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Geological and Geochemical Studies of Granitiod Intrusion, Tagotieb area Red Sea Hills, Sudan.

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Abstract

The granitoid complexes in Tagotieb area intrude mainly the metavolcanic rocks and the older granitites. They are coarse-grained and are highly sheared with numerous faults and joints. Despite the large number of separate granitoid intrusions and the wide range of their lithologies, there is an overall calc-alkaline pattern, which indicates a single, compositionally fairly, and uniform source (Gass, 1977). Isotopic evidence (Kröner, 1991) suggests island arc environment for these granitoids. Petrographically syn-tectonic granitoids are composed of quartz, plagioclase feldspar, alkali feldspar, biotite, hornblende, and accessory zircon, sphene, iron oxides and apatite. According to the quartz, plagioclase, and alkali feldspar contents, the syn-tectonic granitoids are classified into granodiorite and biotite monzogranite. The post-orogenic granites are of pink colour, coarse-grained, non-foliated, and contain quartz, plagioclase and K-feldspar with little amount of mica and hornblende. The syn-orogenic granitoids show chemical characteristics of calc-alkaline subduction-related rocks and can be regarded as I-type granites. The geochemical data show marked continuities in major and trace element abundances versus SiO2 suggesting that all varieties of the syn-tectonic granodiorite-granite suite are genetically related. The primitive nature of the original magma that produced the studied granodiorite-granite suite is evident from the very low Rb/Sr (0.09–0.35), Nb (3–7 ppm), which reflect either garnet lherzolite mantle source or amphibolites lower crust source. On the basis of geochemical variations, it is suggested that crystal fractionation and fluid–rock interaction are the main control of the trace element distribution in the studied post-orogenic A-type granites.

Keywords: Tagotieb , granite, syn tectonic, post granite and A-type granites

1-Introduction:

The Tagotieb area is located in the southern part of the Red Sea Hills, northern Sudan. It occurs at about 80 km to the northwest of the Sudanese Eritrean boundaries. Syn – to late orogenic intrusives widely known as “batholithic granites” or granitoid plutons are composed dominantly of foliated tonalities, granodiorite and granites which occupy more than 60% of the exposed area in the northern Red Sea Hills. These intrusions represent the oldest intrusive in the area (Nour, 1983). The granitoid masses are characterized by coarse grained textures. These granitic rocks are highly sheared and affected by numerous faults and joint. All the contacts between granitoid plutons and volcano sedimentary – sequences (host rocks) in most cases occur along zones of weakness showing regional trends along which Khors and Wadies are now developed (Nour, 1983). Syn–orogenic intrusions are composed dominantly of foliated tonalite, granodiorite and granite, but the post-orogenic complexes are mainly composed of pink alkaline granite, gabbro, and dykes. The post-orogenic intrusions have been divided into three phases; the first and second are associated with the Pan African geotectonic thermal events, but the third phase is clearly undeformed and more alkaline in composition (Nour, 1983). In this paper, we report geological and geochemical data of Neoproterozoic granitiod intrusion (Derudieb area, Red Sea Hills. Sudan), which tectonically locates in the Haya terrain. The main aim is to study the geochemical features and evolution their tectonic setting.

1.2 Research Methodology:

Research methodologies, which are used to accomplish the objectives of the present work, are mainly: (1) fieldwork and sampling of the different rock units (2) preparation of thin sections for most of the collected samples (13) and chemical analyses of major, minor and trace elements. In the field, sampling was conducted by collecting representative rock specimens from specific outcrops in the study area. These specific outcrops include syn tectonic granite (8 samples) and post tectonic granite (5 samples) (Table 1.1).

13 thin sections representing the syn and post tectonic granite were prepared at the Department of Geology, Faculty of Science, and Alexandria University, Egypt. The microscopic study allows investigating the petrographic and mineralogical characteristics of the different rock types. All samples were analyzed for major, and some selected, trace elements by inductively coupled plasma mass spectrometry (ICP-MS). The remaining trace elements and rare earth elements (REE) were analyzed by inductively coupled plasma-atomic emission spectrometry (ICP-AES). All the analyses were carried out at the ACME Analytical Laboratories Ltd.

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Table 1. The coordinates of ~~the~~ samples collected from the study area.

Sample Number	Latitude	Longitude
B 11	36.34783333	17.62711111
B 6-2	36.34194444	17.63447222
C 19	36.2575	17.53244444
B 7-1	36.35938889	17.61552778
D 5	36.14980556	17.53652778
D 1	36.16666667	17.51055556
B 9	36.365	17.61841667
B 13	36.29166667	17.55861111
A1	36.23861111	17.55055556
B 3	36.28666667	17.63638889
C 18	36.25936111	17.52888889
B 6-1	36.34194444	17.63447222
A3	36.23861111	17.55055556

1.2 Geological setting:-

Active crustal accretion in the form of syn- to post orogenic igneous activity characterized the late Proterozoic of NE Sudan, and gave rise to the thermal overprinting of many pre-existing rocks (Klemenic & Poole 1985, Vail 1988).

The area is predominantly comprised of late a Proterozoic metavolcano-sedimentary sequence, which was previously known as the Nafirdieb Formation. The metavolcano-sedimentary rocks are intruded by gabbros and several granitoid phases including syn- and post-orogenic granitoids.

1.2.1 Syn-tectonic Granite:

The study area has been extensively intruded by syn- to late-tectonic plutons, which are intruded into the metavolcano-sedimentary sequence and vary in rock composition from granodioritic to granitic (Fig 1.1). Granodiorite occurs in the southwest and northern part of the study area. In the southwestern part, the granodiorite occurs as elevated outcrops intruding low grade metamorphosed metavolcano-sedimentary rocks. Near Khor Derudieb, in the central part of the area, granodiorite occurs as moderately elevated outcrops (Fig.1.2a). The rocks are typically greenish grey in colour with feldspar phenocrysts and relatively high mafic contents (Fig.1.2b). Syn-tectonic granite intrusions cover several parts with low relief and highly dispersed boulders.

In the central part of the study area, foliated granites occur as large boulders with well-developed exfoliation phenomena (Fig.1.3a, b). These granite boulders are highly weathered, rounded, and lies with its long axis parallel to the regional foliation. In the bank of Khor Dageint (Fig. 1.1), there are outcrops of syn-tectonic granite rocks that occur as highly elevated hills and boulders with an exfoliation surface. These rocks are typically grey to black in color and rich in mica minerals.

1.2.2 Post-tectonic granite

The post-tectonic intrusions were intruded during the late Pan-African events. They are considered as the youngest Precambrian magmatic rocks that are usually non-foliated and unmetamorphosed (Abu Fatima 1992). The Post-tectonic granites in the study area occur as irregular outcrops, which are tabular to circular in form. They are randomly dispersed throughout the study area and were intruded into all older rock units. Near Jeble Wangarmy, in the northwestern part of the study area, there is a moderately elevated granite intrusion that occurs in a dome-like form and is rich in potash feldspar with some veinlets of silica. Furthermore, these rocks are mostly dissected by irregular two sets of joints (Fig.1.4A). In the bank of Khor Awagtieb there is a high elevated outcrop of post-tectonic granite in the form of massive mass with some joints. Most of the post-tectonic granite outcrops in the study area are cut by several basic dykes (Fig.1.4B) such as andesite or dolerite.

