

Geochemistry and Petrogenesis of Dioritic-Gabbroic Pegmatites in the Bulfat Complex, Qala Diza, Northeastern Iraq

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ABSTRACT

The pegmatite dikes and associated plutonic rocks stand as a part of the igneous complexes associated with the Bulfat complex, located in the Zagros Suture Zone (ZSZ), NE Iraq. The Bulfat complex is a part of the ophiolite-bearing terranes that are allochthonous sheets. The complex represents the upper allochthon of the Albian-Cenomanian. The study area is located within Bulfat complex of ZSZ, specifically in the northwestern part of this zone and within the second unit of the Penjween-Walash Subzone. The rock samples were collected from pegmatite dike which is located to the northeast of the Darishmana village, the thickness of dike is about 5 m.

Electron microprobe analyses (EMPA) of plagioclase in 8 spots of dioritic pegmatites ranges between oligoclase (An_{18.00}-An_{28.23}) and andesine (An_{32.53}-An_{33.62}). Bulk whole-rock chemical analysis of fourteen samples using ICP-MS analysis reveals alkalinity Index (AI) of pegmatites to be metaluminous ($A/NK > 2$). Generally, the silica content in these pegmatites is from 46.70 wt. % to 52.67 wt. %.

The relatively flat pattern of REEs is characterized by the slight enrichment of LREEs compared to HREEs indicating the common ancestry of the studied pegmatites. Also, the enrichment of these pegmatites in LILEs (Sr, Pb, Rb) and depletion in HFSEs especially (Nb, Ta, Y) indicate the environment of the island arcs. Moreover, the low ratios of (Rb/Sr)_N and (Ba/Sr)_N refer to that these pegmatites are derived from a basic origin.

Tectonic discriminate diagrams show that the tectonic environment of studied pegmatites is I-type, which is the oceanic island arcs environment of sub alkaline rocks. The pegmatites of the present study have a genesis relationship with intrusions close to them in the study area; these intrusions are gabbros of Wadi Rashid that represent the environment of E-MORB. Moreover, the gabbros of Wadi Rashid and studied pegmatites are part of ophiolite-bearing terranes, they are found within upper allochthon thrust sheet. The current study of pegmatites reflects the oceanic island arcs environment, this indicates the existence of double island arcs, the first adjacent to the Arabian shelf, and the second close to the middle of paleo-ridge.

Numerous evidences support that the gabbros of Wadi Rashid being as the likely parent to the studied pegmatites such as geochemistry, tectonogenesis, and the close spatial distribution of the pegmatites to the gabbros of Wadi Rashid. Moreover, the

studied pegmatites appear to entail further dissection mainly due to the fact that the occurrence of dioritic- and gabbroic-pegmatites with a small-scale in the single intrusion might have its explanation in the liquid associated immiscibility.

Keywords: Bulfat complex, Gabbroic pegmatite, Geochemistry, Petrogenesis.

جيوكيميائية ونشوءية البجماتيت الدايريوتي - الكابروي في معقد بلفات، قلعة دزة، شمال

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الملخص

تُعد القواطع البجماتيتية والصخور الجوفية المرتبطة بها جزءاً من المعقدات النارية المرتبطة بمعقد بلفات الواقع ضمن نطاق الدرز الزاكروسي شمال شرقي العراق. يُعد معقد بلفات جزءاً من الأراضي الحاوية على الاوفيولايت والتي هي عبارة عن ألواح منقولة، إذ يمثل المعقد اللوح العلوي المنقول الذي يعود إلى الألبان - سينوماني. تتموضع منطقة الدراسة ضمن معقد بلفات التابع لنطاق درز زاكروس، وتحديداً في الجزء الشمالي الغربي من هذا النطاق وضمن الوحدة الطولية الثانية من نطاق بنجوين - والاش الثانوي. جمعت النماذج الصخرية من قاطع بجماتيتي يقع شمال شرقي قرية دارشمانه، ويصل سمك هذا القاطع إلى 5 م تقريباً.

يشير التحليل الإلكتروني المجهرى الدقيق (EMPA) للبلاجيوكليس الذي أُجري على ثمانية نقاط في البجماتيت الدايريوتي إلى أن نسبة الانورثايت تتراوح ما بين الأوليكوكليس (An28.23-An18.00) والأنديسين (An33.62-An32.53). تم تحليل 14 نموذجاً باستعمال تقنية البلازما مزدوجة الحث - قياس الطيف الكتلي، يشير المعامل القلوي إلى أن بجماتيت الدراسة الحالية يقع ضمن حقل متغايرة الألومينية ($A/NK > 2$). ويتراوح محتوى السليكا في هذا البجماتيت بشكل عام من 46.70 وزناً٪ إلى 52.67 وزناً٪.

النمط المتوازي نسبياً للعناصر الأرضية النادرة المتميز بالإغناء في العناصر النادرة الخفيفة مقارنةً بالثقيلة يدل على الأصل المشترك لبجماتيت الدراسة الحالية. كما أن إغناء هذا البجماتيت بالعناصر ذات الحجم الأيوني الكبير والنزعة الليثوفيلية (Sr, Pb, Rb) والنضوب في العناصر ذات مجال الجهد العالي لاسيما عناصر (Nb, Ta, Y) يدل على بيئة أقواس الجزر. علاوةً على أنَّ النسب الواطئة من (Rb/Sr)N و (Ba/Sr)N تشير إلى أن هذا البجماتيت مشتق من أصل قاعدي.

تُظهر مخططات التمييز التكتوني أن البيئة التكتونية لبجماتيت الدراسة الحالية تكون أوروغينية من نوع (I-type) الناري الأصل، وهي بيئة أقواس الجزر المحيطية تحت القلوية. إن بجماتيت الدراسة الحالية يرتبط بعلاقة منشئية مع المقححات القريبة منه في المنطقة والمتمثلة بكابرو وادي رشيد والتي تمثل بازلت حلبة أواسط المحيط

المغتنية (E-MORB). علاوةً على أنَّ كابرو وادي رشيد وبكمتايت الدراسة الحالية يُعدان جزءاً من الأراضي الحاوية على الاوفيولايت المتواجدين في اللوح العلوي الزاحف المنقول. يعكس بكمتايت الدراسة الحالية بيئة أقواس الجزر المحيطية، مما يُستدل على وجود أقواس جزرية مزدوجة الأولى محاذية للرصيف العربي والثانية قريبة من منتصف الحاجز القديم.

تؤيد أكثر الدلائل المتمثلة بالجيوكيميائية والنشوائية التكتونية والوجود المكاني أنَّ كابرو وادي رشيد يعدُّ من المحتمل المصدر الأولي لبكمتايت الدراسة الحالية. إن بكمتايت الدراسة الحالية يحتاج الى المزيد من التفصيل بسبب وجود نوعين من البكمتايت (الدايوراييتي والكابروي) في مقياس صغير في مقحم واحد الذي قد يكون تفسيره مرتبط بعدم امتزاجية السوائل.

المصطلحات الدالة: معقد بلغات، البكمتايت الكابروي، جيوكيميائية، نشوائية.

INTRODUCTION

The pegmatite dikes and associated plutonic rocks stand as a part of the igneous complexes associated with the Bulfat complex, located in the Zagros Suture Zone (ZSZ), NE Iraq (Jassim et al., 1982a) (Fig. 1). ZSZ occupies an area about 5000 km² along Iraq-Iran-Turkey borders and within the second unit of the Penjween-Walash Subzone (Buday and Jassim, 1987) (Fig. 1). The Bulfat complex is a part of the ophiolite-bearing terranes that are allochthonous sheets and the complex represents the upper allochthon of the Albian-Cenomanian (Aswad and Elias, 1988; Aswad, 1999), while the Walash-Naopurdan sequence represents the lower allochthon of the Palaeogene (Aswad et al., 2011). Allochthonous sheets are located over the autochthonous deposits represented by the sediments of the Arabian shelf and Tertiary sedimentary rocks (Aswad, 1999) (Fig. 1).

The Iraqi Bulfat complex (100 km² in extents in Iraq) outcrops in the mountain of Bulfat near Qala Diza. It comprises a volcano-sedimentary unit as the Gimo and Sirginil groups, these groups were originally referred to the Bulfat group (Jassim *et al.*, 1982a) (Fig. 1). The Gimo group at Bulfat comprises regionally metamorphosed basalt, diabase, andesite, acidic volcanic, tuffs, calcareous, and argillaceous sediments (Jassim *et al.*, 1982b), as a result of the igneous intrusive, aerosols of hornfels and marble were formed that overprinted the regional metamorphic rocks (Jassim *et al.*, 2006a). Whereas the Sirginil group is located in the northern part of the Bulfat complex, this group consists of pelitic and arenaceous rocks with volcanic flows that have undergone a regional and contact metamorphism (Buday and Suk, 1978), forming the upper part of the Bulfat group (Jassim *et al.*, 2006b) (Fig. 1).

The Bulfat complex is generally composed of plutonic rocks (basic, ultrabasic, intermediate, and acidic-granite), these rocks are mainly composed of gabbro-diorite intrusions and accompanied by syenite and nepheline syenite resulting from late-stage magmatic differentiation (Jassim *et al.*, 2006a), forming many rocks intruded during an early Tertiary (Paleocene-Eocene) (Jassim *et al.*, 2006a). The complex is intruded by minor intrusions and pegmatites (Jassim *et al.*, 2006a). Field investigations of the accessible areas at Darishmana appear to reveal that these pegmatite bodies have

intruded the Albian-Cenomanian metasedimentary sequences (Gimo-Qandil formation) (Aswad and Elias, 1988; Aswad, 1999), which experienced medium-grade regional metamorphism, as overprinted by a high-grade contact metamorphism during Paleogene (Jassim *et al.*, 1982a). Peralkaline magma is produced from the assimilation of the calcareous and pelitic host rocks, these results in the production of pegmatites and nepheline syenite (Buda, 1993). The pegmatites are coarse-grained dikes cutting both the intrusive and surrounding rocks (Jassim *et al.*, 2006a).

The basic intrusions in the Bulfat group have caused contact metamorphism of the surrounding country rocks (Jassim *et al.*, 2006a). The pyroxene-hornblende gabbros are mostly developed in the northeastern part of the complex, forming the high ground of the Bulfat range along Iraqi-Iranian border, and form a large part of the complex (Jassim *et al.*, 2006a) (Fig. 1), while the olivine gabbro rocks are spread in the form of rock bodies containing varying amounts of olivine (Jassim *et al.*, 2006a).

The complex near the village of Pauza (Shaban valley) contains ultramafic rocks represented by peridotite affected by the serpentinization process (Fig. 1). The ultramafic rocks can be divided into three occurrences (Buday and Jassim, 1987): serpentinites, pyroxenites, and Pauza ultramafic body which form 4% of the Bulfat igneous complex, representing the major ultramafic occurrence and exhibiting tectonic emplacement features, tectonic breccia along its western contact.

The study area is located in the northeast of Iraq, specifically 74 km to northeast of Sulaimaniya city. It is located about 13.5 Km to east of Qala Diza subdistric and approximately 4 Km of Darishmana village. The study area extends between longitudes (45°: 13': 27.944") (45°: 19': 43.346")E and latitudes (36°: 14': 43.442") (36°: 10': 28.447")N close to the Iranian border. Geologically, the study area is located within Bulfat complex of ZSZ, specifically in the northwestern part of this zone and within the second unit of the Penjween-Walash Subzone (Buday and Jassim, 1987). The rock samples were collected from pegmatite dike located to the northeast of the Darishmana village (Fig. 1), whose thickness is about 5 m. The sampling started from the first sample (36°: 11': 23.3"N 45°: 17': 6.9"E) and ended with the last sample (36°: 11': 24.2"N 45°: 17': 24.6"E) where the elevation from sea level is reached about 1793 m.

