

Geochemistry of the Um Had Plutonites, Central Eastern Desert, Egypt: Implications for Magma Evolution, and Tectonic Setting

Nedal Qaoud¹

¹ Geology Department, Faculty of Science, Al-Azhar University, Gaza, Palestine

Correspondence: Nedal Qaoud, Geology Department, Faculty of Science, Al-Azhar University, Gaza, Palestine.
E-mail: nedalqaoud@hotmail.com

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Abstract

Geochemistry of gabbroid and granitoid plutonites from the Um Had area indicates island arc subalkaline basic magma with tholeiitic affinity and calc-alkaline, metaluminous and slightly peraluminous magma, respectively. Although different in age both plutonite types were emplaced under compressional regime, where subduction-related environment was dominant. They were formed under relatively low to moderate water-vapour pressure (1–5 k-bars) at moderate depths (20–30 km). Biotite granites were formed at a relatively high temperature range (800–840 °C), while biotite-muscovite granites were formed under relatively moderate temperature conditions (760–800 °C). These two units may represent evolution from island arc to active continental margin. It is suggested that island arc gabbros might have sourced the late subduction-related calc-alkaline granitoids during the waning stages of the pan-African orogeny. The I-type nature of the investigated plutonites in the study area and elsewhere suggests the juvenile character of the basement complex of the Eastern Desert of Egypt.

1. Introduction

The Pan-African basement of the Eastern Desert of Egypt is composed mainly of: 1) island arc assemblage (850–614 Ma; Kröner et al., 1992; Stern, 1981; Stern & Hedge, 1985); 2) ophiolitic sequences (810–730 Ma; Kröner et al., 1992); 3) older granitoids (750–610 Ma; Hashad, 1980; Mogahzi, 1999; Stern & Hedge, 1985); 4) Dokhan volcanic suite (630–580 Ma; Stern & Hedge, 1985; Abdel-Rahman & Doig, 1987; Stern & Gottfried, 1986; Wilde & Youssef, 2000; Breitzkreuz et al., 2010); 5) molasse-type Hammamat sediments (610–585 Ma; Wilde & Youssef, 2002; Willis et al., 1988), and 6) younger granitoids (610–550 Ma; Stern & Hedge, 1985; Mogahzi, 1999; Moussa et al., 2008).

Speculation concerning the origin of the younger granitoids in the Nubian Shield is the case. These granitoids have been considered either as the fractionated end-members of calc-alkaline magmas (e.g., Rogers and Greenberg, 1981) or as the initial expression of withinplate magmatism (e.g., Harris & Marriner, 1980). Sr, Nd and Pb isotopic systematics emphasise on the generation of the younger granitoids by anatexis of older tonalite granodiorite suites (740–610 Ma) and subsequently subjected to an episode of metasomatism of basic magma (e.g., Gillespie and Dixon, 1983) or assimilation of older crustal components (e.g., Bickford et al., 1989; Sultan et al., 1990) as well as by fractionation of mafic melts (e.g., El-Sayed, 1998; El-Sayed et al., 2002).

In this study, the geochemical characteristics of the Um Had-Um Shegila plutonites are addressed to clarify the tectonic environment that the Central Eastern Desert represents.

2. The Um Had Granitoids

The Um Had area contains a large elliptical structure trending northwest outlining a core of medium- to high-grade partly gneissic rocks enclosed by a domed thick mylonitic shear zone (e.g., Fowler, 2001; Figure 1). The core is up-heaved by the Um Had granitoid intrusion. The latter and its equivalents scattered throughout the Egyptian Eastern Desert was emplaced during Pan-African orogeny. These granitoids are referred to as late- to post-orogenic calc-alkaline to transitional A-type granitoids, interpreted by Black and Liegeois (1993) as being the result of delamination of the continental lithospheric mantle following the tectonic collisions of East and West Gondwana. These granitoids are characterised by unfoliated, small, nearly circular to elongate epizonal plutons with sharp intrusive contacts.

The southern, SW and SE contacts of this intrusion dip generally at moderate angles outwards, whereas, the western and eastern contacts are steep and associated with syn-intrusion faulting. On the other hand, the northern edge is defined by the northernmost significant dykes cropping out along Wadi Shegila.

3. Methods

Thirty seven samples (23 from the granitoid rocks and 14 from the gabbroic rocks) were carefully selected for the chemical analyses to avoid the effects of secondary alteration. The samples were then submitted to ACME Analytical Labs ltd. (Canada). Major element data were acquired using X-ray fluorescence spectrometry (XRF) on fused beads and pressed pellets. Trace element data, including rare earth-elements (REE) were obtained using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Based on replicate analyses and international standards, the precision is better than ± 1% for major elements, and ± 5% for most trace elements. Data of chemical analyses are illustrated in (Tables 1 and 2).

