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Occurrence of polymetallic mineralized pegmatite at Wadi El Sheih granite, Central Eastern Desert, Egypt

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Abstract
Uncommon presence of rare-metal mineralization is recorded in the mineralized pegmatite injected in Wadi El Sheih older granitoids at the central Eastern Desert of Egypt. The studied mineralization was found as distinguishable megascopic crystals of economic minerals scattered within the pegmatitic bodies. Detailed mineralogical and chemical investigation were carried out using microscopic examinations, x-ray diffraction (XRD),scanning electron microscope (SEM) providing with energy-dispersive spectrometer (EDS) and x-ray fluorescence (XRF). These studies revealed the presence of several valuable minerals such as euxenite-(Y), fergusonite-(Y), allanite-(Ce), and xenotime-(Y), in addition to uranothorite and zircon. Accordingly, the mineralized Wadi El Sheih pegmatite can be considered as a promising target ore for its rare metal mineralization that includes mainly Nb, Ta, Y, U, Th, and REE together with Zr and Hf.

Key words: *Rare-metal pegmatite; Euxenite-(Y); Fergusonite-(Y); Allanite-(Ce); Wadi El Sheih older granitoids*

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I. Introduction

Pegmatite is important because it often host a diversity of mineral species of great economic interest, and is a source of rare metals such as Be, Sn, Li, Rb, Cs, Nb, Ta, and Ti. In addition, it has been considered a source of rare earth elements (REE) and radioactive elements, such as U and Th. Pegmatite also is a source for high-quality industrial minerals, such as feldspar, kaolinite, quartz, mica, and spodumene that used in ceramic industry. Pegmatite is a source of large variety of highly priced colored gem minerals as topaz, tourmaline, aquamarine, and beryl (Linnen, 2012 and London, 2008).

The Egyptian granitic rocks in general grouped into two major suites older and younger granitoids. The older granitoids are Grey, syn-orogenic or Shaitian granites: They are of wide compositional spectrum of qz-diorite, tonalite, granodiorite and rarely true granite. This suite is wide distribution in the Eastern Desert of Egypt, where they make up 26.7% of the basement outcrops (Stern, 1979).

The younger granites, pink-, and late to post-orogenic:-These rocks range from calc-alkaline to peralkaline rocks (El Gaby, 1975 and Noweir et al., 1990) considered the younger granites of Egypt as transitional phases from calc-alkaline I-type magmatism to normal alkaline and alkaline A-type granites. Younger granites constitute 16.2% of the total basement outcrops in the Eastern Desert (Stern, 1979).

Several rare metal mineralization occurrences have been recorded in different localities of the Eastern Desert of Egypt as well as south Sinai. These mineralization are mainly restricted to the granite pegmatite bodies associated with the younger granite that are widely distributed in the Eastern Desert and Sinai (Omar, 1995; Ibrahim et al., 1996; Abdalla et al., 1998; Ibrahim, 1999;Ammar, 2001; Abdalla and El Afandy, 2003; Ali et al ., 2005; Abd El Wahed et al., 2005; Abd El Wahed et al., 2006; Abdel Warithet al., 2007, Raslan et al., 2010a&b;Raslan, 2015;Raslan et al., 2017; Raslan and Fawzy, 2018 and Fawzy et al.,2020). Otherwise, a late Precambrian biotite schist and quartzite was also recorded as a rare case country rocks enclosing rare-metal mineralized pegmatite (Salah, 2007).

Several studies worldwide have revealed the presence of granite-pegmatite-hosted critical rare-metal mineralization including Nb-Ta oxides and zircon (Matsubaraet al., 1995; Erict, 2005; William et al., 2006; Pal et al., 2007). The critical rare metals and metalloids all exhibit a diverse range of chemical and physical properties. These properties allow the rare metals to be used in a wide range of energy and technology applications. Tantalum and niobium are the most chemically linked pair of rare metals. They are typically found together in the ore columbite-tantalite. Tantalum is primarily used in capacitors for microelectronics due to its high heat and electrical conductivity. Niobium can be used as an alternative to tantalum capacitors, but it is used primarily in alloys for superconducting magnets, rockets, turbines, and medical instruments. Zirconium is used to create heat and radiation resistant alloys, which are often used in nuclear power plants. Zirconium alloys can also serve functional roles in phones and computers) ("Rising Prices and Demand for Zirconium," 2011).

Mineralized pegmatite bodies associated with the older granite in Egypt is very rare so we carried out this work to identify and characterize the mineralogical and chemical characteristics of the rare-metal mineralization as well as the radioactive minerals of the mineralized pegmatite of Wadi El Sheih older granitoids at Central Eastern Desert of Egypt.

II. Geologic setting

Wadi El Sheih area to be dealt with in the present study is located within Pan-African basement complex in the central part of the Eastern Desert of Egypt. It nearly covers an area about 1.2 km^2 and is limited between longitudes 33° 26´ 51´´–33° 28´ 09´´ E and latitudes 26° 37´ 58´´–26° 38´ 11´´ N (Fig.1-A,B&C).The studied mineralized pegmatite is located in southern part of the mapped area. It occurs in two separated areas, along the both eastern and western banks of Qena–Safaga asphaltic road. The geology of the studied area is shown in Fig. 1. The exposed rocks in the study area are arranged chronologically as follows: (a) Older granites (gray granite) (the oldest), (b) Felsitic dykes and (c) Pegmatite (the youngest)

The Gray granite is the main rock type occupying the study area, where it covers about the whole map area. They are strongly jointed, highly weathered and characterized by spheroidal exfoliation and boulder weathering. The gray granite occurs as low to medium isolated hills separated by wide sandy wadies and representing the lowest radioactivity levels in the studied area. Wadi El Sheih Gray graniteis dissected by felsite and pegmatite dykes and bodies. Felsite dykes occur mainly as steeply to sub vertical dykes and have various striking trends and mostly E-W, N-S and NNE-SSW less common trends. The felsite dykes are fine grained, hard and display various colors including reddish pink, reddish brown and pale brown.

The studied pegmatite of Wadi El Sheih is suffered from hardly excavated works that mostly done by mining diggers who looking for intensive potach feldspar masses, which are used mainly in the ceramic and glass industry. Depending on the field geology, the investigated pegmatite in general is mainly composed of potash feldspar with quartz, mica and small amount of plagioclase. Generally, the zoned pegmatite types are composed of quartz grains; rare plagioclase and mica and/or biotite flack occupying the core, while potach feldspars enclose accessory minerals in the rim. Occasionally, mica flacks associated with some accessory minerals are localized as an intermediate zone between potach feldspar outer zone, and quartz internal zone. Pegmatite occurs in various sizes and shapes, ranging in size from few centimeters to few tens of meters, zoned and unzoned types. Sometimes, they occur as sub rounded, elliptical to irregular pockets and lenses, veins and dyke like bodies.

According to the field radiometric measurements those were carried out using the portable scintilla meter (UG-130) that measuring total counts (TC) in terms of count per second (Cps) and also detect equivalent uranium (eU) and equivalent thorium (eTh) in part per million (ppm), the investigated pegmatite divided into barren and mineralized types. Barren pegmatite commonly has little or no radioactive minerals, and commonly possesses potach feldspar, quartz with small mica flacks associated with hematization alteration types. Generally, they occur as small body in size, ranging from few tens of centimeters up to half meters. While the mineralized pegmatite varies from weak, moderate to high radioactive types. According to field geological investigation and radioactivity measurement studies, the highest radioactive pegmatite type displays as huge large irregular shape pegmatite bodies, up to few tens of meters in size and it has been further distinguished and classified into three subtypes. The first highly radioactive pegmatite subtype is dark patch habit rare metal mineral, occur as medium body size and has lowest radioactive measurements ranging between 2500 to 5000 cps, compare to this category. It mainly contains potach feldspar, quartz, mica, and fluorite. The second pegmatite subtype is called well-developed crystal habit rare metal mineral. It displays as medium to large body size and has moderately radioactive values (5000-9000 cps). It possesses well mineral habit crystal, potch feldspar, mica and quartz with accessory mineral such as fluorite and iron oxides. While the last and the highest radioactive values (9000-12000 cps) mineralized pegmatite subtype is called composite patch and well developed crystal habit radioactive rare metal mineral, and occasionally occurs with fluorite secondary quartz, (El Dabe, 2017).

III. Sampling and Analytical Techniques

A large bulk four composite samples representing different mineralized zones of pegmatite bodies of Wadi EL Sheih and weighing approximately 10 kg for each were collected for mineralogical investigation. The samples were initially crushed using jaw crusher to prepare a feed about -3mm for the grinding process. Then, the grinding process was taken place using Denver pilot rod mill to reduce grain size 100% passing 1mm. About three hundred grams for each sample were prepared and sealed for one month then measured using gamma-ray spectrometric analysis with sodium iodine detector in order to determine the contents of the main radio elements (U, Th. Ra, and K). After crushing and grinding processes, dry sieving analysis were take place, then each size fraction and part of the bulk sample were subjected to heavy mineral separation for the purpose of mineralogical identification and calculation of heavy mineral content relative to gangue light mineral percent. The heavy liquid was used for the purpose of separation is bromoform with specific gravity 2.85. From the obtained heavy fractions, pure monomineralic grains were handpicked and investigated under a stereoscopic microscope. The heavy mineral grains were manually picked from each of the obtained heavy fractions under Olympus stereo binocular microscope. Some of these selective picked grains were analyzed using X-ray diffraction equipment (XRD). PAN analytical x-ray diffraction equipment model X′Pert PRO with Secondary Monochromator, Cu-radiation (λ=1.542A^{o}) at 45 K.V., 35 M.A. and scanning speed 0.04 ^{o}/sec. were used. The diffraction peaks between 2θ= 2^{o} and 60^{o}, corresponding spacing (d, A^{o}) and relative intensities (I/I^{0}) were obtained. The diffraction charts and relative intensities are obtained and compared with ICDD files. XRD analyses were carried out at Central Laboratories of The Egyptian Mineral Resources Authority.

