occurs as subhedral to anhedral flakes, which are partially or completely altered to chlorite and epidote. Zircon forms prismatic crystal and occurs as inclusion within plagioclase or biotite. Zircon crystals show color zoning and other crystals attain pleochroic halos due to radiogenic effect.

Monazite occurs as dispersed grains and it is commonly associated with biotite. Apatite occurs as euhedral prismatic crystals, which are enclosed within biotite and iron oxides. Sphene occurs as anhedral crystals that is associated with biotite. Iron oxides are represented by mainly magnetite and ilmenite.

3.2.2. Zoned pegmatites

Zoned pegmatite bodies are composed of three successive zones, which are:

a) The wall zone is composed mainly of quartz, K-feldspar, plagioclase, and minor biotite. Quartz occurs as subhedral phenocrysts (Fig.3c). K-feldspar occurs as subhedral crystals represented by microcline perthite and microcline. Graphic textures between quartz and K-feldspar are common feature (Fig.3d). Patchy and string-types perthites are also common.

Plate 1: Characteristic features of hand specimens of Wadi Ghadir pegmatites, a) Quartz crystals within K-feldspar; b) and c) Variable K-feldspars/ quartz ratio; d) K-feldspar in wall zone; e) Brick-red K-feldspar, intermediate zone; f) Rose color quartz, core zone.

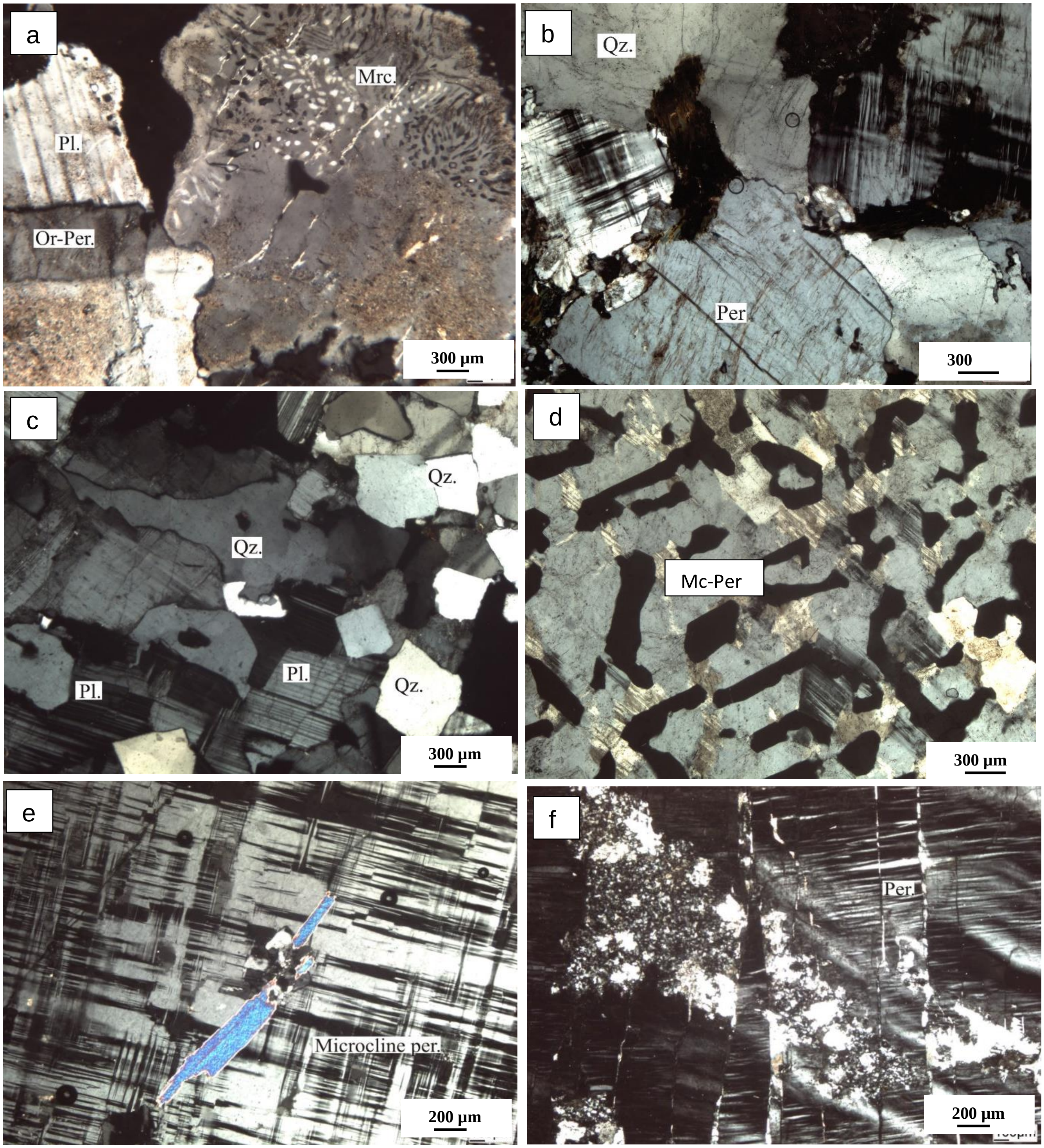


Fig. 3: Photomicrographs showing, a) Myrmekitic intergrowth (Mrc) in monzogranite, *CN*., b) K-feldspar represented by perthite (Per) and microcline-perthite (Mic-Per) in monzogranites, *CN*, c) Subhedral quartz (Qz) crystals and plagioclase (Pl) in wall zone, *CN* and d) Graphic texture between quartz and K-feldspar in wall zone, *CN, e)* string type perthite (Per) in intermediate zone, *CN* , f) microcline perthite (Per) in intermediate zone, *CN*.