This paper focuses on pegmatites in the Bulfat complex, throwing light on the variation in the concentrations of the major, trace, and rare earth elements to clarify the petrogenesis, tectonic setting of pegmatites.

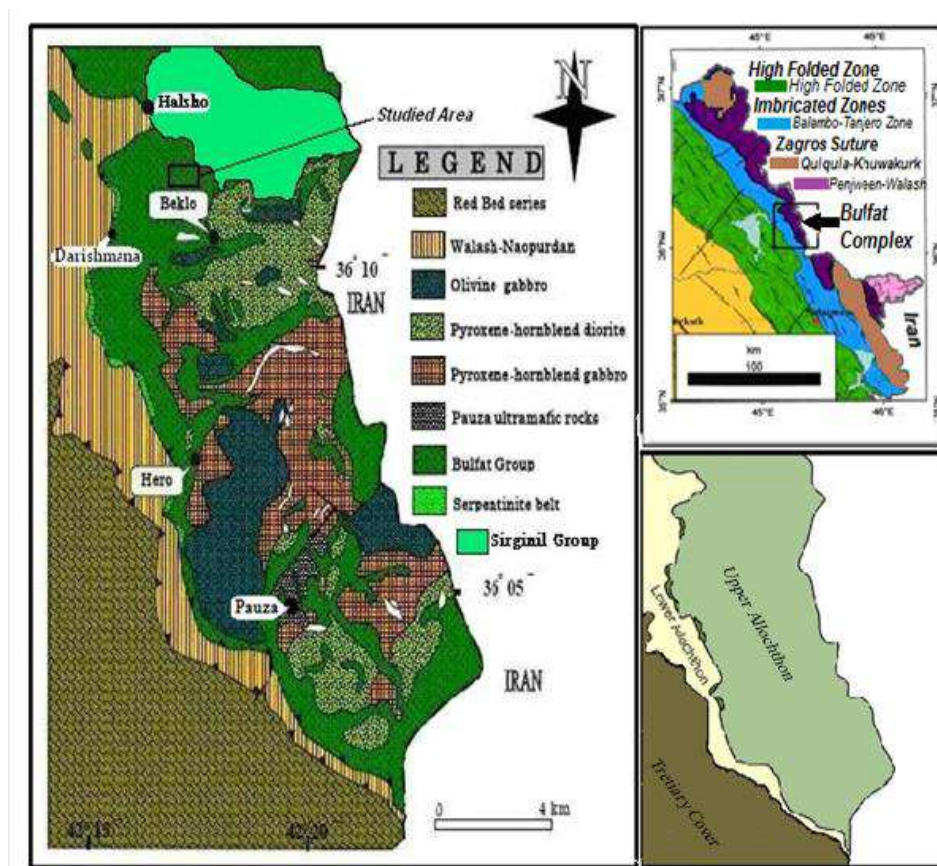


Fig. 1: Geological map of the Bulfat complex (Buday and Jassim, 1987).

METHODOLOGY

Pegmatite as a very coars-grained intrusive igneous rock, whose interlocking grains are usually larger than 2.5 cm in size, any attempt to classify these rocks by means of thin section and chemical classification appears to be unscientific. such methods are discovered to be non-representative of bulk minerals, i.e. the classification zone should be markedly larger than the thin section to calculate the mode analysis (Al-Hamed *et al.*, 2019). To overcome this problem, the staining and digital image processing were used (Al-Hamed *et al.*, 2019). The polished slabs were prepared in the Department of Geology, University of Mosul, Iraq, and stained. The Images have taken for the polished and the stained surfaces by a digital camera. By the ENVI software, they were changed into various image styles to calculate and recalculate the color index M' , quartz, alkali feldspar, and plagioclase proportions (Al-Hamed *et al.*, 2019).

Electron microprobe analyses (EMPA) were carried out at 8 spots to determine the anorthitic component (An mol. %) in D7_B and D7_C samples utilizing a fully automated, CAMECA SX50 Electron Microprobe at Utah University, USA, fitted with 4 wavelength-dispersive spectrometers, accelerating voltage 15 KeV, beam current 30 nA, and spot size 10 μ m.

Major, trace, and rare earth elements analysis of fourteen samples were determined by Perkin Elmer Sciex-Elan 6000 (ICP-MS) with a 4-acid digestion at ACME Analytical Laboratories in Canada (Table 1).

Table 1: Bulk whole-rock chemical analysis of pegmatites.

Sample No.	D2 _A	D2 _B	D3 _A	D3 _B	D3 _C	D5 _A	D5 _B	D5 _C	D6 _A	D6 _B	D7 _B	D7 _C	D8 _A	D8 _B
Major Oxides (wt. %)														
SiO ₂	49.94	52.23	50.15	49.63	50.51	50.10	52.67	48.78	50.11	47.52	51.99	52.38	46.70	46.91
Al ₂ O ₃	15.13	12.13	9.97	12.68	13.58	17.45	16.83	17.19	17.64	16.19	14.94	14.79	15.55	13.28
FeO	4.47	4.18	4.28	4.16	3.75	4.00	3.37	4.52	5.13	5.24	5.76	5.20	6.56	5.93
Fe ₂ O ₃	2.21	1.63	2.07	2.39	2.61	3.17	1.75	3.13	2.83	5.29	1.66	1.30	2.79	3.55
MgO	7.41	8.59	10.98	9.30	8.39	5.16	5.65	5.39	5.67	5.62	5.22	6.38	4.08	4.39
CaO	13.91	14.48	16.79	16.20	14.70	9.91	12.66	12.10	10.94	8.46	12.33	13.44	15.38	17.68
Na ₂ O	3.14	2.79	2.17	2.75	2.86	4.08	3.67	3.74	4.50	3.83	3.22	3.07	2.56	2.63
K ₂ O	0.72	0.58	0.43	0.49	0.54	1.11	0.59	0.92	0.62	0.66	0.96	0.45	0.66	0.46
P ₂ O ₅	0.12	0.08	0.05	0.09	0.11	0.17	0.11	0.15	0.14	0.18	0.06	0.04	1.26	1.47
TiO ₂	1.34	1.10	1.19	1.17	1.11	1.31	1.09	1.97	1.59	2.04	1.82	1.32	2.09	1.75
MnO	0.13	0.12	0.13	0.13	0.13	0.14	0.11	0.13	0.14	0.18	0.13	0.13	0.15	0.15
LOI	1.5	2.1	1.8	1	1.7	3.4	1.5	2	0.7	4.8	1.9	1.5	2.2	1.8
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100
FeO _{total}	6.46	5.65	6.13	6.31	6.10	6.85	4.94	7.33	7.68	9.99	7.25	6.37	9.08	9.13
Mg#	0.500	0.554	0.608	0.574	0.574	0.437	0.503	0.419	0.40	0.393	0.353	0.425	0.273	0.309
Trace Elements (ppm)														
Ni	241.4	120.0	261	168.7	171.0	72.6	63.1	76.2	70.2	74.2	31.4	61.3	16.6	16.4
Sc	29.7	33.5	53.5	44.7	38.7	21.6	24.9	24.3	18.8	22.1	17.5	26.2	5.9	7.2
Cr	49	174	1078	671	455	44	47	57	21	5	1	48	n.d	n.d
Co	35.9	28.2	36	37.3	35.9	31.9	31.4	39.8	49.5	51.8	35.1	34.5	40.7	37.9
V	217	202	260	232	216	131	158	210	172	190	169	178	151	158
Rb	25.3	23.1	14.9	14	16.6	35.5	19.1	32.2	20.8	21	34.9	12.8	24.4	17.5
Pb	5.16	4.63	4.16	4.20	3.85	5.37	3.74	3.45	4.47	4.69	3.77	1.96	2.27	4.62
Ba	95	79	38	60	71	159	91	113	113	126	107	81	105	45
Sr	364	272	191	257	287	458	385	441	483	389	419	436	468	325
Zr	107.9	99	96.8	125.8	119.7	164	118.9	131	136	146.2	116.8	99	239.6	288.8
Y	25.1	21.4	27	27.7	27.6	29.3	23.1	26.4	26.1	35.7	28.6	25.8	39	41.7
Nb	4.94	3.61	2.32	3.80	4.04	8.78	4.39	6.11	6.63	9.08	3.88	2.11	2.39	3.32
Hf	2.75	2.88	3.08	3.33	3.25	3.69	2.93	3.24	3.17	3.81	3.43	3.18	6.25	7.68
Ta	0.4	0.4	0.3	0.6	0.4	0.5	0.4	0.6	1.2	0.6	0.3	0.3	0.2	0.3
Th	1.4	1.7	0.8	1.1	1.4	1.8	1.4	1.6	2.2	2.2	1.1	0.6	1.6	5.2
Mo	0.38	0.29	0.11	0.25	0.23	0.4	0.31	0.35	0.8	0.37	0.18	0.22	0.26	0.33
Sn	1.4	1.2	0.9	1.1	0.8	1.5	1.4	1.3	1.3	1.4	0.9	0.6	1.4	2.1
Ga	14.08	12.45	11.09	11.88	13.48	16.95	13.78	16.89	17.45	18.04	16.01	15.09	18.76	18.10
Cu	63.95	18.01	72	57.96	58.39	24.5	18.12	37.26	24.75	43.12	30.33	20.76	31.98	41.10
Zn	50.2	48.6	39.2	45.9	44.7	66.4	39.4	68.6	74.3	87.5	62.3	54.2	64.9	74.5
Ag (ppb)	76	33	172	93	58	50	61	63	63	35	25	57	104	91
As	n.d	0.3	1	0.6	1.5	2.6	0.9	1.2	2.8	4.2	2.6	0.7	6.1	7.0
Au	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
Cd	0.18	0.18	0.13	0.16	0.25	0.19	0.17	0.14	0.17	0.21	0.19	0.14	0.14	0.25
Sb	0.19	0.17	0.21	0.07	0.14	0.12	0.1	0.09	0.12	0.15	0.13	0.08	0.26	0.43
Bi	0.12	0.08	0.24	0.17	0.08	0.05	n.d	n.d	0.04	0.07	n.d	n.d	0.06	0.08
W	44.6	45.3	62.8	187.8	50.9	26.0	90	78.1	>200.0	66.7	36.7	49.9	42	31.2

Be	1	n.d	n.d	n.d	n.d	n.d	1	n.d	2	1	n.d	n.d	n.d	n.d
S	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	900	n.d	n.d	n.d	n.d	n.d
Li	25.2	33.8	24.6	21.2	24.8	43.5	12.7	18.4	10.3	14.8	17.7	15.6	29.7	31.2
Cs	1.8	0.4	0.4	0.5	1	5.1	1.2	1.2	1.0	0.7	0.3	0.7	0.9	0.2
U	0.4	0.5	0.2	0.3	0.4	0.5	0.3	0.5	0.6	0.4	0.3	0.2	0.4	1
Rare Earth Elements (ppm)														
La	8.3	7.2	5.4	7.7	8.1	13.1	8.5	10	10.4	13.5	9	6.3	19.6	23
Ce	19.26	16.24	15.02	19.25	18.75	29.18	19.77	22.62	24.25	34.41	21.57	16.03	49.28	53.05
Pr	2.7	2.4	2.6	3	3.1	4	2.8	3.2	3	5.2	3.5	2.6	7.1	7.6
Nd	12.1	10.3	11.7	13.7	14.2	16.1	13.8	14.8	15.1	21.2	14.6	14.1	33.4	33.4
Sm	4.1	3.2	4.1	4.3	3.5	4.6	3.3	4.2	3.3	5.7	4.6	3	7.2	7.8
Eu	1	1.1	1.2	1.2	1	1.4	1.2	1.5	1.4	1.6	1.6	1.5	2.1	1.9
Gd	3.7	3.9	5	4.6	4.7	4.5	3.4	5	4.1	5.2	4.8	4.1	8	7.3
Tb	0.6	0.6	0.7	0.8	0.8	0.8	0.6	0.8	0.8	0.9	0.9	0.8	1.1	1.3
Dy	5	4.2	5.3	6.1	4.9	4.4	4.1	5.5	4.7	6.5	5.4	4.8	7.7	7.2
Ho	1	0.9	1	1	0.9	1.1	0.9	1.1	1.1	1.4	1.1	1	1.5	1.7
Er	2.4	2.7	2.7	3.3	3.4	3.0	2.4	2.7	3	3.7	3	3.1	3.6	3.8
Tm	0.5	0.3	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.5	0.4	0.6	0.6
Yb	2.7	2	2.9	2.4	2.9	2.8	2.6	2.9	2.4	4	2.6	2.3	3.7	4.5
Lu	0.4	0.3	0.3	0.5	0.4	0.5	0.4	0.4	0.4	0.5	0.3	0.4	0.6	0.6
Rock Name	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Gabbro	Melano-diorite	Melano-diorite	Gabbro	Gabbro