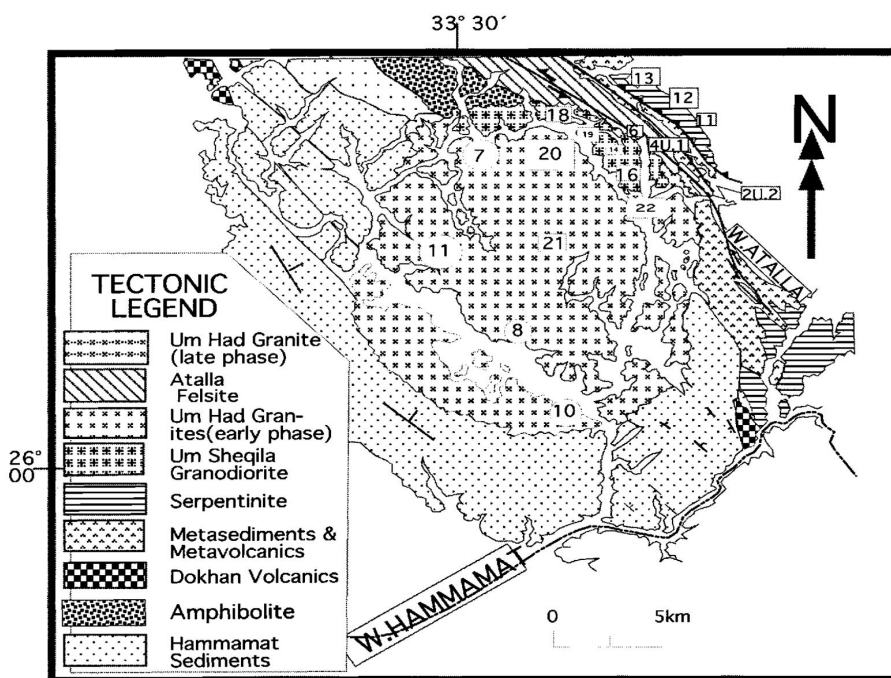


Figure 1. Geological map of the Um Had granitoid intrusion, Central Eastern Desert of Egypt

Table 1. Major oxides and trace elements of granitoid rocks, Um Had area (Table 1a, Table 1b)

Table 1a. Major oxides and trace elements of granitoid rocks, Um Had area (Pink granite)

	Pink granite								
	1	2	3	4	5	6	7	8	9
Major and minor Oxides									
SiO ₂	74.13	74.91	75.91	73.33	76.24	74.79	75.21	74.39	73.19
TiO ₂	0.14	0.17	0.18	0.17	0.21	0.39	0.24	0.31	0.17
Al ₂ O ₃	13.93	13.24	12.91	14.39	12.93	13.96	14.21	13.92	14.11
Fe ₂ O ₃	0.91	0.89	0.93	1.01	0.88	0.93	0.83	0.93	0.91
FeO	0.11	0.13	0.14	0.31	0.13	0.17	0.19	0.21	0.34
MnO	0.13	0.07	0.1	0.07	0.08	0.09	0.03	0.04	0.07
MgO	0.09	0.19	0.12	0.13	0.14	0.15	0.13	0.12	0.12
CaO	1.25	1.29	1.11	1.18	1.12	1.19	1.19	1.71	1.18
Na ₂ O	3.78	3.91	3.89	3.41	4.12	3.76	4.13	4.15	3.78

K ₂ O	4.29	5.21	3.18	3.78	4.92	5.21	5.34	4.15	4.77
P ₂ O ₅	0.04	0.04	0.04	0.05	0.01	0.02	0.09	0.04	0.03
H ₂ O	1.51	1.34	1.23	1.79	0.89	0.14	0.13	0.43	0.91
Trace elements									
Ba	340	352	594	456	458	459	354	148	254
Rb	56	54	58	64	67	59	75	48	67
Sr	364	358	487	256	398	371	458	287	264
Ga	16	15	17	10	16	18	14	13	12
Nb	11	14	16	18	10	13	14	11	12
Zr	124	156	187	100	147	198	132	150	175
Y	10	12	18	16	12	17	12	17	15
Th	6	5	8	2	-	4	-	2	4
U	2	2.4	2.5	2	2	2.1	2.1	2	2.4
Ni	24	45	35	25	27	12	40	35	39
Cu	22	24	11	16	25	14	19	27	35
V	54	76	49	53	59	80	57	49	20
Zn	61	67	75	59	64	68	59	57	63
La	15	11	17	10	19	16	17	10	9
Ce	24	29	45	37	45	26	34	38	47
Nd	18	16	10	17	13	24	15	18	11

Table 1b. Major oxides and trace elements of granitoid rocks, Um Had area (Biotite granite)