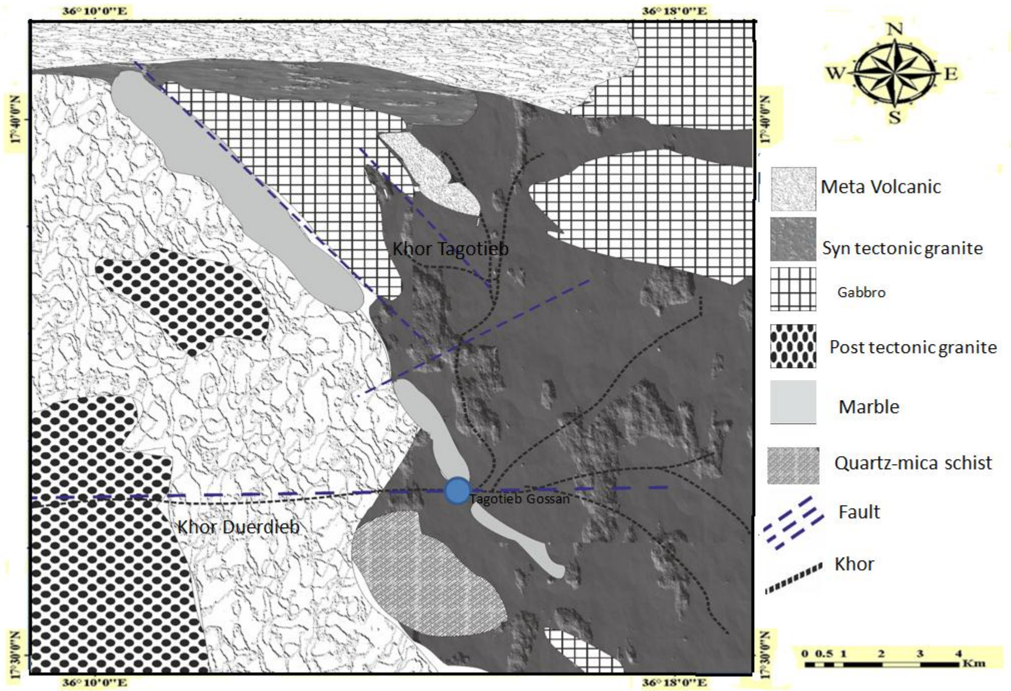

Fig. 1.1. Simplified geological map of the study area.

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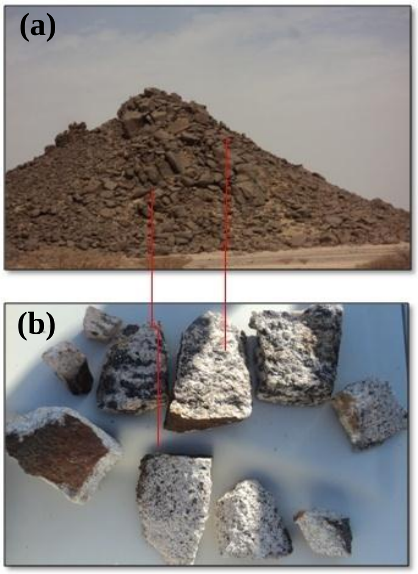

Fig.1.2. Field photograph of the granodiorite intrusions in the study area showing: (a) moderately elevated and rounded mass, (b) fresh surfaces of the granodiorite outcrop.

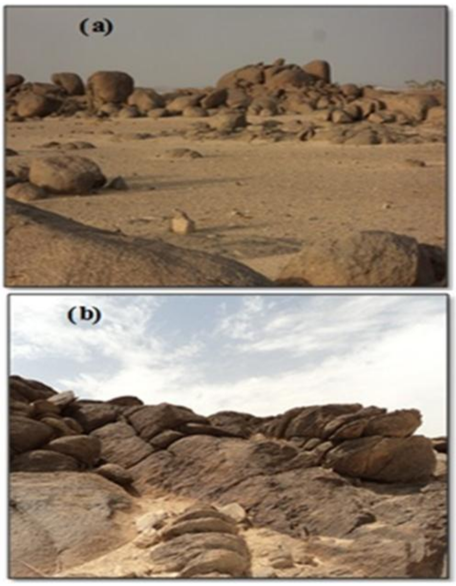

Fig. 1.3: Field photographs near K. Tagotieb showing the boulders of the syn tectonic granite (a) and their arrangement parallel to the foliation (b).

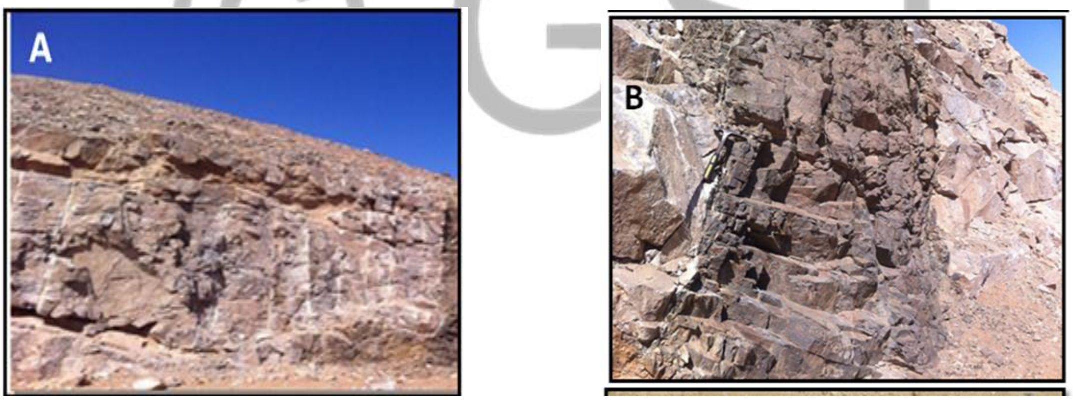

Fig. 1.4: Field photographs of the post-tectonic granite. (A) Granite rock rich in potash feldspar with some veinlets of silica (B) granite rock rich in potash feldspar and cut by andesite dike.

2.1 Petrography :-

About one hundred and twenty thin sections, representing the different granitoid rock units in the study area, were prepared. These sections were used to study the textural characteristic and mineralogical composition of the different granite rock types in the study area. From the petrographic examination, the study granite rock units are classified into:

2.1.1 Syn-tectonic Granitoids

Syn- tectonic granitoids are coarse-to medium-grained; prophyritic varieties are also common. These rocks are generally grey, whitish grey and pale pink in colour. Under microscope, syn-tectonic granitoids are composed of quartz, plagioclase feldspar, alkali feldspar, biotite, hornblende, and accessory zircon, sphene, iron oxides and apatite. According to the quartz, plagioclase, and alkali feldspar contents, the syn-tectonic granitoids are classified into granodiorite and biotite monzogranite.