K-feldspar increases gradually toward intermediate zone. Plagioclase occurs as subhedral crystals showing both albite and pericline twinning. It is commonly cracked and fractured. These fractures are filled with hematite.

b) The intermediate zone is composed mainly of K-feldspar (i.e. orthoclase-perthite and microcline perthite; Fig.3e), Orthoclase-perthite occurs as subhedral to anhedral prismatic crystals and show flame-, string- (Fig.3f) and patchy-types. Microcline perthite occurs as subhedral crystals corroding plagioclase and orthoclase-perthite.

c) The core zone is composed mainly of quartz. Quartz occurs as clear anhedral crystals corroding other mineral constituents. Some quartz crystals possess randomly distributed patches, shades and/or tents of iron oxides, suggesting that these crystals were originated from iron rich melt. The presence of clear quartz beside iron-contaminated crystals may suggest that quartz was crystallized in two successive phases. The first phase was crystallized from iron-poor melt, while the second phase was crystallized after addition of iron oxides to the melt. In addition, secondary small quartz crystals are formed as fracture fillings, indicating a period of silicification after crystallization and cracking.

3.3. Heavy mineral separation

The separated minerals include magnetite [Fe_3O_4], which appears as strongly magnetic black granular masses and shows ideal euhedral crystals (Fig.4a). Magnetite crystals are partially altered to hematite, limonite, and goethite.

Garnet [almandine; $Fe_3Al_2(SiO_4)_3$ and spessartine $Mn^{2+}{}_3Al_2(SiO_4)_3$] is rarely found in pegmatite body and exhibits colors ranging from pink, orange to dark brown. Garnet is mainly occurring as angular to surrounded particles.

Rutile [TiO_2] grains are very rare and commonly occur as prismatic, elongated and tabular in shape. It has faint red color grading into brown and black.

Zircon [$ZrSiO_4$] is recorded within 1.0 and 1.5 ampere magnetic fractions as well as 1.5 ampere nonmagnetic fraction. It occurs as yellow euhedral to subhedral crystals (Fig.4b), or as euhedral crystals, that stained with iron-oxides (Fig.4c). Elongation ratios range between 1.2 and 5, suggesting a magmatic origin of zircon. Few varieties appear clear, while dominant crystals possess several inclusions of different shapes and sizes. It possesses traces of Hf and K and composed mainly of Zr and Si. Zircon shows metamictization due to its uranium and thorium contents.

Gold [Au] normally occurs in very small shapeless grains, very thin sheets and flakes of golden yellow color (Fig.4d), varying in brightness depending on the impurities present (Fig.5).

