Petrochemistry of Atalla I-type younger granite, Wadi Atalla area, Central Eastern Desert, Egypt: implication for petrogenesis and tectonicsetting

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Abstract

The basement rocks exposed in thearea of wadi Atalla are characterized by the intrusion of I-type granites. Petrological and geochemical studies revealed that these granites are dominated by granite in composition. Petrographically, Atalla granite is composed mainly of plagioclase, k-feldspar, and quartz with subordinate amounts of biotite. Sericite, koalinite, epidote, muscovite are alteration products while iron oxides, sphene, zircon, and apatite are common accessories. Geochemically, Atalla granite has calc-alkaline affinities with aluminium saturation index varies from weakly metaluminous to peraluminous. They were formed in volcanic arc setting under compressional regime where subduction-related environments are dominant. Field relation and trace element geochemistry of granites from wadi Atalla suggest their derivation from mantle source.

Key words: calc-alkaline; geochemistry; petrography; Wadi Atalla.

1 Introduction

The crustal evolution of the Arabian Nubian Shield was summarized through four main stages (Gass 1982; Bentor 1985; Stern and Hedge 1985; Stern et al. 1988; Kröner et al. 1990; Stern 1993; Kröner 1993). The rifting followed by sea-floor spreading and the initiation of subduction resulted in formation of oceanic crust and island arcs terranes characterized the first and second stages that occurred at 950–850 Ma and 850–650 Ma respectively. The end of second stage was dominated by welding and accretion of oceanic and island arc terrains to form the Arabian-Nubian Shield. The third stage (650–580 Ma) is the post-collision batholithic stage. During this stage, large scale calc-alkaline magmatism, mainly of intermediate to felsic composition predominated. The post-orogenic stage represents the fourth stage (600–530 Ma) that was characterized by igneous activity of mainly alkaline to peralkaline granites, andesites, rhyolites, and several episodes of dike swarms representing intracratonic within-plate magmatism. Akaad and Noweir (1980) and El Gaby et al. (1988) termed the group of granitic rocks that evolved during the final stage as the younger granitoids. These granitic rocksrepresent a major component of the crust in the basement complex of Egypt. They formabout 30% of the total surface exposure of the basement rocks. They range in composition from granodiorite to granite with I-type characteristics, but some have A-type affinities (Stern and Hedge, 1985; Abdel Rahman and Martin, 1990; Hassanen, 1997). Hussein et al. (1982) divided the Egyptian younger granites into suture related granites (G2-granite) formed in post-orogenic environment and intraplate granites (G3-granite) related to rifting processes. Hassan and Hashad (1990) suggested that the magma of the younger granites was emplaced in three possible tectonic settings: (1) subduction processes in avolcanic arc environment, (2) arc-continent collision event,and (3) within continental plates. Noweir et al. (1990)considered the Egyptian younger granites as transitionalphases from calc-alkaline I-type magmatism to normalalkaline and peralkaline A-type granite. EI-Sayed (1998)classified the Egyptian granites into I-type orogenic arcrelated and A-type anorogenic rift-related granites.A systematic study of particular granitic rock will provide detailed magmatic and geochemical processes that perform in particular area. There has been little systematic study of granitic rocks in wadi Atalla area, therefore, this paper aims to shed the light on the petrological and geochemical characteristics of the granitic rocks in wadi Atalla and deduce theirpetrogenesis and tectonic setting.

2 General Geology

Wadi Atalla area is located to the northwest of the well-known Fawakhair area in the Central Eastern Desert of Egypt. It covers an area of about 250 Km^2 of the basement complex in the Central Eastern Desert of Egypt between latitudes 26° 00̀ 00̀& 26° 15̀ 00̀ N and longitudes 33° 30̀ 00̀& 33° 40̀ 00̀ E (Fig.1). The general geology of wadi Atalla area is dominated by the Pan-African rocks. These rocks comprise serpentinites and related rocks (oldest), metavolcanics and their equivalent pyroclastics, metagabbro-diorite complex, Hammamat sediments, Atalla granites, Atalla felsites, and post-granitic dykes (youngest) (Fig.2). ***El Kasses*** (1974) and ***El kasses and Bakhit*** (1989) studied Wadi Atalla and Wadi Atalla- El Missikat areas respectively from the geological and radioactivity points of view and proposed a classification of the exposed rock units in the light of the geosynclinal theory. ***Akaad et al***(1976) studied the area around Bir El kubbania and prepared a geological map of scale 1: 100,000 in which they described the lithostratigraphic units in the light of geosynclinal theory and arranged them chronologically. **El Bouseily et al.** (1985) mentioned that Gabal Atalla granite is alkali- to monzogranite in composition.Atalla I-type younger granite occupies the central part of the study area (Fig.2). They intrude the preexisting rock units such as metavolcanics, metagabbro, and serpentinites and intruded by numerous post granitic dykes where the contacts are very sharp in some localities. The studied granitic pluton is bounded from the south and north by metavolcanics where the contacts are sharp knife and there is no evidence for thermal effect. They take some metavolcanics as xenoliths within it. Generally,Atalla granite form moderate to high relief terrains characterized by reddish to pinkish and grey to dark greyish colours. They form a pear-like intrusion trending with its long axis in the NW direction and are dissected by minor wadies. They are highly dissected by sets of joints having variable orientations. Atalla granites are medium to coarse in grain size and include dark enclaves of intermediate composition. They are dissected by post granitic dykes that are generally mafic to felsic in composition and range from less than 30 cm to more than 3 meters in width and cut by some quartz veins of variable lengths and widths.