	Biotite granite													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Major and minor Oxides														
SiO ₂	75.41	73.99	74.87	74.91	75.32	74.31	75.91	73.35	72.24	74.78	72.11	73.79	74.25	71.77
TiO ₂	0.12	0.19	0.83	1.11	1.23	1.25	0.71	0.91	0.87	1.21	1.89	0.93	1.23	1.11
Al ₂ O ₃	13.92	13.78	12.96	13.63	12.23	13.29	13.49	13.91	14.21	11.97	15.21	13.11	14.19	12.92
Fe ₂ O ₃	0.87	1.01	1.3	1.02	1.01	0.93	1.02	1.21	1.14	0.99	0.83	1.21	1.27	1.71
FeO	0.21	0.29	0.31	0.31	0.39	0.31	0.39	0.21	0.41	0.35	0.29	0.39	0.29	0.32
MnO	0.07	0.09	0.08	0.08	0.07	0.08	0.1	0.08	0.09	0.07	0.09	0.07	0.07	0.06
MgO	0.09	0.09	0.89	0.11	0.71	0.12	0.09	0.08	0.13	0.14	0.13	0.09	0.08	0.11
CaO	1.67	1.41	1.39	1.41	1.51	1.39	1.47	1.52	1.22	1.15	1.71	1.66	1.37	1.54
Na ₂ O	3.65	4.29	3.84	3.28	3.99	3.91	3.71	2.87	3.64	3.79	2.11	3.81	3.44	3.79
K ₂ O	4.68	4.93	3.91	3.89	4.11	4.91	4.51	4.29	5.35	4.67	3.79	4.71	4.71	5.11
P ₂ O ₅	0.05	0.03	0.04	0.03	0.04	0.04	0.07	0.03	0.05	0.03	0.04	0.02	0.01	0.04
H ₂ O	1.23	0.78	0.89	1.11	0.91	1.3	1.21	1.11	0.93	1.21	1.31	1.15	0.78	0.85
Trace elements														
Ba	359	348	254	278	451	412	254	354	265	458	126	278	297	378
Rb	68	61	59	57	46	72	57	95	76	24	49	61	58	49
Sr	394	361	294	189	275	287	345	267	178	194	97	310	290	318
Ga	12	10	17	8	11	10	15	17	10	13	19	10	12	18
Nb	15	9	11	18	10	14	12	11	11	18	10	13	17	11

Zr	160	178	125	101	124	146	179	156	90	160	105	89	103	141
Y	16	17	13	16	17	9	15	17	6	12	11	17	10	8
Th	6	7	8	1	5	1	5	7	2	3	4	-	-	5
U	4	3.1	2.3	2.1	2	2	1	2.1	2.4	1	2.1	2.4	2.1	2
Ni	57	26	24	19	22	34	47	58	49	57	34	21	29	45
Cu	12	10	16	24	27	11	18	13	15	9	22	24	31	15
V	37	39	75	49	42	76	58	49	37	57	67	69	53	54
Zn	67	62	60	64	81	58	64	36	49	57	53	62	57	49
La	15	13	17	11	12	17	19	8	14	19	16	11	14	10
Ce	22	24	29	38	39	29	50	22	27	38	34	39	29	33
Nd	13	10	17	14	10	22	18	27	10	26	24	13	18	10

Table 2. Major oxides and trace elements of gabbroic rocks, Um Had area

Gabbros														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Major and minor Oxides														
SiO ₂	52.3	48.91	50.11	48.39	46.49	49.1	50.21	48.34	49.97	51.21	45.83	50.39	50.77	47.52
TiO ₂	1.84	1.97	0.44	1.23	1.24	1.73	0.97	1.34	1.92	0.87	1.23	1.11	1.01	0.97
Al ₂ O ₃	17.49	18.11	17.29	17.22	14.13	17.97	15.32	15.21	14.93	17.14	15.73	17.29	17.91	18.21
FeO{t	10.28	11.91	13.41	12.91	14.12	10.19	15.42	16.13	12.83	11.14	14.91	10.11	11.37	11.93
MnO	0.19	0.17	0.19	0.14	0.19	0.15	0.71	0.17	0.13	0.17	0.13	0.19	0.18	0.16
MgO	4.89	4.74	5.21	6.13	6.19	5.32	4.14	4.93	5.21	4.87	5.32	6.17	5.17	5.91
CaO	8.74	10.12	8.16	10.11	13.21	9.71	10.31	8.81	12.14	10.71	11.87	10.74	10.97	11.43
Na ₂ O	2.41	3.15	2.79	3.14	3.19	2.79	2.14	3.14	3.19	2.87	3.14	2.88	2.78	2.49
K ₂ O	0.87	1.01	0.94	0.49	1.11	0.91	0.94	0.79	0.83	0.79	0.96	0.81	0.78	0.32
P ₂ O ₅	0.88	0.54	0.63	0.72	0.79	0.64	0.53	0.43	0.75	0.83	0.79	0.44	0.79	0.83
Total	99.89	100.4	99.17	100.5	100.7	98.51	100.7	99.29	101.9	100.6	99.91	100.1	101.7	99.77
Trace elements														
Ba	340	533	371	410	513	618	344	579	430	520	290	330	441	598
V	120	331	211	140	190	180	182	230	214	419	310	170	179	176
Cr	23	30	18	8	12	21	4	18	21	53	27	18	10	9
Co	19	39	51	40	33	52	43	31	37	39	42	34	33	27
Ni	14	53	49	32	28	19	17	39	29	40	31	34	18	19
Cu	13	19	25	12	33	37	41	32	11	16	21	17	31	26
Zn	109	104	93	117	129	150	139	128	112	120	129	129	137	81
Ga	19	16	20	22	14	19	23	16	18	20	20	18	20	21
Pb	8	9	3	1	4	9	3	2	9	3	1	-	3	-
Rb	73	79	81	19	30	18	53	19	45	39	70	84	93	23
Sr	674	607	699	739	930	579	599	737	719	761	589	289	609	847
Y	31	34	12	19	25	31	39	40	35	23	26	34	20	27
Zr	43	39	59	34	49	94	78	71	59	73	79	84	102	130
Nb	14	18	29	15	12	15	27	6	15	30	14	21	32	15
Ce	531	39	48	58	34	73	54	59	31	51	43	39	11	22

