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Rare Metals Mineralization in Pegmatite at Abu Rusheid Area, South Eastern Desert, Egypt

Ibrahim, M.E[1]., Saleh,G.M[1]., Dawood, M.I[2], Kamar, M. S[1], Saleh, S.M. [1], Mahmoud, M. A[1]. and El- Tohamy, A.M[1]

[1]Nuclear Materials Authority, P.O. Box 530, El-Maadi, Cairo, Egypt
[2]Faculty of science, Minufiya University, Sheben El Kom, Egypt

Abstract: *Two forms of pegmatite have been distinguished (segregations and dikes) hosted in the cataclastic rocks, at the Abu Rusheid area, southeastern Desert of Egypt. The cataclastic rocks covering an area about 2 km^2, and composed of (from base to top); protomylonite, mylonite, ultramylonite, and quartzite with gradational contacts. The segregations are unzoned, flat lenses, less than 1 m, while the dikes, usually of the zoned type, have (2-15 m in length, and 0.3 m in width), trending NNW-SSE and dipping 10-30°/ WSW parallel to banding of the cataclastic rocks. Albitization, chloritization, fluoritization and silicification are the major alteration processes in the cataclastics and pegmatites due to the effect of hydrothermal solution.*

The total REE content in the pegmatite ranges from 44 to 824 ppm with 342 ppm as the average. LREE is more enriched than the HREE in the pegmatite (ΣLREE/ΣHREE =7.8) and related to the presence of allanite-(Ce) and monazite–(Ce). Hydrothermal alteration during post-magmatic stages is shed light on the development of M-type tetrad effect in the REE pattern.

The rare metals-bearing minerals such zircon, monazite – (Ce), allanite – (Ce), Nb-Ta minerals (columbite-(Fe) and euxenite-(Y), base metals (pyrite and molybdite), beryl and radioactive minerals (thorite, uranophane, torbernite and kasolite) have been found in the pegmatites. Isoconcentration maps show abnormal contents of Nb,Zr, Y, Pb, eU and eTh, and could be considered as low grade ores.

The Abu Rusheid pegmatites show low-CaO content (1 % av.), high Fe/Mg ratio (5.9 av.), enrichment of HFSE (Nb, Zr, Y,U, Th), peraluminous, A-type post-orogenic tectonic setting and their mineral composition supporting the NYF nature of the pegmatites.

Keywords: *Abu Rusheid, Pegmatite, Rare Metals, REEs.*

1. Introduction

Highly fractionated granitic pegmatites are sometimes zoned with respect to texture and mineral assemblages, and pegmatites are of great interest for their economic potential, being primary sources of U, Th , Nb, Ta, Li, Be, Cs and ceramic feldspar, however, the origin and petrogenesis of granitic pegmatites are still highly debated. Currently there are two genetic models to explain the origin of pegmatitic melts: (i) fractionation of igneous intrusions (Černý and Ercit 2005; Simmons and Webber 2008) and; (ii) direct anatexis of country rocks (Simmons and Webber 2008).

The mechanism(s) by which the magma enrichment in incompatible elements is of special interest because these residual magma may: (1) be inject into the surrounding rocks to crystallize as rare metal pegmatite, (2) to crystallize in-situ as granites containing primary rare metal minerals; and (3) to partition ore elements into magmatic hydrothermal fluids with precipitation during subsequent pervasive alteration, particularly in tin-bearing system (Cerny, 1991).

The study area is located 90 km south of Marsa Alam City on the Red Sea coast at the southern part of the Eastern Desert of Egypt (Fig.1). The present study aims to investigate the mineralogy and geochemistry of pegmatites at Abu Rusheid area compared with the host rocks (cataclastic rocks). Throw lights on a role of hydrothermal alterations in redistributions and the concentration of rare metals in the pegmatites.

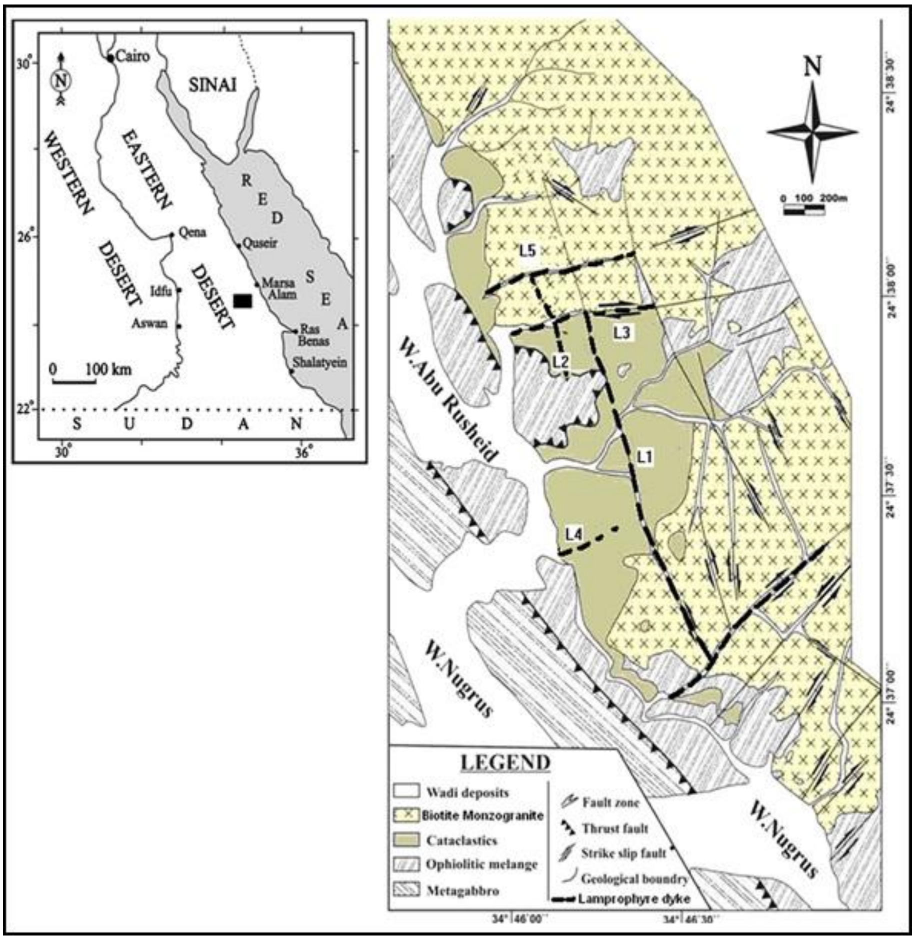


Fig.1. *Geologic map of The Abu Rusheid area, South Eastern Desert, Egypt(after Ibrahim et al., 2010).*

2. METHODOLOGY

Seventy (70) samples from pegmatites were analyzed as major oxides and trace elements and ten (10) samples were analyzed as REE. All chemical analyses have been carried out at Nuclear Materials Authority (NMA), Egypt. The X-ray fluorescence technique (XRF) was used to determine the trace element contents using PHILIPS X'Unique-II spectrometer as well as rare earth elements were measured by ICP-MS spectrometry. The studied rock samples were investigated radiometrically in the field using RS-230 BGO Super-Spec portable radiation detector. This detector is full assay capability with data in K%, eU (ppm), Ra (ppm) and eTh (ppm).

Five technological samples (5 kg for each one) were crushed, grinded and quartered. The samples were sieved and the size fraction –60 to +120 meshes was washed and separated by heavy liquid (bromoform). The heavy fractions were subjected to the magnetic fractionation using Frantz Isodynamic Magnetic Separator (Model LB 1). The intended minerals were picked under binocular microscope to obtain mono-mineral fraction for identification and analysis. The identification was carried out by the Environmental Scanning-Electron Microscope (ESEM model Philips XL30) supported by energy dispersive spectrometer (EDX) unit was used at 25-30 kV accelerating voltage, 1-2 mm beam diameter and 60-120 second counting time, and X-ray diffraction techniques (XRD), using Philips PW 3710/31 diffractometer, scintillation counterr; Cu-target tube and Ni filter .

3. GEOLOGIC SETTING

The tectono- stratigraphic sequence of the Precambrian rocks of the Abu Rusheid area (Fig. 1) arranged as follows: (a) ophiolitic metagabbro, (b) ophiolitic mélange, consisting of ultramafics and layered metagabbro set in metasediment matrix,(c) cataclastic rocks, (d) post-orogenic granites and (e) dykes and veins represented by lamprophyres, pegmatite and quartz veins (Saleh, 1998; Assaf et al. 2000; Ibrahim et al. 2004). These rocks are subjected to polycyclic deformation and metamorphism and characterized by regional WNW–ESE thrusting. Such thrusting is assigned to an age between 682 Ma (the time of emplacement of the older granitoids) and 565 to 600 Ma, the time of intrusion of the younger granites (Stern and Hedge, 1985).

The ophiolitic metagabbros (Fig. 1) are layered, relatively highly foliated and thrusted over the ophiolitic mélange along WNW-ESE direction (Nugrus thrust fault) from the southwest and south with low to high angles (30^o -60^o). The ophiolitic mélange represents the hanging wall of the major thrust in the study area. It comprises a metamorphosed sedimentary matrix (talc-schist, beryliferous tremolite/actinolite schists, sillimanite graphite schist and garnetiferous hornblende biotite schist, phologopite schist and garnetiferous staurolite schistc) enclosing allochthonous serpentinite, ortho-amphibolite fragments mounted in schists. The ophiolitic mélange and ophiolitic metagabbro thrusted over the cataclastic rocks.

The cataclastic rocks (Fig.1) contain blocks of mafic-ultramafic rocks and bands of tremolite-actinolite (1 x 15 m). These rocks are light grey to grey in color, fine to coarse-grained and exhibit layering between protomylonite and mylonites and characterized by absence of enclaves. The altered rock acquires reddish to yellowish colour due to staining with iron solutions. Some pyrite crystals were removed leaving vugs filled with quartz, iron oxides, carbonates and U – minerals.

The cataclastic rocks, covering an area of about 2 km^2, are represented by protomylonite, mylonite, ultramylonite, and quartzite with gradational contacts), highly sheared, banded (N-S) and cut by two approximately perpendicular shear zones (NNW-SSE and E-W trends) differ in length, age and mineralization. The shear zones range from 2 to 10 m in width and 400–1500 m in length with vertical dip and extruded by lamprophyre dikes. The later is a good physical and chemical trap for U, REEs, Cu, Zn, Ag, Pb and Y (Ibrahim et al.2015). The cataclastic rocks have been considered as a passamitic gneisses of sedimentary origin (Hassan, 1964; Saleh, 1998; Assaf et al. 2000), whereas, Ibrahim et al. (2004, 2006, 2007, 2010, 2015) described these rocks as cataclastic rocks. Khour Abalea (1.5 Km in length, 10-20 m in width) located at the middle part of the cataclastic rocks (Fig. 2). It was formed as a result of deep strike-slip faults, forming shear zones in ENE-WSW, NNW-SSE, N-S and NNE-SW trends respectively, with common pegmatites (segregations and dikes) and quartz veins.