Fig.1: Location map of the study area.

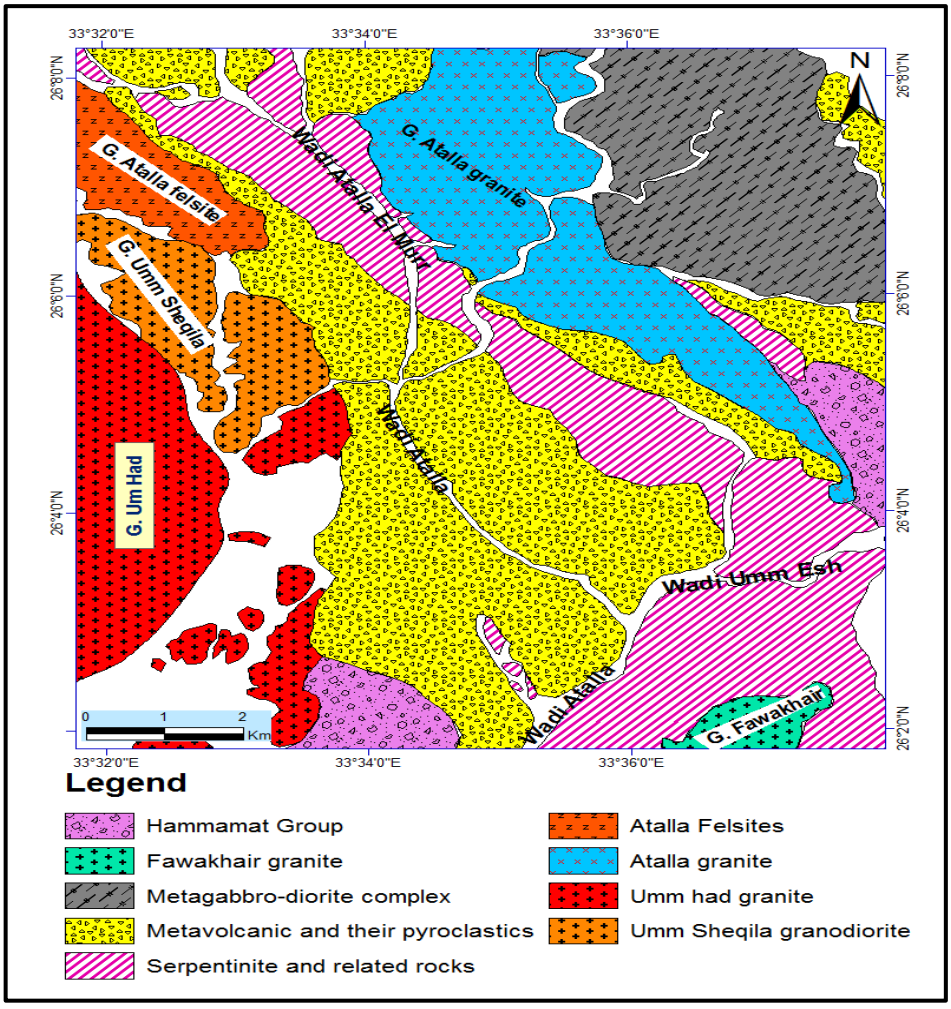

Fig.2: Geological map of wadi Atalla area

3 Petrography

A total of 25 thin sections of representative samples from the granitic rocks were examined.The studied granites aremassive, grey and pink in colour, medium- tocoarse-grained, equigranular to inequigranular, subhedral characterized by a common hypediomorphic granular textureand contain dark enclaves of andesitic composition (Fig.3.2). The major constituent minerals are plagioclase, k-feldspar, quartz, and subordinate amounts of biotite. Zircon, apatite, and iron oxides are thecommon accessories. While chlorite replaced biotite and sericite and epidote are present as secondary minerals.Calcite, chlorite, epidote occur as minor constituents, muscovite, biotite are accessory minerals.***Plagioclase*** occurs as euhedral to subhedral crystals of variable sizes ranging in length approximately from 1 mm to 3 mm and in width from 0.5 mm to 1.5 mm. They are moderately to highly altered to sericite and kaolinite. Muscovite, epidote, and calcite are also alteration products in the highly altered samples (Fig.3.3).Plagioclaze crystals display both carlsbad–albite and polysynthetic twinning and contain inclusions of apatite and iron oxides.***K-feldspars***are represented by orthoclase perthite and microcline perthite with characteristics string and patchy perthite. In some slices, k-feldspar is replacing plagioclase crystals and consequently irregular plagioclases are enclosed within k-feldspar. Generally, feldspars occur as subhedral to anhedral tabular crystals up to 1x0.4 mm and slightly altered to sericite, koalinite and stained by hematitic iron oxides. ***Quartz***forms water clear anhedral crystals filling the irregular spaces among the other