$\text{FeO}_{\text{total}} = \text{Total Fe as FeO}$

$\text{Mg\#} = [\text{Mg} / (\text{Mg} + \text{Fe}^{+2})] \times 100$

n.d = not detected

RESULTS

Based on the staining and digital image processing that provided by Al-Hamed *et al* (2019), the classification of the studied pegmatites was melano-diorite and gabbro (Table 2). The extinction angle of plagioclase was calculated to find out An mol. % in the plagioclase using the Michale Levy method to differentiate between melano-diorite and gabbro (Table 3). The plagioclase composition was andesine in D7_B and D7_C samples and M' > 50%, indicating that these samples are melanocratic. Moreover, electron microprobe analyses (EMPA) of plagioclase in D7_B and D7_C samples are shown in Table 4. The anorthitic component (An mol. %) ranges between oligoclase (An_{18.00}-An_{28.23}) and andesine (An_{32.53}-An_{33.62}) for D7_B and D7_C samples respectively. The difference in plagioclase compositions in the D7_B and D7_C samples from the other studied samples may be related to the magmatic fractionation, revealing more sodic plagioclase with progressive magma differentiation (Shawna *et al.*, 2003).

Table 2: Classification and nomenclature of pegmatites, specifying recalculation of the color index (M' %), Alkali-feldspar (A' %), and plagioclase (P' %) (Al-Hamed *et al.*, 2019).

Samples	M' %	Alkali Feldspar %	Plagioclase %	Total Feldspars = 100		Name of Rock
				A' %	P' %	
D2_A	52	0	48	0	100	Gabbroic pegmatite
D2_B	60	0	40	0	100	Gabbroic pegmatite
D3_A	57	0.6	42.4	1.5	98.5	Gabbroic pegmatite
D3_B	58	0.5	41.5	1.2	98.8	Gabbroic pegmatite
D3_C	56	0.6	43.4	1.4	98.6	Gabbroic pegmatite
D5_A	51	4.1	44.9	8.4	91.6	Gabbroic pegmatite
D5_B	50	3.8	46.2	7.5	92.5	Gabbroic pegmatite
D5_C	51	4.4	44.6	9	91	Gabbroic pegmatite
D6_A	61.5	0	38.5	0	100	Gabbroic pegmatite
D6_B	63.7	0.2	36.1	0.6	99.4	Gabbroic pegmatite
D7_B	61.8	0	38.2	0	100	Melano-dioritic pegmatite
D7_C	51	0	49	0	100	Melano-dioritic pegmatite
D8_A	53	0	47	0	100	Gabbroic pegmatite
D8_B	62.5	0.6	36.9	1.7	98.3	Gabbroic pegmatite

$$M' \% = 100 \times [M / (M+A+P)]$$

$$A' \% = 100 \times [A / (A+P)]$$

$$P' \% = 100 \times [P / (A+P)]$$

$$A' + P' = 100$$

M (Mafic minerals), A (Alkali-feldspar), and P (Plagioclase).

Table 3: The composition of plagioclase in the samples of pegmatites.

Samples	Extinction Angle	An mol. %	Plagioclase	Rock types
D2_A	29-31	52-56	Labradorite	Gabbro
D2_B	33-36	59-64	Labradorite	Gabbro
D3_A	30-33	54-59	Labradorite	Gabbro
D3_B	29-32	52-57	Labradorite	Gabbro
D3_C	30-34	54-60	Labradorite	Gabbro
D5_A	32-33	57-59	Labradorite	Gabbro
D5_B	30-31	54-56	Labradorite	Gabbro
D5_C	29-31	52-56	Labradorite	Gabbro
D6_A	30-33	54-59	Labradorite	Gabbro
D6_B	30-32	54-57	Labradorite	Gabbro
D7_B	20-22	38-41	Andesine	Diorite
D7_C	21-26	40-47	Andesine	Diorite
D8_A	32-34	57-60	Labradorite	Gabbro
D8_B	30-33	54-59	Labradorite	Gabbro

Table 4: EMPA of plagioclase feldspar based on 8 oxygens.

Samples	D7 _{C-A}	D7 _{C-A}	D7 _{B-B}	D7 _{B-B}	D7 _{B-B}	D7 _{B-B}	D7 _{B-B}	D7 _{C-A}
SiO₂	60.766	59.819	62.081	62.086	61.407	61.400	62.779	60.114
TiO₂	0.000	0.000	0.000	0.000	0.044	0.000	0.004	0.024
Al₂O₃	25.854	25.776	24.399	25.050	22.766	22.665	23.093	26.153
FeO*	0.034	0.048	0.019	0.018	0.015	0.074	0.061	0.016
MnO	0.000	0.030	0.016	0.000	0.000	0.000	0.021	0.037
MgO	0.000	0.000	0.021	0.006	0.000	0.001	0.000	0.000
CaO	6.629	6.796	5.251	5.661	3.995	3.934	3.609	6.913
BaO	0.000	0.111	0.054	0.136	0.138	0.017	0.016	0.052
Na₂O	7.530	7.347	8.340	7.829	8.905	8.899	8.929	7.458
K₂O	0.103	0.104	0.154	0.190	0.194	0.199	0.242	0.195
Total	101.277	100.623	100.982	101.498	97.990	97.813	99.430	101.498
Number of Ions calculated on 8 oxygen basis								
Si	2.689	2.672	2.750	2.743	2.789	2.795	2.814	2.657
Ti	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001
Al	1.348	1.357	1.274	1.305	1.219	1.216	1.220	1.362
Fe⁺²	0.001	0.002	0.001	0.001	0.001	0.003	0.002	0.001
Mn	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.001
Mg	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Ca	0.314	0.325	0.249	0.268	0.194	0.192	0.173	0.327
Ba	0.000	0.002	0.001	0.002	0.002	0.000	0.000	0.001
Na	0.646	0.636	0.716	0.671	0.784	0.785	0.776	0.639
K	0.006	0.006	0.009	0.011	0.011	0.012	0.014	0.011
Molecular Ratio								
An	32.530	33.618	25.580	28.227	19.641	19.401	17.997	33.489
Ab	66.870	65.768	73.529	70.646	79.221	79.429	80.564	65.387
Or	0.599	0.614	0.892	1.127	1.137	1.169	1.439	1.124

Geochemistry of Pegmatites:

In order to clarify the geochemical variation of the major oxides and trace elements, the binary variation diagrams using MgO and FeO_{total} were used against the major oxides and trace elements, because MgO and FeO_{total} are concentrated in the mafic minerals are reflected by the variation in the color index (M %) which range between (50-63.7 %) (Table 2), as well as that MgO and FeO_{total} are increased in these rocks.

Major Oxides:

Alkalinity Index (AI) refers to that the studied pegmatites are metaluminous ($A/NK > 2$) (Fig. 2). Generally, the silica range in these pegmatites is from 46.70 wt. % to 52.67 wt. % (Table 1), showing a dispersed correlation with MgO and a negative correlation with FeO_{total} (Fig. 3A, B). The silica correlation with FeO_{total} reflects the magmatic fractionation of plagioclase, where plagioclase becomes more sodic with progressive magmatic fractionation (Shawna *et al.*, 2003).

Al₂O₃ and Na₂O show two continuous trends with MgO (Fig. 3C, E), the first reflects an increase in Al₂O₃ and Na₂O with increasing MgO, indicating the start of plagioclase fractionation; whereas the second trend shows a decrease in these oxides with increasing MgO, indicating fractionation of clinopyroxene. CaO has also two trends with MgO (Fig. 3G), the first represents an increase in CaO with decreasing MgO, indicating fractionation of plagioclase and depletion of Mg in clinopyroxene with stability of Ca content (Sofy, 2003); whereas the second trend shows an increase in CaO with increasing MgO, reflecting fractionation of clinopyroxene. The correlations of Al₂O₃, Na₂O, and CaO with MgO (Fig. 3C, E, and G) may reflect liquid immiscibility in the single intrusion. Al₂O₃, Na₂O, and CaO show a dispersed correlation with FeO_{total} (Fig. 3D, F, H). TiO₂ and MnO have a dispersed correlation with MgO and a positive correlation with FeO_{total} (Fig. 3V, X, Y, Z), this reflects that these oxides occur in the Fe-phase minerals as pyrrhotite.

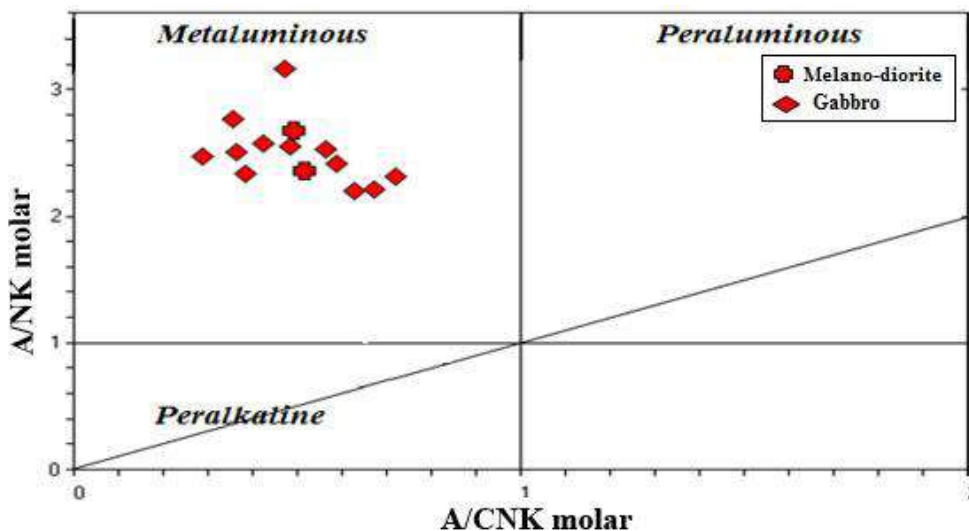


Fig. 2: A/NK (Al_2O_3/Na_2O+K_2O) vs. A/CNK ($Al_2O_3/CaO+Na_2O+K_2O$) plots show field of pegmatites of the Bulfat complex, Iraq, from (Maniar and Piccoli, 1989).