The granodiorite rocks are the predominant granite type in the study area. They are coarse- to medium-grained, light grey in colour and are texturally homogeneous with a hypidiomorphic granular texture. Occasionally, they are foliated with a parallel arrangement of the ferromagnesian minerals giving the rock a gneiss appearance. They consist mainly of plagioclase feldspar, quartz, K-feldspar, hornblende, biotite, with subordinate secondary chlorite, epidote and sericite (Fig. 2.1). Accessory minerals are mainly zircon, titanite, apatite and magnetite. Plagioclase occurs as subhedral prismatic crystals, some of which appear as phenocrysts, and are commonly twinned according to the albite and combined albite-Carlsbad laws (Hall 1987). Zoning is also frequent in plagioclase where the zones are thin and have sharp boundaries. Some plagioclase crystals are partially sericitized and contain hornblende inclusions. Quartz generally occurs either as large crystal with corrosive outlines or as interstitial anhedral grains. Quartz crystal is also present as small blebs in the K-feldspar forming myrmekitic texture (Fig.2.2). K-feldspar occurs as subhedral crystals of microcline and orthoclase composition of which some are vein perthites. Hornblende in the form of euhedral to subhedral green prismatic crystals displays green to green-brown pleochroism (X=dark green, Y=green, Z=brownish green), (Fig.2.3). Hornblende is the most abundant ferromagnesian mineral. Some hornblende crystals appear to be zoned and some others contain inclusions of titanite and/or

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apatite. Biotite occurs both as plates and as anhedral grains. Some biotite grains contain discrete apatite and magnetite inclusions, and some contain titanite and green chlorite as alteration products (Fig. 2.4). Some biotite grains also occur as alteration patches in hornblende.

The granodiorite is characterized by abundant accessory minerals where titanite is the most abundant one. Titanite crystals have either well developed euhedral to subhedral crystals (up to 0.2mm) or are present as anhedral fine inclusions in hornblende and biotite (Deer 1992).

The biotite-monzogranite is typically subsolvus fine- to medium-grained, massive and equigranular. It is composed of nearly sub equal amounts of quartz (38 modal%), K-feldspar (33 modal%) and oligoclase, (28 modal%) together with biotite and accessory titanite, apatite, zircon and magnetite, arranged in decreasing order of abundance. Quartz is present as small anhedral masses as well as fine-grained crystals occupying the interstices between other constituents. It also enclosed by both K-feldspar and plagioclase crystals forming granophyric and myrmekitic textures. Subhedral microcline crystals as well as subhedral to anhedral perthitic crystals with albite stringers mainly represent k-feldspar. Oligoclase occurs mainly as subhedral to anhedral crystals with their characteristic albite twinning. Subhedral to anhedral brown biotite flakes and laths, in amount less than 1% of the rock mode, are the merely ferromagnesian mineral recorded (Fig. 2.5). It sometimes contains minute inclusions of titanite, apatite, and opaques. Late stage chlorite replacing biotite is infrequently observed.

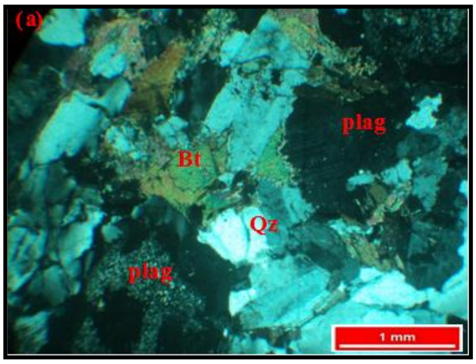

Fig.2.1: Photomicrographs of syn tectonic granodiorite showing plagioclase feldspar (Plag), quartz (Qz) and biotite (Bt), with frequent zoning in plagioclase .(arrow); CN

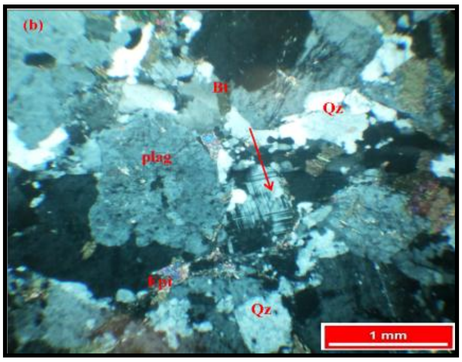

Fig. 2.2: Photomicrograph of syn tectonic granodiorite showing subhedral tabular K-feldspar (microcline) crystals forming .myrmekitic texture (arrow); CN

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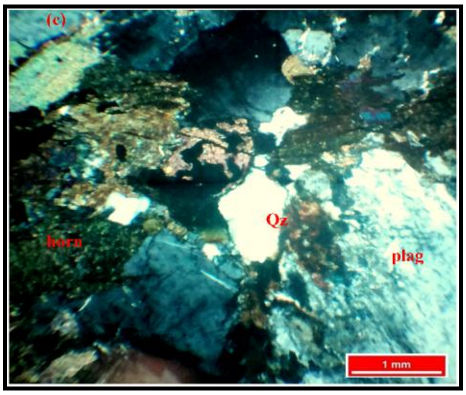

Fig. 2.3: Photomicrograph of syn tectonic granodiorite showing hornblende in the form of euhedral to subhedral crystals; CN.

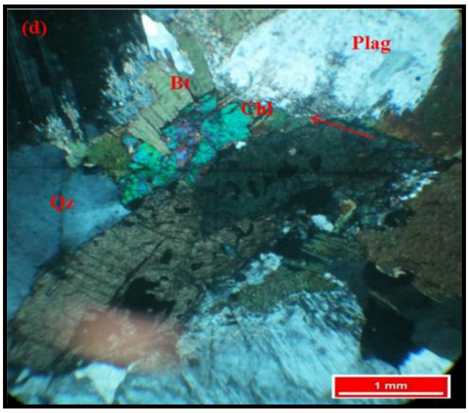

Fig. 2.4: Photomicrographs of syn tectonic granodiorite showing plagioclase (Plag), quartz (Qz), biotite (Bt) and chlorite (Chl) with (grain of titanite (arrow).

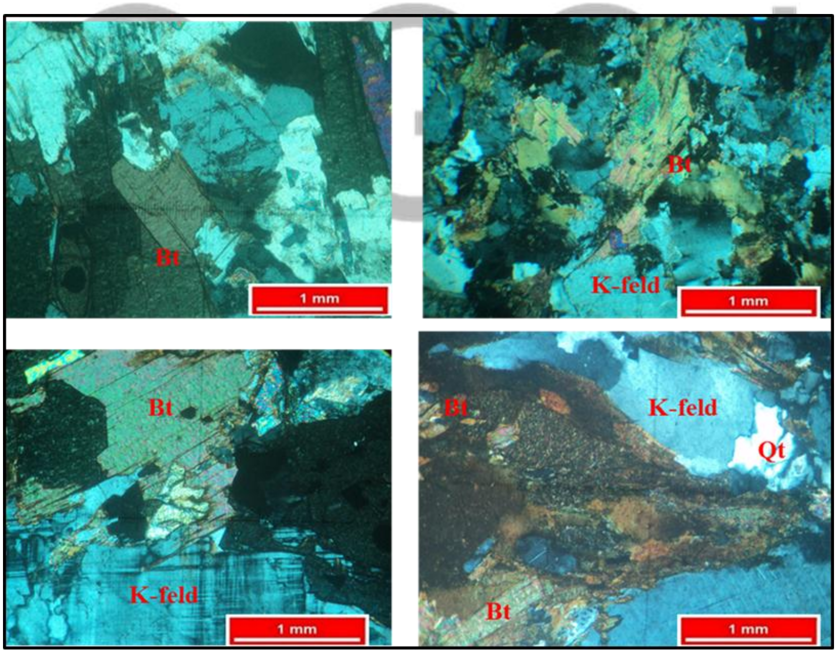

Fig. 2.5: Photomicrographs of biotite granite rocks consist of quartz (Qz) K-feldspar (K-feld) and biotite (Bt), CN.