4. Results

4.1 Geochemistry of the Granitoids

The Um Had granites reveal general decrease of major oxides (TiO_2 , Al_2O_3 , MgO , Fe_2O_3 and CaO) in relation with SiO_2 , which can be attributed to fractional crystallisation processes. These granitoid rocks can be classified by using normative An-Ab-Or ternary diagram of Barker (1979) and Q-ANOR of Streckeisen and Matiere, (1979), where all samples fall within the monzogranite field (Figures 2a and 2b). On the Zr versus 10^4 Ga/Al binary diagram of Whalen et al. (1987), the studied samples fall within I & S Type granites field (Figure 2c). Chappell and White (1974) used the Mol. $\text{Al}_2\text{O}_3 / (\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ ratio against Rb/Sr ratio to differentiate between I-type and S-type granites. On this binary diagram (Figure 2d) all the studied granitoid samples fall within the I-type field, except one biotite granite sample lies at the boundary separating between the two fields of I-type and S-type granites. Moreover, White and Chappell (1983) as well as Liew et al. (1989) used the $\text{Na}_2\text{O}-\text{K}_2\text{O}$ binary diagram (Figure 3a) to discriminate between I-type, S-type and T-type granites. Plots of the all granitoid samples lie in the I-type granite field indicating igneous source materials for the studied granites, except two biotite granite samples fall within the transition (T-type) field.

All plots of the investigated granitoids fall within the calc-alkaline field (Figure 3b) on the AFM ternary diagram of Irvine and Baragar (1971). Moreover, Petro et al. (1979) used the AFM ternary diagram to discriminate between compressional and extensional suites. Plots of the studied granitoids mostly have the trend of compressional suite. On the SiO_2 vs. K_2O diagram of Peccerillo and Taylor (1976), the studied granitoid samples fall within the field of high-K calc-alkaline series (Figure 3c).