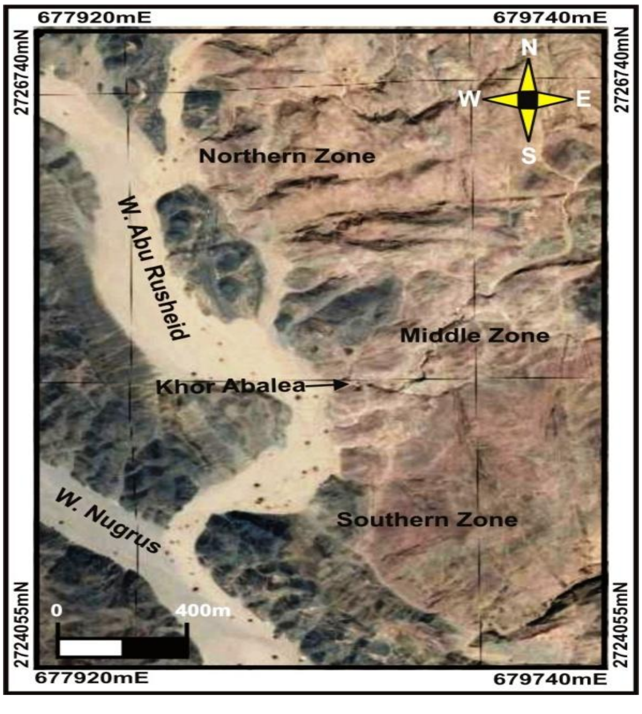


Fig.2. *Google Earth image of the Abu Rusheid area showing the location of Khour Abalea zone and northern and southern zones, Abu Rusheid area.*

The geology, geochemistry and mineralogy of the cataclastic rocks and associated lamprophyre dykes at Abu Rusheid area were studied by Ibrahim et al. (2006, 2007, 2010 and 2015).

Abu Rusheid granitic pluton is an elongated body extending NW-SE for about 12 km with width about 3 km (outside the mapped area). The Late- to Post-orogenic granitic rocks occupy the major part of the mapped area intruded the cataclastic rocks with sharp contacts.

They are represented from the NW direction by porphyritic biotite monzogranites followed by two mica peraluminous granites, and muscovite granites occupy the SE part of the pluton (Ibrahim et al. 2004).

Two morphological types of pegmatites have been distinguished (segregations and dikes) intruded in the cataclastic rocks. The segregations are formed by segregation of the host rocks (Fig. 3), so they have not sharp contacts with the host rocks, compared with the dikes (Figs. 3c - d). The pegmatite segregations are flat lenses (less than 1 m), distributed heterogeneous in the cataclastic rocks. The pegmatite dikes intruded in the cataclastic rocks (protomylonite, mylonite, ultramylonite), except quartzite. These dikes trending in NNW-SSE and dip 10^o-30^o / WSW and are emplaced parallel to cataclastic bands. Albitization, chloritization and fluoritization were major hydrothermal alteration processes. The pegmatite dikes (2-15 m in length and 0.3 m in width) are usually of the zoned type. The zonation starts with quartz at the core (smoky to milky in color) associated with micas (muscovite or Li –mica) followed by feldspars at the margins. The feldspars vary in colors from pink to milky and in composition from K-feldspar to Na-feldspar. Sometimes intercalations of both types are common due to albitization of k-feldspars. Some pyrite crystals were removed leaving vugs. These vugs are common in quartz and decrease in feldspars and could be considered as physical traps for mineralization.

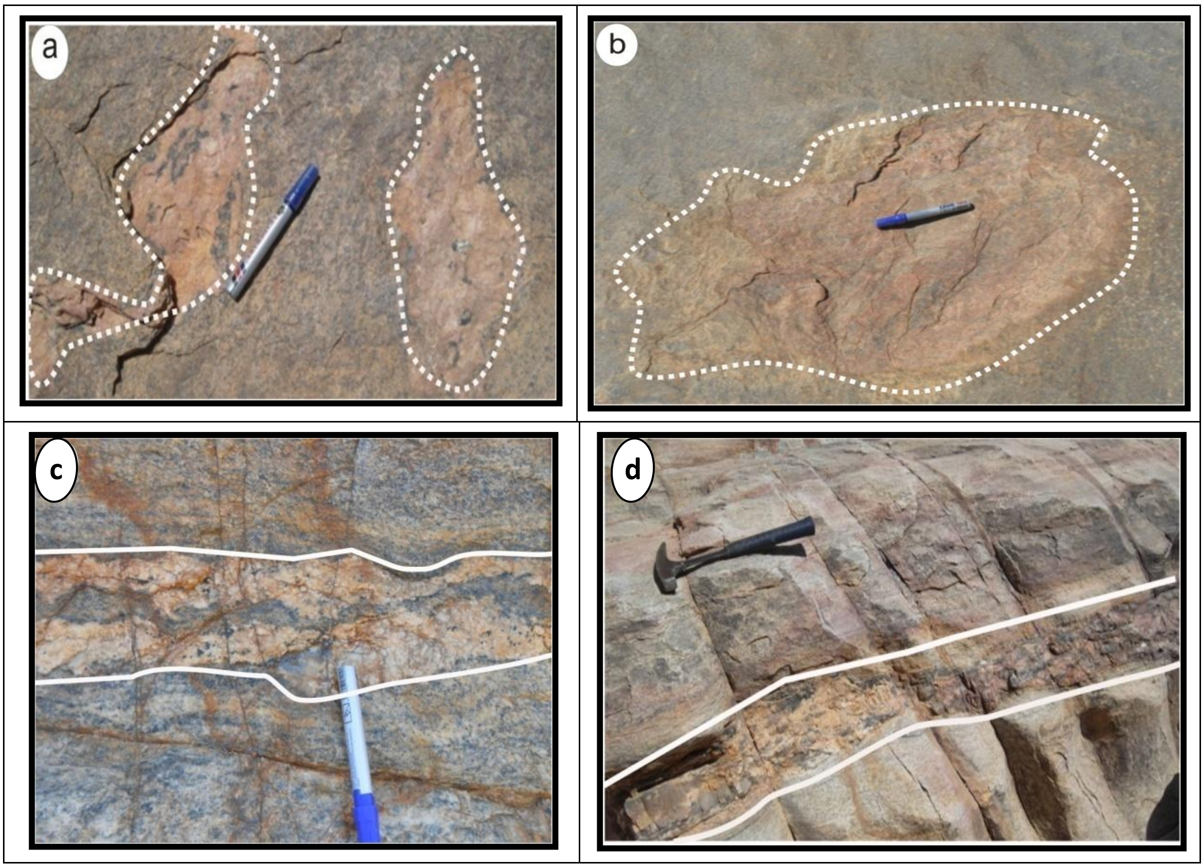


Fig.3. *Photomicrographs showing a-b) pegmatite segregations andc-d)dikes parallelto banding planes of the cataclastic rocks. Abu Rusheid area, Looking NW.*

The pegmatites are composed of euhedral to subhedral alkali feldspars, sodic plagioclase, quartz, muscovite and biotite. Garnet (spessartine), allanite-(Ce), zircon, apatite, fluorite, beryl, ilmenite and monazite-(Ce) are the common accessories. Perthite is probably developed due to the action of Na–bearing solutions penetrating through the cleavage planes in the K-feldspar resulting the replacement of the K-feldspar by sodium and the precipitation of albite. Myrmekite texture is common. Plagioclase (**An_{6-18}**) presents as sub-to euhedral crystals that are often corroded and infiltrated by quartz. Garnet occurs as pale pink small equi-dimensional crystals free from quartz inclusions. It obvious high relief, isotropic, irregular and rounded shape. Sometimes, faint layering of muscovite and garnet are locally encountered. It is argued that the increase in the hydroxyl and fugitive constituents as well as, silica and alkali as well as the relative decrease in ferromagnesian (Fe and Mg) would discourage the development of biotite, but localized changes in fluid chemistry resulting in locally more peraluminous environments enabling crystallization of peraluminous minerals (garnet and muscovite). Allanite-(Ce) occurs as minute anhedral crystals sporadically scattered in the rock but often associated with biotite and garnet.

4. MINERALOGY

The mineralogical study on pegmatites reveal the presence of 1) radioactive minerals represented by metatorbernite, uranophane, Β-uranophane, kasolite and thorite, 2) Nb-Ta minerals include ; columbite-(Fe) and euxenite–(Y) , 3) base metals (pyrite and molybdite), and 4) rare metal-bearing minerals (zircon, monazite –(Ce), allanite- (Ce), xenotime –(Y), and beryl) as shown in Table (1) compared with the main mineralogy of the cataclastic rocks reported by Ibrahim et al. (2004).

Table1. *Summary of the recorded minerals in the cataclastic rocks after Ibrahim et al., (2004) and in the present pegmatite rocks, Abu Rusheid area.*

Minerals	Cataclastic rocks	Mineralized pegmatite present study
U- minerals	Kasolite [Pb(UO2)SiO3.(OH)2], Curite [3PbO.8UO3.4H2O], Boltwoodite [K2(UO2)2(SiO3OH)2.5H2O], Autunite [Ca(UO2)2(PO4)2.8H2O)], Coeffinite [U(SiO4)(OH)], Carnotite [K2(UO2)(VO4)2.3H2O], Uranophane and β –uranophane [CaO.2(UO3).2(SiO2).6(H2O)] Torbernite [Cu(UO2)2(PO4)2.8-12(H2O)]	Torbernite [$Cu(UO_2)2(PO_4)2.8\text{-}12(H_2O)$] Uranophane and β –uranophane [$CaO.2(UO_3).2(SiO_2).6(H_2O)$] Kasolite [$Pb(UO_2)SiO_3.(OH)_2$]
Th- minerals	Uranothorite [(Th,U,Ce)SiO4], Thorite [ThSiO4], Cheralite [(Th,Ca,LREEs,U)(P,Si)O4] and Thorianite	Thorite [$ThSiO_4$], uranothorite
Niobium – Tantalum Minerals	Ishikawaite[(U,Fe,Y)(Nb,Ta)2O6], Columbite- Tantalate, Tapiolite	Columbite [$(Fe,Mn)(Nb,Ta)2O_6$] Euxenite[$(Y,Ce,Ca,U,Th)(Nb,Ta,Ti)2O_4$]
Base metals	Arsenopyrite, Pyrite, Chacopyrite, Bunsenite, Ilsemanite, Galena and Nimite	Pyrite and Molybdite
Iron oxide minerals	Hematite, Goethite, Ilmenite, Jarosite, Thuringite and Magnetite	Magnetite, Hematite and Ilmenite
Associated minerals	Zircon, Monazite, Fluorite, Allanite, Xenotime and REE-silicate	Zircon, Monazite-(Ce), Fluorite, Allanite-(Ce), Xenotime-(Y), Beryl

1-Radioactive minerals:

1. A. **Uranium minerals: Metatorbernite**; is a uranium phosphate mineral, and is formed by the dehydration of torbernite and contains 75% U, 11% Cu with a minor amount of Al, Fe, Ni and P as confirmed by SEM (Fig.4a). **Uranophane** is usually associated with its dimorph, namely, beta-uranophane and composed of 86.7%U, 5.3 %Ca, 3.3 %Si, 3.3 % Fe and 1.4 %Al(Fig.4b). **Kasolite** constitutes of 60.22%U,25.4%Pb, 5.8%Si, 2.3%Al,3.4%K and 2.88% Fe(Fig.4c).