2.1.2. Post tectonic Intrusions

Plutons displaying no foliation and intruding the metasedimentary, metavolcanic, and syn-tectonic granites are interpreted in the present work as post-tectonic magmatic intrusions. The post-tectonic intrusions are medium-grained, massive, nonfoliated with equigranular hypidiomorphic texture. Petrographic study and modal analysis supplemented by the chemical data allow distinguishing post-tectonic granite.

The post-tectonic granites are pink-colored and medium- to coarse-grained rocks (Younis 2010). They form generally high topographic circular to irregular plutons and could be distinguished microscopically into syenogranite and alkali feldspar granite.

The syenogranite consists of K-feldspar, quartz, plagioclase feldspar and biotite (Fig.2.6 a). Zircon, apatite, titanite and ilmenite are accessories while chlorite and clay minerals are the alteration minerals. K-feldspar crystals are mostly represented by perthites (flame and patch-type perthites) and microcline. The crystals are coarse-grained (5mm up to 15 mm in diameter) with subhedral form Poikilitic scattered inclusions are abundant that include quartz, plagioclase feldspar laths and biotite shreds (Fig.2.6 b). Quartz crystals occur as fine to medium-grained, anhedral with granular form. The large crystals of quartz are mechanically strained with development of strong undulose extinction.

Plagioclase feldspar has an oligoclase composition (An_{15}–An_{20}), medium-grained and subhedral with lath-like shape. Some crystals are strongly zoned, with normal and oscillatory type zoning (Fig.2.6a). They show prominent selective alteration to sericite and clay minerals in the core and in some zones. Biotite is the most common and abundant ferromagnesium minerals in the rock. The biotite crystals are fine-to medium-grained, subhedral with flaky form. They are scattered in the rock or form cluster aggregates. Some biotite flakes are partially to completely altered to green chlorite (penninite, with negative elongation sign). Titanite is relatively abundant accessory mineral. The titanite crystals are fine-grained, subhedral to euhedral with characteristic spheroidal shape. Apatite is also abundant accessory mineral in the syenogranite. The crystals are fine-grained, euhedral with prismatic to acicular form. The crystals either scattered in the rock or commonly associated with the biotite flakes.

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The alkali feldspar granite is quite similar to the syenogranite but with high modal proportion of k-feldspar represented by perthites. The rocks are of red to buff colour and medium-grained with occasionally porphyritic texture. The rock consists of quartz, alkali-feldspar, plagioclase and minor green biotite (Fig.2.7). Accessory minerals include abundant zircon, rod-like opaques and rare allanite. Quartz and microcline occur as large subrounded phenocrysts containing abundant fine albite laths inclusions developing snow ball-like texture. The groundmass comprises interlocking fine-grained quartz, microcline and albite laths. Zircon is the most common and abundant accessory minerals. The crystals are very fine-grained, anhedral to skeletal form often occur in cluster aggregates

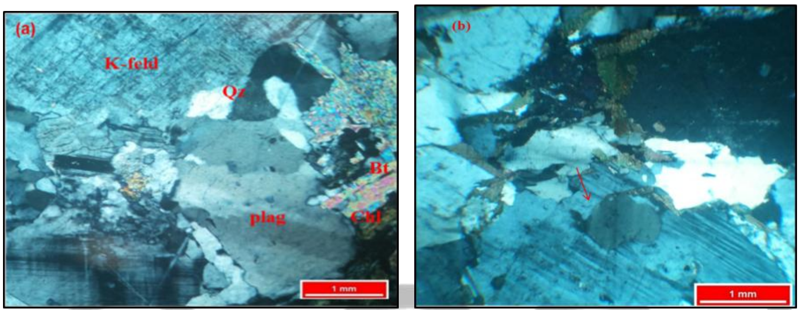


Fig.2.6: Photomicrograph of syenogranite showing (a) K-feldspar (K-feld), quartz (Qz) plagioclase feldspar (plag), and biotite (Bt) altered to chlorite (Chl) .(b) K-feldspar crystals are mostly represented by perthites form poikilitic textuer (arrow); CN.

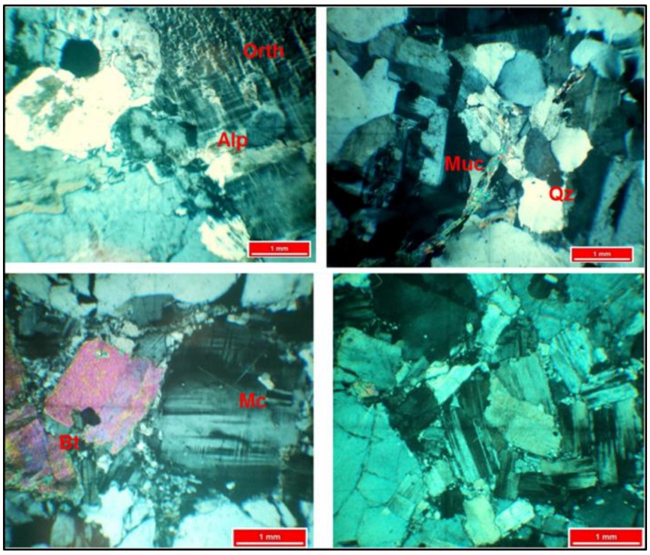


Fig.2.7: Photomicrographs of alkali feldspar granite showing variation of mineral composition such as quartz (Qz), microcline (Mc), orthoclase (Orth), muscovite (Muc), biotite (Bt) and albite (Alp); CN.

3.1. Geochemistry of the Granitoid Rocks

The geochemical data of major, trace and rare earth elements of 13 representative samples of the studied granitoid rocks are given in Table 1.1. The syn-orogenic granitoids and post-orogenic granite are discussed here together to depict differences in their chemical characteristics and tectonic setting. Using the Q- ANOR diagram of (Streckeisen and Le Maitre 1979), the data points of the syn-orogenic granitoid plot in the granodiorite and monzogranite fields, whereas samples of the post-orogenic granite indicate a syenogranite to alkali feldspar granite composition (Fig. 3.1).