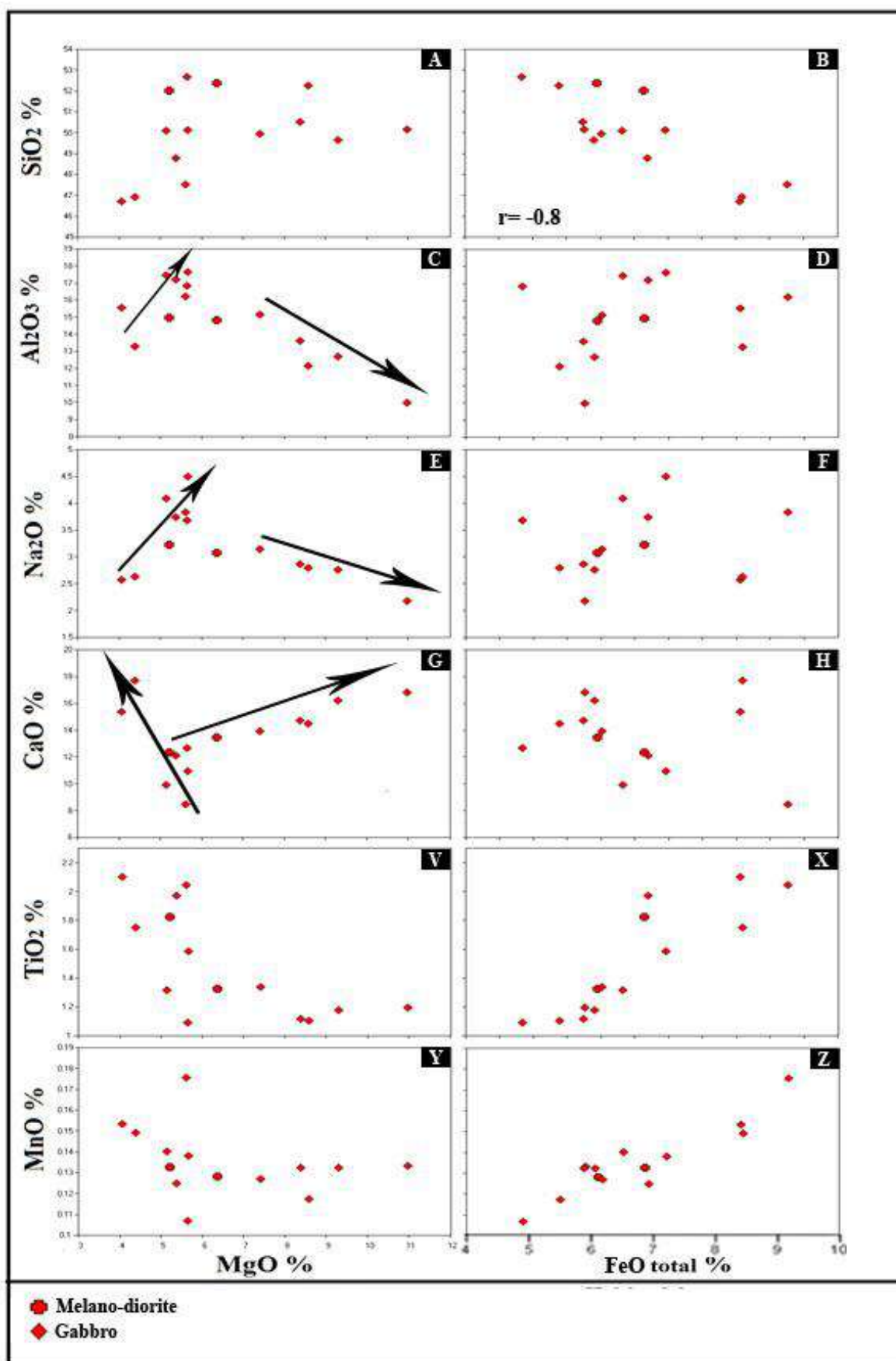


Fig. 3: Variation diagram of MgO and FeO_{total} vs. major oxides of pegmatites in the Bulfat complex.

Trace Elements:

Ni shows a positive correlation with MgO ($r^{\text{MgO/Ni}} = 0.82$) and a dispersed correlation with $\text{FeO}_{\text{total}}$ (Fig. 4A, B), this reflects that Ni^{2+} replaces Mg^{2+} in clinopyroxene (augite) (Rollinson, 1993). Also Sc and V show a dispersed correlation with $\text{FeO}_{\text{total}}$, indicating the scarcity of their presence in accessory Fe-rich phases (Fig. 4D, F). Whereas, Sc and V have a strong positive correlation with MgO ($r^{\text{MgO/Sc}} = 0.91$ and $r^{\text{MgO/V}} = 0.83$) (Fig. 4C, E) which confirms their presence in one phase (augite) (Mason and Moore, 1982; Wodepohl, 1978). Co has a dispersed relationship with MgO and is positively associated with $\text{FeO}_{\text{total}}$ ($r^{\text{FeO total/Co}} = 0.68$) (Fig. 4G, H), this reflects that Co increases in accessory Fe-rich phases, especially ferric, where Co has a positive correlation with ferric ($r = 0.7$).

LILEs (Rb, Ba, Sr) show a negative correlation with MgO and a dispersed correlation with $\text{FeO}_{\text{total}}$ (Fig. 5A, B, C, D, E, F), indicating that Rb, Ba, and Sr are associated with felsic minerals (Mason and Moore, 1982) since the felsic minerals in these rocks are dominated by plagioclase, so this mineral is the host of Rb, Ba, and Sr. Cs and Li do not show any clear correlation with MgO and $\text{FeO}_{\text{total}}$ (Fig. 5G, H, V, X), Cs is highly incompatible due to the very large ionic radius but is associated with feldspars and micas (Linnen *et al.*, 2012), while Li has a much smaller ionic radius than that of other alkali metals and is associated with amphiboles and micas by coupled substitution reactions (London, 2005a). Generally, the melts crystallize under equilibrium conditions, whereas pegmatitic melt crystallizes under super-cooled conditions far from the equilibrium (Chakoumakos and Lumpkin, 1990; Morgan and London, 1999; Webber *et al.*, 1999). Therefore, the difference occurs in the fractionation and behaviour of LILEs from what is expected in other melts (London, 2005b).

HFSEs have a medium negative correlation with MgO and a positive with $\text{FeO}_{\text{total}}$ (Fig. 6A, B, C, D, E, F), indicating their presence in Fe-rich minerals. Zr, Y, and Hf elements show a strong positive correlation with each other (Fig. 7), reflecting their common existence where be formed from a single source of mafic magma by fractional crystallization (Wilson, 1989). Nb and Ta have an unclear correlation with MgO and $\text{FeO}_{\text{total}}$ (Fig. 6G, H, V, X). Th and U show a dispersed correlation with MgO and $\text{FeO}_{\text{total}}$ (Fig. 8), indicating that they are associated with accessory minerals.

Chalcophile elements (Sn, Zn, Cu) show divergent correlations with MgO and $\text{FeO}_{\text{total}}$ (Fig. 8). Sn and Cu show a dispersed correlation with MgO and $\text{FeO}_{\text{total}}$ (Fig. 9A, B, E, F). Zn exhibits a negative correlation with MgO and a strong positive correlation with $\text{FeO}_{\text{total}}$ ($r = 0.9$) (Fig. 9C, D), this indicates that Zn entered Fe-rich phases, it replaces ferrous due to the similarity of charge and radius (Zn^{2+} 0.74Å, Fe^{2+} 0.74Å).

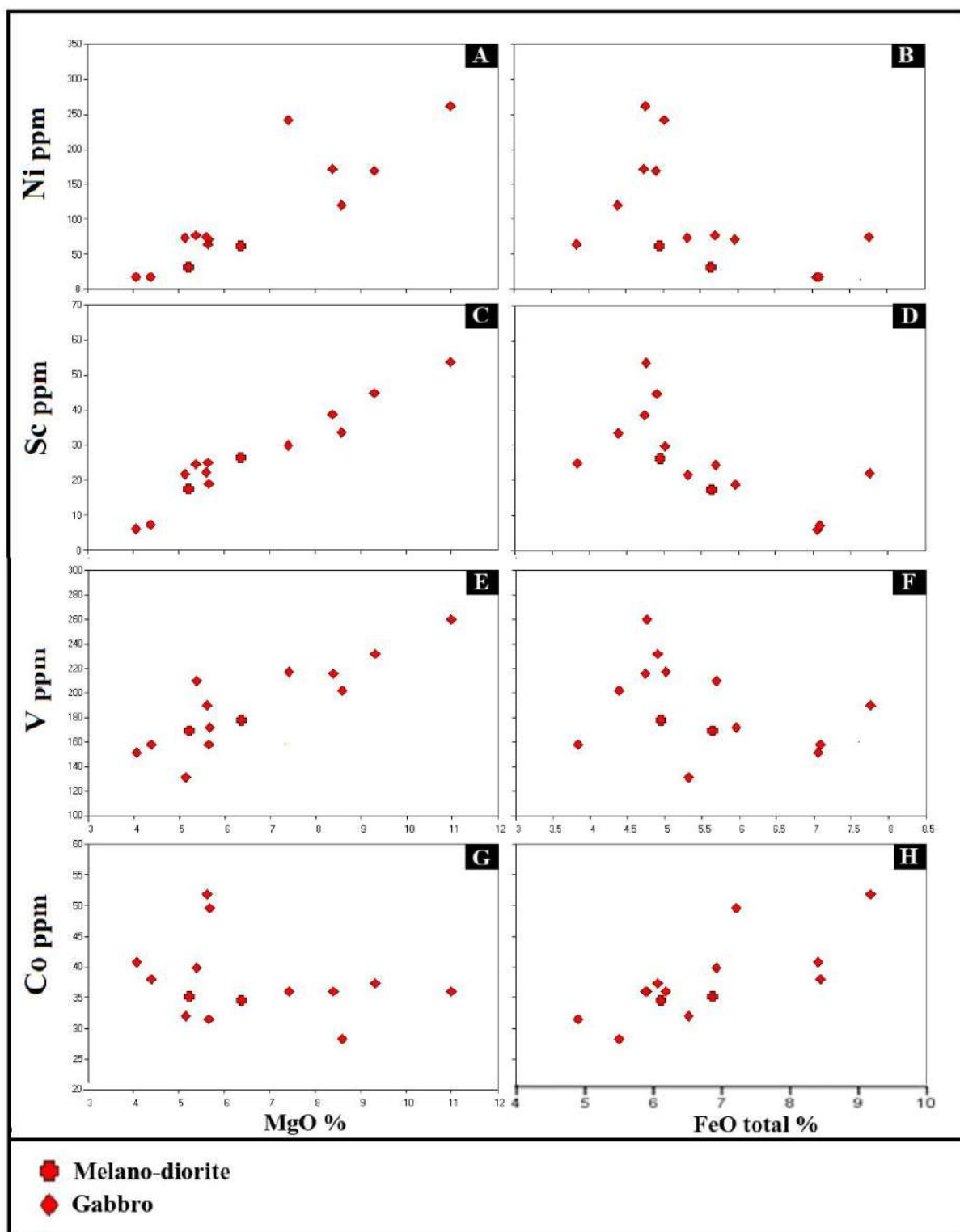


Fig. 4: Variation diagram of MgO and FeO_{total} vs. Ni, Sc, V, and Co of pegmatites in the Bulfat complex.