1. B. Thorite: Thorite is associated with fluorite, pyrite, zircon and iron oxides. Thorite mostly occurs at high-temperature hydrothermal formation. Thorite composed of 62.5%Th, 5.4%U, 15.6%Si, 10.3%Fe and 6.2% Al with low U/ Th (11.6) (Fig.4d).The ESEM analyses of uranothorite in the pegmatite include, 52.9%Th, 13.7 % U, 11.5 % Si, 8.7% Fewith low U/Th (0.26) (Fig.4e).

2-Nb- Ta minerals

2.A.Columbite- (Fe): The ESEM analyses for columbite indicate a predominance of columbite (Nb > Ta), in association with UO_2, ThO_2, CaO and TiO_2. The ESEM analyses show its typical composition of ferocolumbite (Fig.4f) and composed of 57% Nb, 20 % Fe, 6 %Ta, 5.2% Ti and 10.3% Si with Nb/ Ta ratio = 9.6.

2.B.Euxenite- (Y): Occurs as an orthorhombic prismatic crystals; typically metamict mineral. It is characterized by brittle, brilliant submetallic, waxy to resinous luster. The obtained chemical analysis 27.86 % Nb, 4.85 % Ta, 13.17 % U, 3.99 % Th, 17.99 % Y, 19.26 % Ti, 3.06 % Ca and 7.13 % Fe were confirmed by ESEM techniques (Fig.4g).

3- Base metals

3.A.Pyrite: Occurs as large subhedral to anhedral grains with different sizes and shapes, characterized by its pale brass yellow color and ESEM analyses show 50.88 %Fe and 40.82 % S(Fig.4h).

3.B. Molybdite: The ESEM analyses of molybdite show its typical composition, where Mo up to 93.3% with 3.4 % Caand 3.3% Si(Fig.4i).

4-Rare metals

4.A. Zircon: Two types of zircon at Abu Rusheid pegmatite have been recorded; the first one is unaltered zircon, where the second type is altered zircon (Fig.4j). In spite of the fact that zircon is a good host of the HREE, they have not been detected in unaltered one of the analyzed zircon due to their mobilization during alteration. The EDX analysis of unaltered one indicates marked enrichment Zr where Zr/Hf ratio (33.5) always below the chondritic limit (35), suggesting relative enrichment of the heavier isovalent (Hf) due to metasomatism and its alteration products. While the second one have total REEs equal to 50% and Zr/Hf ratio (14.7). Wang et al. (2000) reported that the Hf enrichment in zircon, and the association of exotic REE and HFSE bearing minerals are linked to hydrothermal activity, suggesting that during the last stage of crystallization of the A-type magma, fluids enriched in REE, HFSE, F, CO^{2-} and PO^{3-}_4 were released.

The majority of scanned spot is composed of ThO_2 content more common than UO_2 content and have ThO_2/UO_2 ratio equal to 1.9.

4.B. Allanite–(Ce):Occurs as irregular grains and crystals in reddish feldspars associated with zircon. It is brown, pitch-black occasionally yellow in color. Allanite –(Ce) have formed from a volatile-enriched magma. Allanite–(Ce) common in some NYF-type pegmatite (Williams, 2002) and is confirmed by ESEM containing 33.57% Ce, 16.26% La, 12.41% Nd, 11.87% Th, 3.71% Pr, 3.04% U and 2.39% Y (Fig.4k).

4.C. Monazite–(Ce): Usuallyassociated with xenotime-(Y), columbite-(Fe) and zircon. Monazite-(Y) prefers NYF-type, but may occur in small quantities in LCT-type pegmatites (Williams, 2002). The ESEM analyses of monazite – (Ce) composed of 33.5% P, 10.6% Th,48.8% LREEsand 1.3%U(Fig.4l).

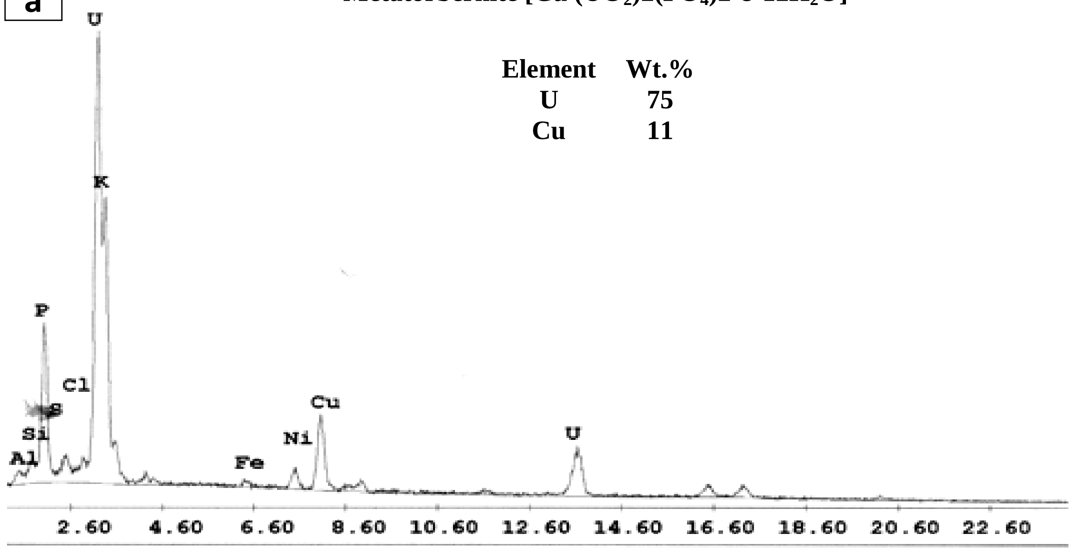
4.D. Xenotime-(Y): Occurs associated with fluorite and hematite and its ESEM analyses show 49%Y, 26.8%P,12.95% HREEswith rare Si and Al (Fig.4m).

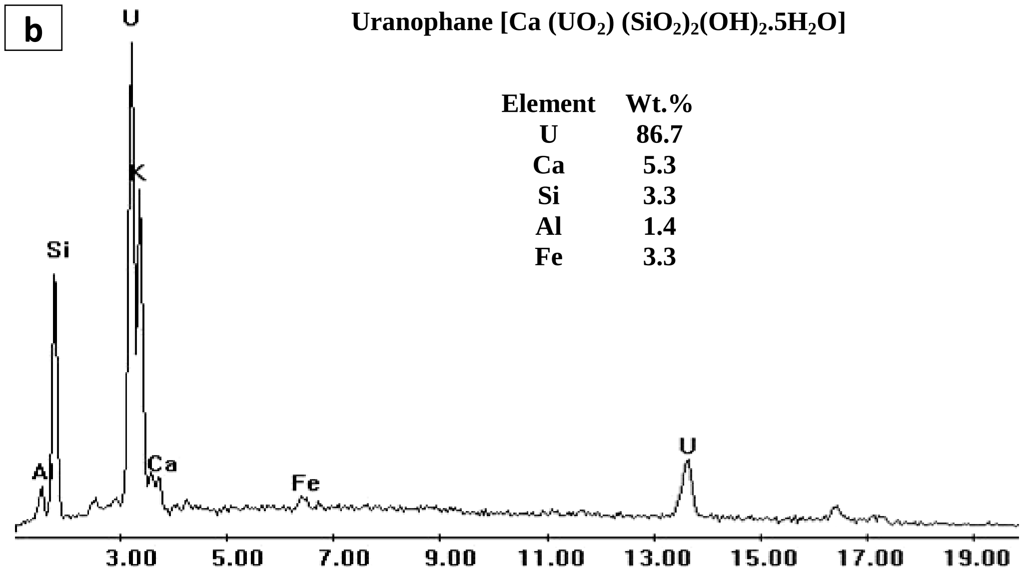
4.E. Fluorite crystals have variable colors as colorless, blue, and deep violet. The ESEM analyses show 15.8% F,2% Yand 82.19%Ca (Fig.4n).

a

Metatorbernite [Cu $(UO_2)2(PO_4)2$-8-$12H_2O$]