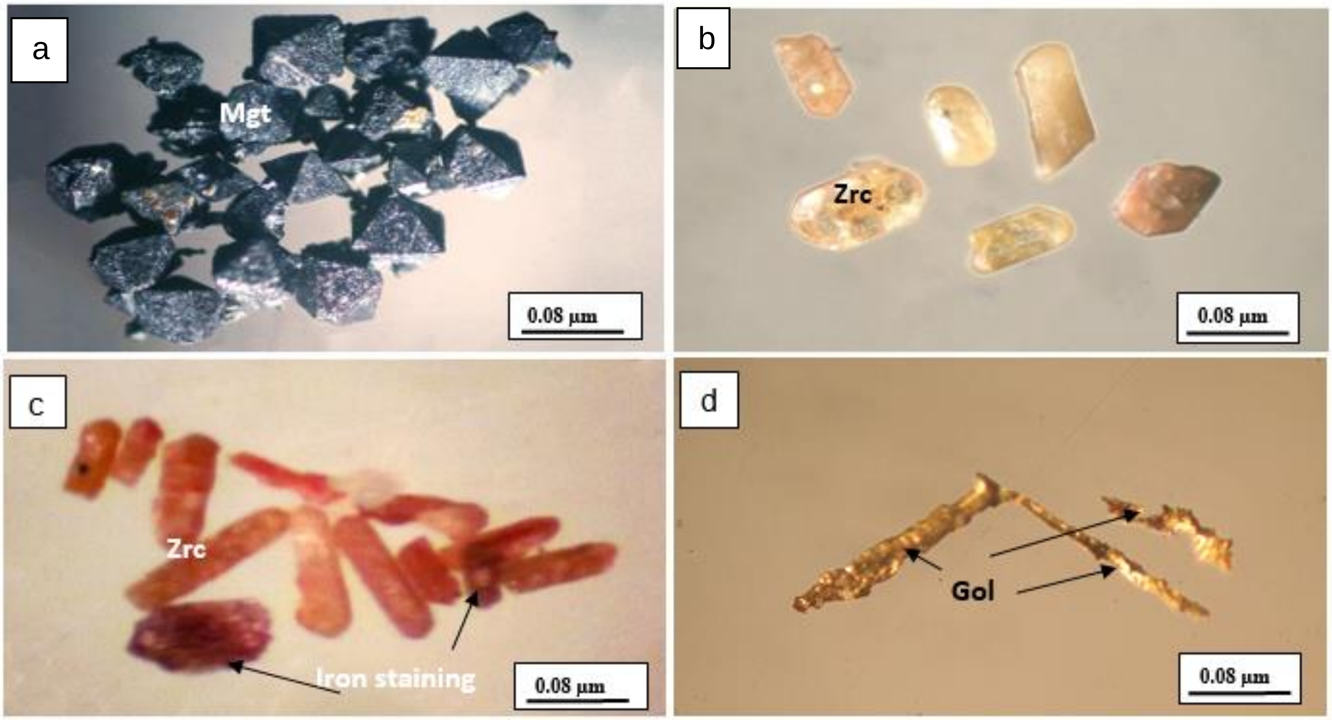
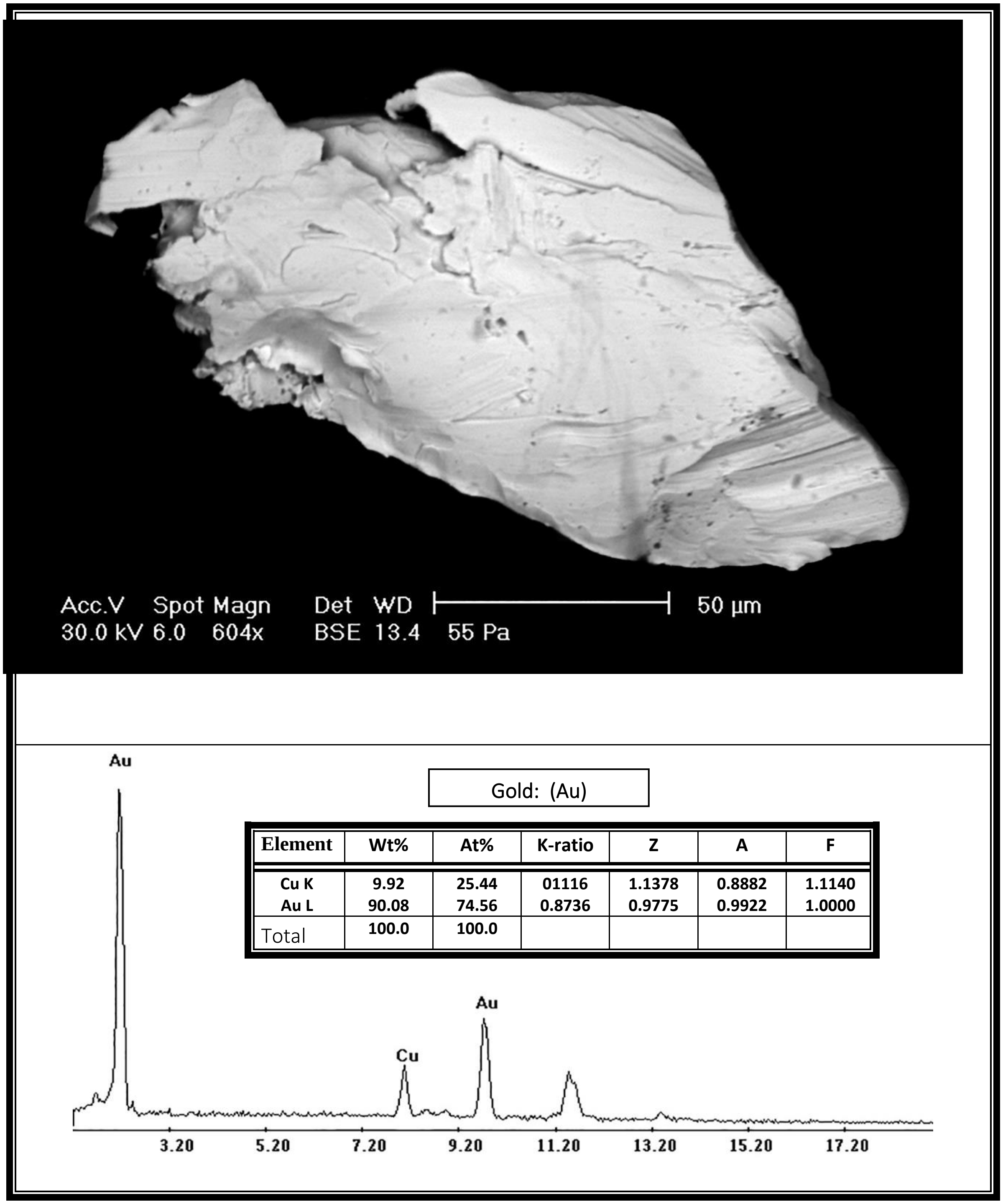


Fig. 4: Photomicrographs in wadi Ghadir separated heavy minerals, showing a) euhedral to subhedral magnetite (Mgt) with variable degrees of alteration to goethite and hematite, b) subhedral zircon grains (Zrc) with honey yellow color, within 1.5 ampere non-magnetic fraction, c) subhedral to euhedral zircon grains (Zrc) usually stained with iron oxides, within 1.0 ampere magnetic fraction and d) gold with shapeless sheets (Gol), within 1.5 ampere nonmagnetic fraction.