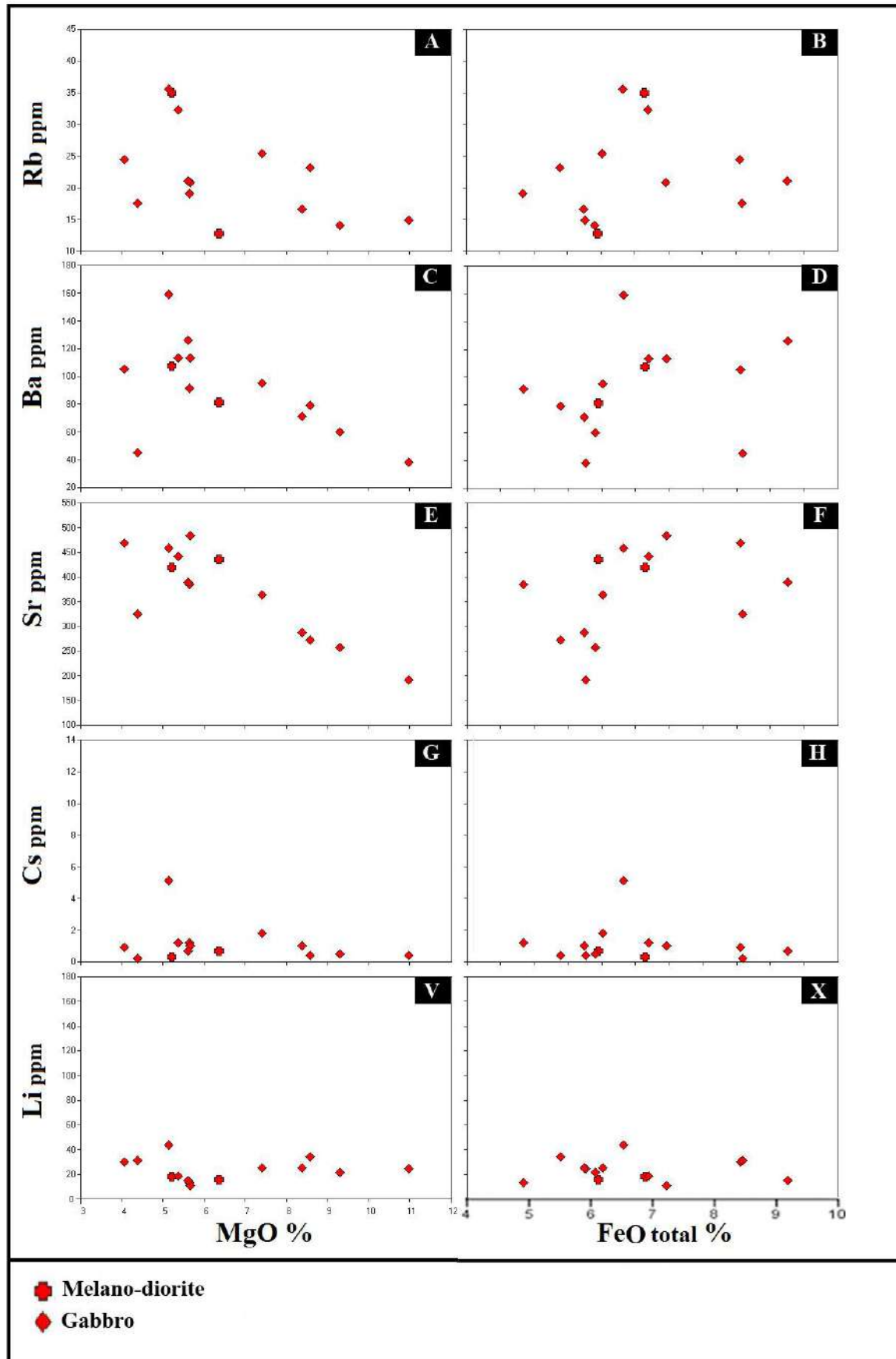


Fig. 5: Variation diagram of MgO and FeO_{total} vs. LILEs of pegmatites in the Bulfat complex.

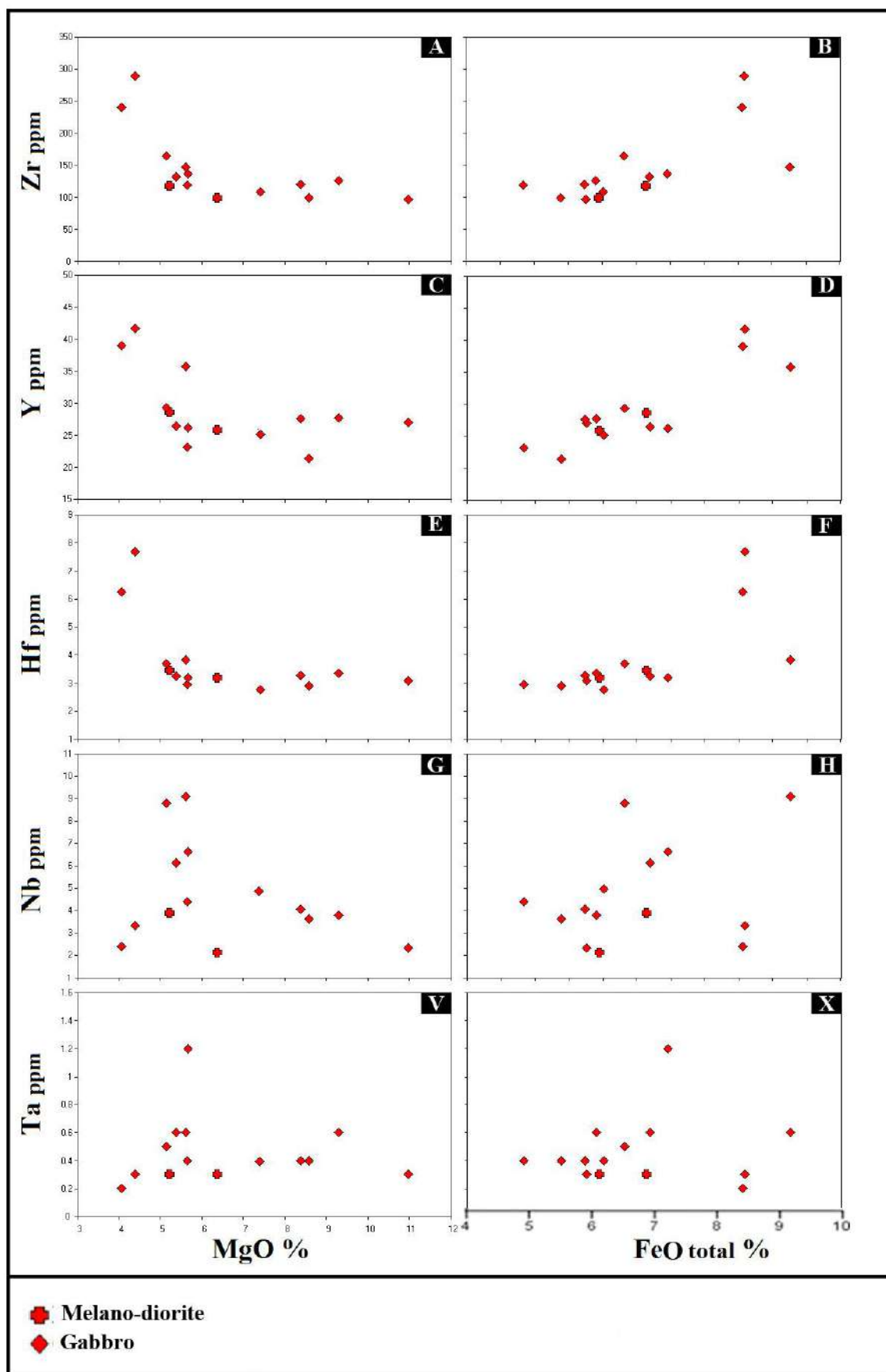


Fig. 6: Variation diagram of MgO and FeO_{total} vs. HFSEs of pegmatites in the Bulfat complex.

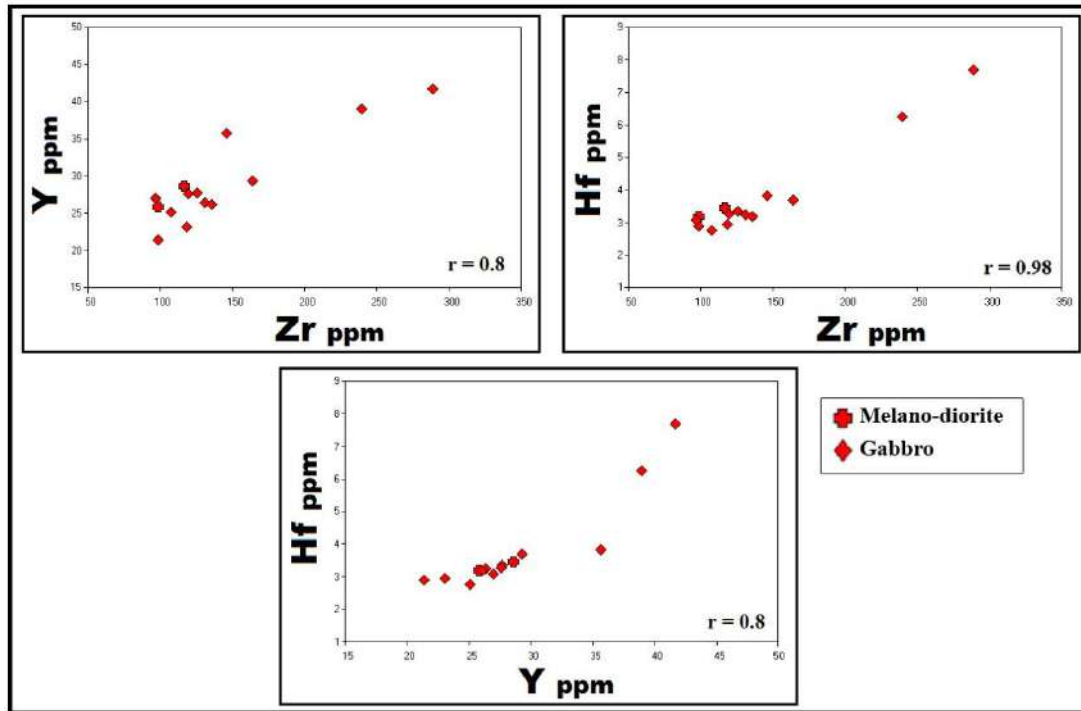


Fig. 7: Variation diagram of Zr vs. Y and Hf; Y vs. Hf of pegmatites in the Bulfat complex.

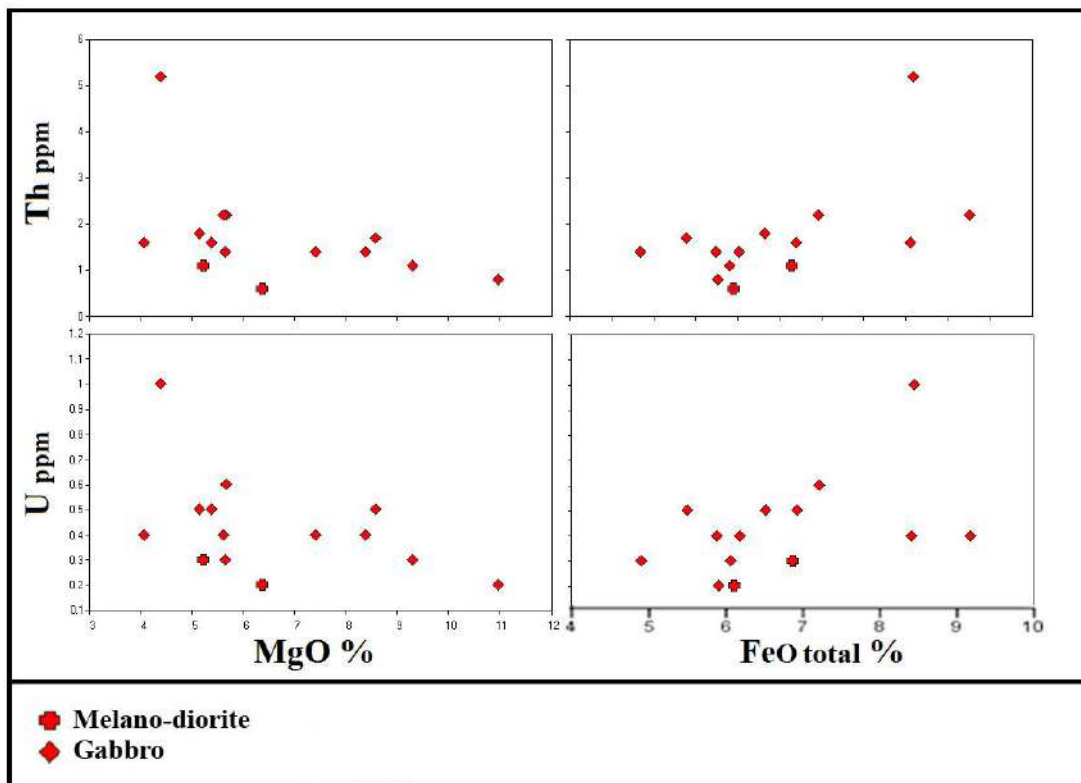


Fig. 8: Variation diagram of MgO and FeO_{total} vs. Th and U of pegmatites in the Bulfat complex.