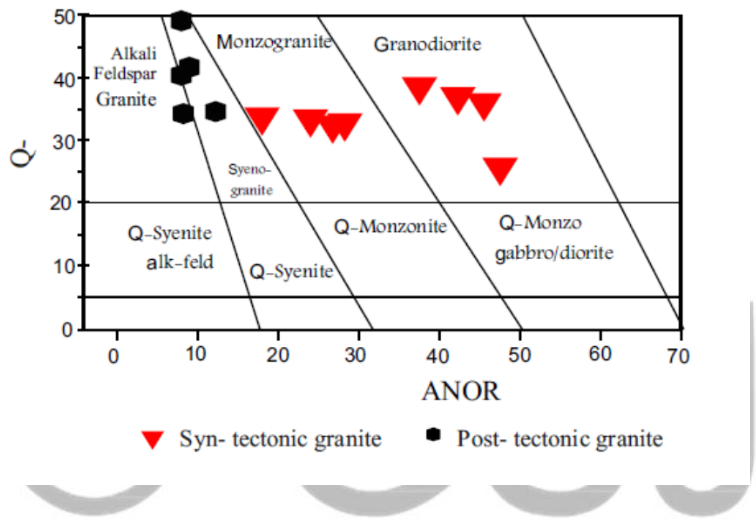


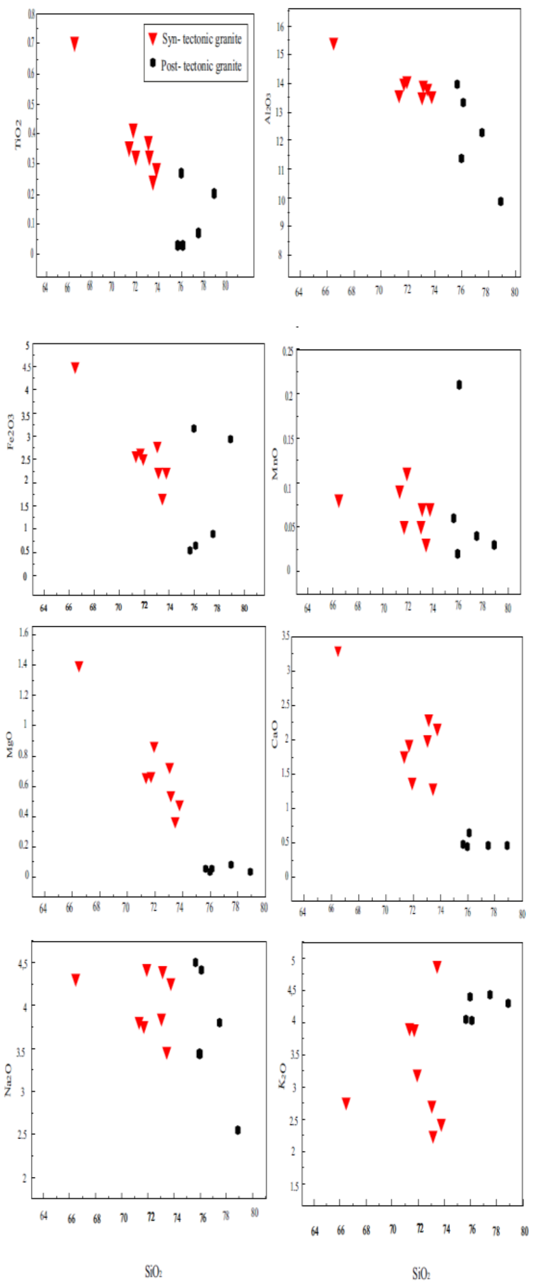
Fig. 3.1: Q\ - ANOR geochemical classification diagram for the studied granitoid rocks Streckeisen and Le Maitre (1979). Q and ANOR are calculated using norm values: Q= 100/ (Q+Qr+Ab+An), ANOR=100An/ (An+Qr).

Characteristically, the syn-orogenic granitoids have higher Al2O3, MgO, CaO, Fe2O3, TiO2, Ba, Zr, and V, but lower total alkalis, SiO2, Th, U, and REE, compared to the post-orogenic granite (Table 1.2). The Harker variation diagrams of some major elements abundances show trends of increasing K2O and Na2O and decreasing MgO, CaO, Fe2O3, and TiO2 with increasing SiO2 (Fig. 3.2 & 3.3).

Table 2. Geochemical data of major (wt %) and trace elements (ppm) for the studied granites.

	Syn tectonic granite							
	B11	**B6-2**	**C19**	**B7 -1**	**D5**	**D1**	**B9**	**B13**
SiO_2	66.52	73.06	71.35	73.46	73.80	73.14	71.95	71.73
TiO_2	0.70	0.37	0.35	0.24	0.28	0.32	0.32	0.41
Al_2O_3	15.37	13.44	13.53	13.75	13.48	13.86	14.03	13.94
Fe_2O_3	4.47	2.77	2.55	1.63	2.20	2.19	2.50	2.62
MnO	0.08	0.05	0.09	0.03	0.07	0.07	0.11	0.05
MgO	1.39	0.72	0.65	0.36	0.47	0.53	0.86	0.66
CaO	3.27	1.98	1.75	1.28	2.15	2.27	1.36	1.91
Na_2O	4.29	3.83	3.80	3.45	4.25	4.38	4.40	3.74
K_2O	2.74	2.70	3.89	4.86	2.41	2.23	3.18	3.87
P_2O_5	0.22	0.11	0.11	0.06	0.07	0.07	0.16	0.14
LOI	0.6	0.7	1.6	0.7	0.7	0.8	0.9	0.6
Sum	99.65	99.73	99.67	99.82	99.88	99.86	99.77	99.67
Cr	116	130	328	95	109	68	136	116
Ni	7.7	5.9	8.1	3.5	2.7	2.6	5.6	3.5
Sc	8	5	5	3	5	6	7	5
Ba	1530	1467	1424	897	456	456	868	1663
Be	7	3	5	4	4	2	4	<1
Co	9.1	4.9	4.9	2.6	3.9	3.4	4.1	4.6
Cs	0.2	0.5	0.2	0.2	0.5	0.7	0.6	0.2
Ga	20.1	17.5	18.0	16.5	14.6	14.8	19.0	18.1
Hf	7.8	6.6	5.1	4.7	4.4	4.0	5.3	7.1
Nb	7.8	2.9	6.0	3.8	6.7	7.0	6.0	6.9
Rb	43	37	57	66	59	49	59	57
Sn	3	1	2	1	2	2	2	2
Sr	484	286	239	199	203	210	167	313
Ta	0.6	0.1	0.6	0.2	0.6	0.6	0.4	0.6
Th	3.9	2.9	4.5	4.8	3.2	2.6	6.7	5.1
U	1.5	0.7	1.2	0.8	1.1	0.9	1.0	1.0
V	68	43	36	23	30	27	29	39
W	0.5	1.2	<0.5	<0.5	1.3	0.9	1.1	0.8
Zr	328	247	181	164	168	148	187	261
Y	29	9	25	5	26	29	44	21

	Post tectonic granite				
	A1	**B3**	**C18**	**B6-1**	**A3**
SiO_2	78.91	75.68	77.53	76.12	76.00
TiO_2	0.20	0.03	0.07	0.03	0.27
Al_2O_3	9.86	13.96	12.26	13.29	11.35
Fe_2O_3	2.93	0.53	0.88	0.64	3.16
MnO	0.03	0.06	0.04	0.21	0.02
MgO	0.03	0.05	0.08	0.05	0.03
CaO	0.46	0.48	0.46	0.65	0.45
Na_2O	2.54	4.49	3.79	4.41	3.43
K_2O	4.30	4.04	4.42	4.02	4.39
P_2O_5	0.02	0.04	0.02	<0.01	0.01
LOI	0.6	0.6	0.4	0.5	0.8
Sum	99.88	99.96	99.95	99.92	99.91
Cr	68.43	82.11	88.94	130.08	75.27
Ni	2.9	2.8	2.2	2.2	1.7
Sc	<1	4	4	10	1
Ba	128	24	54	39	137
Be	<1	2	7	10	1
Co	2.2	1.9	1.6	1.5	1.4
Cs	<0.1	0.9	0.1	0.6	0.2
Ga	19.9	26.5	20.1	22.9	21.8
Hf	8.3	3.7	4.2	5.6	8.1
Nb	10.6	28.4	8.3	25.4	11.1
Rb	25.7	193.1	82.0	134.0	27.1
Sn	1	4	1	2	1
Sr	11.6	10.1	12.3	11.9	9.7
Ta	0.4	4.5	0.4	2.9	0.4
Th	2.4	10.7	8.8	11.0	0.7
U	0.7	10.1	2.0	18.2	0.5
V	32	13	18	21	14
W	<0.5	1.0	0.8	1.0	<0.5
Zr	534.7	28.0	76.9	82.0	493.2
Y	27.8	38.4	48.6	118.5	21.2