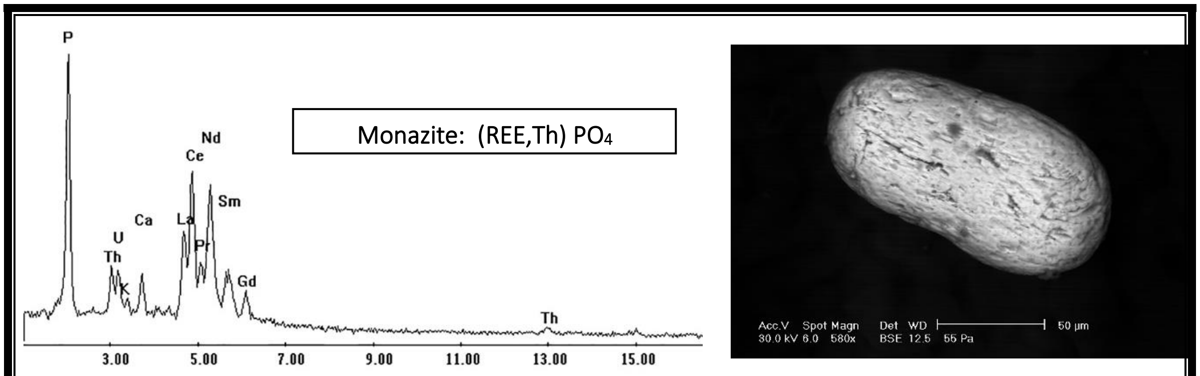


Element	Wt%	At%	K-ratio	Z	A	F
Cu K	9.92	25.44	01116	1.1378	0.8882	1.1140
Au L	90.08	74.56	0.8736	0.9775	0.9922	1.0000
Total	100.0	100.0				

Fig. 5: Microphotograph and EDX chart for gold of Wadi Ghadir pegmatites using Scanning Electron Microscope (SEM). *Z: error in atomic No., A: error in atomic weight and F: error in fluorescence signal intensity*.

Monazite [(REE, Th) PO_4] is recorded within 0.2 and 1.5 ampere magnetic fractions. It occurs as isolated grains or as inclusions in mica. The dominant REEs in monazite are La, Ce and Nd. Monazite usually possesses adequate amounts of U and Th, so it is radioactive (Fig.6).

Uranothorite [U, Th) SiO_4] occurs as inclusions within feldspars, quartz and zircon. It is recorded within 1.0 ampere magnetic fraction. U/Th ratio is about 0.3 + 0.08. The major elements of uranothorite are Si and Th. Ti, U and Y are the secondary elements and Ca, Fe and Al oxides occur as trace impurities.



Element	Wt%	At%	K-ratio	Z	A	F
P K	19.6	52.89	0.0698	1.1458	0.3088	1.0034
U M	4.83	1.69	0.0376	0.8713	0.8933	1.0008
K K	0.05	0.11	0.0004	1.1852	0.5971	1.0241
Ca K	2.09	4.35	0.0160	1.2094	0.6111	1.0329
La L	15.66	9.39	0.1296	0.9384	0.8799	1.0029
Ce L	27.25	16.21	0.2322	0.9471	0.8985	1.0012
Pr L	3.83	2.27	0.0338	0.9585	0.9205	1.0000
Nd L	12.05	6.96	0.1076	0.9526	0.9377	1.0000
Sm L	2.42	1.34	0.0211	0.9449	0.9222	1.0000
Gd L	2.48	1.32	0.0201	0.9327	0.8681	1.0000
Th L	9.69	3.48	0.0823	0.8463	1.0039	1.0000
Total	100.0	100.0				

Fig. 6: Microphotograph and EDX chart for monazite of Wadi Ghadir pegmatites using Scanning Electron Microscope (SEM). *Z: error in atomic No., A: error in atomic weight and F: error in fluorescence signal intensity.*

3.4. Fluid inclusions

As noted by Roedder (1984), some workers use the term fluid inclusion to describe only those inclusions that have trapped a fluid and have remained in the fluid state during cooling to ambient temperatures. Fluid inclusions sufficiently large to study with the heating and freezing stage include those with sizes greater than about 12 micrometers.

Primary fluid inclusions are formed during, and as a direct result of growth of the surrounding host crystal. If a crystal fractures after it has been formed, some fluid may enter the fracture and become trapped as secondary fluid inclusions as the fracture heals. Thus, secondary inclusions are trapped after crystal growth is complete. If fracturing occurs during growth of the crystal, pseudo-secondary fluid inclusions may be trapped during continued crystal growth. Goldstein & Reynolds (1994) introduced the concept of the Fluid Inclusion Assemblage (FIA) to describe a group of fluid inclusions that were all trapped at the same time. An FIA thus defines the most finely discriminated fluid inclusion trapping event that can be identified based on petrography (Goldstein, 2003). This requirement further implies that the inclusions in the FIA were all trapped at approximately the same temperature and pressure, and all trapped in a fluid of approximately the same composition.

Fluid inclusion study has gained more importance in recent years in various disciplines such as ore mineralization modeling, hydrocarbon estimations, geothermal fields, metamorphic petrology etc. The fluid inclusion studies play a potentially vital role in exploration and mine assessment because they confirm the possibility of great depth extension of the gold deposits.