minerals and ranging in size from 0.5 to 1.5 mm. in the slightly deformed samples, quartz displays undulatory extinction and dissected by cracks which are filled with fine grained muscovite and carbonates (Fig.3.4). It encloses iron oxide, apatite, and zircon grains and crystals as inclusions (Fig.3.5). Sometimes, quartz occurs as inclusions within plagioclase and biotite.***Biotite***occurs as small flakes and plates up to 0.4 mm long of brown colours and strongly pleochroic to yellow and dark brown and highly altered to chlorite, epidote, and iron oxides where they are aligned along the cleavage planes (Fig.3.6). Some biotite crystals are bent and displaying both undulatory extinction and kink band suggesting effect of deformation process. Few biotite crystals are perforated by quartz and dissected by microfaults. **Chlorite** occurs as alteration products of biotite where the inherited one set of cleavage plane of biotite can be traced. Chlorite forms thick patches and dense aggregates of green colour, weakly pleochroic from pale green to green colour and exhibits anomalous inky and bluish interference colour. In some samples, chlorite actively corrodes plagioclases and other constituents. ***Iron oxides***occur as both accessory constituents of cubic grains and/or irregular aggregates enclosed within plagioclase, Quartz and if not, is scattered throughout the rock whereas as the secondary ones are commonly associated with biotite and chlorite. ***Muscovite***occurs as alteration products of biotite and/or plagioclase. It is usually associated with chlorite when it occurs as alteration products of biotite. Muscovite displays high interference colors, and has clear one set of cleavage. ***Sericite and koalinite*** occur as alteration products of fine honey aggregates after plagioclase and potash feldspar. In the highly altered samples, they mask the twinning planes of plagioclase. ***Calcite***occurs either as alteration products at the expense of plagioclaze indicating high stages of alterations or forms patches between the other constituents and/or as veinlets that filling the cracks. ***Epidote***occurs as secondary products after biotite and plagioclase and commonly associated with chlorite. ***Apatite*** forms tiny euhedral tabular to acicular crystals that are commonly enclosed within plagioclases and quartz. ***Zircon*** occurs as tiny euhedral prismatic crystals enclosed within quartz and plagioclase. Some zircon crystals display zoning. **Clinozoisite** occurs as alteration products of plagioclase with diagnostic yellowish to abnormal bluish interference colour.

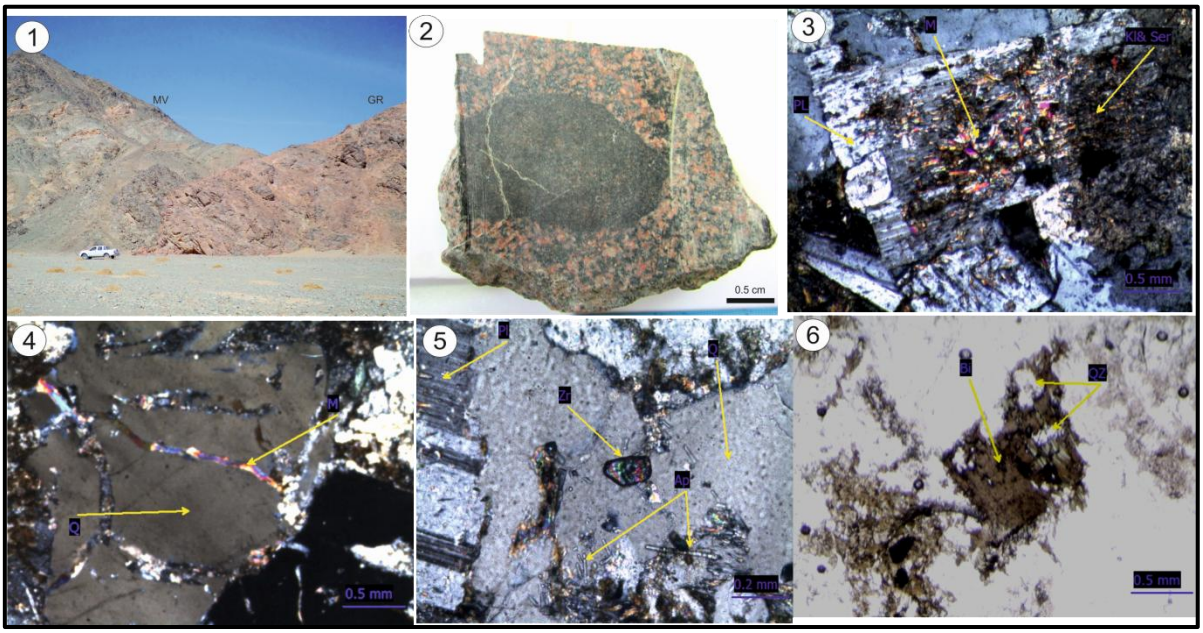

Fig.3: photograph showing 1) Sharp contact between Atalla granite and its neighbouring metavolcanics. 2) Polished slab of granitic samples includes dark enclaves of andesitic composition. 3) Highly altered plagioclase crystal. 4) Quartz crystal dissected by fractures filled by fine grained muscovite and calcite 5) Quartz crystal encloses euhedral crystal of zircon. 6) Biotite crystal perforated by quartz and is partially altered to chlorite along cleavage planes.

4 Geochemistry

Eight samples were carefully selected on petrographic criteria to ensure that a complete range of compositions was obtained. Major and trace element analyses were determinedby inductively coupled plasma source spectrometry techniquesat ACME lab in Canada. The results of major and trace element compositions were listed in table 1.