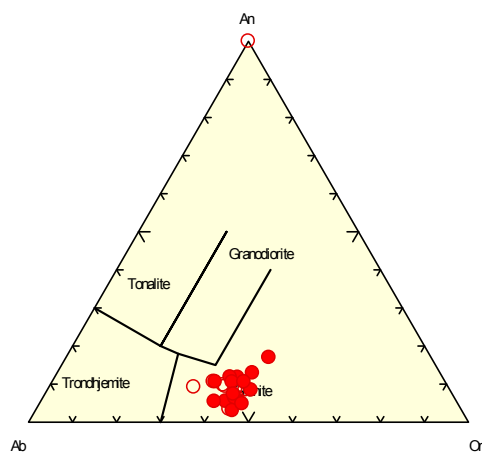


Figure 2a

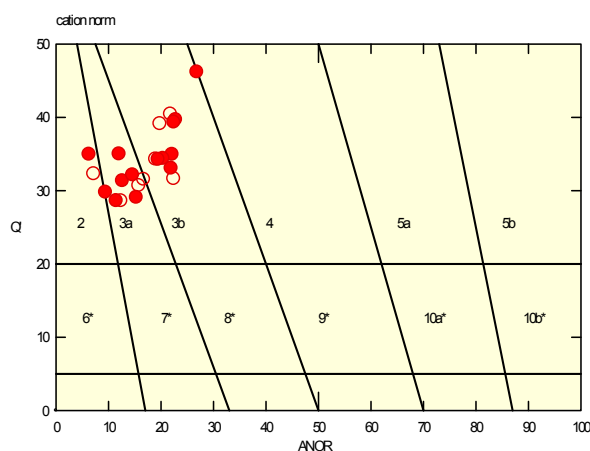


Figure 2b

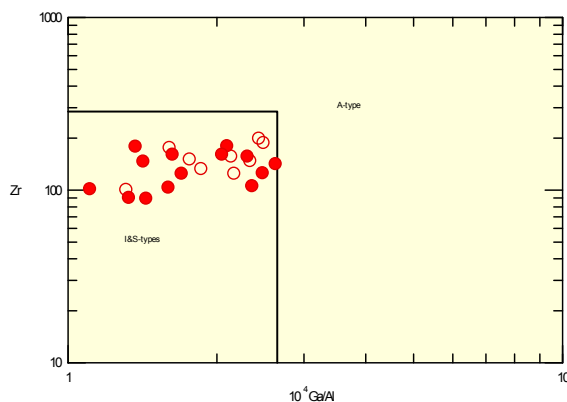


Figure 2c

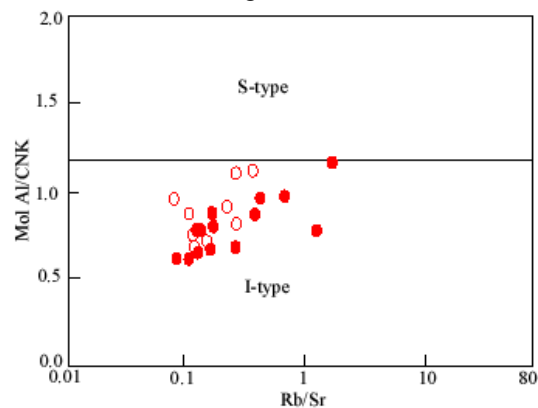


Figure 2d

Figure 2. Plots of the analyzed granitoid rocks on A) An-Ab-Or ternary diagram (after Barker, 1979), B) Q-ANOR diagram of Streckeisen and Matiere, (1979), C) Zr vs. 10^4 Ga/Al diagram of Whalen et al. (1987), D) Mol. $\text{Al}_2\text{O}_3 / (\text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O})$ versus Rb/Sr diagram (after Chappell and White, 1974) discriminating between I-type and S-type granites. Symbols: Filled red circles are biotite granite, while open circles are pink granite

On the $Al_2O_3 / (CaO + Na_2O + K_2O)$ versus $Al_2O_3 / (Na_2O + K_2O)$ binary diagram of Maniar and Piccoli (1989), all plots of these younger granites are of peraluminous to metaluminous nature (Figure 3d). Plots of studied granitoids on the Y vs. Nb and Y+Nb vs. Rb binary diagrams (Figures 4a and 2b) of Pearce et al. (1984) reveal that these granites were formed within volcanic arc tectonic environment.

On the normative An-Ab-Or ternary diagram of Barker (1979) all plots of biotite granite and the two mica granite samples fall in a region of low to moderate water-vapour pressure ranging from 1 to 5 k-bars. Meanwhile, the biotite granites were emplaced under high temperature conditions, ranging from about 800 to 840 °C, whereas the two mica granites were emplaced under moderate temperature conditions ranging from about 760 to 800 °C (Figure 4c). The Rb-Sr binary diagram (after Condie, 1973) shows that the Um Had granites have emplaced at relatively shallow to moderate depths between 20 and 30 km (Figure 4d).