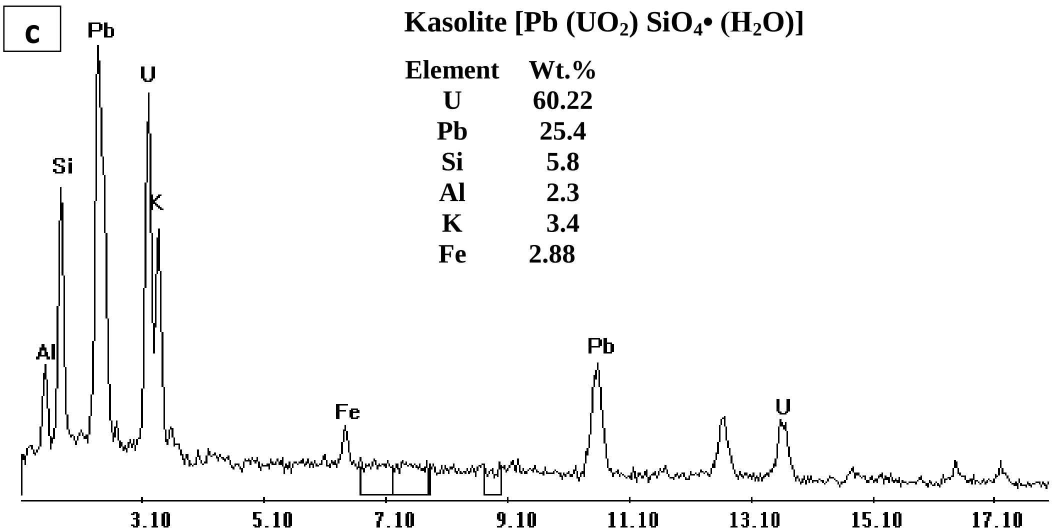
Element	Wt.%
U	75
Cu	11





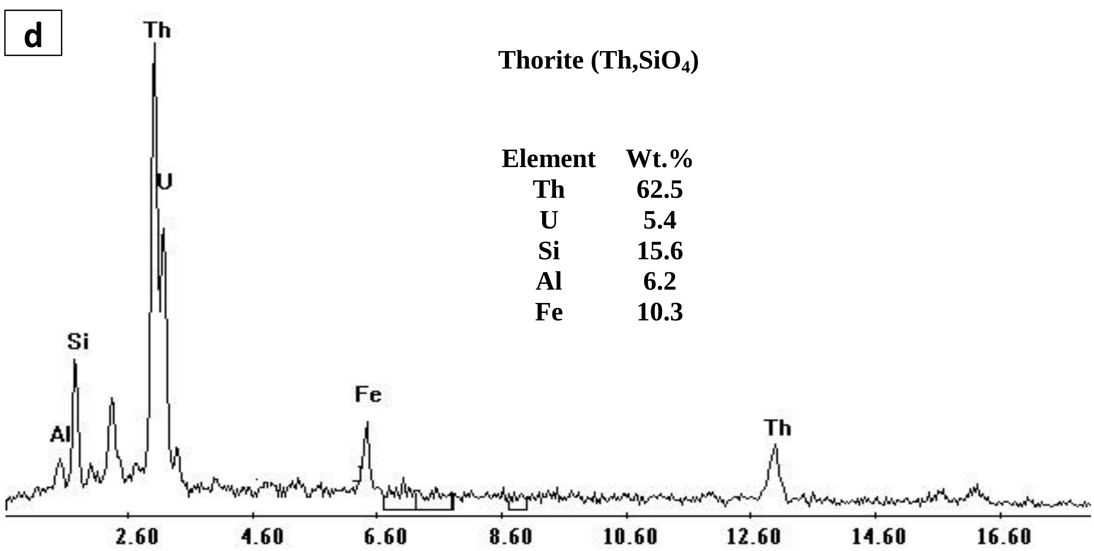
Uranophane [Ca (UO_2) $(SiO_2)_2(OH)_2.5H_2O$]

Element	Wt.%
U	86.7
Ca	5.3
Si	3.3
Al	1.4
Fe	3.3



Kasolite [Pb (UO_2) SiO_4• (H_2O)]

Element	Wt.%
U	60.22
Pb	25.4
Si	5.8
Al	2.3
K	3.4
Fe	2.88

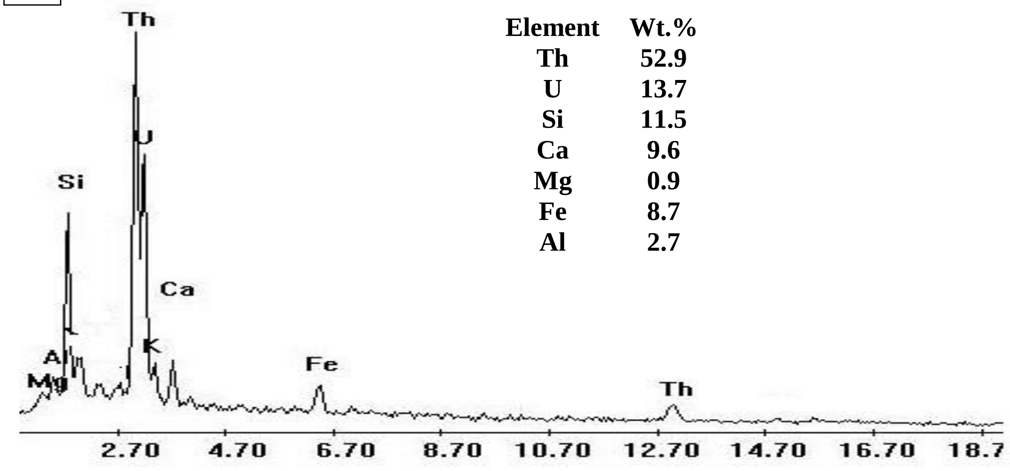


Thorite (Th,SiO_4)

Element	Wt.%
Th	62.5
U	5.4
Si	15.6
Al	6.2
Fe	10.3

e

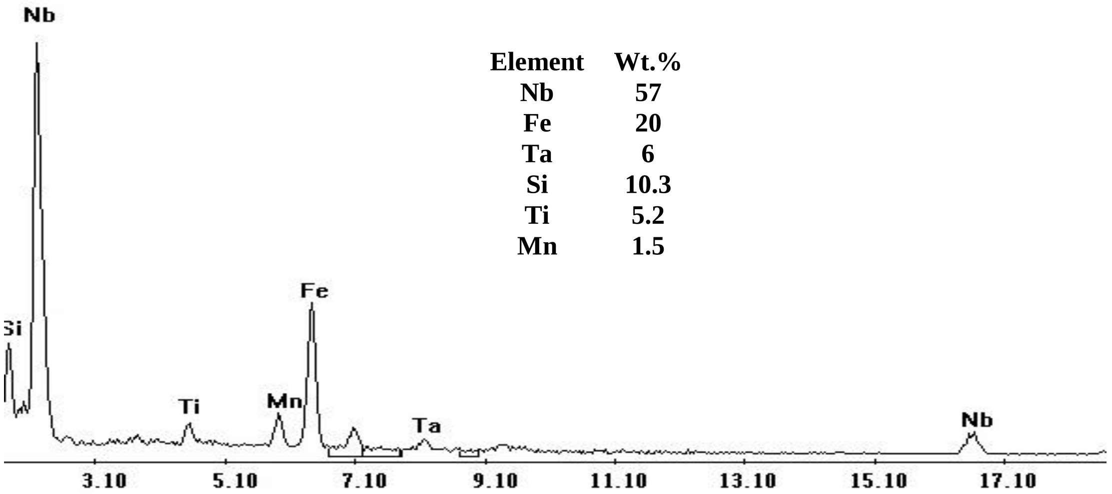
Uranothorite (Th, U) SiO_4



Element	Wt.%
Th	52.9
U	13.7
Si	11.5
Ca	9.6
Mg	0.9
Fe	8.7
Al	2.7

f

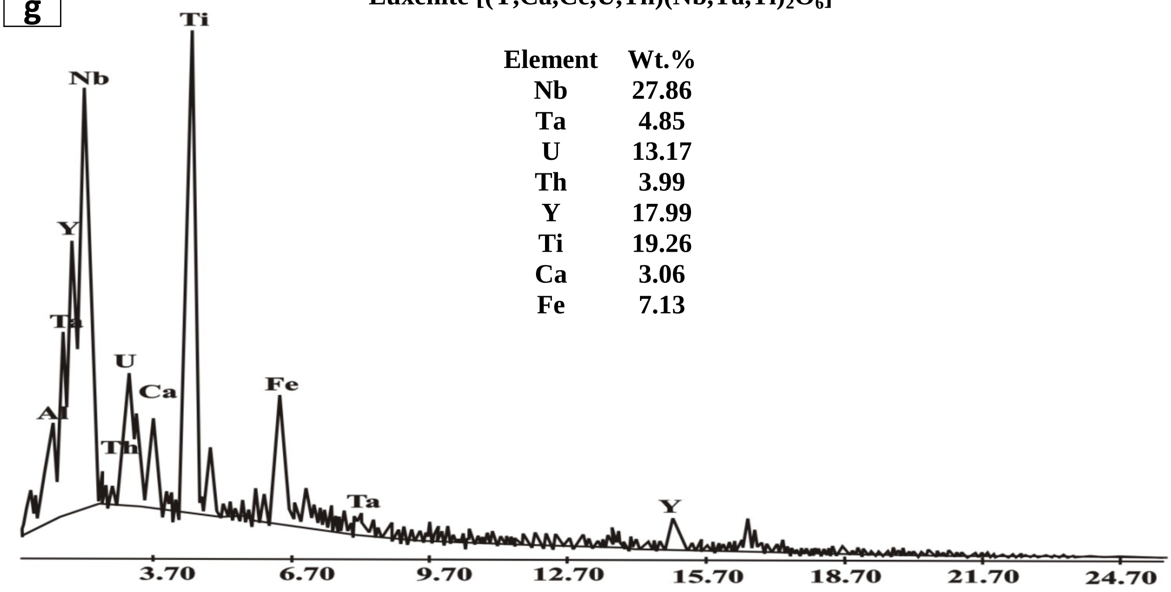
Columbite [(Fe, Mn, Mg) (Nb, Ta) $_2O_6$]



Element	Wt.%
Nb	57
Fe	20
Ta	6
Si	10.3
Ti	5.2
Mn	1.5

g

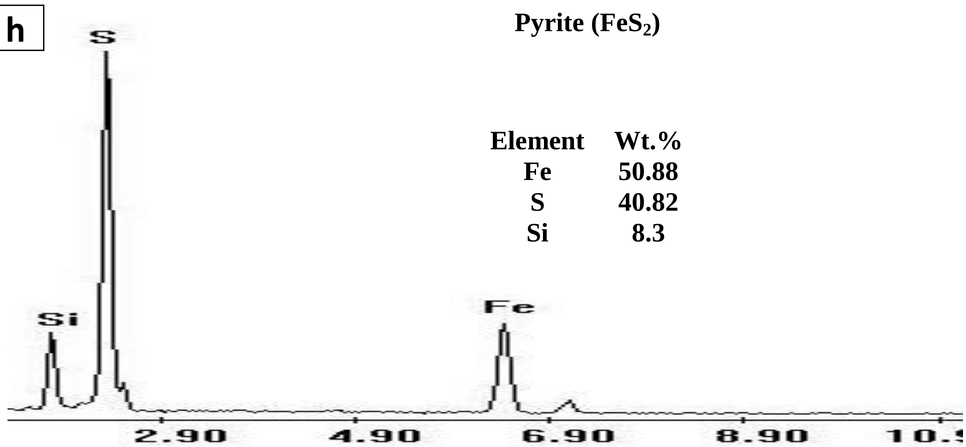
Euxenite [(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)$_2O_6$]



Element	Wt.%
Nb	27.86
Ta	4.85
U	13.17
Th	3.99
Y	17.99
Ti	19.26
Ca	3.06
Fe	7.13

h

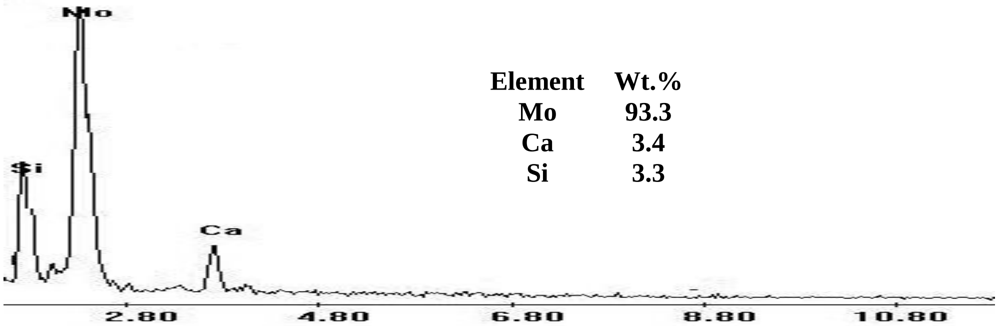
Pyrite (FeS_2)