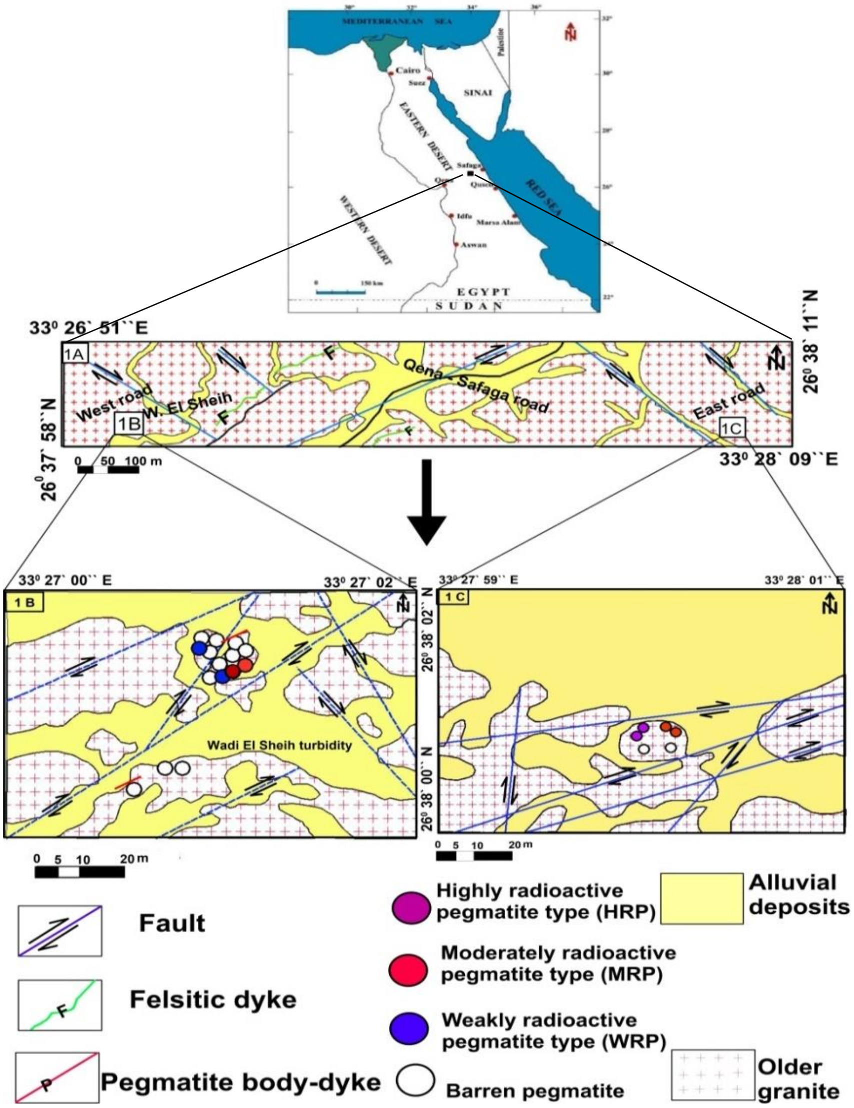

Fig.1: Geological map of the studied area Wadi El Sheih, Central Eastern Desert, Egypt

Some of the separated grains were examined by Scanning Electron Microscope (SEM). This instrument includes a Philips XL 30 energy-dispersive spectrometer (EDS) unit. The applied analytical conditions were an accelerating voltage of 30 kV with a beam diameter of 1μm for a counting time of 60-120 s and a minimum detectable weight concentration ranging from 0.1 wt. % to 1wt %. X-ray fluorescence technique (XRF) was used to determine the trace element contents using PHILIPS X Unique-II spectrometer with automatic sample changer PW 1510 (30 positions). This instrument is connected to a computer system using X-40 program for spectrometry. The contents of the main radio elements; U, Th, Ra, (ppm) and K (%) in the collected samples were radiometrically determined using the high efficiency multichannel analyzer of gamma-ray spectrometry with sodium iodine detector. SEM, XRF and Gamma-ray spectrometry analyses were carried out at the laboratories of the Egyptian Nuclear Materials Authority (NMA).

IV. Results and Discussion

Gamma-ray spectrometric analysis results with sodium iodine detector was used to determine the contents of the main radio elements U, Th, K and Ra concentrations in the highly anomalous granitic pegmatite of Wadi El Sheih (Table 1). The uranium contents (eU) ranges between 415 to 762 ppm with an average of 640 ppm whereas thorium contents (eTh) ranges between 877 to 1150 ppm with an average of 965 ppm.

Trace elements average of Wadi El Sheih studied pegmatite sample is tabulated at Table 2. The present data shows high enrichment in Zr (ave. 2210 ppm), Y (ave. 1963 ppm), and Nb (ave. 472 ppm).

The systematical and detailed mineralogical investigation of the bulk composite sample of the Wadi El Sheih pegmatite sample manifested that, the essential minerals present in the studied sample are quartz (ave. 29.17 mass%), and feldspar (ave. 64.23 mass%) that represent totally about 93.4 mass %. Also, the content of the heavy valuable minerals in the studied bulk composite sample is approximately 7.6 mass % which includes the existence of Nb-Ta oxide minerals (euxenite-(Y) and fergusonite-(Y)) (ave. 1.56 mass %), REE-rich minerals as allanite-(Ce) (ave. 2.66 mass %) and xenotime-(Y) (ave. 0.04 mass %), radioactive minerals as uranothorite and zircon (ave. 0.18 mass %). In addition to the presence of iron oxides (ave. 1.87 mass %) and muscovite (ave. 0.31 mass %).

Table 1: Radioactive elements measurements of Wadi El Sheih Pegmatite

Sample no.	e U ppm	e Th ppm	Ra Ppm	k %
1	762	877	2008	242
2	723	949	2049	272
3	415	1150	2083	247
4	658	882	2165	241
Min.	415	877	2008	241
Max.	762	1150	2165	272
Average	640	965	2076	251

Table 2: Trace elements analyses of Wadi El Sheih pegmatite

Sample no.	Ni	Zn	Zr	Ga	Sr	Y	Rb	V	Nb	Pb	Ba	Cr	Cu
1	110	34	1803	47	64	1711	2	34	383	27	398	u.d.	u.d.
2	155	39	2894	48	106	2386	u.d.	32	636	34	244	u.d.	u.d.
3	111	35	1931	33	67	1785	15	43	398	27	686	u.d.	2
4	120	36	2210	45	80	1970	10	41	470	31	451	u.d.	u.d.
Min.	110	34	1803	33	64	1711	2	32	383	27	244	u.d.	u.d.
Max.	155	39	2894	48	106	2386	15	43	636	34	686	u.d.	2
Average	124	36	2210	43	79	1963	9	38	472	30	445	u.d.	-

4.1. Nb-Ta oxide minerals

Euxenite-(Y) is a member of euxenite-group minerals which is a group of niobium-tantalum oxides that occur in Y, REE-rich pegmatite, they have general formula AM_2O_6, where A site is occupied mostly by Y, REE, U, and Th whereas M represents Nb, Ti, and Ta. Members of euxenite-group minerals include euxenite-(Y), [$Y(Nb,Ti)_2O_6$], tanteuxenite-(Y), [$Y(Ta,Ti,Nb)_2O_6$], polycrase-(Y),[$Y(Ti,Nb)_2O_6$], and uranopolycrase, [UTi_2O_6] (Erict, 2005b). Polycrase-(Y) and euxenite-(Y) are most properly differentiated: if Ti exceeds (Ta + Nb), then the mineral is polycrase-(Y), and the reverse for euxenite-(Y).The euxenite group minerals are typically metamict owing to the incorporation of U and Th. Their chemical composition is a sensitive and useful indicator of the degree of geochemical fractionation (Szuszkiewicz et al. 2016).

Euxenite and aeschynite group minerals have the same general formula of AM_2O_6, and they are typically metamict, altered, and can be difficult to identify on a structural basis (XRD); consequently, examination of the sample composition may be the most reliable approach to their identification. A working differentiation of the euxenite group from the aeschynite group can be done according to the preliminary calculations of Ewing 1976: the aeschynite group has LREE > 0.326 Ti – 0.060 Nb + 3.1 (oxide mass %), whereas for the euxenite group, the converse applies. In the present study, the euxenite-(Y) variety has been well identified using microscopic investigation using stereo binocular microscope, and proper analysis by ESEM, field-emission scanning electron microscope, as well as by using XRD analyses.

Stereo microscopic examination of Wadi El Sheih euxenite-Y picked grains revealed that, they are generally massive grains of subhedral to anhedral and granular form with resinous, semi metallic or vitreous luster. Also, the investigated mineral crystals are generally translucent, compact, metamict and hard. Wadi El Sheih euxenite-Y crystals are commonly honey brown while others are dark brown to brownish black in color under the stereoscopic binocular microscope and distributed through all size fractions (Figure 2Aand B).