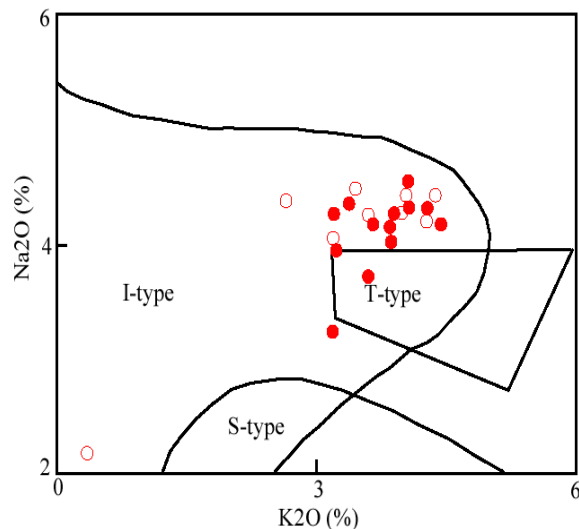


Figure 3a

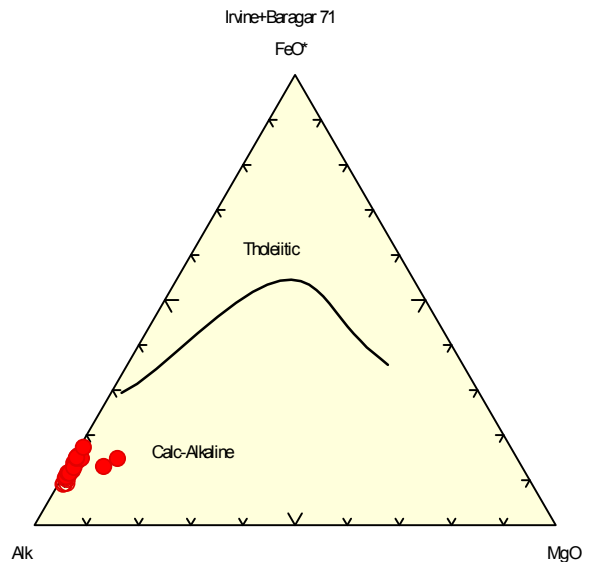


Figure 3b

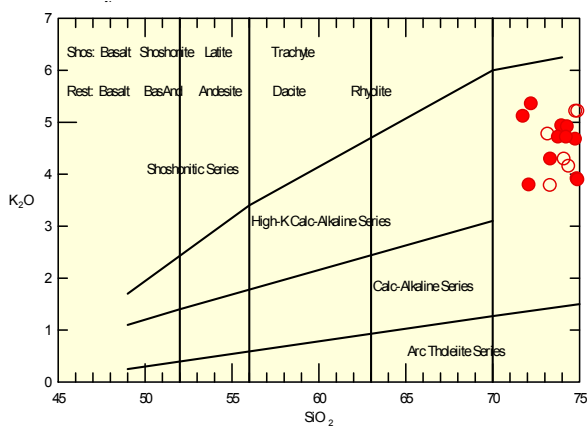


Figure 3c

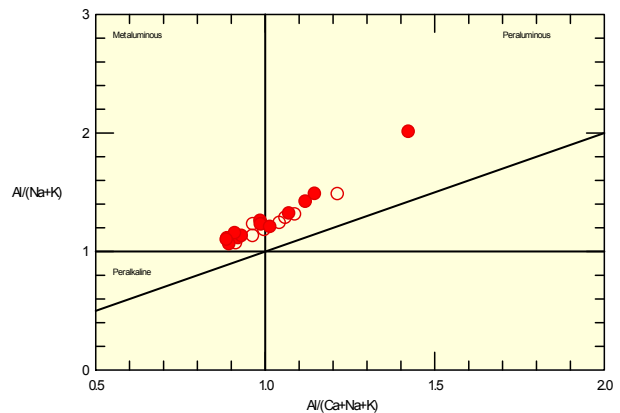


Figure 3d

Figure 3. Plots of the analyzed granitoid rocks on A) The Na_2O versus K_2O binary diagram (after White and Chappell (1983), the T-type field after Liew et al. (1989)), b) AFM ternary diagram (Irvine & Baragar, 1971), on C) SiO_2 vs. K_2O diagram (after Peccerillo and Taylor (1976)), D) $Al_2O_3 / (CaO + Na_2O + K_2O)$ vs. $Al_2O_3 / (Na_2O + K_2O)$ diagram (after Maniar and Piccoli (1989))

4.2. Geochemistry of the Gabbros

The total alkalis vs. silica classification diagrams (after Le Bas et al., 1986; Cox et al., 1979) were used to classify the studied gabbros. All plots of gabbros fall within the basalt (gabbro) field (Figures 5a & b). Plotting of the studied gabbros on $Na_2O + K_2O$ vs. SiO_2 and AFM diagrams of Irvine and Baragar (1971) favors that these

gabbros were derived from subalkaline magma (Figure 5c), with tholeiitic nature (Figure 5d). Also, on the SiO_2 vs. FeOt/MgO diagram of Miyashiro (1974) all the plotted samples of the different gabbroic members lie in the tholeiite field (Figure 5e).

There are two models that have been proposed for the geotectonic environment and magma sources of the younger gabbros. These are the tensional environment or rift-related (El Gaby et al., 1988; El-Mettwaly, 1992) and the subduction-related or island-arc environment (Mohamed & Hassanen, 1996). On the AFM diagram, Petro et al. (1979) defined two tectonic trends discriminating between the compressional and extensional suites. The studied gabbros are concordant with the compressional trend indicating their origin in compressional environment (subduction-related or island-arc environment). Plots of the studied gabbros on the Y vs. Cr discrimination diagram (after Pearce, 1982) favor the arc-related tectonic setting for these gabbros, where all plots of gabbros fall within the field of volcanic-arc basalts (Figure 5f).