Element	Wt.%
Fe	50.88
S	40.82
Si	8.3

i

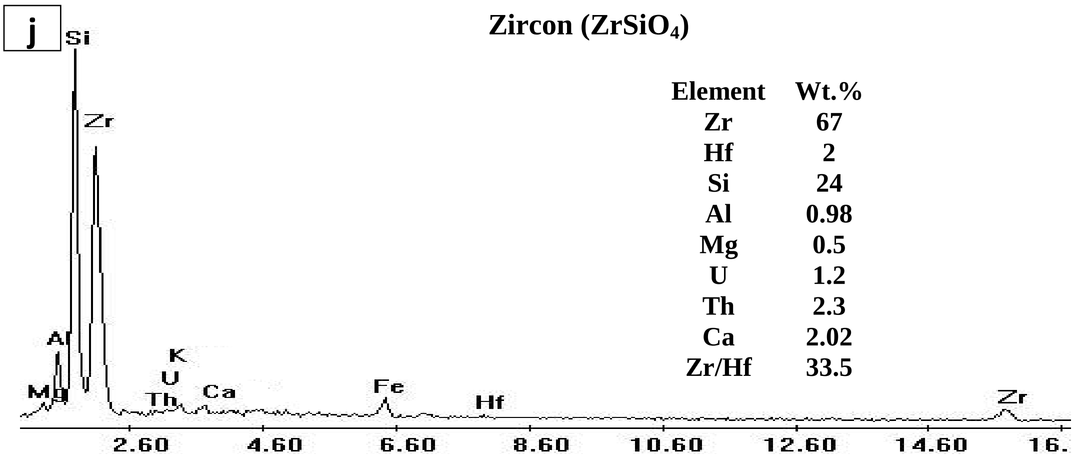
Molybdite (MoO_3).



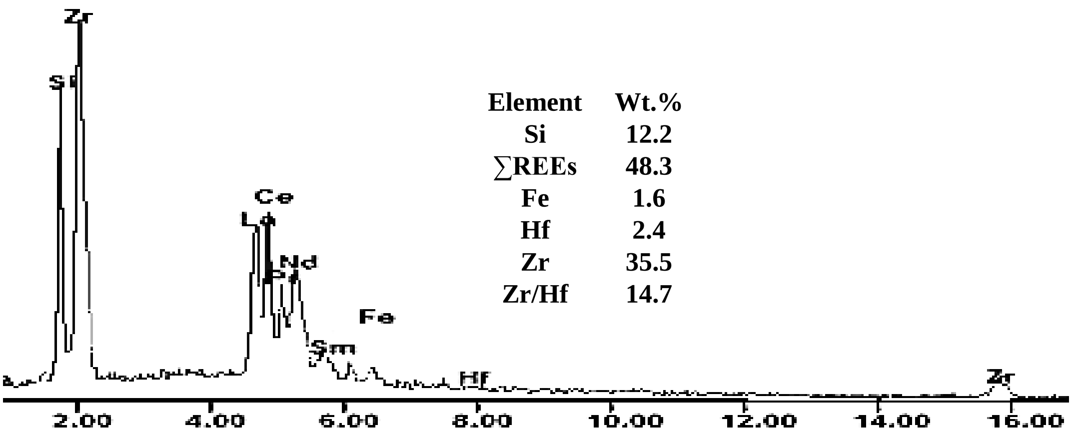
Element	Wt.%
Mo	93.3
Ca	3.4
Si	3.3

j

Zircon ($ZrSiO_4$)

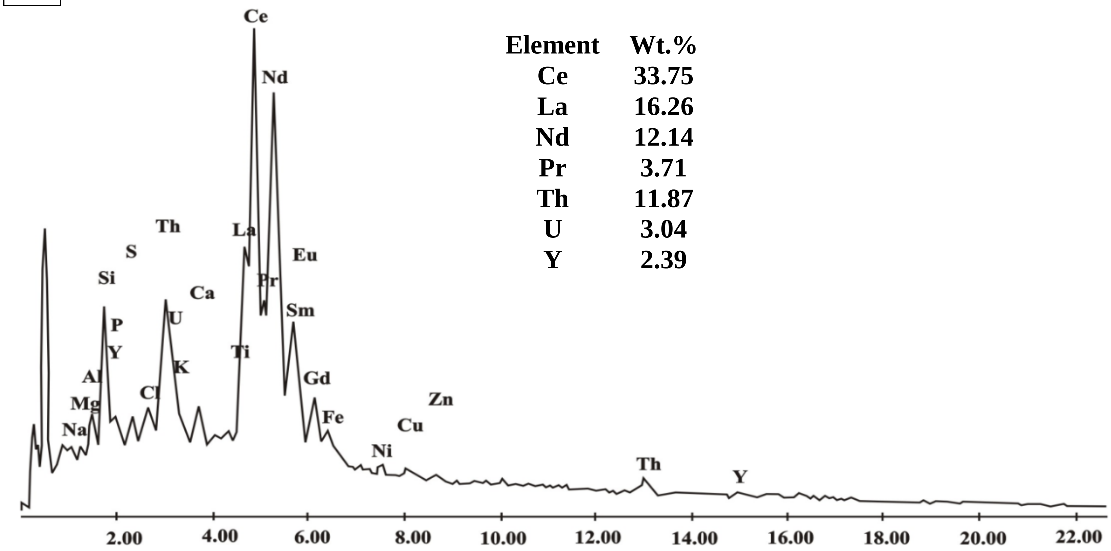


Element	Wt.%
Zr	67
Hf	2
Si	24
Al	0.98
Mg	0.5
U	1.2
Th	2.3
Ca	2.02
Zr/Hf	33.5

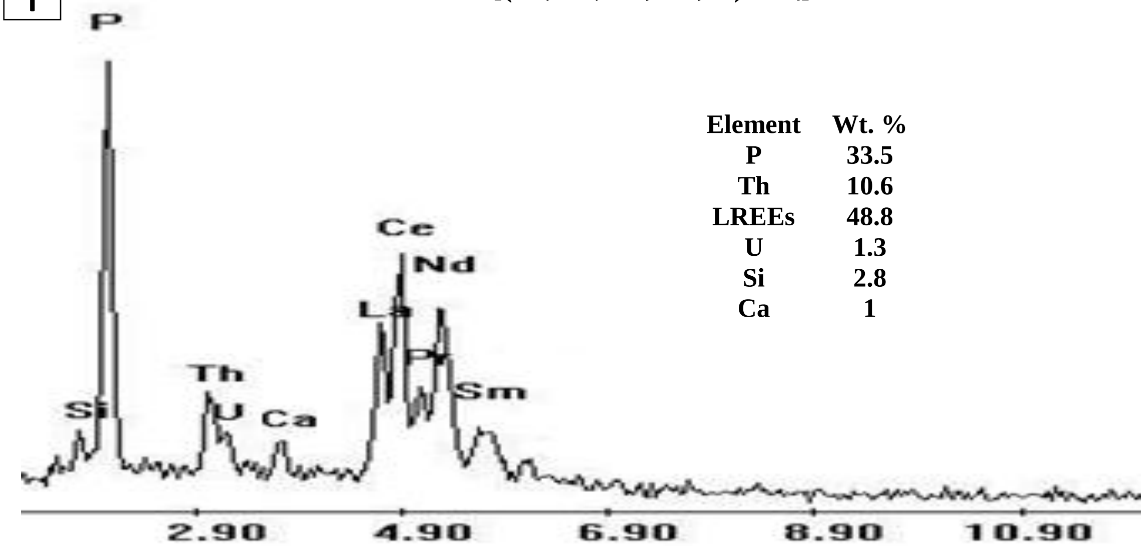


Element	Wt.%
Si	12.2
∑REEs	48.3
Fe	1.6
Hf	2.4
Zr	35.5
Zr/Hf	14.7

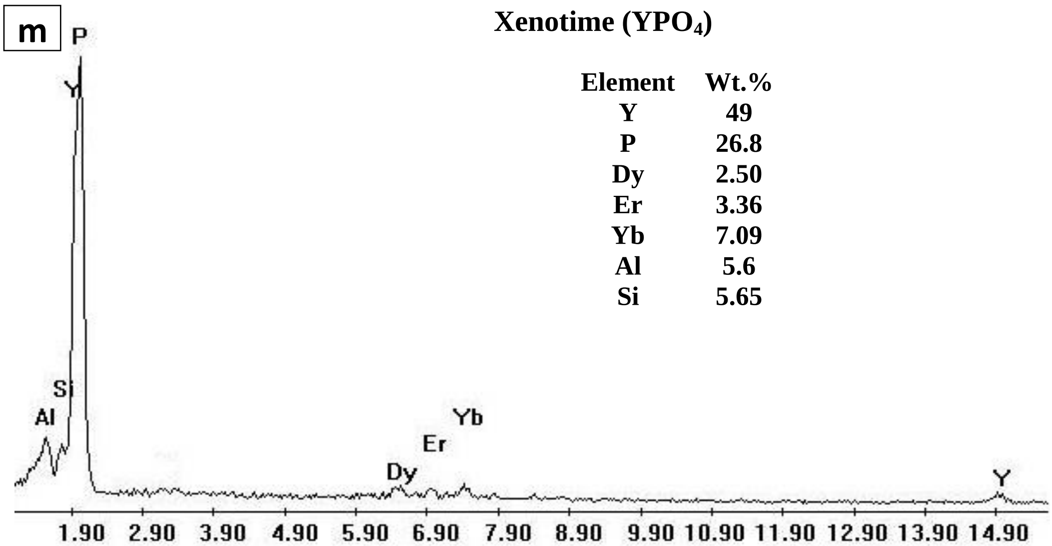
k **Allanite [(Ce, Ca, Y, Th)$_2$(Al, Fe, Mg)$_3$Si$_3$O$_{12}$(OH)]**

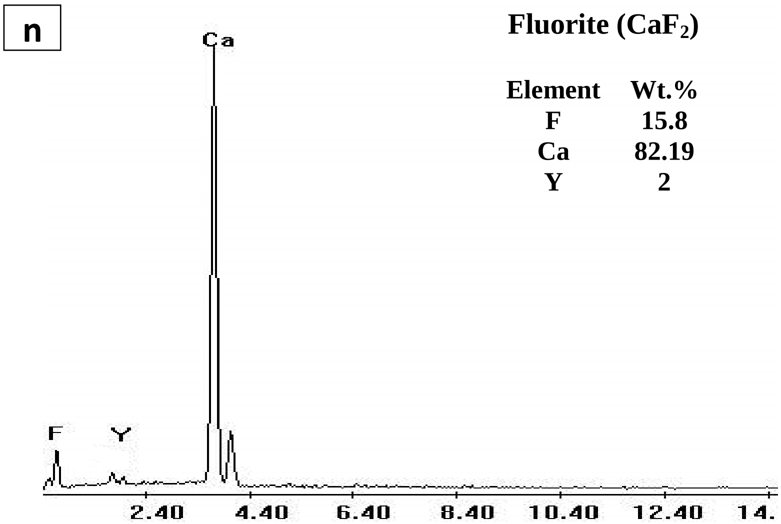


l **Monazite [(Ce, La, Th, Nd, Y) PO$_4$]**



m **Xenotime (YPO$_4$)**





Fluorite (CaF_2)

Element	Wt.%
F	15.8
Ca	82.19
Y	2

Figs.4. *EDEX of the recorded minerals, Abu Rusheid uraniferous pegmatites, SED, Egypt*

5. GEOCHEMISTRY

5.1. Major Elements

Abu Rusheid cataclastic rocks subdivided into three sub-zones based on Khour Abalea as base line into; a) northern Abalea zone, b) khour Abalea (middle) zone and c) southern Abalea zone (Fig. 2). Pegmatites have moderate to high silica (74.5% av.), Al_2O_3, (13.04% av.), normal TiO_2 (0.11% av.), MnO (0.03% av.), MgO (0.24% av.), Na_2O (4.4%av.) and K_2O(4.2% av.)contents, low-CaO content (1% av.) and high Fe/Mg ratio (5.9 av.) (Fig.5). Average value of Na_2O /K_2O and mol A/CNK ratio are generally >1%.