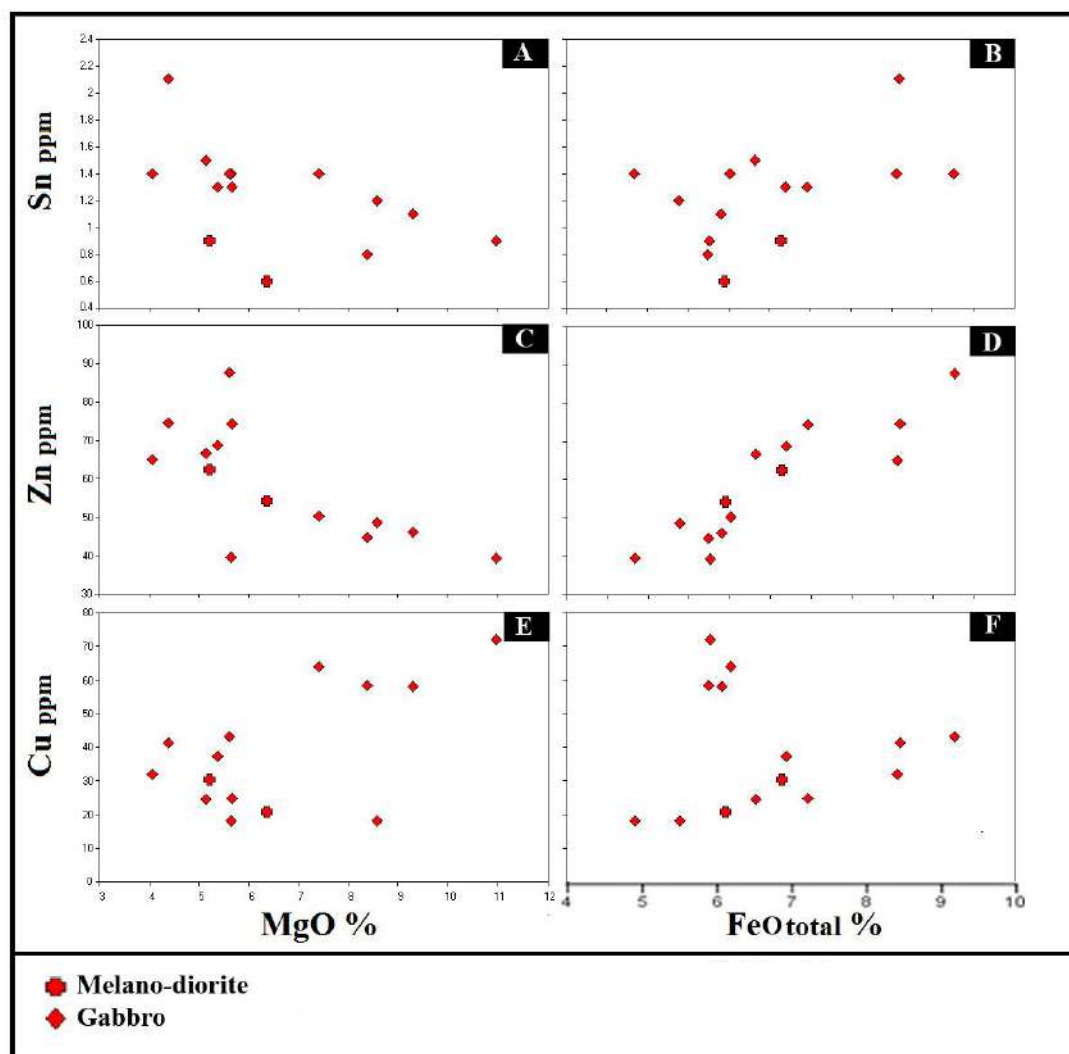


Fig. 9: Variation diagram of MgO and FeO_{total} vs. Sn, Zn, and Cu of pegmatites in the Bulfat complex.

Rare Earth Elements (REEs):

The pattern diagram of REEs after normalization with chondrite (Sun and McDonough, 1989) is accomplished (Table 5 and Fig.10).

Generally, The REEs are characterized by a relatively flat pattern (Fig. 10), this reflects the one origin. Σ REEs range between (55.34-153.75 ppm) (Table 6). The rates of LREEs and HREEs in these pegmatites range between (31.36-68.57 ppm) and (28.84-60.95 ppm) respectively (Table 6).

The ratio $(La/Sm)_N$ shows enrichment and depletion in LREE, this ratio ranges between (0.85-2.03) (Table 7). It is noted that this ratio is greater than one (except D3_A sample) (Table 7), which reflects the enrichment of these rocks in the LREEs content.

The ratio $(Gd/Yb)_N$ indicates the variation in HREEs content, this ratio ranges between (1.07-1.78) (Table 7) and these values reflect a limited variance, which explains the homogeneity and flatness in the HREEs.

In general, the ratio $(La/Yb)_N$ shows the variation in the REEs behavior, as it indicates enrichment or depletion in LREEs relative to HREEs content, this ratio extends between (1.34-3.80) (Table 7) reflecting the enrichment of these rocks with LREEs compared to HREEs, whereas the ratio $(La/Yb)_N$ is consistent with the ratio $(La/Sm)_N$.

Moreover, an anomaly in the behavior of (Eu) element is observed in the REEs pattern, which can be illustrated by using the ratio (Eu_N / Eu^*) through the equation $Eu_N / Eu^* = (Eu)_N / (Sm_N * Gd_N)^{0.5}$. Most samples show a small negative anomaly, indicating the fractionation of plagioclase (Zhang *et al.*, 2003; Van Wagoner *et al.*, 2002), while some samples show a positive anomaly, reflecting the accumulation of plagioclase as a result of the magmatic processes (Ottonello *et al.*, 1984; Trubelja *et al.*, 1995) (Table 7).

A negative correlation is observed between Mg# and Σ REEs, where the REEs increase with the decrease of Mg# and this is due to the fractionation process of the mafic minerals (Fig. 10).

Table 5: The concentrations of REEs in the pegmatites normalized with the same concentrations of chondrite elements from (Sun and McDonough, 1989).

Rocks	Melano-diorite		Gabbro												Chondrite
Samples REEs	D7 _B	D7 _C	D2 _A	D2 _B	D3 _A	D3 _B	D3 _C	D5 _A	D5 _B	D5 _C	D6 _A	D6 _B	D8 _A	D8 _B	
La	37.975	26.582	35.021	30.380	22.785	32.489	34.177	55.274	35.865	42.194	43.882	56.962	82.700	97.046	0.237
Ce	35.245	26.193	31.471	26.536	24.542	31.454	30.637	47.680	32.304	36.961	39.624	56.225	80.523	86.683	0.612
Pr	36.842	27.368	28.421	25.263	27.368	31.579	32.632	42.105	29.474	33.684	31.579	54.737	74.737	80.000	0.095
Nd	31.263	30.193	25.910	22.056	25.054	29.336	30.407	34.475	29.550	31.692	32.334	45.396	71.520	71.520	0.467
Sm	30.065	19.608	26.797	20.915	26.797	28.105	22.876	30.065	21.569	27.451	21.569	37.255	47.059	50.980	0.153
Eu	27.586	25.862	17.241	18.966	20.690	20.690	17.241	24.138	20.690	25.862	24.138	27.586	36.207	32.759	0.058
Gd	23.301	19.903	17.961	18.932	24.272	22.330	22.816	21.845	16.505	24.272	19.903	25.243	38.835	35.437	0.206
Tb	24.324	21.622	16.216	16.216	18.919	21.622	21.622	21.622	16.216	21.622	21.622	24.324	29.730	35.135	0.037
Dy	21.260	18.898	19.685	16.535	20.866	24.016	19.291	17.323	16.142	21.654	18.504	25.591	30.315	28.346	0.254
Ho	19.298	17.544	17.544	15.789	17.544	17.544	15.789	19.298	15.789	19.298	19.298	24.561	26.316	29.825	0.057
Er	18.072	18.675	14.458	16.265	16.265	19.880	20.482	18.072	14.458	16.265	18.072	22.289	21.687	22.892	0.166
Tm	101.961	90.196	105.882	78.431	113.725	94.118	113.725	109.804	101.961	113.725	94.118	156.863	145.098	176.471	0.026
Yb	15.294	13.529	15.882	11.765	17.059	14.118	17.059	16.471	15.294	17.059	14.118	23.529	21.765	26.471	0.17
Lu	12	16	16	12	12	20	16	20	16	16	16	20	24	24	0.025

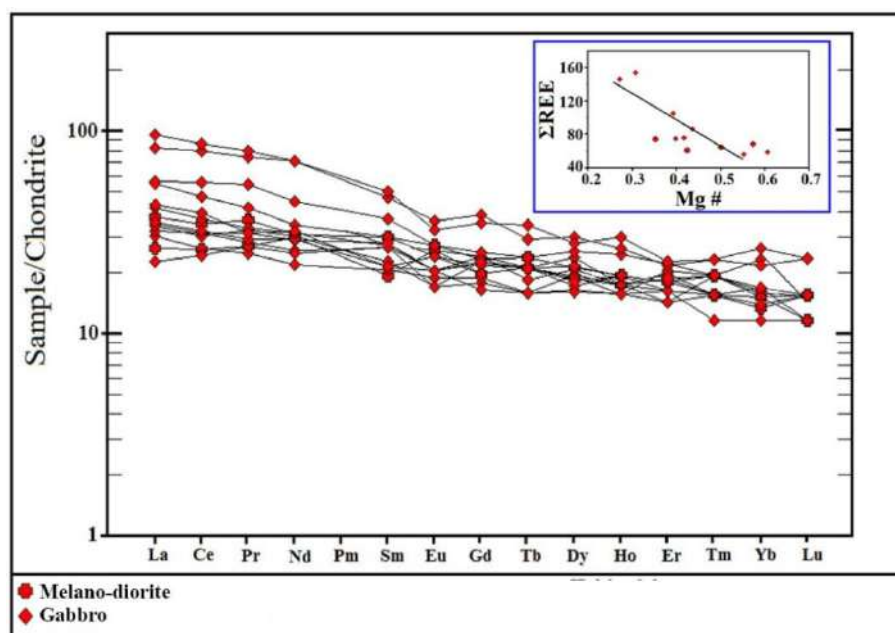


Fig. 10: Chondrite-normalized REEs diagram of pegmatites, data from (Sun and McDonough, 1989).

Table 6: Average concentrations and Σ REEs of pegmatites normalized with the same concentrations of chondrite elements from (Sun and McDonough, 1989).

Samples Avg. REE	D7 _B	D7 _C	D2 _A	D2 _B	D3 _A	D3 _B	D3 _C	D5 _A	D5 _B	D5 _C	D6 _A	D6 _B	D8 _A	D8 _B
LREE	39.67	36.69	41.43	31.36	43.22	39.36	44.41	44.21	39.95	44.51	37.99	60.17	58.27	68.57
HREE	36.07	33.69	36.93	28.84	38.73	36.11	40.42	39.85	35.70	39.80	34.67	53.86	52.17	60.95
ΣREE	73.47	60.43	63.76	55.34	58.32	68.25	67.15	85.98	64.17	75.12	74.35	104.3	145.5	153.8

Table 7: The ratios of REEs of pegmatites normalized with the same concentrations of chondrite elements from (Sun and McDonough, 1989).