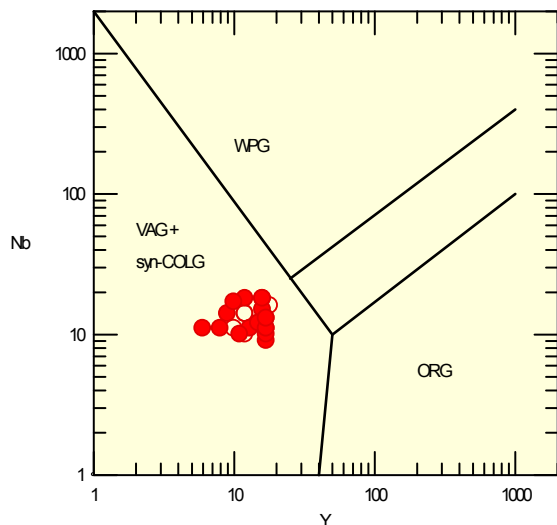


Figure 4a

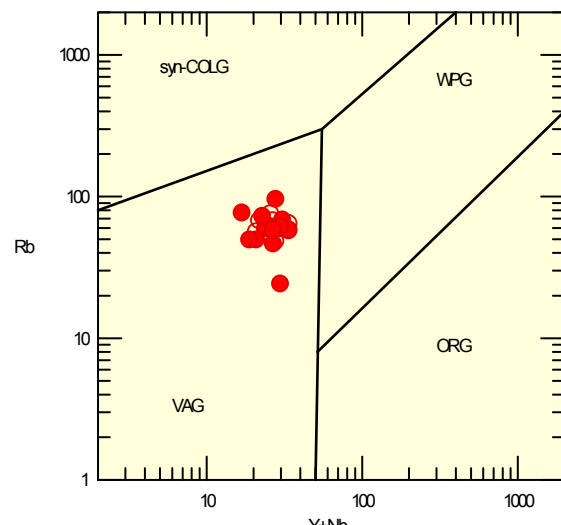


Figure 4b

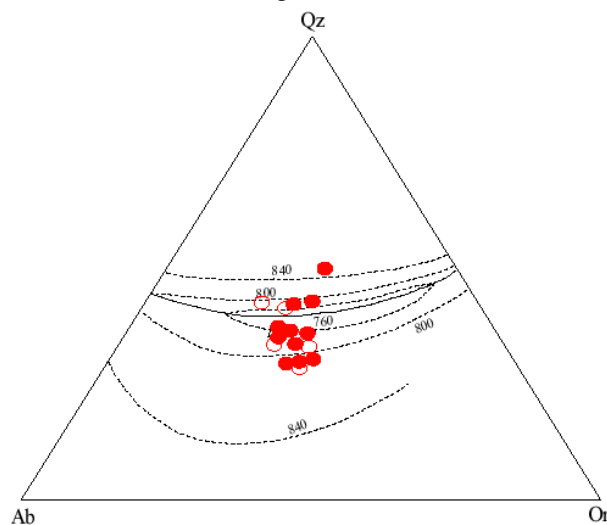


Figure 4c

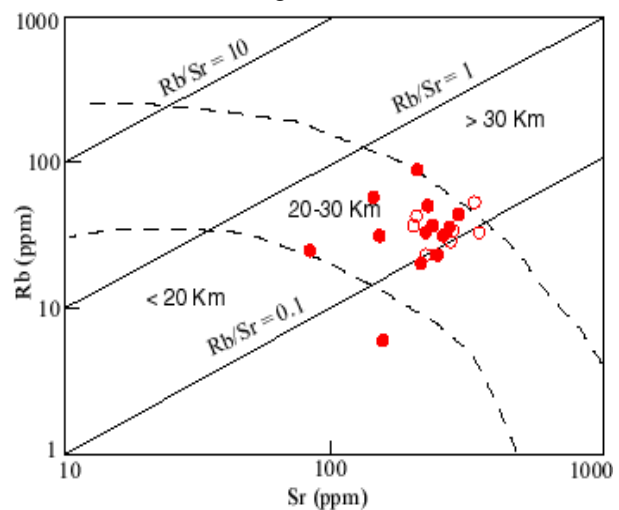


Figure 4d

Figure 4. Plots of Um Had granitoids A) Y vs. Nb diagram (after Pearce et al., 1984), B) Y+Nb vs. Rb diagram (after Pearce et al., 1984), C) Q-Ab-Or normative diagram (after Barker, 1979), D) SR vs. Rb binary diagram (after Condie, 1973)