Table 1. The result of major and trace elements composition of the studied granites

Sample	1	2	3	4	5	6	7	25
SiO2	73.27	72.19	72.35	77.76	67.11	70.04	68.03	67.61
Al2O3	13.84	14.11	13.96	11.75	15.21	14.62	14.83	14.98
Fe2O3	2.13	2.47	2.59	0.99	4.04	3.23	3.79	4.03
MgO	0.42	0.45	0.43	0.04	0.8	0.58	1.2	0.79
CaO	0.69	0.87	0.78	0.14	2.04	1.44	2.65	2.04
Na2O	4.69	4.99	4.84	3.44	5.28	4.89	4.53	4.9
K2O	3.5	3.33	3.28	5.09	2.37	3	2.72	2.97
TiO2	0.33	0.38	0.38	0.06	0.58	0.43	0.56	0.58
P2O5	0.05	0.05	0.05	0.01	0.14	0.1	0.11	0.14
MnO	0.03	0.05	0.05	<0.01	0.08	0.06	0.09	0.11
Cr2O3	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	0.002	0.006
LOI	0.9	1	1.1	0.6	2.2	1.5	1.3	1.7
Sum	99.92	99.91	99.91	99.94	99.88	99.92	99.89	99.89
Trace elements (ppm)								
Ba	438	491	455	456	580	465	436	475
Sc	5	5	6	<1	8	6	8	8
Be	2	2	4	3	3	2	2	2
Co	2.2	2	1.9	1.5	4.1	3.3	6.7	3.8
Cs	0.9	0.7	0.5	0.2	1	0.5	0.8	0.2
Ga	20.3	17.9	19.5	13.9	18	18.3	17.4	17.2
Hf	9	8.2	9.1	10	9.4	8.7	7	9.3
Nb	12.4	12.2	12.9	15.3	11.2	10.2	8.3	11.5
Rb	37.7	34.6	37.8	39.2	31.5	36.3	39.5	47.5
Sn	4	3	4	2	2	2	2	2
Sr	110.3	103.5	110.7	61.8	273.5	150.4	270.5	210
Ta	1.2	0.8	0.9	1.8	0.7	0.7	0.7	0.8
Th	7.4	5.8	6.8	15.3	4.8	5	4	4.2
U	3.6	2	2.8	6.8	1.8	2.2	1.5	1.6
V	8	<8	<8	<8	20	15	42	16
Zr	321.3	336.1	339.5	178.8	400.1	327.6	266.2	388.4
Y	42.9	38	43	94.7	36.2	34.9	30.1	37.8
La	28.9	30.6	33.2	30.7	26.4	24.3	23	25
Ce	69	70.1	74.6	75.6	58.4	53.8	50.4	57.9
Pr	7.67	8.1	8.73	8.39	7.16	6.4	5.89	7.31
Nd	31.4	32.2	33.4	31.7	29	26.2	23	30.1
Sm	6.52	6.51	7.45	7.92	6.4	5.75	4.85	7.05
Eu	1.12	1.32	1.23	0.27	1.54	1.31	1.16	1.61
Gd	6.77	6.62	7.44	8.88	6.34	5.87	5.12	6.66
Tb	1.16	1.1	1.24	1.89	1.06	1.03	0.89	1.13
Dy	7.66	6.86	7.92	13.88	6.33	6.61	5.31	6.7
Ho	1.64	1.45	1.61	3.14	1.22	1.32	1.08	1.4
Er	4.92	4.08	4.71	10.4	3.82	4.13	3.26	4.15
Tm	0.76	0.65	0.74	1.71	0.59	0.6	0.47	0.62
Yb	5.45	4.53	5.01	11.77	4.04	4.35	3.2	4.45
Lu	0.84	0.66	0.79	1.82	0.63	0.66	0.51	0.7

4.1 Major elements geochemistry

The major element concentrations are plotted against SiO_2 on the Harker diagrams (Fig.4) to reveal the relationships among these variables with the progress of magmatic processes. From these

plots, it is clear that Al_2O_3, Fe_2O_3, TiO_2, CaO, P_2O_5, and MnO negatively correlate with SiO_2while K_2O shows positive correlation with SiO_2. Na_2O displays poor-defined trends with SiO_2 consistent with what was reported by Bateman and Dodge (1970) that the Na_2O concentrations don't vary systematically with differentiation. The negative correlation between Al_2O_3, Fe_2O_3, TiO_2, CaO, and MnO and SiO_2 can be attributed to the fractional crystallization processes. Negative correlation between CaO and SiO2 can be attributed to the fractional crystallization of plagioclase. The decrease in P2O5, MgO and FeO during magmatic evolution indicates separation of apatite and mafic mineral (such as biotite) during crystallization. TiO_2 decrease with increasing silica content may be due to the formation of Ti-magnetite and/or ilmenite.