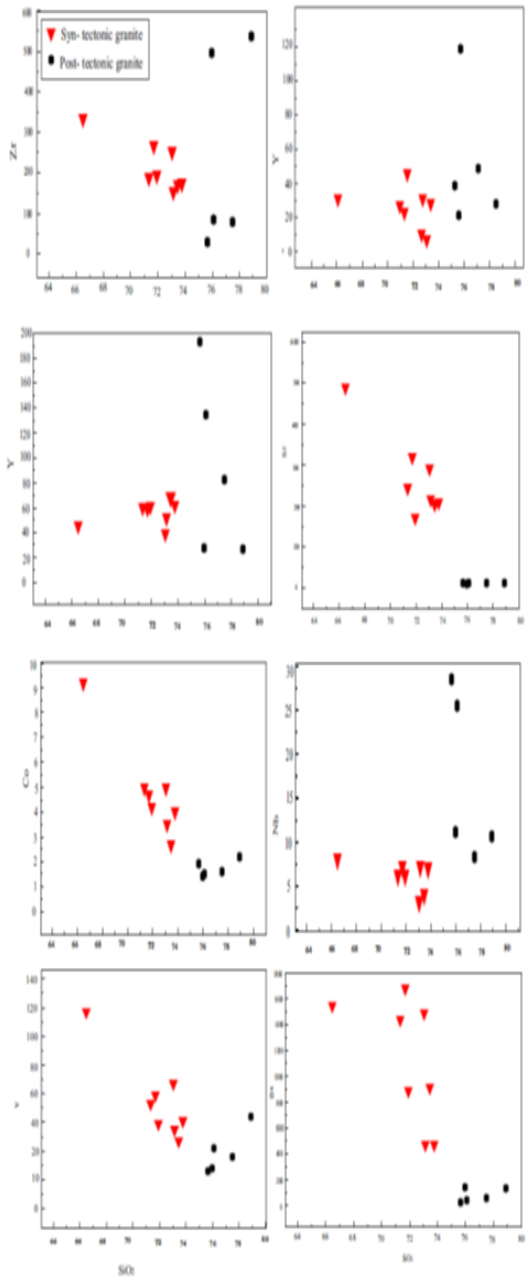


Fig. 3.2: Harker variation diagram for major element oxides of granitoid rocks in the study area.

Fig. 3.3: Harker variation diagram for some trace elements vs. SiO2 of granitoid rocks in the study area.

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The trace element contents show slightly clear trends in the investigated syn- to post-tectonic granite rocks (Fig 3.3). The large ion lithophile elements (LILE) Ba and Sr show geochemical behavior indicating fractionation of a mineral assemblage rich in plagioclase and K – feldspar, which would cause depletion of melt in Ba and (Moghazi 1994) . The variation diagrams shows increasing of Ba with increasing SiO_2 in post-tectonic granite due to plagioclase fractionation (Hall 1987). The high field strength elements (HFSE) Y, Nb and Zr exhibit increasing trends with increasing SiO_2 in the post-tectonic granite samples.

Table 3. REE elements data of the granitoid rocks in the study area.

		Syn tectonic granite							Post tectonic granite				
	B11	**B6-2**	**C19**	**B7-1**	**D5**	**D1**	**B9**	**B13**	**A1**	**A3**	**B6-1**	**C18**	**B3**
La	37.2	30.2	35.5	34.9	13.6	19	24.5	44	52.3	26.6	2.9	11.1	5.9
Ce	78.9	49.3	67.8	62.1	27.2	41.1	50.5	91.8	118.9	56.4	7.2	36.3	15.9
Pr	9.32	5.66	7.7	6.29	3.33	5.23	6.79	10.45	14.24	7.3	0.86	4.85	1.96
Nd	34.7	19.4	27.8	19.6	13.1	19.9	27.8	36.4	57.2	29.2	3.9	20.6	7.8
Sm	7.06	3.17	5.81	2.68	3.24	4.44	6.93	5.93	10.08	5.13	2.5	7.04	4
Eu	1.8	1.26	0.97	0.81	0.99	1.08	1.6	1.42	0.92	0.9	0.19	0.27	0.21
Gd	6.26	2.71	5.06	2.19	3.92	4.8	7.41	5.28	7.78	4.68	5.95	7.87	4.74
Tb	0.93	0.35	0.81	0.22	0.66	0.79	1.29	0.74	1.1	0.73	1.75	1.53	1.05
Dy	5.61	1.79	4.56	1.15	4.11	4.75	7.61	3.76	5.66	4.01	14.33	9.15	6.29
Ho	1.04	0.32	0.93	0.2	0.97	1.03	1.53	0.77	1.05	0.84	3.65	1.98	1.33
Er	2.94	0.99	2.44	0.59	2.97	3.23	4.71	2.33	3.07	2.52	12.3	5.7	3.89
Tm	0.45	0.15	0.38	0.09	0.47	0.52	0.71	0.34	0.5	0.33	2.23	0.86	0.66
Yb	3.03	0.96	2.62	0.67	3.39	3.86	4.78	2.39	3.57	2.39	17.21	5.16	4.96
Lu	0.45	0.16	0.37	0.12	0.54	0.57	0.75	0.39	0.61	0.36	2.83	0.72	0.73
ΣREE	**189.69**	**116.42**	**162.75**	**131.61**	**78.49**	**110.3**	**146.91**	**206**	**276.98**	**141.39**	**77.8**	**113.13**	**59.42**
$(La/Yb)_n$	**8.81**	**22.57**	**9.72**	**37.36**	**2.88**	**3.53**	**3.68**	**13.21**	**10.51**	**7.98**	**0.12**	**1.54**	**0.85**
$(La/Sm)_n$	**3.40**	**6.15**	**3.94**	**8.41**	**2.71**	**2.76**	**2.28**	**4.79**	**3.35**	**3.35**	**0.75**	**1.02**	**0.95**
$(Gd/Yb)_n$	**1.71**	**2.34**	**1.60**	**2.70**	**0.96**	**1.03**	**1.28**	**1.83**	**1.80**	**1.62**	**0.29**	**1.26**	**0.79**
(Eu/Eu*)	**0.83**	**1.31**	**0.55**	**1.02**	**0.85**	**0.72**	**0.68**	**0.78**	**0.32**	**0.56**	**0.15**	**0.11**	**0.15**

The abundance of the rare earth elements (REEs) in the different granite types of the study area is given in Table 1.2 and their variation and behavior are manifested as Chondrite-normalized REE patterns (Fig.3.4 a,b) with chondritic values from Sun and McDonough (1989). In general, there is a pronounced increase in the ΣREE, decrease of LREE fractionation and depth of the Eu anomalies from the syn-orogenic to the post-orogenic granites. The syn-orogenic granite samples are characterized by high fractionated REE patterns (La/Yb_n = 3.53 – 37.4), lowest total REE content (Σ REE = 78 – 206ppm), and flat to moderately fractionated HREE (Gd/Ybn = 1.0 - 2.7). This indicates that HREE-bearing minerals such as garnet and/or zircon are not fractionated phases during the crystallization of granodiorite. Except two samples, which have positive Eu-anomalies (Eu/Eu*= 1.02 and 1.31), most samples of the syn-tectonic granites exhibit small negative Eu – anomalies (Eu/Eu*= 0.85 – 0.55). Comparing with the syn-tectonic granites, the post-tectonic granites have variable total REE (ΣREE = 277 - 60 ppm), with moderately to weakly fractionated REE patterns (La/Yb_n = 10.51 – 0.12) and (Gd/Yb_n = 1.8 – 0.29)) and relatively deep negative Eu anomalies {$(Eu/Eu^*)_n$ = 0.56 – 0.11}.