Several backscattered-electron (BSE) images and Energy dispersive X-ray spectroscopy (EDX) spectrum of discrete euxenite-(Y) grains are presented in Figure 2C, D, E, F, G, and H. The obtained composition results show that the euxenite grains are enriched in niobium, titanium, yttrium and uranium. Semi quantitative chemical composition of represented ten grains of Wadi El Sheih euxenite-Y are displayed in Table 3.The chemical analyses of euxenite grains give mainly Nb_2O_5 ranging between 12.8 to 40 with average about 26.4 mass %, TiO_2 ranging between 9.5 to 45 with average of 24.2 Mass %, Y_2O_3 ranging between 4 to 24 with average of 15.6, and UO_2 ranging between 2.4 to 19.5 with average of 12.3 mass %.. Rare earth (REE) oxides content for Wadi El Sheih euxenite-Y grains show enrichment in heavy REE (HREE) oxides (3.96 mass %) relative to light REE (LREE) oxides (0.40 mass %).

Fergusonite-(Y) is detected in the studied sample of Wadi El Sheih pegmatite as anhedral to subhedral granular form. Most of fergusonite-(Y) grains having a characteristic vitreous or resinous luster. Also, they are generally translucent, compact, metamict and hard. The fergusonite crystals are mainly pale to dark yellowish brown in color (Figure 3A and B). Scanning Electron Microscope (SEM) data of the studied fergusonite grains (Figure 3C, D, E, F, G and H) shows that the mineral is enriched in niobium, yttrium and HREE than LREE elements. The semi quantitative chemical composition of eight studied fergusonite-Y grains using scanning electron microscope are shown in Table 4.The obtained results in average are revealed that 43.65 % Nb_2O_5, 1.79 % Ta_2O_5, 24.31 % Y_2O_3,1.11 % ΣLRE_2O_3 and 8.92 %ΣHRE_2O_3.

The XRD data for euxenite-(Y) and fergusonite-(Y) after annealing for 1 hour at 1000^o C is presented in Figure 4. The data confirms to the PDF-2 card no. 5-603 for heated euxenite-Y and PDF-2 card no. 9-443 for fergusonite.

Table 3: Chemical analyses of euxenite-(Y) grains from Wadi El Sheih pegmatite

Elemental Oxide	1	2	3	3	4	5	6	7	8	9	10	Min	Max	Ave.
Al_2O_3	1.88	2.45	3.36	2.52	1.90	1.90	2.03	3.06	2.58	2.15	1.53	1.53	3.36	2.31
SiO_2	1.94	3.92	6.10	3.13	3.33	3.84	9.38	4.98	4.89	6.36	0.00	0.00	9.38	4.35
ThO_2	0.00	2.55	2.57	2.97	0.00	0.00	3.70	5.18	3.36	0.00	3.48	0.00	5.18	2.16
UO_2	17.84	8.34	11.15	5.42	12.97	17.99	2.42	11.35	11.19	19.48	17.24	2.42	19.48	12.31
Fe_2O_3	2.24	1.01	4.59	3.02	1.20	3.55	7.49	3.33	4.44	3.20	2.59	1.01	7.49	3.33
CaO	0.73	0.57	0.88	0.95	0.65	2.91	4.32	2.42	1.54	3.83	1.96	0.57	4.32	1.89
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.47	0.00	0.00	0.00	0.00	2.47	0.22
K_2O	0.33	0.00	0.27	0.00	0.23	0.00	0.00	0.10	0.00	0.12	0.00	0.00	0.33	0.10
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	2.12	0.00	2.01	0.00	0.00	0.00	2.12	0.38
MgO	0.00	1.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.85	0.17
Ce_2O_3	0.00	0.00	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.99	0.13
Ho_2O_3	0.00	0.00	0.00	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81	0.16
Gd_2O_3	0.89	2.27	0.00	0.00	1.17	0.00	0.00	1.70	1.83	0.00	0.86	0.00	2.27	0.79
Sm_2O_3	0.31	0.00	0.00	1.12	0.00	0.00	0.00	0.00	0.89	0.00	0.00	0.00	1.12	0.21
Nd_2O_3	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.06
Eu_2O_3	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.03
Dy_2O_3	2.49	2.95	0.00	0.00	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.95	0.68
Er_2O_3	0.00	2.85	0.00	2.71	1.37	0.00	0.00	0.00	2.03	0.00	0.00	0.00	2.85	0.81
Yb_2O_3	3.08	2.94	1.51	0.00	2.29	0.00	0.72	2.63	3.12	0.00	0.00	0.00	3.12	1.48
Y_2O_3	18.39	16.41	17.92	24.43	20.19	16.38	4.00	10.46	14.61	14.04	15.26	4.00	24.43	15.64
TiO_2	21.89	19.79	17.93	9.51	18.34	20.38	45.09	37.53	26.28	25.45	24.11	9.51	45.09	24.21
TaO	1.42	3.24	3.21	1.76	1.77	2.49	1.80	1.94	2.11	2.53	2.01	1.42	3.24	2.21
Nb_2O_3	26.56	28.86	29.52	40.00	32.25	30.56	16.92	12.84	19.13	22.81	30.57	12.84	40.00	26.37
ΣLRE_2O_3	0.31	0.00	0.99	1.78	0.00	0.00	0.00	0.00	0.89	0.00	0.41	0.00	1.78	0.40
ΣHRE_2O_3	6.46	11.01	1.51	4.52	7.17	0.00	0.72	4.33	6.98	0.00	0.86	0.00	11.01	3.96

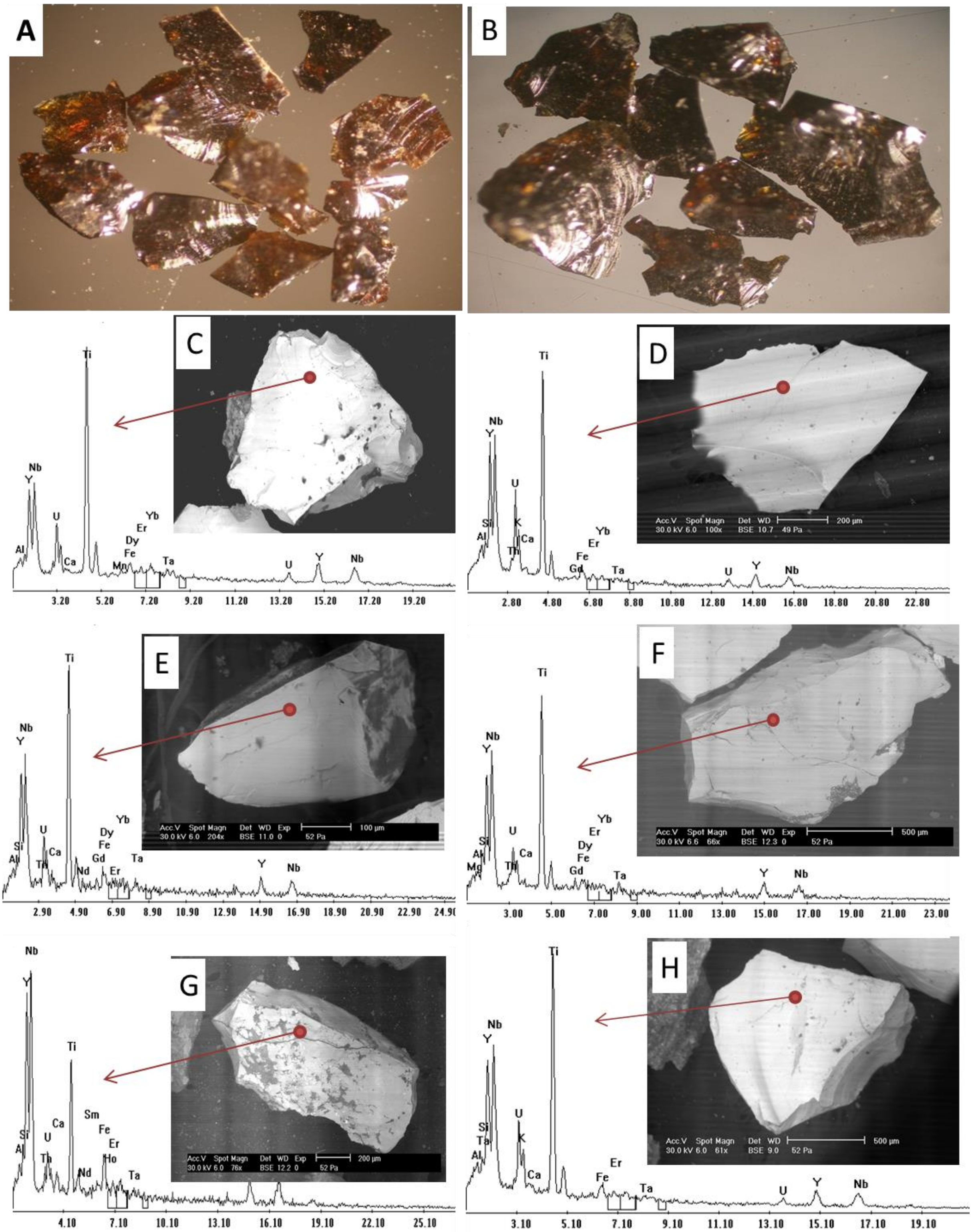

Fig.2:Stereo microscopic images of euxenite-Y grains show the color and shape (A-B). BSE images and EDX spectrum of euxenite-Y grains show their chemical composition (C, D, E, F, G and H).