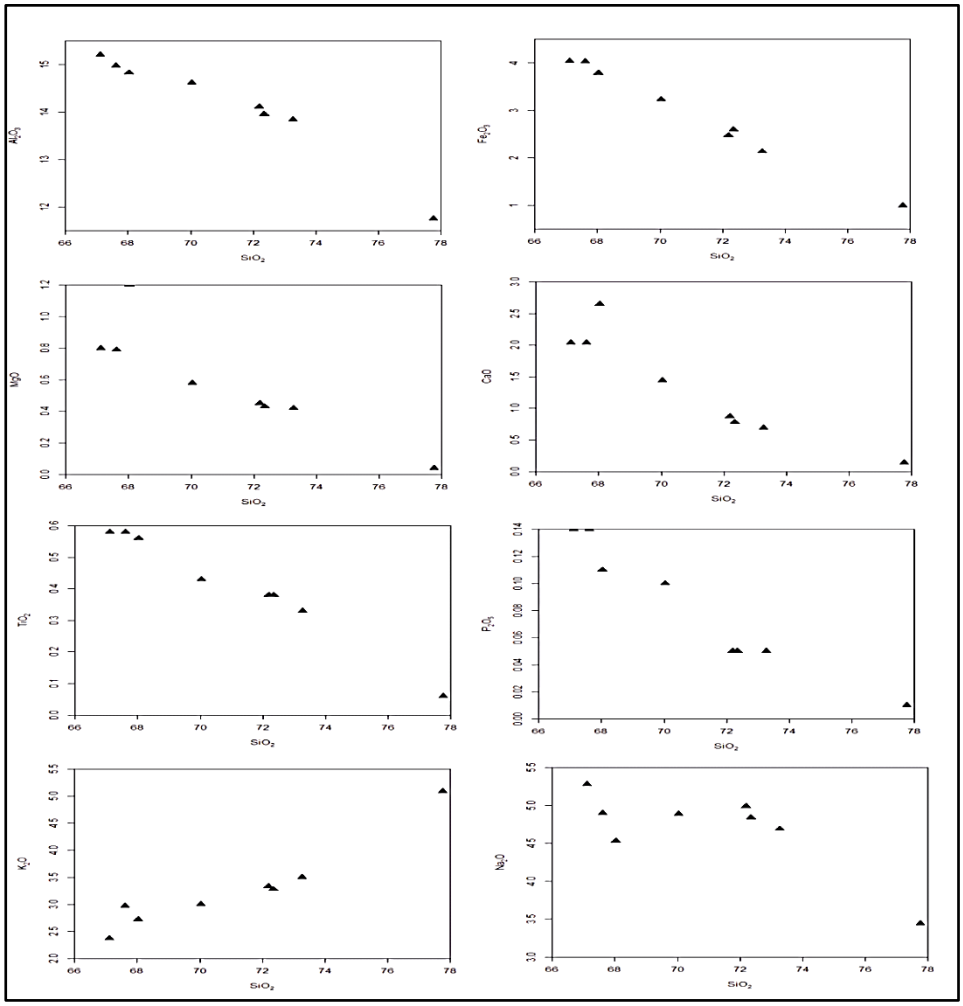

Fig.4: variation diagrams (major oxides vs. SiO_2)

4.2 Petrochemical classification

Streckeisen (1976) used the normative minerals albite, orthoclaze, and anorthite to classify the granitic rocks (Fig.5a). According to this classification, the studied granitic rocks fall mostly within the fields of monzogranite and syenogranite except for one sample that falls within the alkali feldspar granite field. By plotting the studied granitic rocks on the classification diagram suggested by Cox et al (1979) (Fig.5b), they fall within the field of granite.The majority of data points were plotted within the field of granite on the classification diagram suggested by De Le Roche et al. (1980) (Fig.5c).