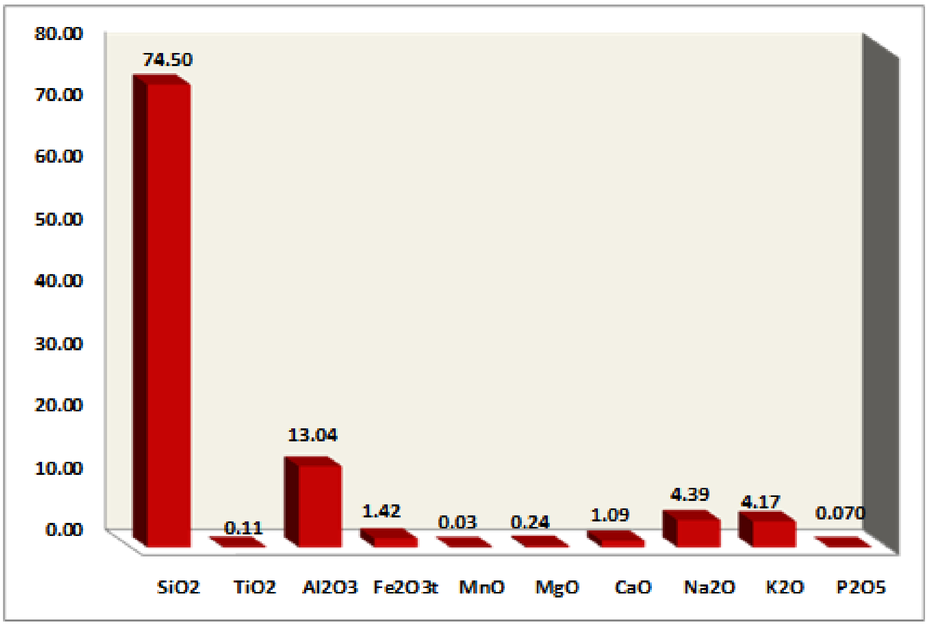


Fig.5. *Bar diagram showing the average contents of major oxides (Wt. %) in pegmatites, Abu Rusheid area.*

5.2. Trace Elements

Trace element data with some critical element ratios a usually employed for inferring regional characteristic, nature of source rocks (Whalen et al. 1987) and tectonic setup (Pearce et al. 1984; Brown et al. 1984). In general, the pegmatites from northern to southern zone, shows moderate to high abundance of Sr(19-181ppm, av. 96 ppm), Ba (23-405 ppm, av. 90 ppm), high Rb (116-3084 ppm, av.1427 ppm), high Nb (78-1179 ppm, av.382 ppm) and high Y(116-1932 ppm, av.891 ppm) (Table 2). The critical element ratio is significant in characterization of pegmatites and interpretation of petrogenetic history.

The pegmatites show low K/Rb (0.0024), Ba/Rb (0.05-0.11) and high Rb/Sr (11.4-18.3), which are essential criteria for uranium exploration in differentiated granite (Viswanathan, 1993). In general, ratio of Ba/Sr increases with fractionation, which indicates enrichment of Ba over Sr. But in studied rocks, Sr depletion, may be accompanied by drop in Ba where Ba/Sr varies from (0.74-1.2)in pegmatites. The enrichment of uranium in pegmatites (57-455 ppm) and cataclastics (50-975 ppm) are related to secondary U- minerals (uranophane, B-uranophane, torbernite and kasolite) (Table 2).

Table2. Average of trace elements (in ppm) of pegmatite at the northern, middle and southern Khour Abalea zone respectively, compared with cataclastics of the Abu Rusheid area

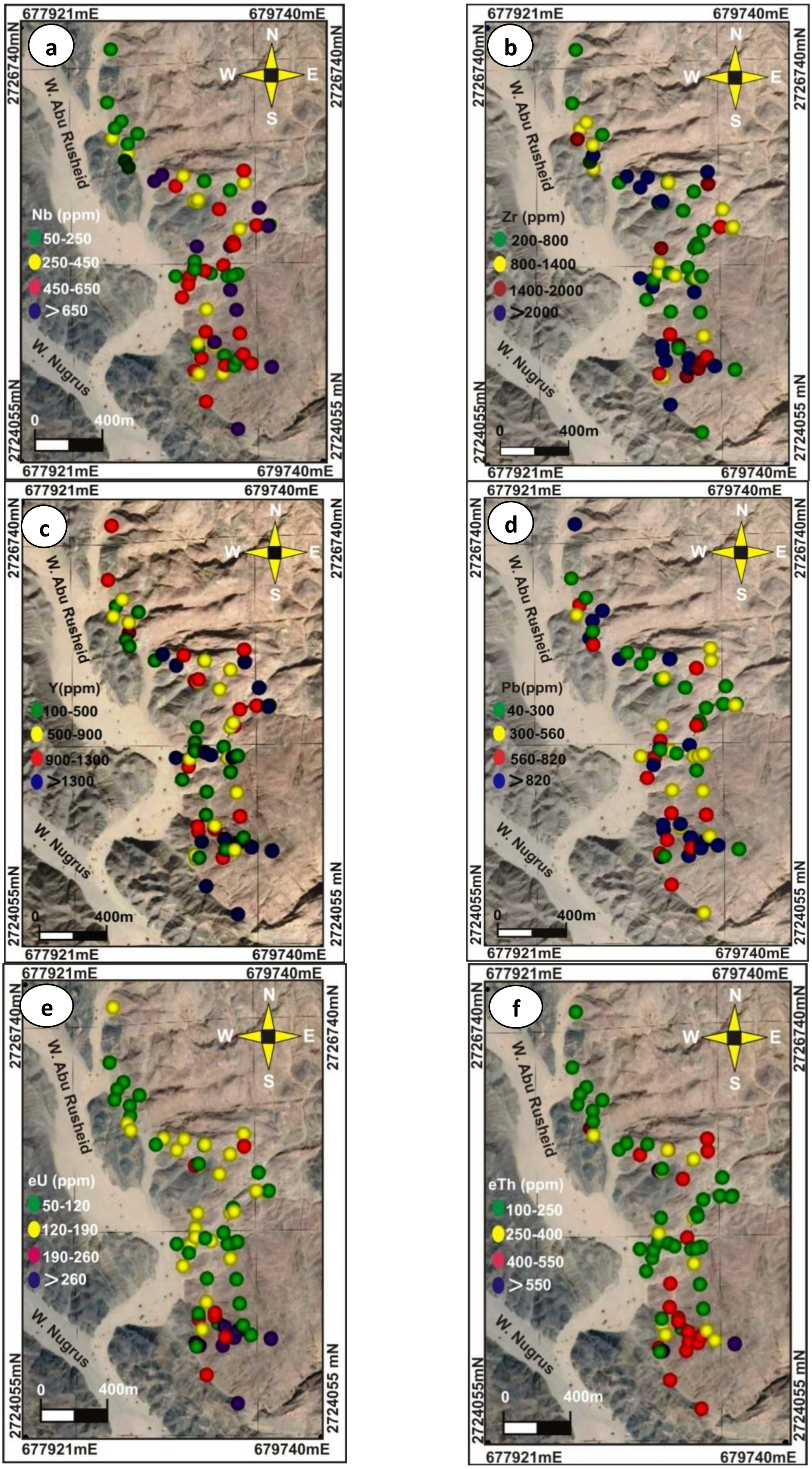
Trace element (ppm)	Northern Abalea Zone (n=11)	Middle Abalea Zone (n=44)	Southern Abalea Zone (n=15)	Cataclastics Host Rock N=5
Cr	34 (10-34)	41 (21-61)	40 (16-95)	15-80
Ni	10 (2-17)	18 (7-41)	12 (5-25)	20-38
Cu	126 (25-319)	66 (9-289)	143 (25-501)	15-333
Zn	224 (76-401)	434 (122-1515)	1026 (308-3549)	662-2750
Zr	969 (260-2214)	1331 (207-4316)	1738 (442-3384)	1611-3037
Rb	1906 (1031-3084)	1347 (300-2993)	1029 (116-1717)	884-1345
Y	626 (179-1289)	852 (116-1932)	1196 (480-1863)	226-1200
Ba	91 (30-405)	70 (23-245)	109 (25-302)	144-234
Pb	673 (194-1091)	514 (40-2592)	754 (246-1591)	600-1915
Sr	104 (19-134)	94 (21-217)	90 (22-181)	25-200
Nb	264 (84-1179)	443 (78-990)	439 (91-767)	400-1300
eU	87 (57-134)	129 (58-249)	275 (76-455)	50-975
eTh	228 (134-495)	310 (101-1939)	426 (132-633)	126-2200

n=number of the samples

Isoconcentration maps (Fig.6) were constructed for some trace elements (Nb, Zr, Y and Pb) showing their surface distribution in pegmatites. Nb- content (ranges from 50 to > 650 ppm, on average 400 ppm) and attributed to the presence of columbite- (Fe) and euxenite-(Y) minerals. Zr- content (varies from 200 to > 2000 ppm, on average 1000ppm), Y- content (ranges from 100 to >1300 ppm, on average 500ppm) and related to xenotime- (Y). Pb- contents (vary from 40 to 900 ppm, on average 600ppm). The average contents of rare metals in the host rocks (Zr=2000ppm, Y=500ppm, Nb=500ppm and Pb=200ppm, Ibrahim et al. 2010) are relatively comparable with the intruded pegmatites.