Table 4: Chemical analyses of fergusonite-(Y) grains from Wadi El Sheih pegmatite

Elemental oxide	1	2	3	4	5	6	7	8	Min	Max	Average
Al_2O_3	0.93	0.68	1.38	3.13	2.36	1.90	1.23	1.17	0.68	3.13	1.60
SiO_2	3.44	1.28	3.42	4.64	5.84	2.13	2.39	2.06	1.28	5.84	3.15
ThO_2	12.11	5.63	6.69	3.43	1.74	2.68	6.88	2.81	1.74	12.11	5.25
UO_2	5.44	6.67	7.59	3.18	4.07	3.45	8.84	4.25	3.18	8.84	5.44
Fe_2O_3	1.88	0.59	0.55	0.90	1.57	1.58	4.92	1.71	0.55	4.92	1.71
CaO	1.25	0.65	0.48	0.62	1.44	1.13	1.73	1.21	0.48	1.73	1.06
MgO	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	2.40	0.30
Pr_2O_3	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.04
Pm_2O_3	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.05
Ho_2O_3	0.95	0.00	0.00	0.00	0.00	0.00	0.00	1.54	0.00	1.54	0.31
Gd_2O_3	2.04	2.84	2.36	2.81	1.64	2.20	1.59	0.00	0.00	2.84	1.94
Sm_2O_3	0.95	1.74	0.00	0.00	0.00	1.00	0.00	0.87	0.00	1.74	0.57
Nd_2O_3	0.00	1.21	1.10	0.00	0.56	0.00	0.43	0.73	0.00	1.21	0.50
Dy_2O_3	3.80	3.33	3.20	4.19	4.05	3.26	0.00	0.00	0.00	4.19	2.73
Er_2O_3	2.45	3.12	2.45	2.85	2.47	0.00	1.37	1.85	0.00	3.12	2.07
Yb_2O_3	2.90	3.43	2.81	2.77	3.08	0.00	0.00	0.00	0.00	3.43	1.87
Y_2O_3	21.26	23.09	22.09	25.13	25.35	29.95	18.35	29.26	18.35	29.95	24.31
TiO_2	0.94	2.10	2.93	0.89	1.09	1.42	1.92	1.39	0.89	2.93	1.59
TaO	1.46	3.39	2.30	2.10	1.56	1.37	1.17	1.00	1.00	3.39	1.79
Nb_2O_3	38.18	38.20	40.65	40.97	43.19	47.94	49.19	50.15	38.18	50.15	43.56
ΣLRE_2O_3	0.95	3.24	1.10	0.00	0.56	1.00	0.43	1.60	0.00	3.24	1.11
ΣHRE_2O_3	12.14	12.72	10.82	12.62	11.24	5.46	2.96	3.39	2.96	12.72	8.92

4.2 REE rich minerals

Allanite-(Ce) (orthite) is a rare earth sorosilicate of the epidote mineral group with general formula $A_2M_3Si_3O_{12}(OH)$, where the A site can contain large cations as Ca^{2+}, Sr^{2+}, and rare earth elements, and the M site admit Al^{3+}, Fe^{3+}, Mn^{3+} among others. However, a large amount of additional elements, including Th, U, Zr, and others may be present in the mineral (Gribble, 1989). Members of allanite group include: allanite-(Ce), allanite-(La), allanite-(Nd), and allanite-(Y), depending on the dominant rare earth present. Allanite can contain significant amounts of REE (up to 51% RE oxide) and is found frequently worldwide as an accessory mineral in igneous, metamorphic, metasomatic and sedimentary rocks (Sorensen, 2004).

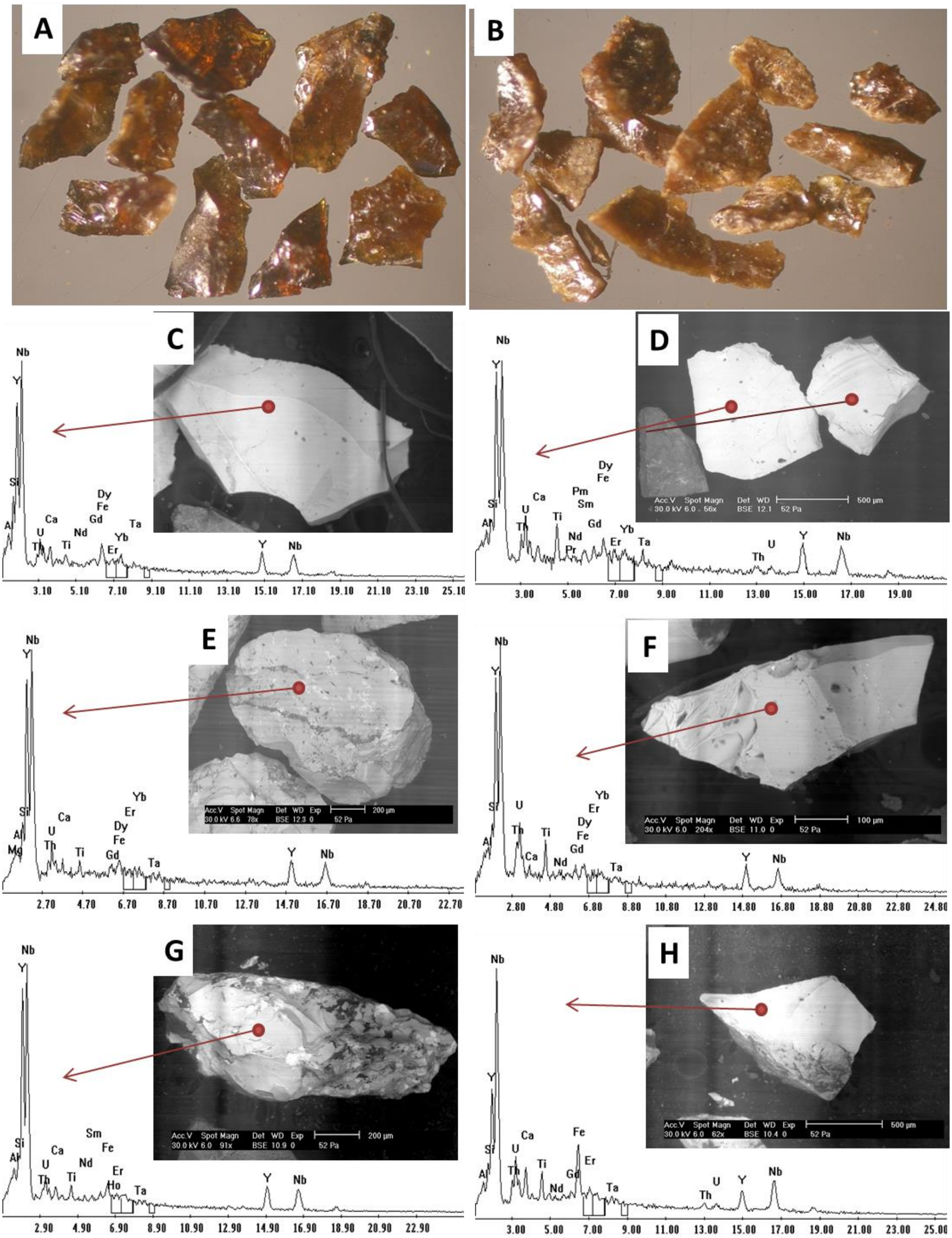

Fig. 3: Stereo microscopic images of fergusonite-Y grains show the color and shape (A&B). BSE images and EDX spectrum of fergusonite-Y grains show their chemical composition (C, D, E, F, G and H).

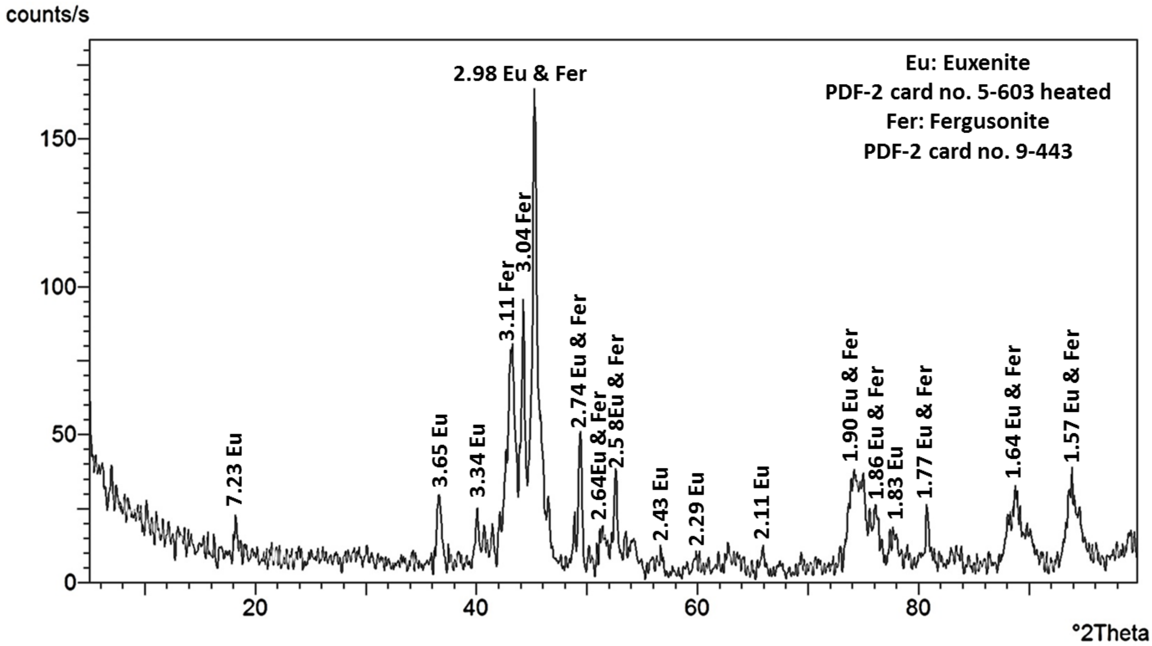

Fig. 4: XRD pattern for euxenite and fergusonite of Wadi El Sheih pegmatite sample