3.4.1. Fluid inclusion petrography

Fluid inclusions study in Wadi Ghadir pegmatite revealed on the following types:

3.4.1.1. Primary two phase (L+V) aqueous inclusions.

In this type of inclusion of small quantity of CO_2 may be present as indicated from CO_2- melting and clathrate melting during microthermometric measurements. This type is distributed in isolated or small clusters, which were considered by Roedder (1984) as primary inclusions (Fig.7a). The shape is subrounded, triangular to negative crystal shapes, and the size range from 10 to 20 µm with vapor phase represents from 30 to 70 % of the total volume of inclusions.

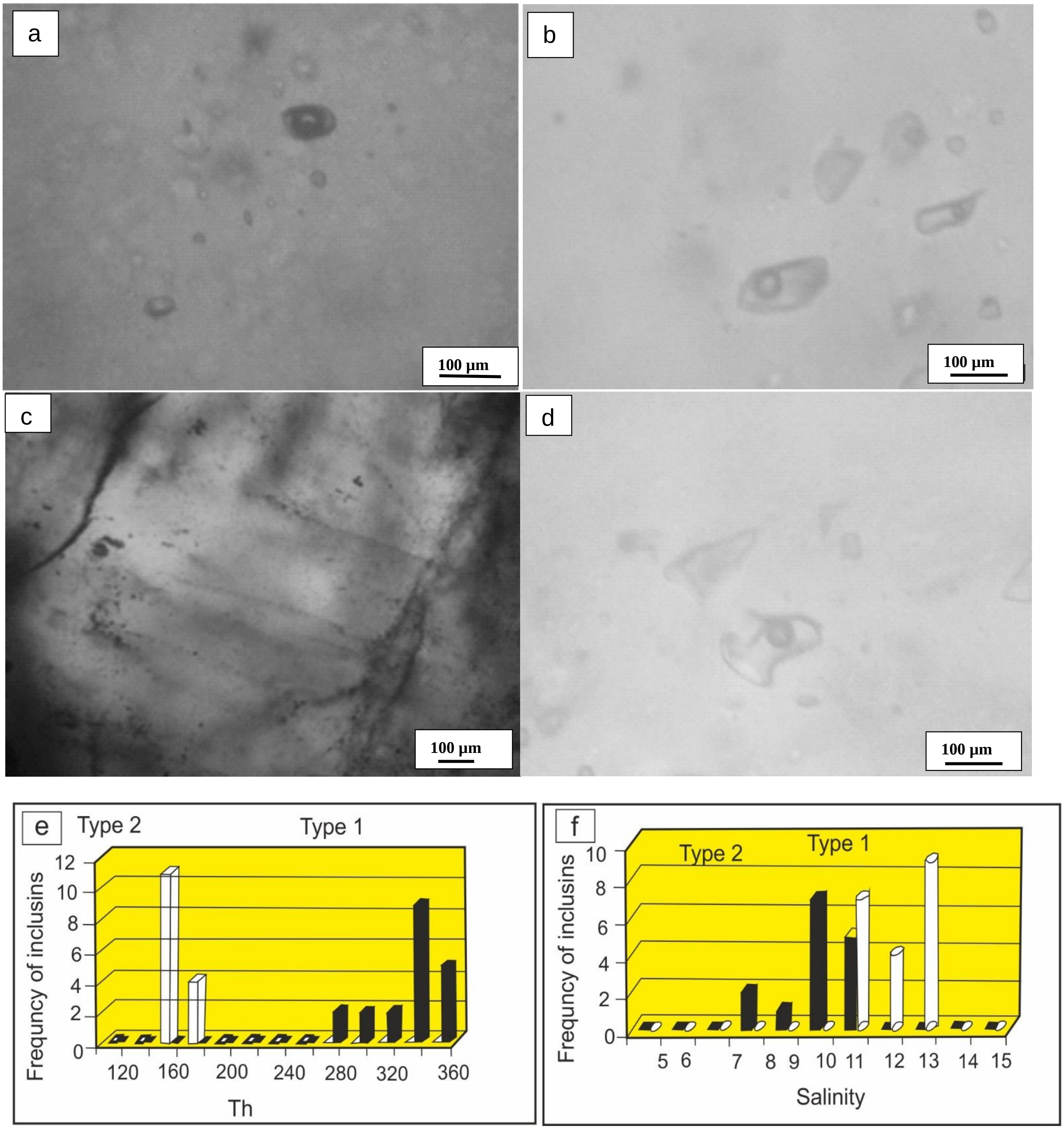


Fig. 7: Photomicrographs in quartz weavers showing a) primary two-phase aqueous inclusions b) Type 2 inclusions, c) Secondary distribution of type 2 inclusions, d) Subtype poly-phase (L+V+S) inclusion**,** e) Graph showing the microthermometric salinity- frequency distribution of the inclusion and f) Graph showing, the microthermometric homogenization temperature (Th)- frequency distribution of the inclusion in the studied pegmatites.

3.4.1.2. Secondary inclusions

These inclusions are distributed along lines of healing microfractures as (Fig.7b & c) secondary inclusions (Roedder op. cit.). Based on the number of the physical phases, there are two sub types of secondary inclusions occur in within the same region:

a) Subtype 2a, two-phase aqueous inclusions. The shapes of these inclusions are subrounded to elongated inclusions and the size range from 15 to 30 µm, with regular vapour phase up to 20 to 40% of the total volume of inclusions. Monophase liquid inclusions coexist with this subtype (Fig.7c).

b) Subtype 2b, Poly-phase inclusions (L+V+S). This subtype is coexisting with type 2a inclusions. The solid phase represents by daughter crystals up to 2 µm size and cubic shape (Fig.7d). Petrographically, these crystals may be halite or sylvite.