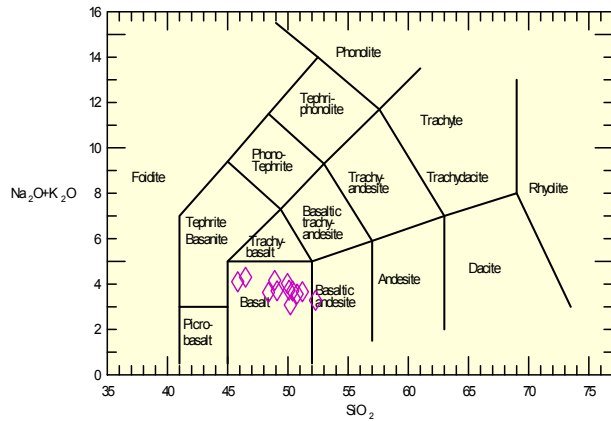


Figure 5a

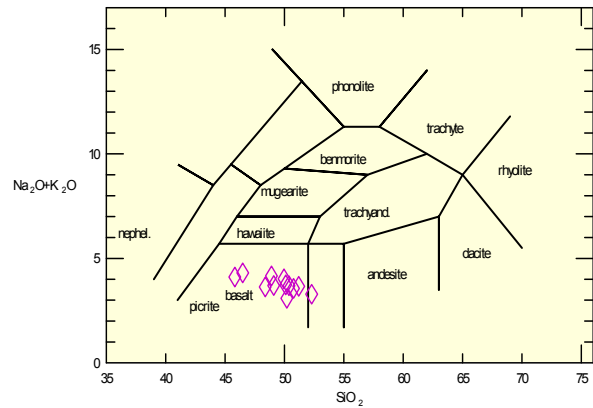


Figure 5b

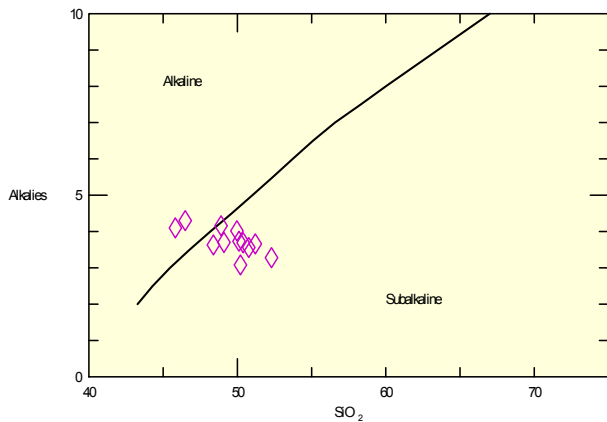


Figure 5c

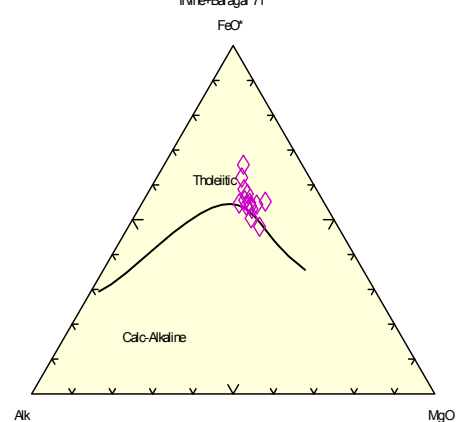


Figure 5d

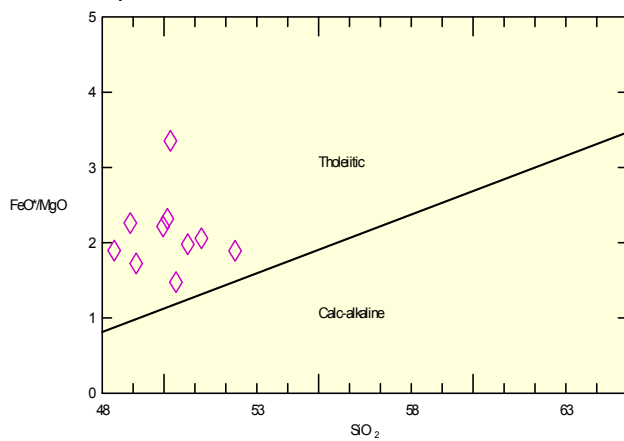


Figure 5e

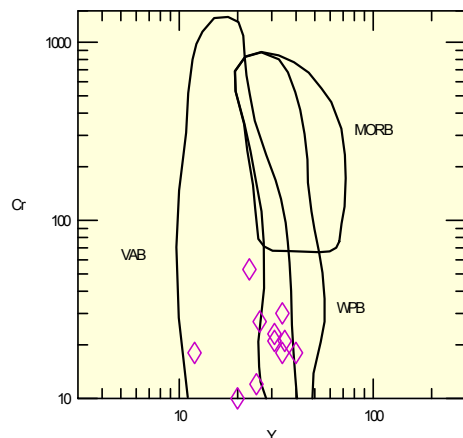


Figure 5f

Figure 5. Plots of the studied gabbros on A) TAS classification diagram (after Le Bas et al., 1986), B) TAS classification diagram (after Cox et al. 1979), C) SiO₂ vs. Na₂O+K₂O diagram (after Irvine and Baragar, 1971), D) AFM diagram (after Irvine and Baragar, 1971), E) SiO₂ vs. FeO^t/MgO diagram (after Miyashiro, 1974), F) Y vs. Cr diagram (after Pearce et al., 1982)

5. Summery and Conclusions

The late to post-tectonic granites of Um Had area are typically monzogranites (biotite granites and biotite-muscovite granites). They have calc-alkaline, metaluminous to slightly peraluminous nature and potassic affinity. Both biotite-granites and biotite-muscovite granites have emplaced during late-orogenic regime in compressional suite. They were formed under relatively low to moderate water-vapour pressure (1-5 k-bars) at

moderate depths (20–30 km). Biotite granites were formed under relatively high temperature range (800–840 °C), while biotite-muscovite granites were formed under relatively moderate temperature conditions (760–800 °C). The gabbros have been derived from subalkaline basic magma exhibiting tholeiitic nature. They were emplaced in compressional subduction-related environment having characters of the island-arc and active continental margin. Although caution is required in using the tectonic setting discrimination diagrams (Verma, 2010), results and graphical plots of the investigated rocks seem reasonable and convincing. It is therefore, concluded that island arc gabbros might have sourced the late subduction-related calc-alkaline granitoids are the convergent plate setting was long prevailed during the waning stages of the pan-African orogeny.

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