Pure allanite grains were separated and examined under the stereoscopic binocular microscope and also SEM with EDS technique. The studied allanite grains possesses four colored varieties; yellowish brown (Fig.5A), reddish brown (Fig. 5E), black (Fig. 6A) and dark brown allanite (Fig. 6E).The Different colored allanite grains occur as massive translucent crystals of anhedral to subhedral form and have a characteristic vitreous luster (Fig.7A).The semi-quantitative analyses of different colored allanite grains are studied and presented in Table5. The results revealed that, allanite grains are enriched in silica, alumina, iron, calcium and REE elements. The distribution of rare-earth elements (REE) in allanite was first described by Goldscmidt and Thomassen 1924, who noted that allanite, like monazite concentrates the light rare-earth elements (LREE). The REE content of the Wadi El Sheih allanite is ranging from 25.6 to 67.5 percent with an average of 41.7 percent. The most abundant rare earth element in all colored allanite classes is cerium, varying between 9.6 and 27.1 wt. % Ce_2O_3. The second most abundant REE is neodymium ranging between 6.1 to 15.6 wt. % Nd_2O_3, followed by lanthanium (2.9-9.3 wt. % La_2O_3) and samarium 90.8-5.1 wt. % Sm_2O_3). On the other hand, uranium content in the studied allanite is in ranging from0 to 1.8 percent with an average of 0.44 percent and thorium content is ranging from 0 to 9.3 percent. The high content of the radio elements in the studied allanite can lead to the destruction of the lattice and therefore to metamictization. Metamictization results from the α-decay of ^{238}U, ^{235}U and ^{232}Th and their daughter isotopes. Metamictization process is accompanied by hydration, reduction in density, reduction in hardness and also causes color changes.

The XRD patterns for different colored allanite are presented in Figures7 and 8. The data confirms to the PDF-2 card no. 010-0366 for allanite-(Ce) and PDF-2 card no. 005-0619 for allanite-(Ce).

Table 5: Chemical analyses of different colored allanite grains from Wadi El Sheih pegmatite

Elemental	Yellowish brown Allanite			Reddish brown Allanite			Black Allanite			Dark Brown Allanite			
Oxide	1	2	3	4	5	6	7	8	9	10	11	12	Aver.
Al_2O_3	23.4	18.6	10.7	14.5	16.3	13.7	14.7	14.7	13.2	9.6	19.1	11.4	15.32
SiO_2	26.9	20.1	17.9	19.7	20	21.4	27.5	27.8	18	11.7	20.8	12.8	21.07
ThO_2	4.1	5.1	4.3	4.7	3.6	6.3	2	1.9	5.2	0	2.9	9.3	3.65
UO_2	0.7	1.2	0	1.3	0	0	0.6	0.6	0	0	0.4	1.8	0.44
Fe_2O_3	4.3	5	2.9	9.9	26.5	11.2	14.5	13.2	14.6	8.7	10.7	8.5	11.05
CaO	3.2	3.4	1.2	3.7	2.5	1.6	6.9	6.1	6	2.6	2.7	7.6	3.63
K_2O	0.6	0.7	3.5	1.9	0	6.4	0	0	0	0	0.8	0.1	1.26
Ce_2O_3	13	17.8	26.3	17.4	19.6	13	11.4	11.1	9.6	27.1	17.1	10.5	16.67
La_2O_3	5.8	7	9.3	8.1	4.1	6.8	4.5	4.1	2.9	10.1	6.4	1.9	6.28
Pr_2O_3	5.5	2.4	3.5	0	0	3.3	1.5	4.5	1.7	0	5.9	4.1	2.57
Gd_2O_3	0	2.2	2.4	3.1	0	2.1	0	0	0	0	0	2.9	0.89
Sm_2O_3	1.6	3.2	3.6	4.3	0.8	3.5	2.1	1.7	3.2	5.1	1.3	4.2	2.76
Nd_2O_3	10.1	10.1	13.6	11.4	6.6	10.8	6.1	6.5	11.4	15.6	10.8	13	10.27
Y_2O_3	0	3.2	0	0	0	0	0	0	10.3	9.5	0	10.9	2.09
TiO_2	0.1	0	0.9	0	0	0	0.6	0.9	2.3	0	1.2	1.1	0.55
MnO	0	0	0	0	0	0	7.7	7.6	0	0	0	0	1.39
Eu_2O_3	0	0	0	0	0	0	0	0	1.8	0	0	0	0.16
ΣRE-oxides	36.0	45.9	58.7	44.3	31.0	39.4	25..6	27..9	40..9	67..5	41.4	47.4	41..7

Xenotime-(Y) grains of Wadi El Sheih pegmatite are generally massive of anhedral to subhedral and granular form and having a characteristic vitreous or resinous luster. Also, xenotime crystals are generally translucent, compact, and hard. Xenotime grains were occurred in yellowish brown color (Fig. 9A)

BSE and EDX of xenotime grains are presented in Figure 9 B, C, and D. Most common in xenotime, apart from yttrium content, are replaced by other HREE as erbium, dysprosium and ytterbium. If the level of ytterbium exceeds that of yttrium, the mineral is called xenotime-(Yb). Semi-quantitative analysis of Wadi El Sheih xenotime grains are listed in Table 6 and the represented data indicated that yttrium is the most abundant REE, varying between 43.2 and 57.36 with an average of 49.7 wt. percent Y_2O_5. The second most abundant HREE is ytterbium ranging between 3.5 to 5.9 wt. percent Yb_2O_5, followed by erbium (2.9-4.4 wt. % Er_2O_5), dysprosium (0-5.6 wt % Dy_2O_5) and hollonium (0-1.23 wt. % Ho_2O_3). Thus, all analyzed xenotime grains showed be termed xenotime-(Y). The content of thorium in the analyzed xenotime ranges from 0 to 1.06 with an average of 0.66 wt % ThO_2. The XRD pattern for xenotime is presented in Figure 12, and the data confirmed to the PDF-2 card no. 1-77-1296 for xenotime.