Samples ratios	D7 _B	D7 _C	D2 _A	D2 _B	D3 _A	D3 _B	D3 _C	D5 _A	D5 _B	D5 _C	D6 _A	D6 _B	D8 _A	D8 _B
(La/Sm)_N	1.26	1.36	1.31	1.45	0.85	1.16	1.49	1.84	1.66	1.54	2.03	1.53	1.76	1.90
(Gd/Yb)_N	1.52	1.47	1.13	1.61	1.42	1.58	1.34	1.33	1.08	1.42	1.41	1.07	1.78	1.34
(La/Yb)_N	2.48	1.96	2.21	2.58	1.34	2.30	2.00	3.36	2.35	2.47	3.11	2.42	3.80	3.67
Eu_N/Eu*	1.04	1.31	0.79	0.95	0.81	0.83	0.75	0.94	1.10	1.00	1.17	0.90	0.85	0.77

Spider diagram:

The spider diagram is accomplished after normalization with primitive mantle (Sun and McDonough, 1989) (Table 8).

The spider diagram of the studied pegmatites (Fig. 11) shows a positive anomaly in Sr, Pb, and Rb elements in most samples relative to neighboring REEs (Table 9), with a noticeable flatness in the pattern from Zr to Sm. While Y, Ta, and Nb elements show a negative anomaly in most samples relative to adjacent REEs (Table 9), this anomaly reflects the island arcs environment (Aswad *et al.*, 2013).

Generally, the ratios of (Rb/Sr)_N and (Ba/Sr)_N are low in these rocks (Table 9), which suggests that these pegmatites are derived from a basic origin, whereas the high ratios of (Rb/Sr)_N and (Ba/Sr)_N refer to a non-basic origin (Rogers and Greenberg, 1990).

Table 8: The concentrations of the elements in the pegmatites normalized with the same concentrations of primitive mantle elements (P.M) from (Sun and McDonough, 1989).

Rocks	Melano-diorite		Gabbro												P.M
Samples Elements	D7 _B	D7 _C	D2 _A	D2 _B	D3 _A	D3 _B	D3 _C	D5 _A	D5 _B	D5 _C	D6 _A	D6 _B	D8 _A	D8 _B	
Cs	14.286	33.333	85.714	19.048	19.048	23.810	47.619	242.857	57.143	57.143	47.619	33.333	42.857	9.524	
Rb	58.167	21.333	42.167	38.500	24.833	23.333	27.667	59.167	31.833	53.667	34.667	35.000	40.667	29.167	0.60
Ba	16.212	12.273	14.394	11.970	5.758	9.091	10.758	24.091	13.788	17.121	17.121	19.091	15.909	6.818	6.60
Th	13.836	7.547	17.610	21.384	10.063	13.836	17.610	22.642	17.610	20.126	27.673	27.673	20.126	65.409	0.08
U	14.778	9.852	19.704	24.631	9.852	14.778	19.704	24.631	14.778	24.631	29.557	19.704	19.704	49.261	0.02
K	33.241	15.374	24.931	19.945	14.959	17.036	18.698	38.228	20.360	31.579	21.191	22.853	22.853	15.790	0.03
Nb	5.897	3.207	7.508	5.486	3.526	5.775	6.140	13.343	6.672	9.286	10.076	13.799	3.632	5.046	0.66
Ta	8.108	8.108	10.811	10.811	8.108	16.216	10.811	13.514	10.811	16.216	32.432	16.216	5.405	8.108	0.04
La	13.889	9.722	12.809	11.111	8.333	11.883	12.500	20.216	13.117	15.432	16.049	20.833	30.247	35.494	0.65
Ce	12.878	9.570	11.499	9.696	8.967	11.493	11.194	17.421	11.803	13.504	14.478	20.543	29.421	31.672	1.68
Pb	25.133	13.067	34.400	30.867	27.733	28.000	25.667	35.800	24.933	23.000	29.800	31.267	15.133	30.800	0.15
Pr	14.000	10.400	10.800	9.600	10.400	12.000	12.400	16.000	11.200	12.800	12.000	20.800	28.400	30.400	0.25
Sr	21.055	21.910	18.291	13.668	9.598	12.915	14.422	23.015	19.347	22.161	24.271	19.548	23.518	16.332	19.9
Nd	11.680	11.280	9.680	8.240	9.360	10.960	11.360	12.880	11.040	11.840	12.080	16.960	26.720	26.720	1.25
Zr	11.124	9.429	10.276	9.429	9.219	11.981	11.400	15.619	11.324	12.476	12.952	13.924	22.819	27.505	10.5
Hf	12.120	11.237	9.717	10.177	10.883	11.767	11.484	13.039	10.353	11.449	11.201	13.463	22.085	27.138	0.28
Sm	11.330	7.389	10.099	7.882	10.099	10.591	8.621	11.330	8.128	10.345	8.128	14.039	17.734	19.212	0.41
Eu	10.390	9.740	6.494	7.143	7.792	7.792	6.494	9.091	7.792	9.740	9.091	10.390	13.636	12.338	0.15
Gd	8.889	7.593	6.852	7.222	9.259	8.519	8.704	8.333	6.296	9.259	7.593	9.630	14.815	13.519	0.54
Tb	9.091	8.081	6.061	6.061	7.071	8.081	8.081	8.081	6.061	8.081	8.081	9.091	11.111	13.131	0.10
Dy	8.012	7.122	7.418	6.231	7.864	9.050	7.270	6.528	6.083	8.160	6.973	9.644	11.424	10.682	0.67
Ti	9.025	6.548	6.614	5.458	5.904	5.813	5.516	6.507	5.400	9.752	7.845	10.107	10.388	8.646	0.20
Y	6.651	6.000	5.837	4.977	6.279	6.442	6.419	6.814	5.372	6.140	6.070	8.302	9.070	9.698	4.30
Ho	7.383	6.711	6.711	6.040	6.711	6.711	6.040	7.383	6.040	7.383	7.383	9.396	10.067	11.409	0.15
Er	6.849	7.078	5.479	6.164	6.164	7.534	7.763	6.849	5.479	6.164	6.849	8.447	8.219	8.676	0.44
Tm	7.776	6.221	7.776	4.666	6.221	6.221	7.776	7.776	6.221	6.221	6.221	7.776	9.331	9.331	0.06
Yb	5.896	5.215	6.122	4.535	6.576	5.442	6.576	6.349	5.896	6.576	5.442	9.070	8.390	10.204	0.44
Lu	4.444	5.926	5.926	4.444	4.444	7.407	5.926	7.407	5.926	5.926	5.926	7.407	8.889	8.889	0.07

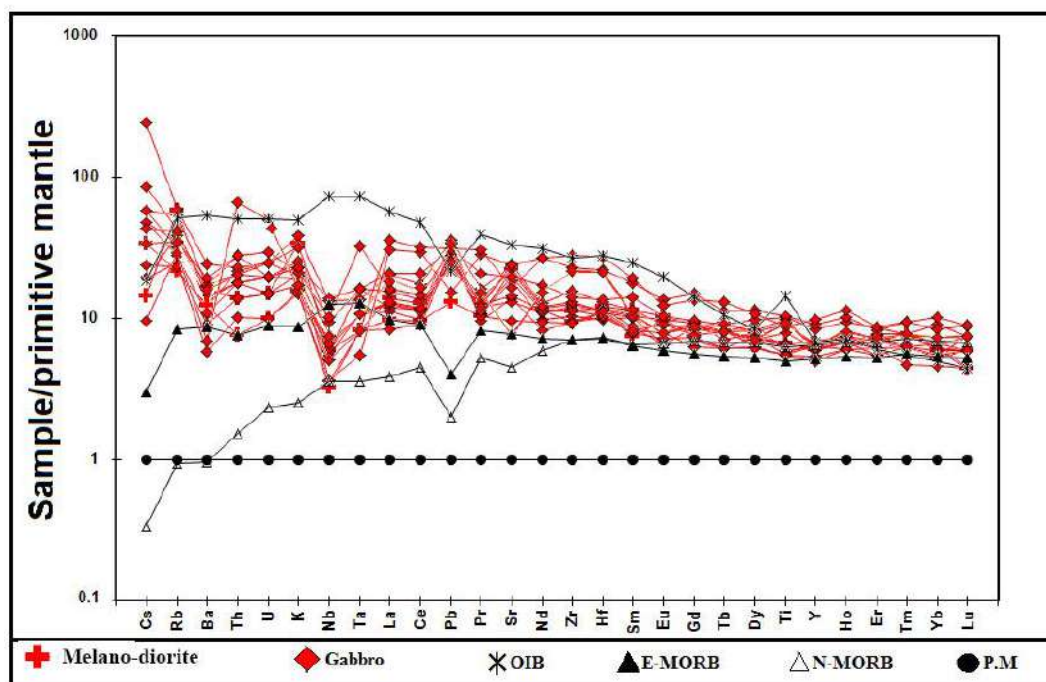


Fig. 11: Spider diagram of the elements in the pegmatites after normalization with the same concentrations of primitive mantle elements (P.M) from (Sun and McDonough, 1989).

Table 9: The ratios of the elements in the pegmatites normalization with the same concentrations of primitive mantle elements from (Sun and McDonough, 1989).

Samples	(Rb/La) _N	(Ba/La) _N	(Nb/La) _N	(Ta/La) _N	(Pb/Ce) _N	(Sr/Nd) _N	(Y/Ho) _N	(Rb/Sr) _N	(Ba/Sr) _N
D7 _B	4.188	1.167	0.425	0.584	1.952	1.803	0.901	2.763	0.770
D7 _C	2.194	1.262	0.330	0.834	1.365	1.942	0.894	0.974	0.560
D2 _A	3.292	1.124	0.586	0.844	2.992	1.890	0.870	2.305	0.787
D2 _B	3.465	1.077	0.494	0.973	3.184	1.659	0.824	2.817	0.876
D3 _A	2.980	0.691	0.423	0.973	3.093	1.025	0.936	2.587	0.600
D3 _B	1.964	0.765	0.486	1.365	2.436	1.178	0.960	1.807	0.704
D3 _C	2.213	0.861	0.491	0.865	2.293	1.270	1.063	1.918	0.746
D5 _A	2.927	1.192	0.660	0.668	2.055	1.787	0.923	2.571	1.047
D5 _B	2.427	1.051	0.509	0.824	2.112	1.752	0.889	1.645	0.713
D5 _C	3.478	1.109	0.602	1.051	1.703	1.872	0.832	2.422	0.773
D6 _A	2.160	1.067	0.628	2.021	2.058	2.009	0.822	1.428	0.705
D6 _B	1.680	0.916	0.662	0.778	1.522	1.153	0.884	1.790	0.977
D8 _A	1.344	0.526	0.120	0.179	0.514	0.880	0.901	1.729	0.676
D8 _B	0.822	0.192	0.142	0.228	0.972	0.611	0.850	1.786	0.417

DISCUSSION AND CONCLUSIONS

During the last three decades, many researchers have used various geochemical methods to isolate tectonic environments from each other depending on binary and ternary variation diagrams known as tectonic discriminate diagrams, by relying on some of the major, trace, and rare earth elements.

Figure (12A) shows that the studied pegmatites are of igneous origin (I-type). The SiO_2 - K_2O diagram explains the evolution of the volcanic arc from tholeiite to shoshonite, this diagram shows the presence of these pegmatites in the calc-alkaline field (Fig. 12B), which are sub alkaline rocks (Fig. 12C). The studied pegmatites in the mentioned diagrams are consistent with the intrusive rocks close to the study area that are gabbros of Wadi Rashid studied by Aswad *et al* (2013).