3.4.2. Microthermometric results

Microthermometric results are given in (Table 1).

Table 1: Microthermometric results of the studied pegmatites.

Inclusion type and parameters	Measurements
1. Two- phase (L+V) aqueous inclusions. Th_{tot} (˚C): T_{mice}: Salinity in wt% NaCl eq.: T_e (˚C): Distributon:	150 ˚C to 180 ˚C -7 ˚C to -5˚C 7.86 ˚C to 10.49 ˚C -49 ˚C p
2. Poly-phase (L-V-S) inclusions. T_s:	430 ˚C

L (liquid), V (Vapor), S (Solid), Th_{tot} (temperature of homogenization), T_{mic} (final melting of ice), Th_{bulk} (bulk homogenization temperature), p (primary) and s (secondary).

3.4.2.1. Primary two phase (L+V) aqueous inclusions.

In the two phase (L+V) aqueous inclusions, the eutectic temperature (Te) has been observed in few inclusions at temperature between -49 ºC to – 52 ºC, indicating the presence of NaCl and $CaCl_2$ dissolved salts. The ice melting of is achieved at temperature (Tm_{ice}) between -7 ºC to -9 ºC, corresponding to salinity between 10.49 to 13 wt.% NaCl eq. with majority at 13wt.% NaCl eq. (Fig.7e). The bulk homogenization temperatures ($Th_{bulk.}$) were achieved by disappearance of the vapor bubble between 275 ºC to 360 ºC, with maximum peak at 340 ºC (Fig.7f).

3.4.2.2. Secondary inclusions

a) Liquid-rich two-phase aqueous inclusions

The final melting of ice (Tm_{ice}) measured at temperature between -4.3 ºC to -7 ºC, corresponding to salinity range of about 6.88 to 10.49 wt.% NaCl eq., with the majority at 10 wt.% NaCl eq. Bulk homogenization (Th_{bulk}) was measured for most inclusions at temperatures between 150 ºC to 230 ºC, with maximum peaks at 160 ºC (Fig.7f).

b) Poly-phase inclusions (L+V+S)

Dissolutions of daughter crystals (Ts) have been observed at temperatures between 440 ºC to 450 ºC, indicating high salinity between 51 to 54 wt. % NaCl eq. (Brown, 1989).

3.5. Geochemical characteristics of wall and border zones

Wadi Ghadir pegmatite bodies are characterized by their silica content increases from granitic rocks through intermediate zone to wall zone (Table 2). The intermediate and wall zones of Wadi Ghadir pegmatites have lower values of Fe_2O_3, CaO and MgO when compared with the average composition of monzogranite (Kamar, 2015). The Al_2O_3 contents decrease from granitic rocks through intermediate zone to wall zone. On the other hand, the concentration of K_2O decreases from intermediate zone through granitic rocks to wall zone.

According to A/CNK vs. A/NK diagram of Shand (1947), the average monzogranite composition has a typical characteristic of peraluminous granite, while the wall zone samples have metaluminous to peraluminous characters (Fig.8a). The plots of SiO_2- Fe * (FeO_{tot} / FeO_{tot}+ MgO) diagram (Frost and Frost, 2008) indicate that the magmatic source of monzogranites and wall zone samples are ferroan (Fig.8b). The curved trend on the diagram of (Fig. 8c) is typical of magmatic differentiation and is compatible with the fractional crystallization trend (Garcia et al., 1994), which indicating that the studied pegmatite has been derived from the residual granitic melt. The temperature of crystallization of pegmatite bodies can be estimated by using Al-Ti thermometer (Jung & Pfänder 2007). They range from 565 ° C to 572.7 ° C (Table 2).

3.6. Suitability of the studied pegmatites for ceramic industry

Pegmatites are the main source of several industrial minerals, such as quartz, kaolin, feldspars, and rare elements (Li, Ta, Nb, Ga, Yb, etc.). These minerals and elements are used in important branch industries such as ceramics, optical fibers, electronic circuits, satellites, and batteries.

The comparison between the chemical analyses results of the collected samples from monzogranites, wall zone and intermediate zone (i.e. K-feldspar) with the standard chemical specifications for feldspars used in ceramic industry by Ceramic Cleopatra Company is given in table (2).

Wadi Ghadir feldspars have SiO_2 (75.11 wt. %), TiO2 (0.02 wt. %), Al_2O_3 (13.07 wt. %), Fe_2O_3 (0.16 wt. %), MnO (0.01 wt. %), MgO (0.01 wt. %), CaO (0.10 wt. %), Na_2O (1.80 wt.%), K_2O (9.26 wt. %) and P_2O_5 (0.01 wt. %). Comparing these results with the standard chemical standards to evaluate the composition of feldspars that are used in ceramic industry indicates a good similarity.

Table 2: Major element concentration (wt. %) of monzogranites and wall zone of Wadi Ghadir pegmatites, with standard limits after Ceramica Cleopatra Company (Personal communication) for chemical composition of ceramic raw materials.