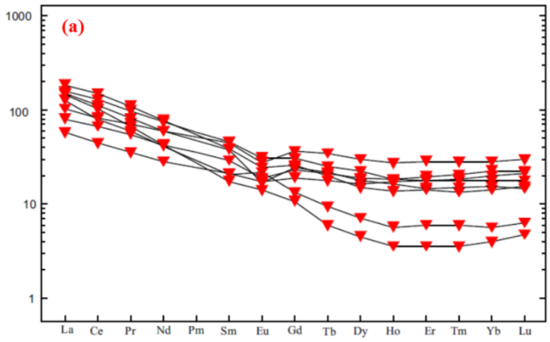

Fig. 3.4 a: Chondrite-normalized REE patterns of the syn-tectonic granitiods in the study area. Normalizing values are from Sun and McDonough (1989).

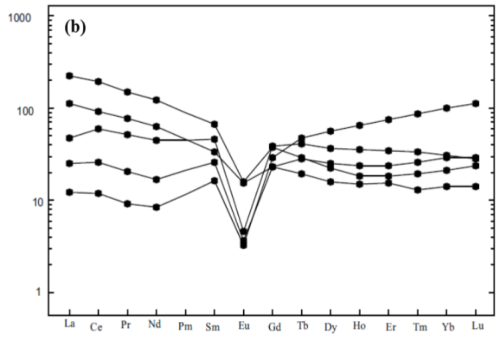

Fig. 3.4 b: Chondrite-normalized REE patterns of the post-tectonic granitiod rocks in the study area. Normalizing values are from Sun and McDonough (1989).

The trace elements enrichment/depletion and their systematic variations are demonstrated on mantle-normalized diagrams (Fig.3.5) using mantle values (Wood 1979). The different granite types show characteristic LILE-enriched patterns. Despite some discrepancies in the elements enrichment/depletions, the rocks of the syn-tectonic granites are collectively enriched in the LIL elements and have high LILE/HFSE ratios and significant Nb, Sr, Ti and Th negative anomalies. These chemical features are common and characterize arc-related magma (Pearce et al., 1982,) or granites derived from a crustal source, which itself were derived from arc crust (Whalen et al., 1987). Such anomalies also emphasize the role of feldspar and Fe-Ti oxides separation during the crystallization of these rocks. Compared with the syn-tectonic granites, the post-tectonic granites show high contents of trace elements and close similar patterns with strong development of negative K, Ba, Sr, and Ti anomalies. This marked depletion would be consistent with a greater degree of fractionation of K- feldspar, apatite and Fe- Ti oxides (Moghazi 1994).

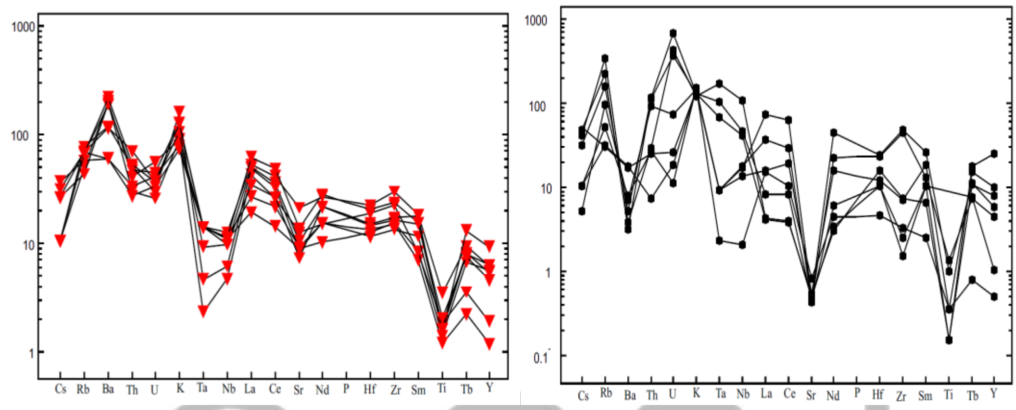

Fig. 3.5: Mantle-normalized trace- element spider-diagrams (Wood, 1979) for the studied granitoid samples.

The magma type and tectonic setting of the studied granitiod rocks will be discussed using some discrimination diagrams such as 100(MgO + $FeOt$ + TiO_2 + SiO_2) vs. (Al_2O_3 + $CaO/FeOt$ + Na_2O + K_2O) discrimination diagram (Sylvester, 1998) and Nb vs. Y , Rb vs. Y+Nb, Rb vs. Y+Ta and Yb vs. Ta diagrams of(Pearce et al 1984).

On the 100(MgO + $FeOt$ + TiO_2 + SiO_2) vs. (Al_2O_3 + $CaO/FeOt$ + Na_2O + K_2O) diagram (Fig. 3.6) of (Sylvester 1998), the syn-tectonic granite samples lie in the field of calc-alkaline granite, but most of the post-tectonic granite samples plot in the field of alkaline and highly fractionated calc-alkaline granites. According to the K_2O – Na_2O – CaO ternary diagram (Barker and Arth, 1976), all the granitoid samples follow the calc-alkaline trend, but the alkali feldspar granite samples lie near the K_2O –Na_2O line, which may indicate more alkaline character (Fig. 3.7).

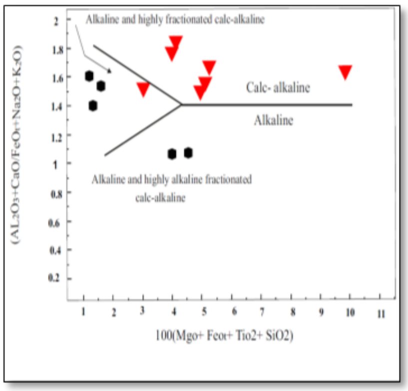

Fig. 3.6. 100(MgO + FeOt + TiO2 + SiO2) vs. (Al2O3 + CaO/FeOt + Na2O + K2O) discrimination diagram (Sylvester, 1998) for the studied granitoid rocks.

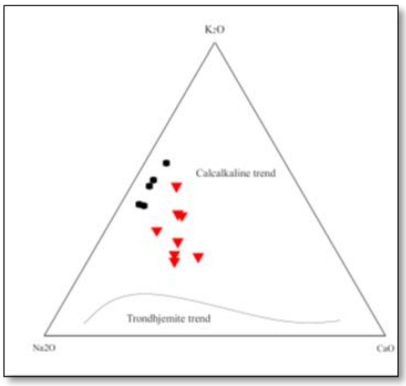

Fig. 3.7: K2O –Na2O – CaO ternary diagram (Barker and Arth, 1976) showing all the studied granitoid samples follow the calcalkaline trend.

Pearce et al (1984) classified granitoid rocks according to their tectonic setting into: ocean ridge granite (ORG), collision granite (COLG), volcanic arc granite (VAG) and within plate granite (WPG). On the discrimination diagrams Nb vs. Y, Rb vs. Y+Nb, Rb vs. Y+Ta and Yb vs. Ta (Fig. 3.8) of (Pearce et al 1984), the syn tectonic granite samples fall in the volcanic arc granite (VAG) field. The post-tectonic granites plot in both the volcanic arc granite (VAG) field and the within-plate granite (WPG) field but most samples lie within (VAG).