Using (Ta/Yb) against (Th/Yb) of (Pearce, 1982) to sort between volcanic arc basalts (VAB), mid oceanic ridge basalts (MORB), and within plate basalts (WPB), the studied pegmatites veer from MORB field and occur in VAB field of calc-alkaline type (CA) (Fig. 12D). The tectonic discriminate diagrams (Hf-Th-Ta) and (Nb-Zr-Y) (Fig. 13A, B) show most pegmatites are located in the volcanic arc basalts field. Moreover, Fig.(13) shows some samples are located in MORB; this indicates that these rocks were erupted in an extensional stress regime (Aswad *et al.*, 2013). Nevertheless, Fig. 13 emphasizes the volcanic arc environment of studied pegmatites. The SiO_2 - $\text{K}_2\text{O}/\text{Na}_2\text{O}$ diagram (Fig. 14) shows that the environment of studied pegmatites is oceanic island arcs.

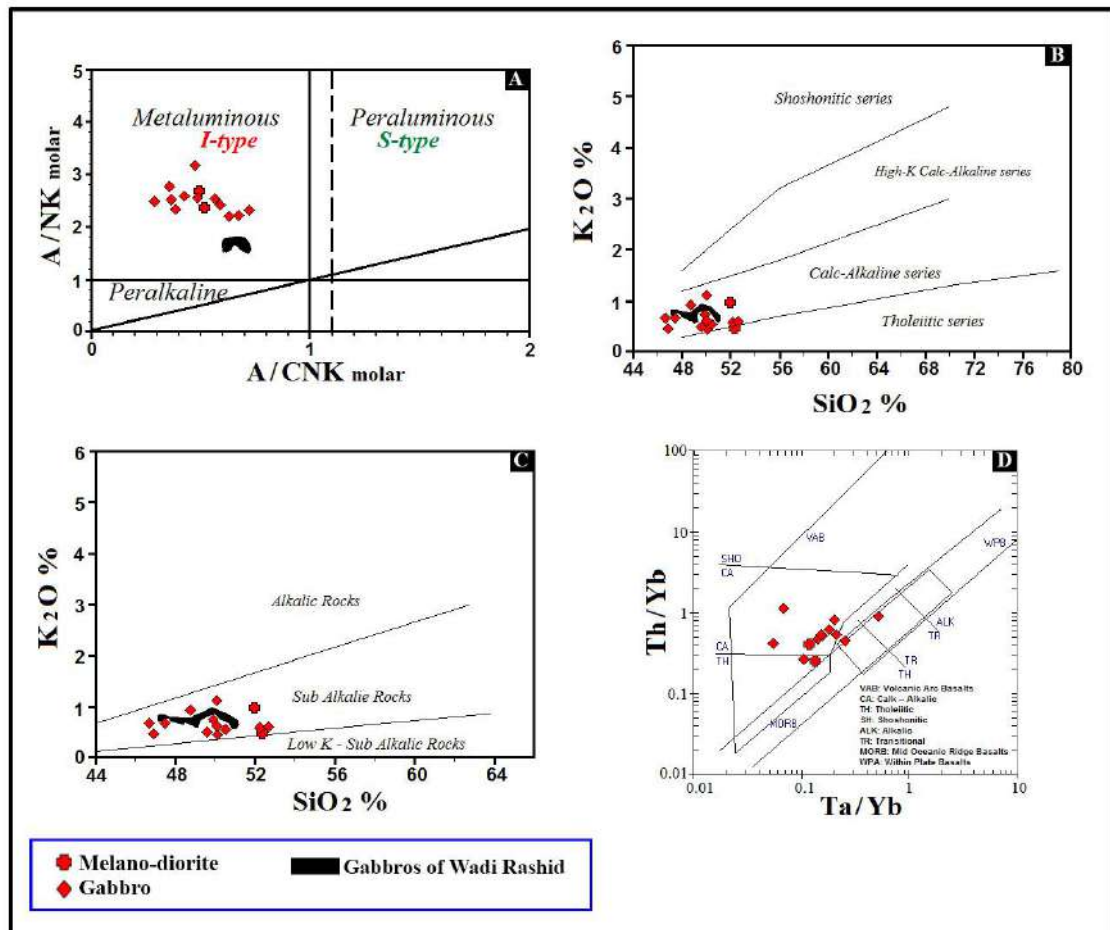


Fig. 12: Tectonic environment of the studied pegmatites. **A:** The molar relationship between A/NK and A/CNK for sorting between the type of alumina saturation from (Maniar and Piccoli, 1989) and type of rocks from (Chappell and White, 1974). **B** and **C:** SiO_2 vs. K_2O diagram to distinguish the type of pegmatites from (Peccerillo and Taylor, 1976) and (Middlemost, 1975) respectively. **D:** Ta/Yb vs. Th/Yb diagram to distinguish tectonic of the studied pegmatites from (Pearce, 1982). In comparison with gabbros of Wadi Rashid from (Aswad *et al.*, 2013).

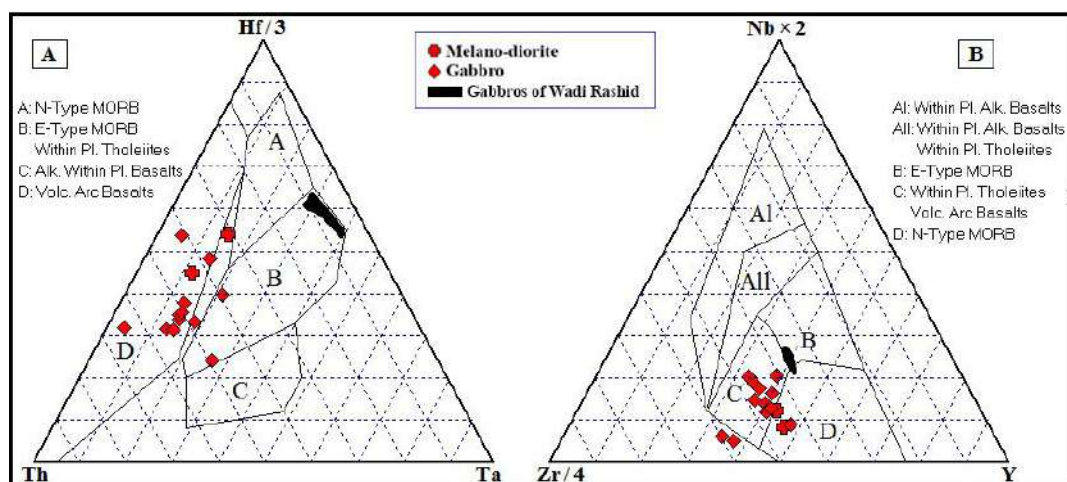


Fig. 13: Tectonic discriminate ternary diagrams of the studied pegmatites. A: from (Wood, 1980). B: from (Pearce, 1982). In comparison with gabbros of Wadi Rashid from (Aswad *et al.*, 2013).

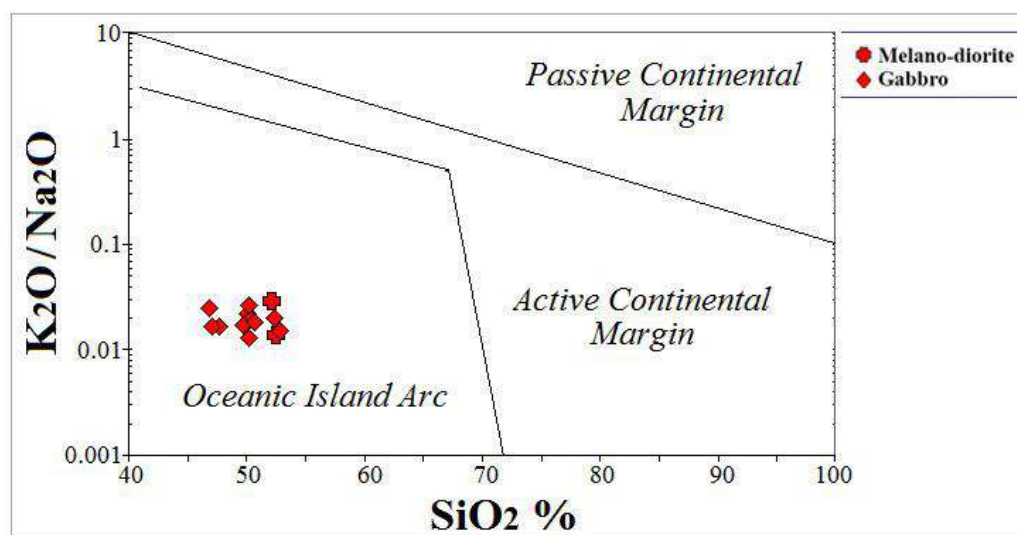


Fig. 14: SiO_2 vs. $\text{Log (K}_2\text{O/Na}_2\text{O)}$ diagram to characterize the tectonic environment of the studied pegmatites, modified from (Bathia, 1983).

The relatively flat pattern of REEs is characterized by the enrichment of LREEs compared to HREEs (Fig. 10) indicating the common ancestry origin of the studied pegmatites. Also, the enrichment in LILEs (Sr, Pb, Rb) and depletion in HFSEs especially (Nb, Ta, Y) (Fig. 11) indicate the environment of the island arcs. The enrichment of LILEs is due to their migration by aqueous solutions derived from the subducted oceanic slab to the mantle wedge above it by dehydration, and an indication of the added fluids from the subducted slab to the mantle wedge (Breeding *et al.*, 2004), whereas the HFSEs are immobile through these solutions and remain in the subducted oceanic slab (Breeding *et al.*, 2004). In addition, the pegmatitic melt crystallizes far from equilibrium (Chakoumakos and Lumpkin, 1990; Morgan and London, 1999; Webber *et al.*, 1999). Therefore, the difference occurs in the fractionation and behavior of LILEs from what is expected in other melts (London, 2005b). Moreover, the low ratios of

(Rb/Sr)_N and (Ba/Sr)_N refer to that these pegmatites are derived from a basic origin (Rogers and Greenberg, 1990).

The previously presented tectonic discriminate diagrams show that the tectonic environment of the studied pegmatites is I-type, which is the oceanic island arcs environment of sub alkaline rocks. The pegmatites of the present study have a genesis relationship with intrusions close to them in the study area, these intrusions are gabbros of Wadi Rashid that represent the environment of E-MORB (Aswad *et al.*, 2013) and the age of these intrusions is 40 Ma (Aswad *et al.*, 2016). The gabbros of Wadi Rashid and studied pegmatites are part of ophiolite-bearing terranes (Aswad *et al.*, 2011), they are found within upper allochthon thrust sheet of Albian-Cenomanian (Aswad and Elias, 1988; Aswad, 1999). In addition, there are volcanic arc activities in the lower allochthon of Palaeogene, represented by walash volcanic (basic rocks) that have island arcs environment type island arc tholeiite (IAT) and calc-alkaline basalt (CAB) having the age between 32-43 Ma (Koyi, 2006). Whereas, the current study of pegmatites reflects the oceanic island arcs environment, this indicates the existence of double island arcs, the first adjacent to the Arabian shelf, and the second close to the middle of paleo-ridge.

Numerous evidences support the gabbros of Wadi Rashid as the likely parent to the studied pegmatites such as geochemistry, tectonogenesis, and the close spatial distribution of the pegmatites to the gabbros of Wadi Rashid. Moreover, the studied pegmatites appear to entail further dissection mainly due to the fact that the occurrence of dioritic- and gabbroic-pegmatites with a small-scale in the single intrusion might have its explanation in the liquid associated immiscibility.

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