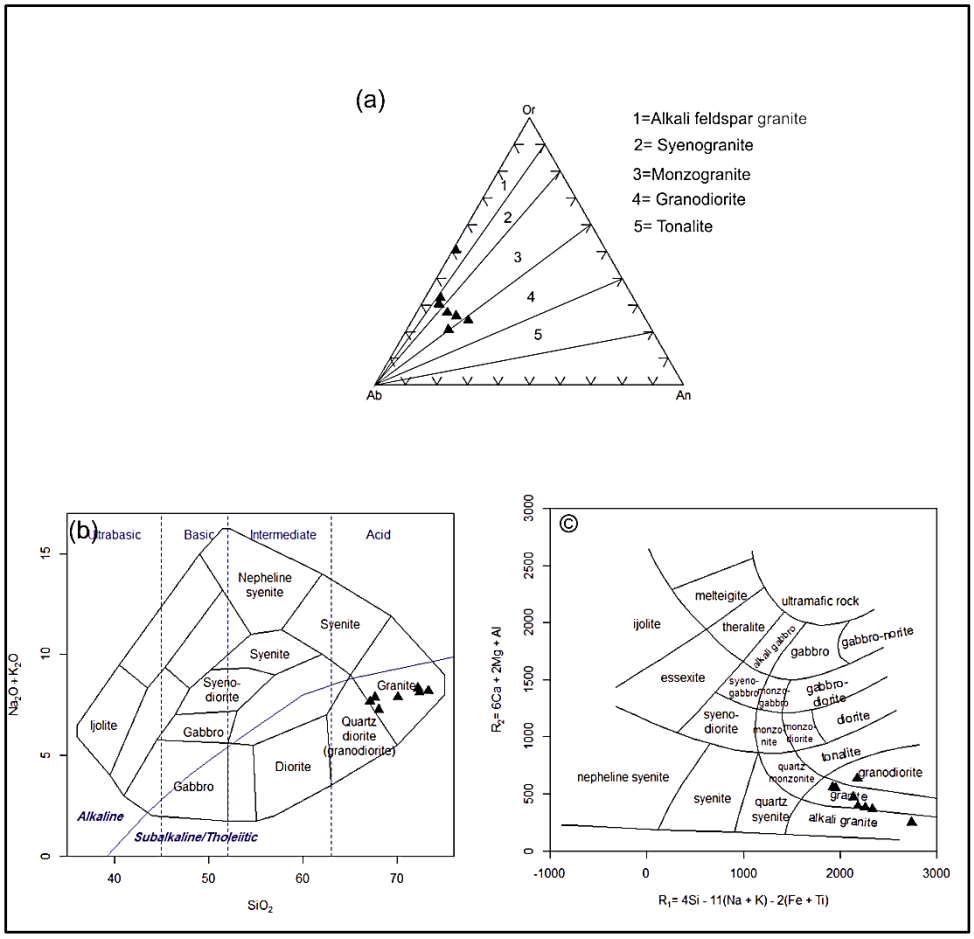

Fig.5: Classification diagrams of the granitic rocks. (a) Ab-Or-An (Streckeisen, 1976), (b) Na2O+K2O vs. SiO2 (Cox et al., 1979), (c) R1-R2 (De Le Roche et al., 1980).

4.3 Magma type

On the AFM ternary diagram of Irvine and Baragar (1971) (Fig.6a), all plots of the investigated granitoid rocks fall within the calc-alkaline field. Irvine and Baragar (1971) used the relationship between silica content and total alkalis (Na_2O+K_2O) (Fig.6b) to deduce the magma type of the granitoids. From this diagram, the investigated granitoid rocks are closely plotted within the subalkaline field. . The relationship between CaO, Al_2O_3 and (Na_2O+K_2O) is plotted in the ternary diagram (Fig.6c) (Shand, 1951) to discriminate between peraluminous, metaluminous, and peralkaline magmas. It is obvious that the studied granitic rocks exhibit peraluminous character supporting the previous results. To identify the source of the magma from which the granitic rocks were generated, the samples were plotted on the K_2O-Na_2O and SiO_2 binary diagrams (Fig.6d) suggested by White and Chappell (1974), the analysed samples fall within the I-Type granite field indicating igneous source material for the studied granites.