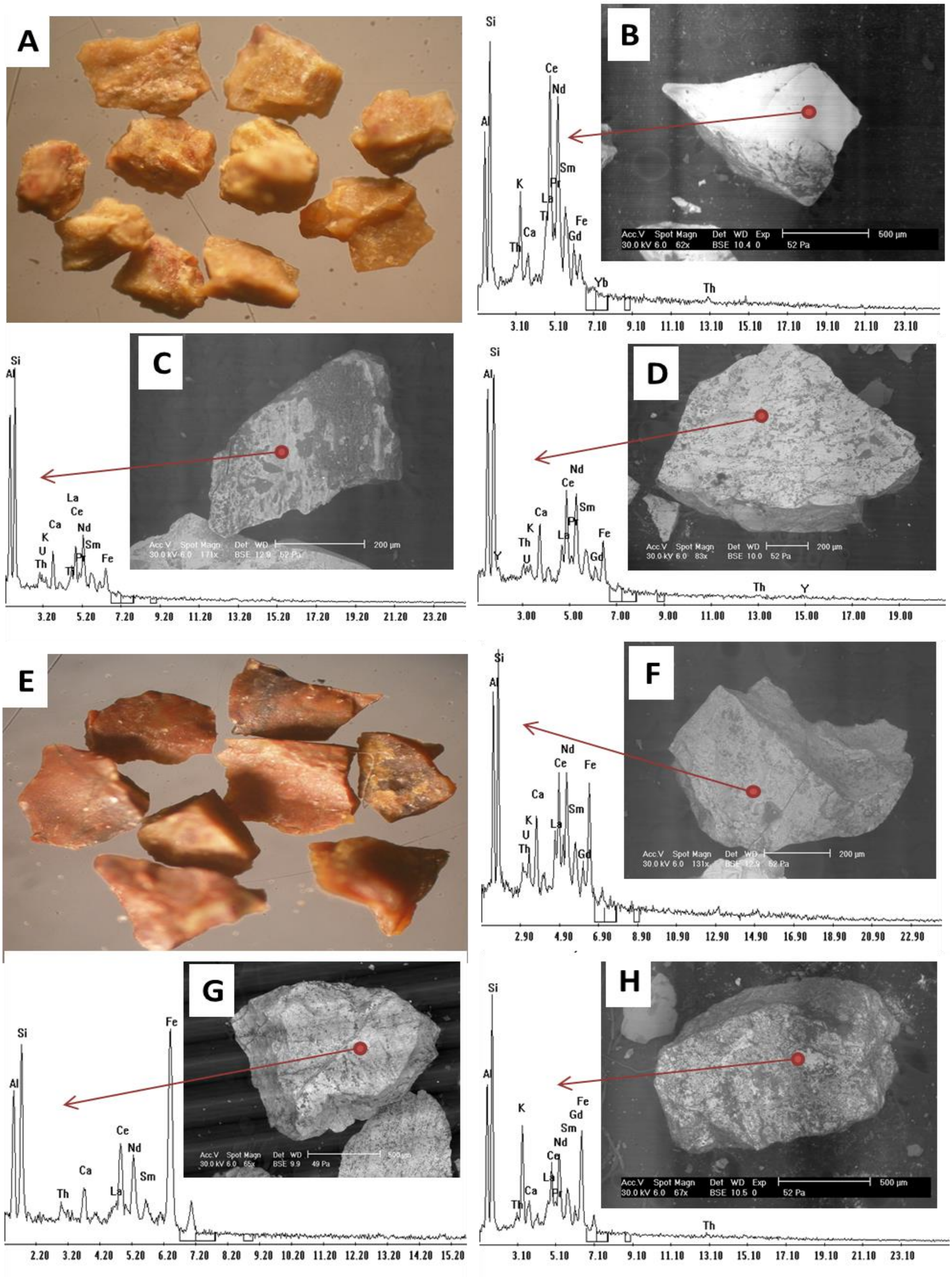

Fig. 5: Stereo microscopic images of yellowish brown allanite grains show the color and shape (A). BSE images and EDX spectrum of yellowish brown allanite grains show their chemical composition (B, C and D).Stereo microscopic images of reddish brown allanite grains show the color and shape (E). BSE images and EDX spectrum of yellowish brown allanite grains show their chemical composition (F, G and H).

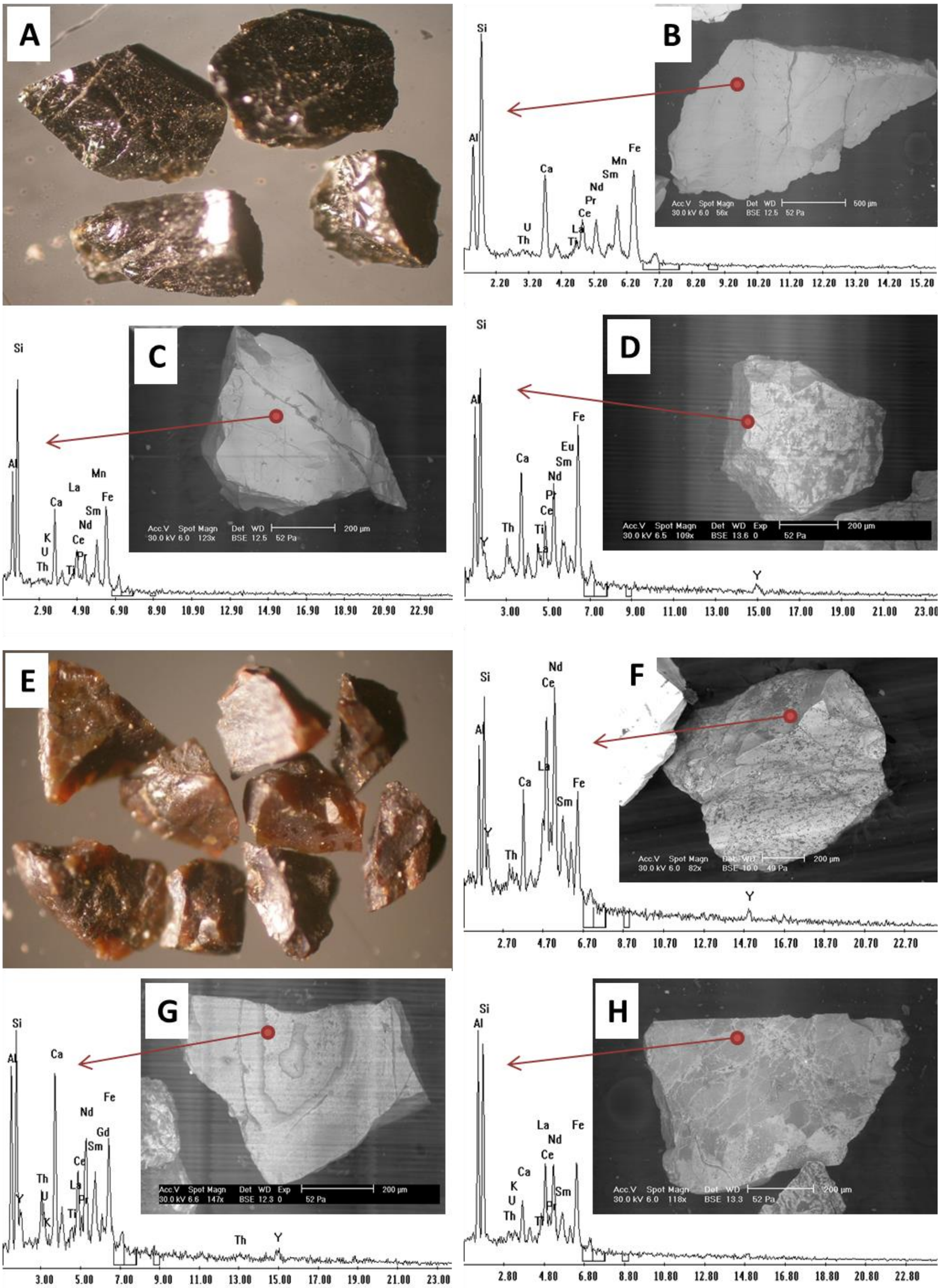

Fig. 6: Stereo microscopic images of black allanite grains show the color and shape (A). BSE images and EDX spectrum of black allanite grains show their chemical composition (B, C and D).Stereo microscopic images of dark brown allanite grains show the color and shape (E). BSE images and EDX spectrum of dark brown allanite grains show their chemical composition (F, G and H)