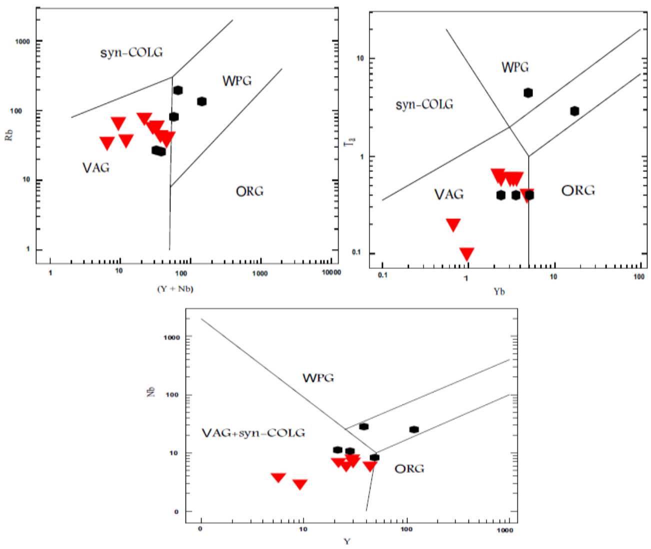

Fig. 3.8: Tectonic discrimination diagrams for the studied granitoid samples. Fields of within plate granite (WPG), ocean ridge granite (ORG), volcanic arc granite (VAG) and collision granite (COLG) are from Pearce et al (1984).

One of the most popular classifications of granitoid rocks is the I- and S-type granitoid classification. These two contrasting granite types were recognized by (Chappell and White 1974) as they proposed a genetic subdivision of the granitic rocks into those extracted from sedimentary protoliths (S-type) and those derived from igneous source rocks (I –type). Granites were interpreted as being derived by partial melting with composition that directly reflects their source compositions. Another group of granites has been designated A-type by (Loiselle and Wones 1979). The term A-type granite was used to emphasize the anorogenic tectonic setting, the relatively alkaline composition, and the supposed anhydrous character of the magmas. Based on Zr+ Nb+Ce+Y vs (Na_2O+ K_2O) diagram (Whalen et al 1987), the studied granitiod rocks fall in three fields. The syn tectonic granite samples lie within the I- and S- type granite fields and some samples fall in the field of highly fractionated I-type granite (Fig. 3.9). On the other hand, all the post-tectonic granite samples plot in the A- type granite field (Fig. 3.9).

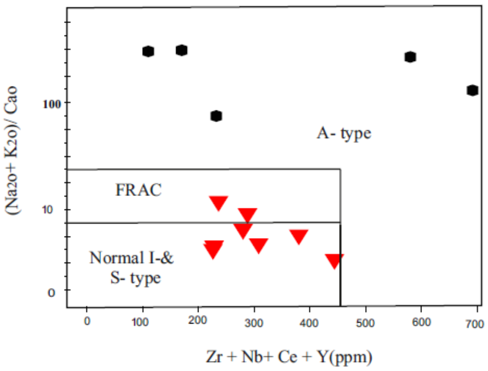

Fig 3.9: Zr+ Nb+Ce+Y vs (Na2O+ K2O) diagram after (Whalen et al 1987). The syn-tectonic granite samples lie within the field of I- & S- type granite and the post- tectonic granite samples plot in the field of A- type granite.

(Eby 1990, 1992) subdivided the A-type granites into two groups: A1, which represents differentiates of mantle-derived oceanic island basalts (anorogenic or rift zone), and A2, which represents crustal derived granite of a post-orogenic setting. On the Y/Nb vs. Rb/Nb diagram (Eby, 1990, 1992), which can be used to distinguish between the A1 (rift-related) and A2 (post-collision) sub-types of the A-type granites, most of studied granites plot in the A1 and A2 sub-type granites (Fig. 3.10). Moreover, the SiO_2 vs Al_2O_3 discrimination diagram of (Maniar and Picoli 1989), which is designed to separate the granitoid rocks into Island arc granite (IRG),

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continental arc granite (CAG), continental collision granite(CCG), rift related granite (RRG), post-orogenic granite (POG) and continental epirogenic uplift granite (CEUG). Most of the syn-tectonic granite samples fall in the CAG+ IRG+ CCG (volcanic arc field) whereas the post-tectonic granite samples plot in the field of post-orogenic granite (POG) (Fig. 3.11).

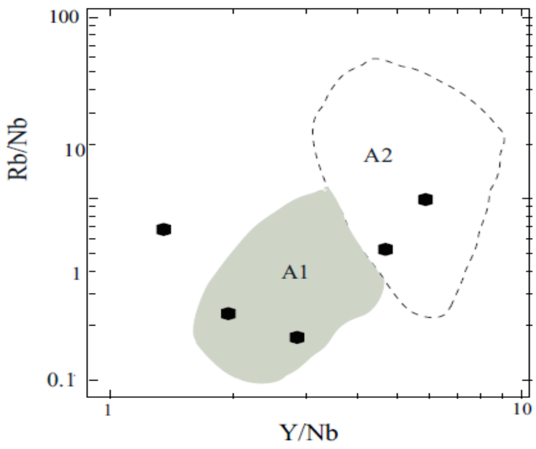

Fig. 3.10: Y/Nb vs. Rb/Nb diagram (Eby, 1992) distinguishing between the A1 (rift-related) and A2 (post-collision) subtypes of the A-type granites.

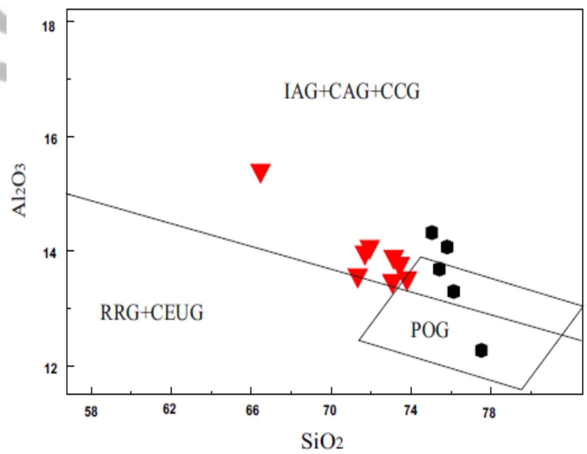

Fig. 3.11: SiO_2 vs. Al_2O_3 discrimination diagram of Maniar and Picoli (1989). The syn-tectonic granite samples fall in the volcanic arc field (CAG+ IRG+ CCG) whereas the post-tectonic granite plots in the post-orogenic granite (POG) field.

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Conclusion:

The study area has been extensively intruded by syn- to late-tectonic plutons, which are intruded into the metavolcano-sedimentary sequence and vary in rock composition from granodioritic to granitic. The Post-tectonic granites in the study area occur as irregular outcrops, which are tabular to circular in form. They are randomly dispersed throughout the study area and were intruded into all older rock units. Using the Q-ANOR diagram of (Streckeisen and Le Maitre 1979), the data points of the syn-orogenic granitoid plot in the granodiorite and monzogranite fields, whereas samples of the post-orogenic granite indicate a syenogranite to alkali feldspar granite composition. The syn tectonic granite samples lie within the I- and S- type granite fields and some samples fall in the field of highly fractionated I- type granite. On the other hand, all the post-tectonic granite samples plot in the A- type granite field. Most of the syn-tectonic granite samples fall in the CAG+ IRG+ CCG (volcanic arc field) whereas the post-tectonic granite samples plot in the field of post-orogenic granite.

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