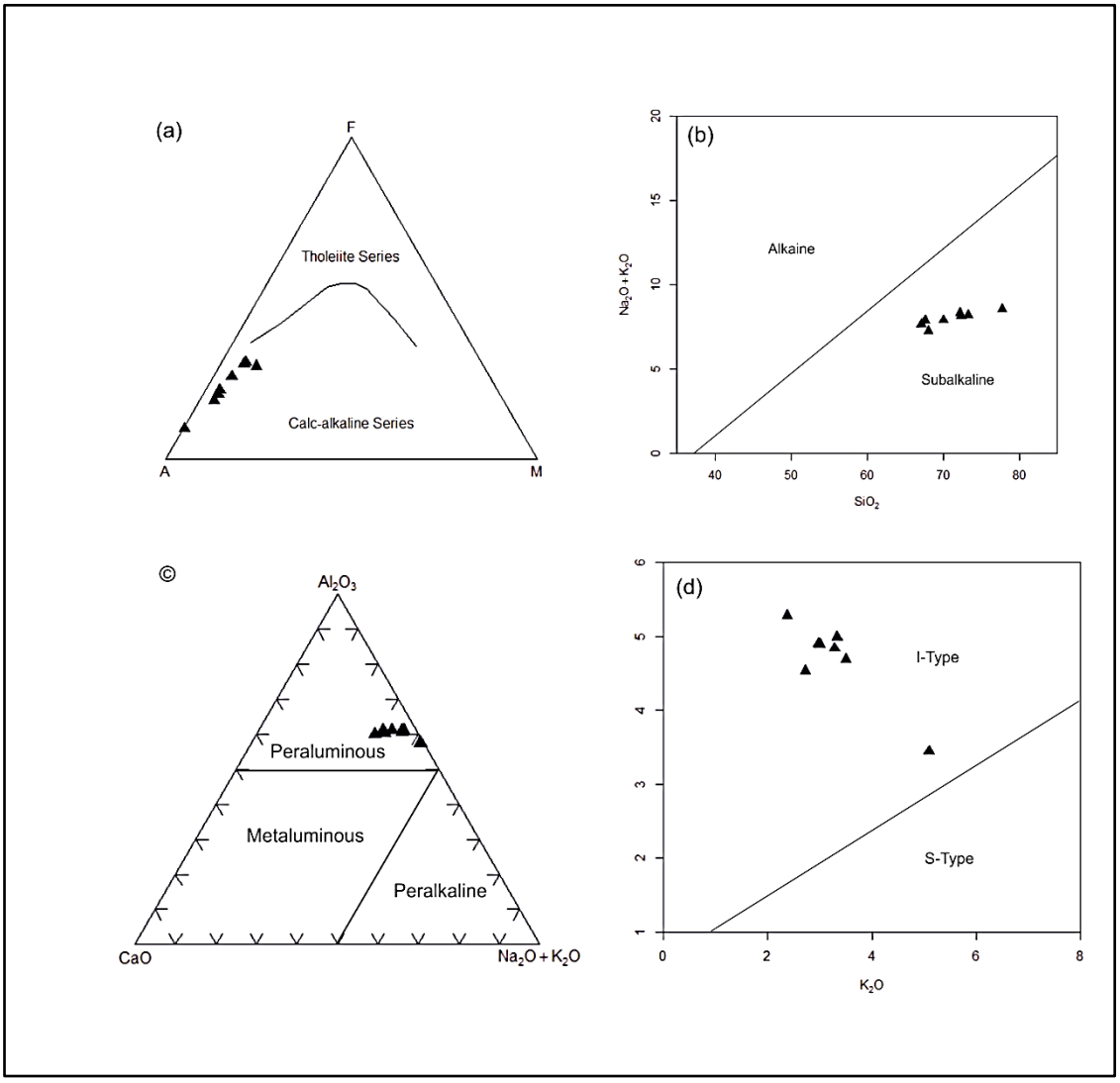

Fig.6: Magma type discrimination diagrams.(a) AFM ternary diagram of Irvine and Baragar (1971), (b)SiO_2vs. (Na_2O+K_2O)(Irvine and Baragar, 1971), (c) CaO-Al2O3-(Na2O+K2O) (Shand, 1951), (d) K2O vs. Na2O (White and Chappell, 1974).

4.4 Tectonic setting

The two groups of the incompatible elements 1) large ion lithophile elements (LILE) and 2) high field strength elements (HFSE) can be used as indicators of the magmatic processes and tectonic settings for the formation of granitic rocks. The first group includes elements with large ionic radii e.g., K, Rb, Sr, Ba and Cs, while the second contains elements with higher valencies including Zr, Th, U, Ta, REE etc. various discriminant diagrams based on LILE and HFSE are used for the determination of tectonic settings of granitic rocks (Pearce et al., 1984). The Rb versus Ta+Yb (Fig.7a) (Pearce, 1982), Rb versus SiO_2(Fig.7b) (Pearce et al., 1984), and Nb versus SiO_2 (Fig.7c) (Pearce and Gale, 1979) discriminant diagrams are employed here to investigate a probable tectonic setting of the Atalla I-type younger granites. On the basis of these diagrams, the studied samples fall within the volcanic arc. The abundance of Niobium element can be used to discriminate between the tectonic setting of magmas responsible for the formation of volcanic-arc granites and within-plate granites (Pearce and Gale, 1979). The Nb abundance in volcanic-arc granites is markedly lower (<14 ppm) than that in within-plate granites (with Nb content exceeding 100 ppm) across the entire range of SiO2. On this basis, all the studied Atalla granitoids show volcanic arc magmatic setting. On the tectonic discrimination (Na2O+K2O)-FeO-MgO ternary diagram (Fig.7d) introduced by Petro et al

(1979), the studied granitoid rocks make an angle with the AF side which suggested that these rocks were formed in compressional regime rather than extensional regimes.