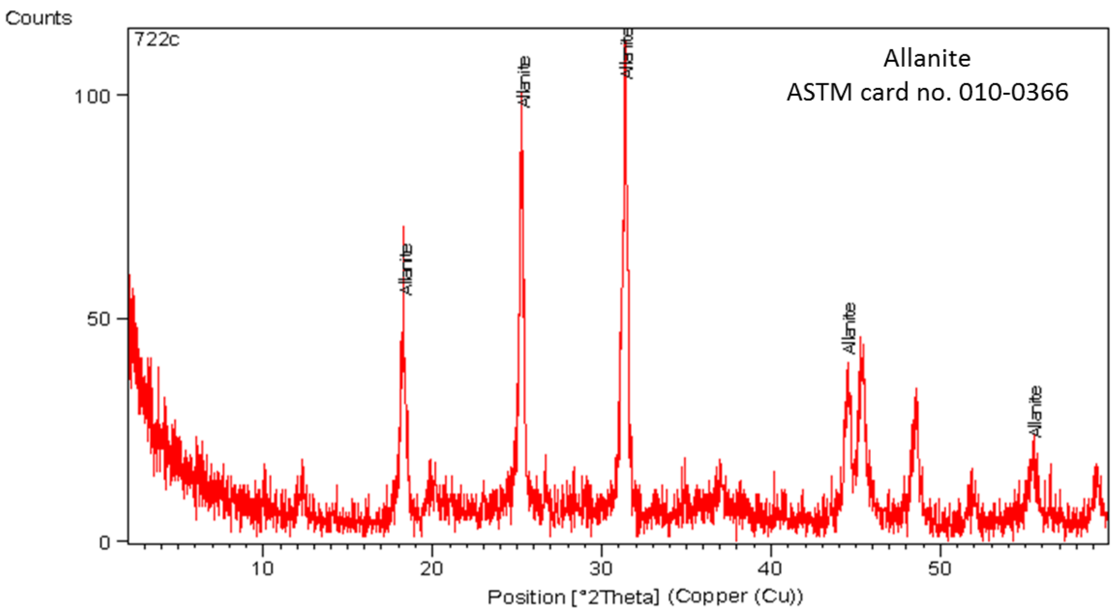

Fig. 7: XRD pattern for allanite of Wadi El Sheih pegmatite sample

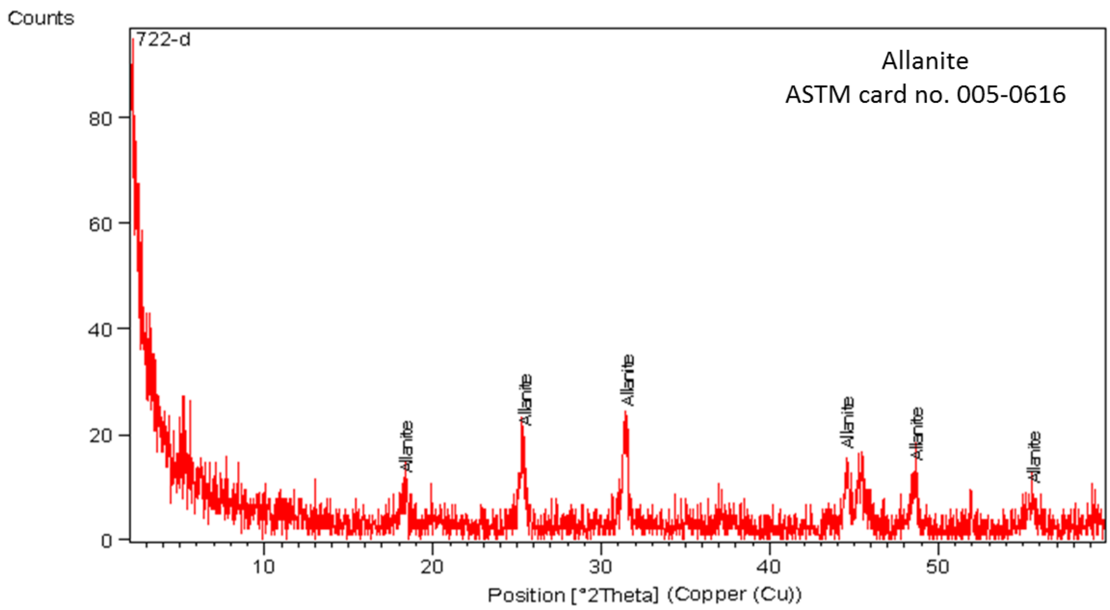

Fig. 8: XRD pattern for allanite of Wadi El Sheih pegmatite sample

4.3 Zircon: [$ZrSiO_4$]

Wadi El Sheih zircon grains exist in brown color. They are translucent to opaque with massive and compact nature (Fig. 10A).BSE and EDX of zircon grains are presented in Figure10 B, C and D. The geometrical surface of the zircon grains is generally ill-defined, rough, and dull. Pure zircon has 67.22 % by mass ZrO_2 and 32.78% by mass SiO_2. Comparing these data with semi-quantitative analyses of Wadi El Sheih zircon grains that listed in Table 6 revealed that, zirconium oxide content ranges from 53.9 to 56.75 wt. % while silicon oxide ranges from 30.9 to 33.2 wt. %. In addition to the element zirconium, the chemically very similar element hafnium is always built into the crystal structure of the mineral zircon in ranges of 0.5 to 2% by mass. The content of HfO_2 in Wadi El Sheih zircon ranges between 2.6-5.7 wt. percent. In addition to hafnium and zirconium, mineral zircon also contains larger quantities of uranium and thorium. This renders zircon one of the main sources of radioactivity. This radioactivity can lead to the destruction of the lattice. A uranium and thorium content in the studied zircon ranges from 0 to 1.1 wt. %UO_2 and 0 to 0.9 wt. % ThO_2.The XRD pattern for zircon is presented in Figure 12. The data confirms to the PDF-2 card no. 0081-0590 for zircon.

4.4 Uranothorite: [(Th, U) SiO_4]

Uranothorite grains were detected in the studied pegmatite of Wadi El Sheih sample. It occurs as pale to dark yellow color grains that are generally translucent to opaque. They are found as massive grains of rounded to sub rounded and granular form, having a characteristic vitreous or resinous luster (Fig.9E). BSE and EDX of uranothorite grains are presented in Figure 9F, G and H. The semi-quntitative chemical analysis data presented in Table 6 reflected that the major elements of the uranothorite content are included ThO_2 (49.5 wt. %), SiO_2 (15.98%) and UO_2 (15.99%). Also, minor amounts of Fe_2O_3 and CaO were reported as substitution in uranothorite. Also, minor amount of REE was reported as substitution for Th.

Table 6: Chemical analyses of xenotime-(Y), uranothorite and zircon grains of Wadi El Sheih pegmatite sample

Elemental oxide	Xenotime				Uranothorite				Zircon		
	1	**2**	**3**	**Aver.**	**1**	**2**	**3**	**Aver.**	**1**	**2**	**Aver**
Al_2O_3	3.36	3.19	2.39	2.89	0.00	3.10	3.37	2.16	4.06	1.70	2.88
SiO_2	3.09	3.1	4.66	3.62	19.53	16.60	11.82	15.98	30.85	33.21	32.03
CaO	0.00	0.00	0.00	0.00	0.00	0.97	0.82	0.60	0.91	0.96	0.94
MgO	1.78	1.78	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.49
Fe_2O_3	0.00	0.00	4.75	1.58	0.00	1.49	8.41	3.30	1.92	4.60	3.26
TiO_2	0.00	0.00	0.00	0.00	0.00	1.07	0.00	0.36	0.00	0.00	0.00
UO_2	0.00	0.00	0.00	0.00	17.19	7.86	22.91	15.99	1.11	0.00	0.56
ThO_2	1.06	0.92	0.00	0.66	59.65	36.17	52.68	49.50	0.88	0.00	0.44
P_2O_5	30.43	28.36	20.92	26.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hf_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.56	5.66	4.11
ZrO_2	0.00	0.00	0.00	0.00	0.00	20.55	0.00	6.85	56.75	53.87	55.31
Gd_2O_3	2.08	2.33	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Er_2O_3	4.39	2.89	4.04	3.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dy_2O_3	5.57	4.7	0.00	3.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ho_2O_3	1.23	0.76	0	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yb_2O_3	3.85	3.48	5.88	4.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Y_2O_3	43.16	48.5	57.36	49.67	3.62	12.19	0.00	5.27	0.00	0.00	0.00

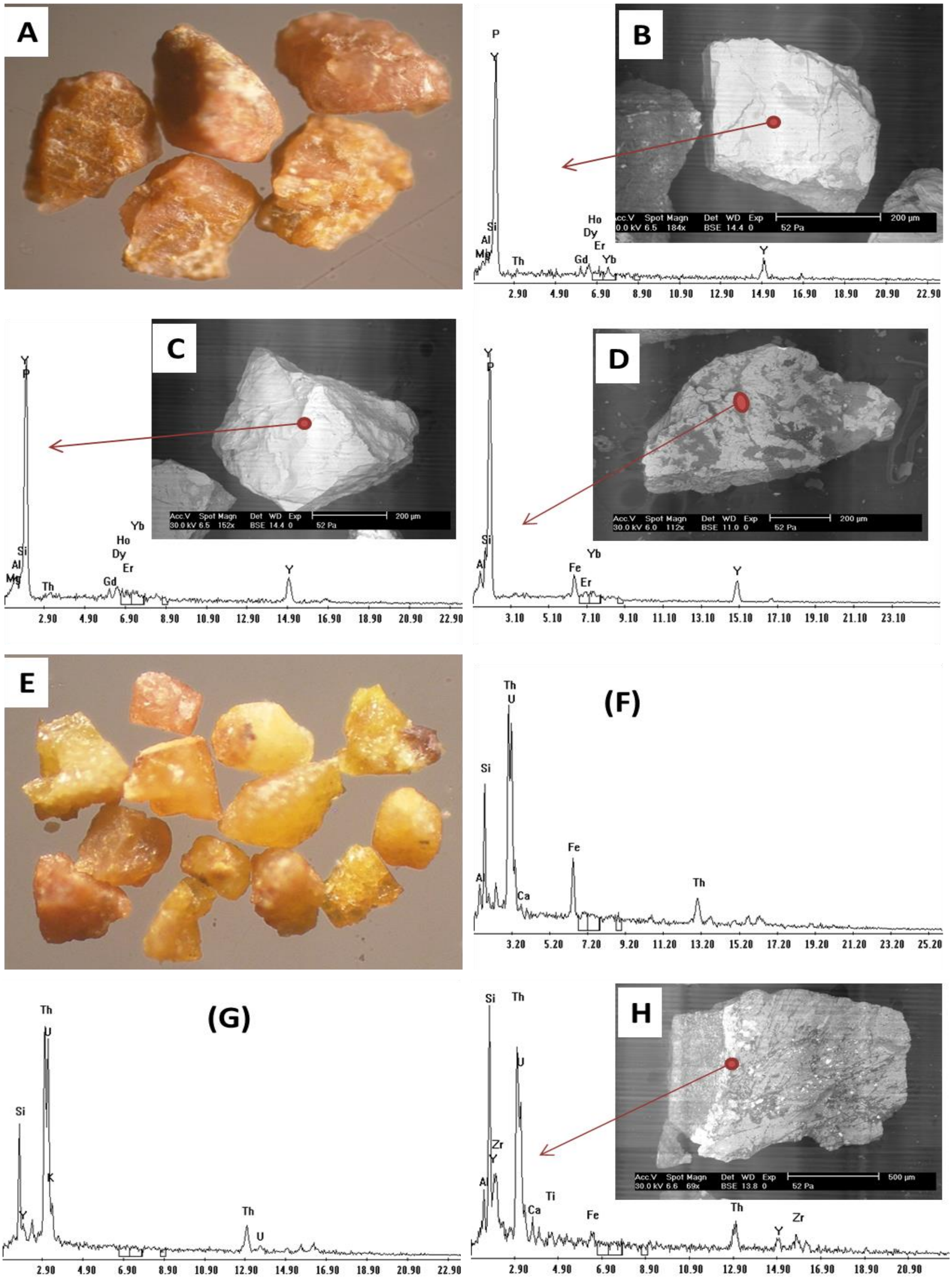

Fig.9: Stereo microscopic images of xenotime grains show the color and shape (A). BSE images and EDX spectrum of xenotime grains show their chemical composition (B, C and D).Stereo microscopic images of uranothorite grains show the color and shape (E). BSE images and EDX spectrum of uranothorite grains show their chemical composition (F, G and H)