Locality	**Wadi Ghadir**					**Standard limits**	
Rock type	**Monzogranites** **Av. (6)** *	**Wall zone**			**Intermediate zone (K-feldspar)**	after (Ceramica Cleopatra Company**)**	
Oxides		**G18**	**G24**	**G23**	**G15**	**From**	**To**
SiO_2	72.03	77.75	78.82	77.64	75.11	68	78max.
TiO_2	0.24	0.02	0.02	0.02	0.02	0	0.1
Al_2O_3	15.06	12.37	12.16	12.88	13.07	11	16
Fe_2O_3	2.01	0.24	0.25	0.46	0.16	0	2max.
MnO	0.02	0.01	0.01	0.01	0.01	0	0.5
MgO	0.47	0.01	0.01	0.01	0.01	0	1max.
CaO	1.59	0.13	0.62	0.01	0.10	0	1max.
Na_2O	3.93	4.75	5.42	5.58	1.80	1	4
K_2O	4.61	4.30	2.20	2.35	9.26	4%nim.	over
P_2O_5	0.08	0.01	0.01	0.01	0.01	0	0.5
Cl	Nd	0.01	0.01	0.01	0.01	-	-
L.O.I	1.07	0.14	0.22	0.27	0.18	-	-
Total	101.11	99.74	99.75	99.25	99.74	-	-
T_{Al-Ti} °C**	902.2	570.4	572.7	565	-	-	-

*Average of monzogranites from (Kamar, 2015)

****T_{Al-Ti} °C** is crystallization temperature obtained by calibrated Al-Ti thermometer (Jung & Pfänder, 2007).

3.7. Physical testing

There are many tests that were done for feldspar to adapt the quality of feldspars for ceramic industry. These tests include shrinkage, water absorption and bending strength, surface hardness and resistance to thermal shocks. These tests were applied on a biscuit sample (Table 3). The prepared green ceramic samples are 5 cm in width and 10 cm in length with 1.52 cm thickness. Each green ceramic sample was dried and fired, then shrinkage testing was carried out using Vernier caliper 150 x 0.05 mm. Shrinkage is the rate of change in length and width for inspection sample. Shrinkage is directly proportional to total alkali content and inversely proportional with water absorption and bending strength. Finally, the water absorption was measured for each sample. The results of physical testing are shown in table (3), which indicate that the green biscuit ceramic samples that prepared from Wadi Ghadir pegmatite bodies are suitable for floor ceramic tiles industry rather than wall tiles (Table 3).

4. Concluding remarks

Wadi Ghadir pegmatite bodies are located in the southern Eastern Desert. They are represented by two bodies. The larger lies at the intersection latitude 24°48'28.83"N and longitude 34°52'38.43"E. The smaller body is located at the intersection of latitude 24°48'25.75"N and longitude 34°52'46.65"E. They are hosted by the monzogranites. Three different successive zones are identified in pegmatites of Wadi Ghadir they are: a) wall zone, which represents a reaction zone between K-feldspars and the hosting rocks. This zone is usually thin and discontinuous, b) the intermediate zone, which is composed of K-feldspars and usually represents the main constituent of the pegmatite body.