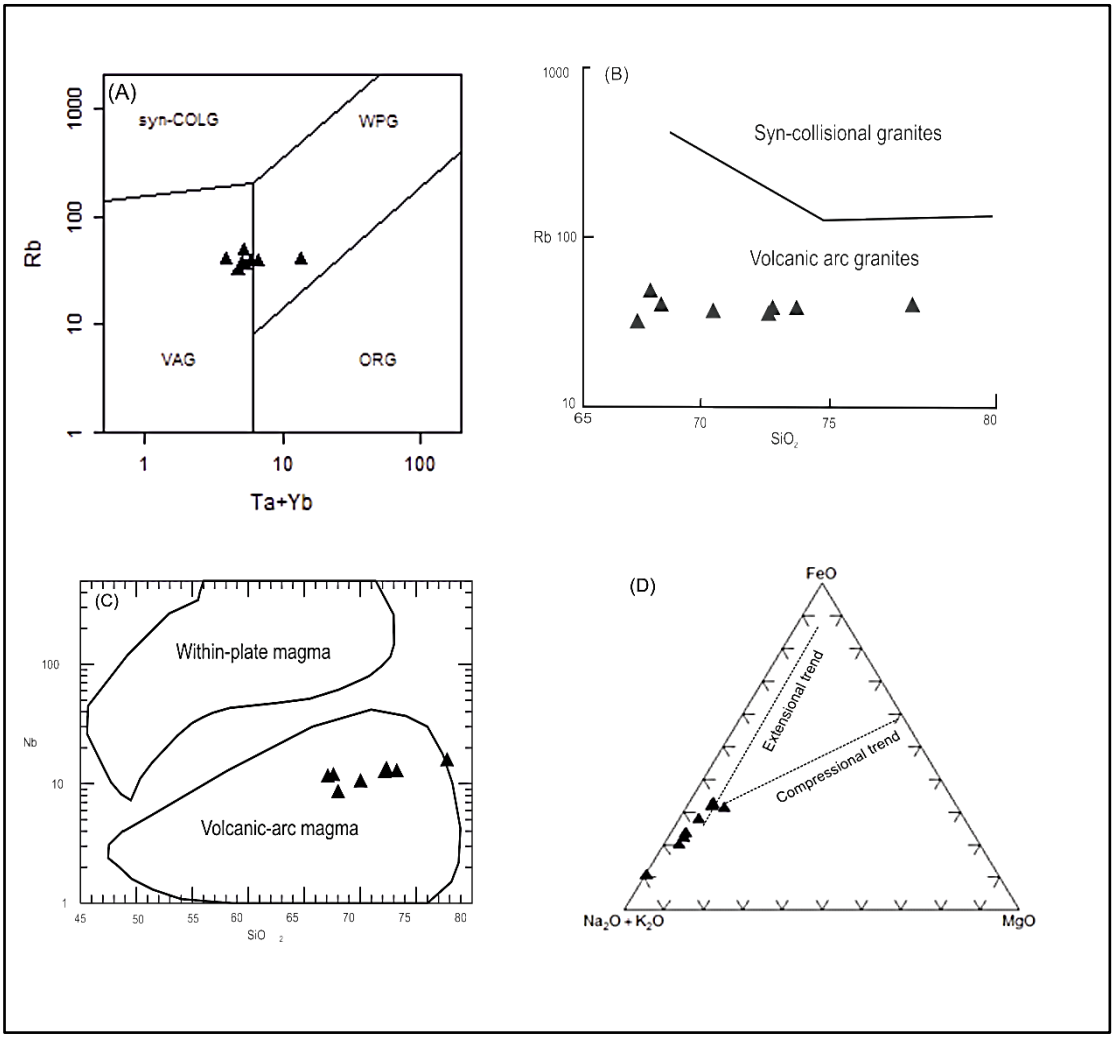

Fig.7: Tectonic setting discrimination diagrams: (a) Rb vs. Ta+Yb (Pearce et al., 1982), (b) Rb vs. SiO_2 (Pearce et al., 1984), (c) Nb vs. SiO_2 (Pearce and Gale, 1979), (d) Na2O+K2O-FeO-MgO ternary diagram (Petro et al., 1979).

4.5 Petrogenesis

The presence of mafic rocks associated with these granites indicates that they were derived from mantle rather than crustal material. On the K-Rb binary diagram (Fig.8a), all the studied granites plot around the mantle line (K/Rb=1000) suggested byShaw (1968) and away from the crustal line (K/Rb=250) given by Taylor (1965).This reflects their low K concentrations that suggest their derivation from upper mantle source rather than upper crustal materials.Moreover, on the constructed the K-Ba binary diagram (Fig. 8b) (Mason, 1966) All the plots are located below the average crustal line (K/Ba=65), showing relatively low K enrichment and K/Ba ratio less than 65, except one sample plots above the crustal line.The studied granite samples plotted on this diagram supports their derivation from a mantle material.The Ba/Rb ratios are more sensitive than K/Rb ratio in tracing the differentiation in K-feldspars (Taylor and Heier 1960). On the Ba-Rb binary diagram of Mason (1966)(Fig. 8c), the studied granite samples are plotted above the crustal line (Ba/Rb=4.4) favoring derivation of these granites from partial melting of mantle materials.

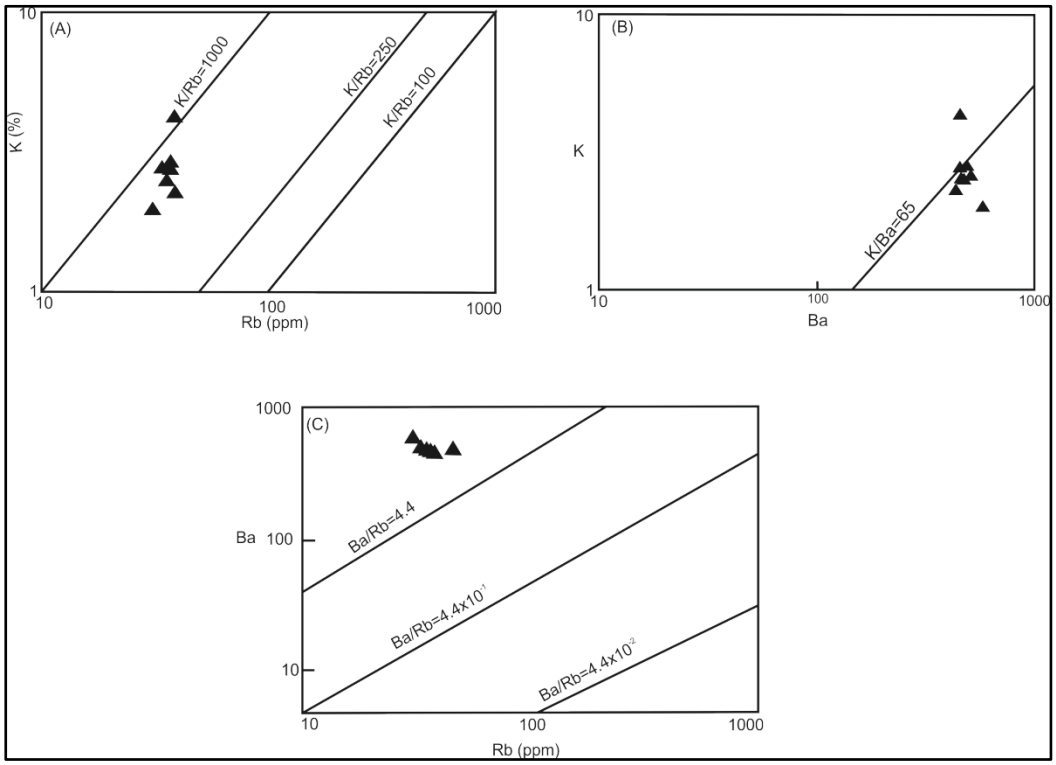

Fig.8: (a) K vs. Rbdiagram (Shaw 1968) shows the average crustal K/Rb ratio ofTaylor (1965), (b) K-Ba binarydiagram. The average crustalK/Ba ratio after Mason (1966), (c) the Ba-Rb binarydiagram (Mason 1966).

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