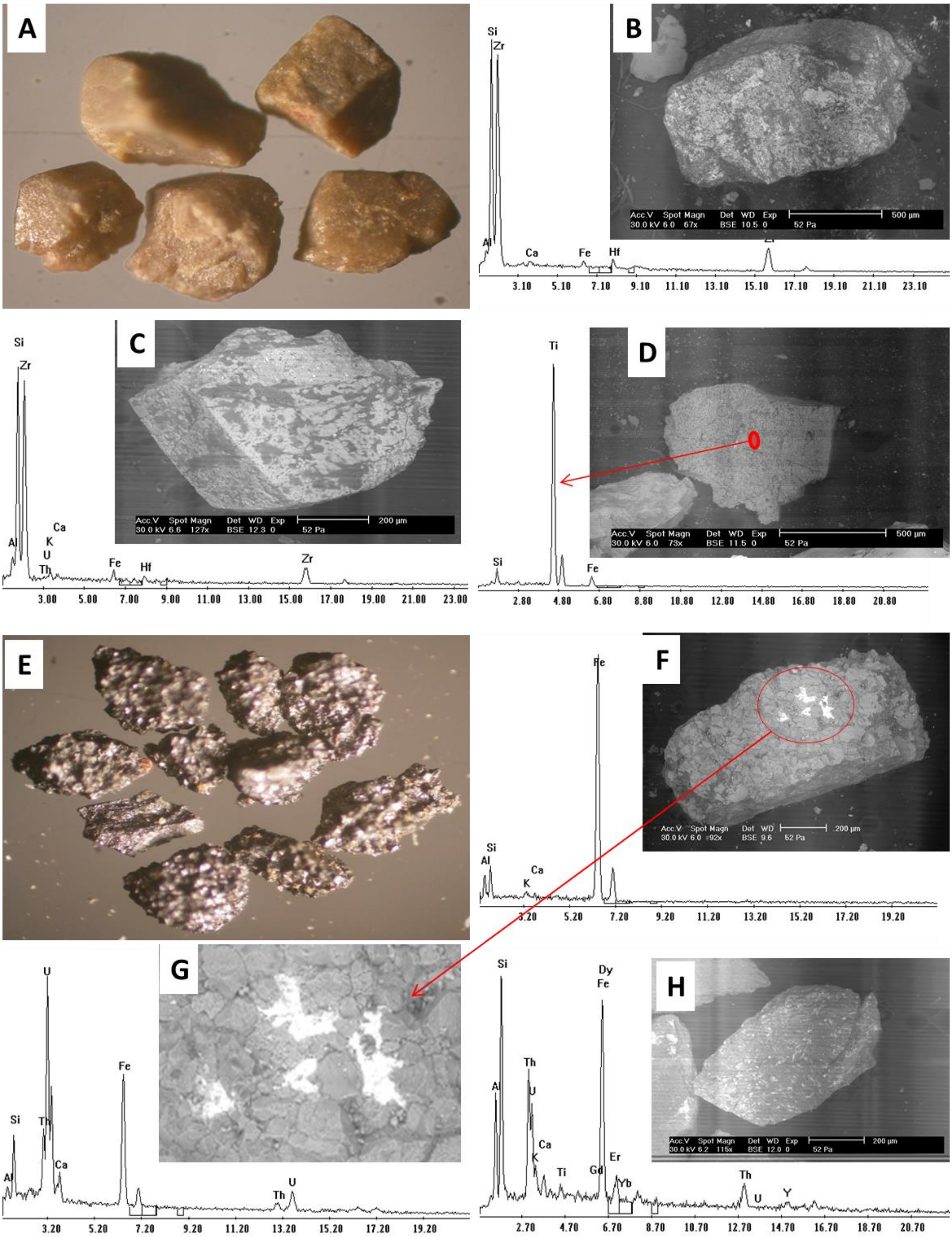

Fig.10: Stereo microscopic images of zircon grains show the color and shape (A). BSE images and EDX spectrum of zircon grains show their chemical composition (B, C and D).Stereo microscopic images of iron oxides grains show the color and shape (E). BSE images and EDX spectrum of iron oxides grains show their chemical composition (F, G and H)

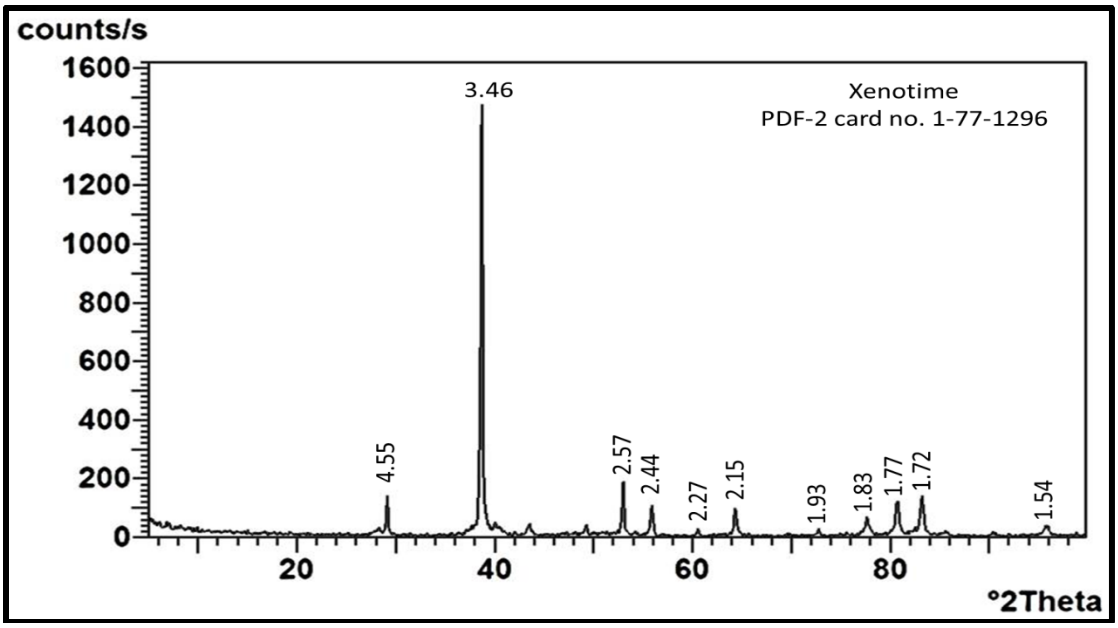

Fig.11: XRD pattern for xenotime of Wadi El Sheih pegmatite sample

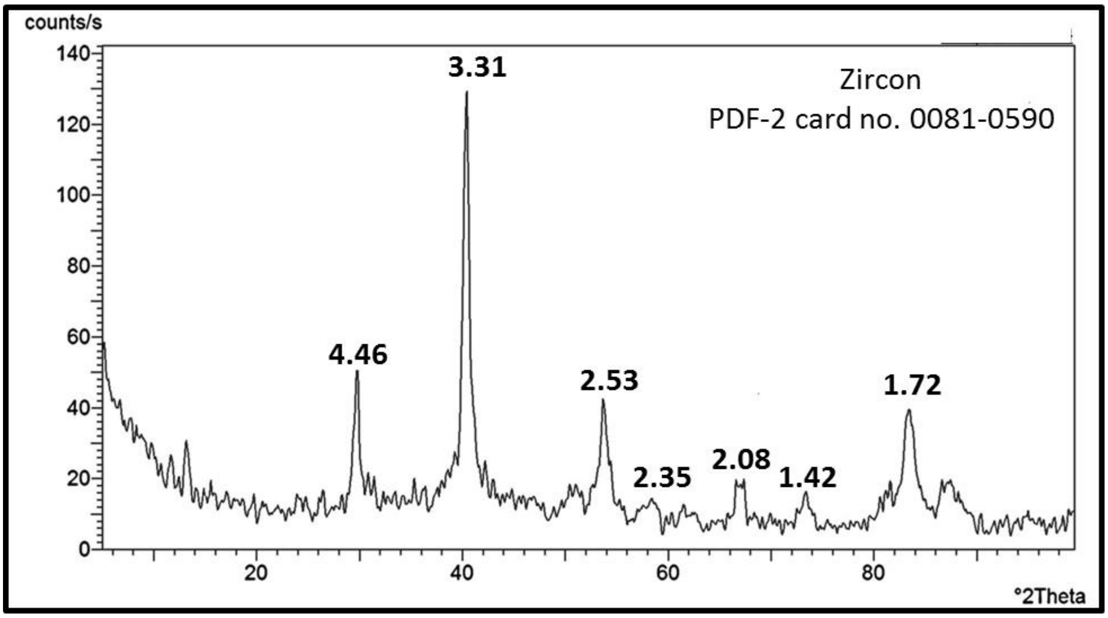

Fig.12: XRD pattern for Zircon of Wadi El Sheih pegmatite sample

V. Conclusions

Rare recording of economic and strategic rare-metal minerals at the mineralized pegmatite that injected in Wadi El Sheih older granitoids at the central Eastern Desert of Egypt, considered important source for several rare-metal, rare earth and radioactive elements as Nb, Ta, Ti, REEs, Zr, U, and Th. According to the chemical and mineralogical investigation of the pegmatitic bodies of Wadi El Sheih older granitoid, Microscopic examination, x-ray diffraction and scanning electron microscope confirmed the presence of economic and strategic minerals such as euxenite-(Y), fergusonite-(Y), allanite-(Ce), xenotime-(Y), zircon, and uranothorite. Wadi El Sheih pegmatite granitoid is considered to be a promising locality as a source of Nb, Ta, Y, REE, Zr, U, and Th. Therefore, the physical beneficiation is recommended to upgrade the content of economic minerals and prepare them for chemical treatment to extract valuable elements and make use of them.

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