The distribution of trace elements (Fig.6a-d) revealed that, Khour Abalea and its southern zone are richer in Zr, Zn, Y, Pb and Nb elements (Table 2) than the northern zone. This related to the pathways (NNE, NE and ENE trends) and the common occurrence of zircon, xenotime-(Y), galena and columbite-(Fe). Whereas the northern part of Abalea is more enriched in Rb (1906 ppm) than the other two zones (1347 and 1028 ppm respectively) due to the presence of amazonite veinlets (Table 2).

In light of the Abu Rusheid pegmatites, the following observations can be pointed out: 1-Geochemical maps based on 70 pegmatite samples were used to delineate the most suitable locations for the surface and probable hidden mineralization (Figs. 4). 2- The area have background U and Th values higher than the corresponding Clark value, it was also observed that, Nb Pb, Y and Zr have abnormal contents and could be considered as low grade ores.



Figs.6. *Distribution of some trace elements and eU, eTh (ppm) (in ppm) in Abu Rusheid pegmatite.*

5.3. Rare Earth Elements

The rare earth elements (REE) of the pegmatite and cataclasics (Table 3) were plotted in the normalized pattern (normalized to the chondrite values of Sun, (1980) (Figs. 7a -b). The REE contents have been upgraded from cataclastics rocks (134 ppm, on average) to pegmatites (342 ppm on average). Cataclastic samples exhibit fractionated REE patterns [(La/Yb) N=0.29 on average] and display relatively flat LREE [(La/Sm) N= 2.52 on average] with relatively enriched HREE [(Gd/Lu) N= 0.66 on average] and negative Eu anomalies (Eu/Eu*= 0.11). All the analyzed rocks show negative Eu anomaly, Eu/Eu* =0.01 – 0.28 (Fig.7). Eu anomaly could be related to REE mobility (Boynton 1984) or due to Eu leaching by the volatile phase rich in fluorine, H_2O and low temperature(650^{0} C)(Taylor et al. 1981 and Monecke et al. 2002) or attributed to sericitization (Alderton et al. 1980 and Bau, 1996). LREE is more enriched than the HREE in pegmatite (ΣLREE/ΣHREE = 7.8) and related to the presence of allanite-(Ce) and monazite-(Ce). Also, the presence of positive Ce anomaly (Ce/Ce*) ranging from 0.7 to 1.22 is attributed to occurrence of monazite- (Ce) and to oxidizing conditions.

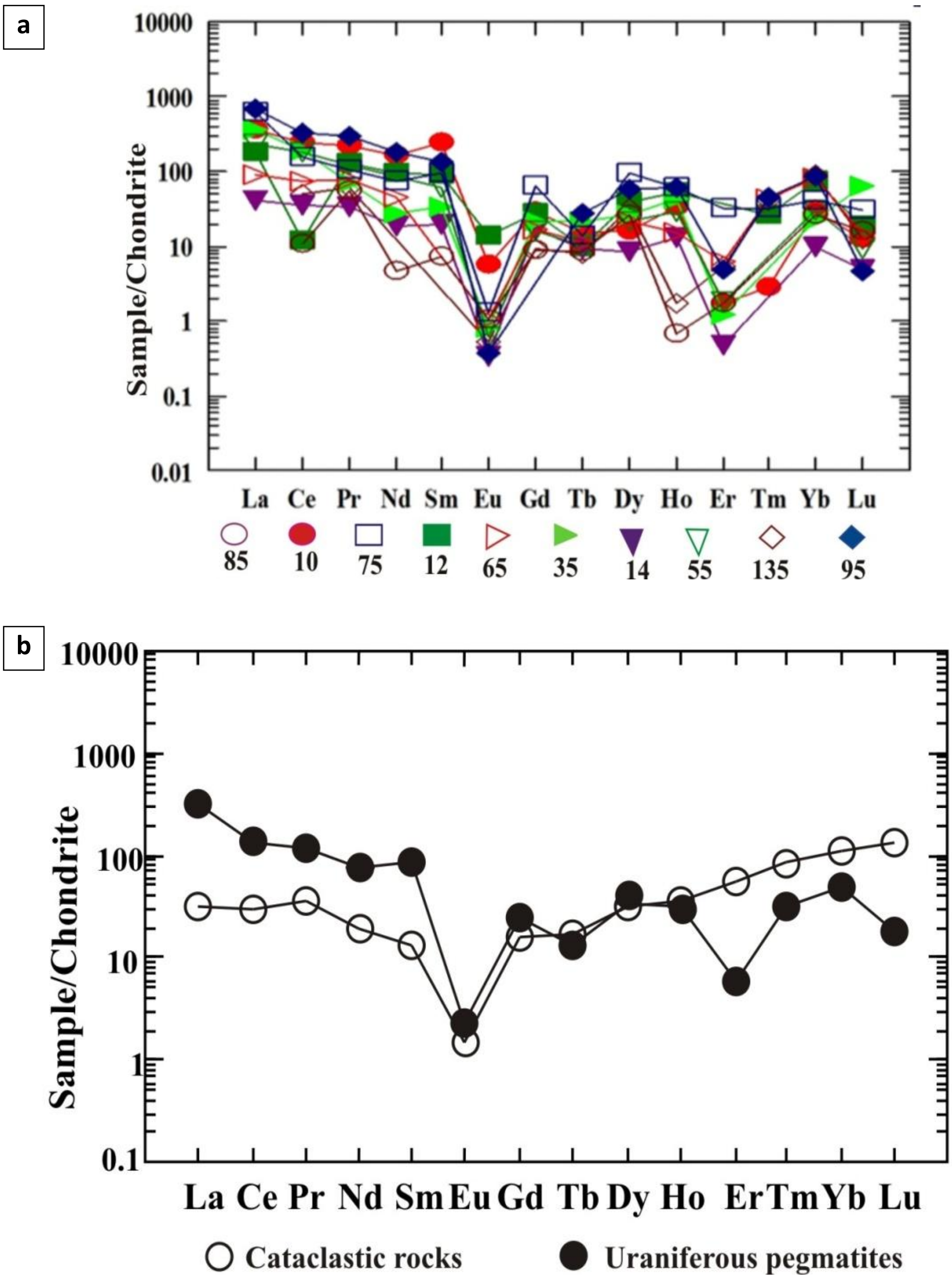


Fig.7. *(A)Chondrite-normalized REE patterns for the Abu Rusheid pegmatite (B)Averages of chondrite-normalized REE patterns of pegmatite and cataclastics, Abu Rusheid area, Normalizing values after Sun, (1980).*

6. REE TETRAD EFFECT

The tetrad effect manifests as a split of the chondrite normalized REE patterns into four segments called tetrads (first tetrad La-Ce-Pr-Nd; second tetrad, (Pm)-Sm-Eu-Gd; third tetrad, Gd-Tb-Dy-Ho; fourth tetrad, Er-Tm-Yb-Lu). Masuda et al. (1987) classified the tetrad effect into two different types, M-and W-type (M-type in solid sample as residues and W-type in the interacting fluids as extract).

Masuda et al. (1994) and Minami and Masuda, (1997) presented a mathematical method to evaluate the degrees of lanthanide tetrad effects. Irber, (1999) proposed an alternative method of quantification to determine the intensity of the tetrad effect. In this case, only the first and the third tetrad are used for quantification of the tetrad effect and only samples with values of TE 1,3>1.10 are considered. The REE tetrad effect was mainly observed in late magmatic differentiation related to strong hydrothermal interactions or deuteric alteration (Jahn et al. 2001).

The calculated TE1,3 values for the REE patterns of the pegmatites are significantly lower than unity except two samples ranging from 0.59 to 1.1 (Table 3). The chonderite-normalized REEs patterns of the Abu Rusheid pegmatites show M-type tetrad effect similar to that quoted by Masuda et al. (1987).

Table3. Concentrations of rare earth elements of the pegmatites and cataclastics of the Abu Rusheid area

Sample No.	10	I2	14	35	55	65	75	85	95	I35	Average (n=10)	Catac. (n=5)
La	135.12	66.58	15.22	134.6	85.62	33.84	228.6	n.d	254.5	n.d	95.41	12
Ce	233.08	111.3	33.89	181.6	173.25	72.83	149.5	10.29	307.0	47.01	131.97	29
Pr	30.48	17.50	4.72	9.62	16.47	10.55	14.63	7.61	39.74	8.38	15.97	5
Nd	118.98	68.34	13.42	19.91	n.d	32.54	51.68	3.39	127.17	n.d	43.54	14
Sm	57.59	21.32	4.53	7.67	14.10	n.d	21.75	1.64	31.70	n.d	16.03	3
Eu	0.50	1.23	0.03	0.07	0.053	0.094	0.11	0.09	0.033	0.046	0.23	0.13
Gd	8.89	8.53	5.20	6.61	4.86	5.25	19.23	2.69	11.0	2.80	7.51	5
Tb	0.88	0.57	0.55	1.23	0.59	0.66	0.81	0.50	1.57	0.47	0.78	1
Dy	6.14	14.68	3.29	10.01	8.05	8.34	35.58	9.79	21.60	12.35	12.98	12
Ho	2.83	4.37	1.12	3.70	2.50	1.33	5.25	0.058	5.18	0.146	2.64	3
Er	0.43	n.d	0.12	0.31	0.46	1.58	7.98	0.44	1.20	1.36	1.39	14
Tm	0.10	0.92	n.d	n.d	n.d	1.55	1.16	n.d	1.63	1.48	0.68	3
Yb	7.08	18.11	2.41	5.56	7.43	20.14	10.37	6.54	21.83	22.54	12.2	28
Lu	0.48	0.71	0.19	2.40	0.35	0.55	1.19	0.62	0.18	0.48	0.72	5
∑REEs	602.58	334.16	84.69	383.3	313.73	189.25	547.8	43.65	824.33	97.062	342	134
Eu/Eu*	0.07	0.28	0.02	0.03	0.02	---	0.02	0.13	0.01	---	0.06	0.1
Ce/Ce*	0.8	0.7	0.97	1.22	1.12	0.93	0.77	--	0.7	--	0.859	1.1
TE1,3	0.68	0.686	0.86	0.93	--	1.06	0.59	--	1.1	--	0.8	1.2
Sr/Eu	320	107	3600	457	3415	202	1927	811	1455	2348	--	--
Y/Ho	683	113	990	81	98	203	22	30897	337	1226	--	--
La/Gd	15.2	7.8	2.9	20.4	17.6	6.4	11.9	0.0	23.1	0.0	12.7	2.4
∑LREEs	575.8	286.3	71.8	353.5	289.5	149.9	466.3	23.0	760.1	55.4	303.2	63.1
∑HREEs	26.83	47.89	12.8	29.82	24.24	39.4	81.57	20.63	64.19	41.626	39	71
∑LREEs/HREEs	21.5	6.0	5.6	11.9	11.9	3.8	5.7	1.1	11.8	1.3	7.8	0.9

n= Number of samples analyzed. Pegm.=pegmatites, Catac.=cataclastics.