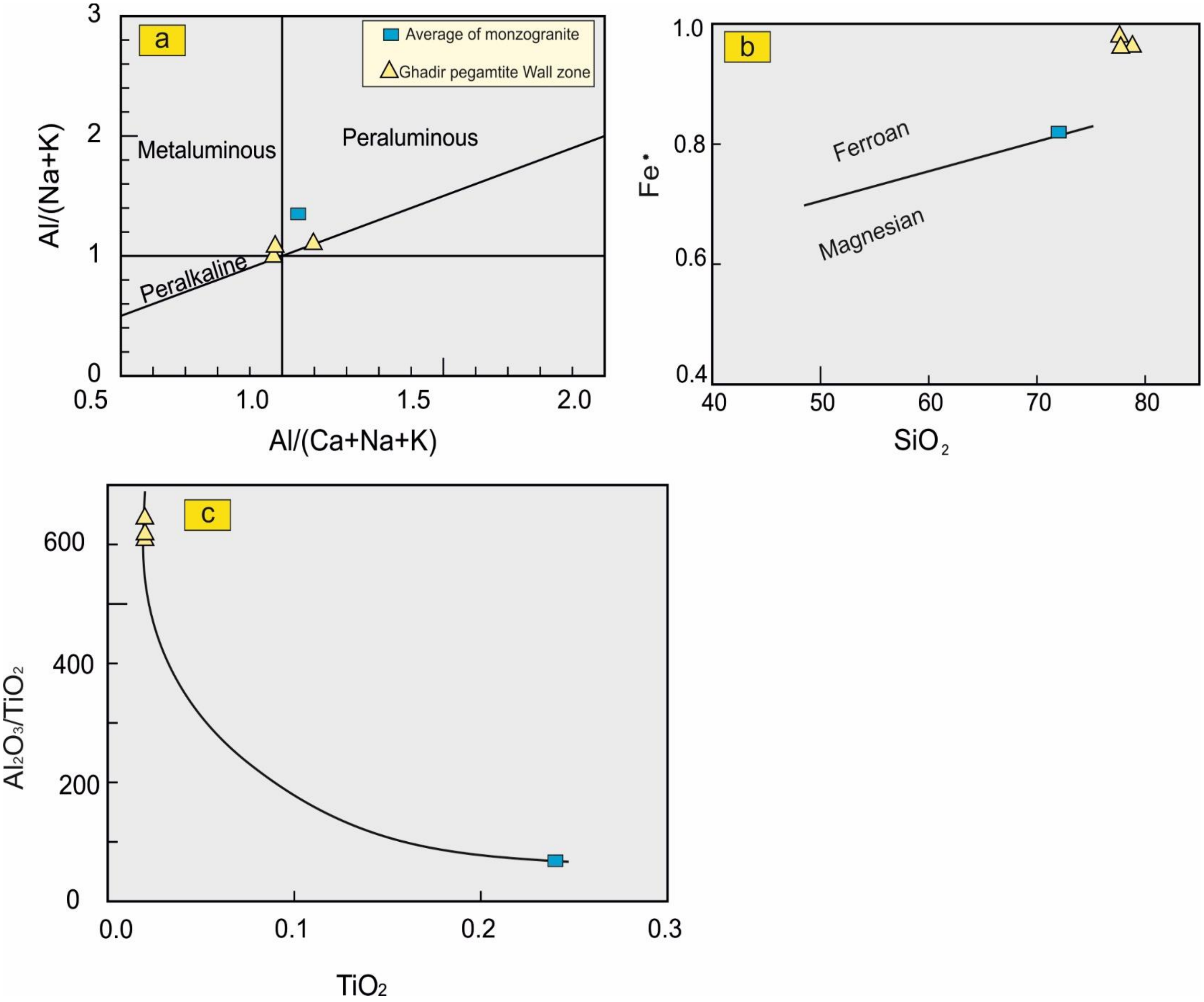


Fig. 8: a) A/CNK vs. A/NK diagram of Shand (1947), b) SiO_2- Fe * (FeO_{tot} / FeO_{tot}+ MgO) diagram (Frost and Frost, 2008) and c) TiO_2 versus Al_2O_3/TiO_2 diagram.

Table 3: The ceramic physical parameters for the tested samples from the studied pegmatites compared with standard limits after (Knota, 1980).

Sample no.	**G15 (Av. 3)**	**G18 (Av. 3)**	**Standard limits**	
			Floor	**Wall**
Shrinkage %	5.2%	4.5%	<3%	14-17%
Bending stress	34.6	35.2	>27.5 newtons/cm^2	>17 newtons/cm^2
Water absorption %	0.7%	0.57%	0-3%	5-6.5%

This zone forms gradational contacts with wall zone and sharp contacts with core zone. K-feldspar increases gradually towards the intermediate zone. Biotite and muscovite flakes are rarely distributed in the K-feldspars. The color of K-feldspars sometimes becomes brick-red due to ferrugination and c) the core zone, which is composed of quartz and encloses isolated flakes of muscovite.

The heavy minerals separated from this pegmatite include magnetite, garnet, zircon, rutile, monazite, uranothorite and gold elements. The presence of patches, shades and/or tents of magnetite, suggesting that these crystals originated from iron rich melt. The origin of garnets in these pegmatites could be either to the assimilation from Al-rich country rocks (Brammall and Harwood, 1932) or garnet crystallized with muscovite as alternative to biotite from volatile-rich magma (Gindy, 1956). The presence of gold in pegmatites is restricted to the quartz-veins associated with pegmatite bodies, this may refer to relation of the found gold in pegmatites to the country monzogranites. Fluid inclusions in quartz in the core zone are mainly represented by secondary inclusions representing two generations. The early fluid generation is higher in temperature and salinity relative to the late one (Fig. 7e & f). The minimum conditions of trapping calculated from microthermometric results and isochors at temperature 360 ºC, and pressure up to 2585 bars for the early generation, and 170 ºC, 139 ºC for the second fluid generation.

The contemporaneous presence of two immiscible fluids (H_2O - CO_2) makes it possible to estimate the P-T conditions of their trapping by the intersection of isochors of both fluids (Hollister et al., 1981). For immiscible fluids, an intersection of isochors of both H_2O - and CO_2-rich inclusions suggests trapping conditions at temperatures between 170°C and 400°C and pressures between 900 and 2000 bars. The comparison of chemical composition of K-feldspar samples, Wadi Ghadir area fit well with the standard values of ceramic chemical composition after Ceramica Cleopatra Company (Personal communication; Tables 2). This confirms the suitability of the feldspars from Wadi Ghadir pegmatite bodies for ceramic industry. On the other hand, the results tested physical parameters on green and fired ceramics, that prepared from Wadi Ghadir pegmatite fit well with the standard values of floor ceramic tiles rather than wall tiles (Table 3).

Generally, pegmatites are commonly interpreted to have formed from residual melts derived from crystallizing granitic plutons (e.g. Černý, 1991; Černý & Ercit, 2005; London, 2008), this applicable especially for pegmatites that are hosted within the parental pluton (e.g. Thomas and Davidson, 2016, Roda-Robles et al., 2018). The studied pegmatite has metaluminous to peraluminous characters and ferroan magmatic source. The nature of magma and the fractionation trend from monzogranite to pegmatite indicate that the pegmatite originated from the residual granitic melt of monzogranite (Fig. 8 a, b & c). Garent, uranothorite and fluorite represent the source of Nb,Y and F respectively**.** Consequently the studied pegamtites may be classified as NYF type. NYF pegmatites are interpreted as deriving from mantle-sourced anorogenic magmas with a peralkaline signature (Estrade et al., 2001; Schmitt et al., 20022).

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