The tetrad effect is possibly caused by (1) fractional crystallization during igneous crystallization (Pan and Breaks, 1997), (2) fluid–melt interaction during crystallization of the silicate melt (Zhao et al. 2002, 2010), (3) hydrothermal alteration during hydrothermal fluid–rock interaction (Moneckeet al. 2007), and (4) weathering after granite formation (Takahashi et al. 2002).

7. SPECTROMETRIC PROSPECTING

Uranium and thorium tend to concentrate in the residual phases and enter the accessory minerals such as zircon, columbite–(Fe) and monazite-(Ce) (Rogers and Adams, 1969). Also, they may form minerals of their own such as thorium and uranium minerals. It has been shown that the accessory minerals and their sequence of crystallization play a major role in controlling the geochemical behavior of uranium and thorium in silicate melts (Simpson et al. 1979). The early crystallization of uranothorite would lead to significant U-enrichment in the residual fluids. On the other hand, the early crystallization of zircon and/or xenotime would lead to Th-enrichment in the residual fluids (Pagel, 1982).

The eU and eTh contents in the pegmatite range from 50 ≥ 250 ppm and from 100 ≥ 550 ppm respectively. The average contents of eU and eTh (in ppm) in the pegmatite at khour Abalea (77 ppm and 245 ppm) are higher than both southern and northern Abalea zone (83 ppmU and 128ppmTh) (36ppm U, 112ppm Th respectively). The strike–slip faults in Abalea zone played good pathways for transportation and redeposition of U – Th mineralization.

The average eU (83 ppm) content in pegmatite at the southern part of Abalea is more than the northern part (36 ppm) (Fig. 6e-f). The average of eU/eTh ratios in pegmatites greater than 0.4 (0.42), so that they are fertile pegmatites (Hall and Walsh, 1969). The studied pegmatites have eTh/eU ratio averaging 1.69 indicating high effect of hydrothermal solution and affected by post–magmatic processes. Sminov, (1984) suggested that the low Th/U ratio (less than 3) is due to the effect of fluids carrying uranium mineralization. Cathelineaus and Holluger, (1987) stated that the uranium mineralization is affected by the different stages of alteration, these stages of leaching; mobility and redeposition of U are affected by hydrothermal solutions and supergene fluids causing oxidation of the medium. Also, the presence of amazonite tends to enhance the content of U and Th.

Radioactive minerals (metatorbernite, uranophane, B-uranophane, kasolite and thorite) in addition to zircon, monazite–(Ce), xenotime–(Y), fluorite, allanite-(Ce) and columbite- (Fe) are the main sources of the radioactivity in the studied pegmatites. The origin of the supergene secondary uranium minerals in pegmatites is mainly related to alteration of tetravalent primary U-minerals by the action of oxidized fluids and mobilization of uranium through pathways and redeposition along fracture planes and adsorbed on clay minerals and iron oxides as secondary minerals

8. DISCUSSION AND CONCLUSION

Two forms of pegmatite (segregations and dikes) have been intruded thecataclastic rocks at Abu Rusheid area. The pegmatites trending NNW-SSE with dip of about 10-30° due WSW parallel to banding of the cataclastic country rocks. They shows a zonal distribution from the barren core to mineralized wall-zone in the metals; Zr, Nb, Y,Zn, Pb, Th and U. Albitization, chloritization, fluoritization and silicification are the common alteration processes in pegmatites due to the effect of hydrothermal solution. The zoned pegmatite dikes characterized by cavities and vugs. These vugs are common in quartz and decrease in feldspars and could be considered as physical traps for rare metal mineralization.

On the basis of mineralogical and chemical characteristics, the cataclastic rocks are derived from S-type magma. Therefore, during late stage of anatexis silica is predominant phase than alumina due its higher mobility (Tracy and McLellan, 1985). Quartzite was formed at the late stage of cataclastic rocks without banding or gneissosity or even intruded by pegmatites. Low CaO content and enrichment of HFSE (Nb, Zr, Y, U, Th) in cataclastic rocks, suggest that they are primarily derived from felsic source.

LCT- pegmatite type suit are enriched in Li, Cs, Ta and B and derived from undepletet upper-crustal lithological suffering their first anatectic event, which mobilizes the most volatile component into low-temperature, low-percentage melts. NYF-type suite is characterized by; 1) high economic concentration of Zr, Nb, Y, Zn, Pb, Th and U , 2) have the geochemical signature of A-granites and 3) may be derived by melting of depleted lower-crustal sources. The high Rb/Sr, Ba/Sr, K_2O% and moderate Rb and low Sr content exclude derivation of the pegmatites from basic parentage (Rogers and Greenberg, 1990). The studied Abu Rusheid pegmatites have low-CaO content (1 % on average), high Fe/Mg ratio (5.9 on average), peraluminous, A-type post-orogenic tectonic setting (Ragab, 2003) and equivalent to NYF- pegmatite type.

The REE contents have been upgraded from cataclastics rocks (134 ppm on average) to pegmatites (342 ppm, on average). Cataclastic samples exhibit relatively enriched HREE [(Gd/Lu) N= 0.66 on average]. The pegmatites have clear enrichment of LREE relative to HREE as indicate by the presence of zircon, allanite-(Ce) and monazite-(Ce). Also, the presence of positive Ce anomaly (Ce/Ce*) ranging from 0.7 to 1.22 is attributed to occurrence of monazite- (Ce) and to oxidizing conditions. Hydrothermal alteration during post magmatic stages is also identified through the development of M-type tetrad effect in the REE pattern of pegmatite.

The rare metals enrichment in the study area are formed due to the subsequent processes; including the ascending hydrothermal solutions (alkaline followed by acidic hydrothermal solutions), with further contribution of the descending acidic meteoric water; supergene enrichment processes. The origin of uranium appears to be closely associated with the rare metals mineralization and may be reflects readily their intimate coherence. The later conclusion is compatible with Ibrahim et al. (2004) on cataclastic rocks and could be related to the same origin.

Uranium bearing pegmatitic segregation in parallel to cataclastics banding may be formed before segregation of silica-rich melt and forming quartzite during culmination stage of cataclastic rocks (protomylonite, mylonite and ultramylonite). According to Jahns and Burnham (1969), early appearance of vapour phase during crystallisation history can segregate and form large pegmatite but late stage of saturation can only permit to form small segregation parallel to the banding of cataclastic rocks. Similarly highly mobile elements like uranium, probably derived from fertile host rocks (cataclastic rocks), can easily be saturated in vapour charged silica-rich pegmatitic fluids. With change of physico-chemical conditions of the rock, Zr, Nb, Y, Th and U- minerals are crystallized syn-magmatically. Abu Rusheid area could be considered as low grade for U, Th, Nb ores (Figs. 8) and moderate grade for Zr ore.

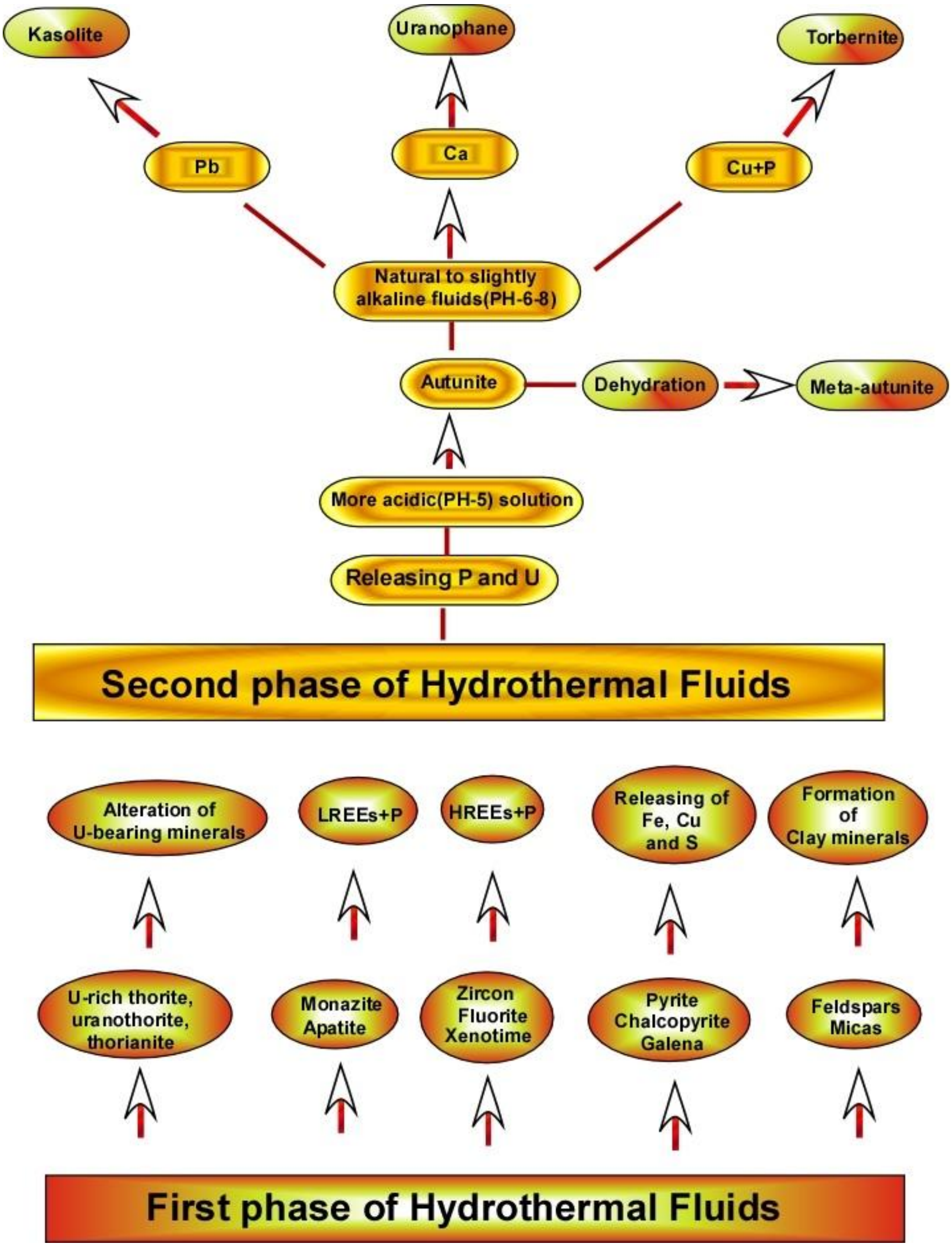


Fig.8. *Paragenetic model of the uranyl minerals from the Abu Rusheid area with major modification after (Ibrahim et al., 2004 and Dawood, 2010)*

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