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The Petrology and Geochemistry of Granitoid Rocks of Troud Area in South-West of Shahrood

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Abstract

The area of study is located 120 Km north-east of Shahrood city. In terms of structure and geological classification, this area is located in the northern part of central Iran zone. Granitoids of Troud ranging from monzonite to granite. The main minerals of granitoids are quartz, plagioclase, and orthose. The accessory minerals are biotite, hornblende, sphene, and opaque minerals. Various textures of granular, graphic and prethite are observed in these rocks. Based on various diagrams of major and trace elements, this rock is I-type arc calk-alkaline, Meta to para-aluminous with continental origin form at subduction zone. All these characteristics, combined with low Al_2O_3/(FeO + MgO + TiO_2) and (Na_2O +K_2O)/(FeO + MgO + TiO_2) ratios and high Mg# values, suggest an origin through dehydration melting of alkaline mafic of lower crustal source rocks.

Keywords: *Petrology, Troud, Central Iran, Back-arc, Crust melting.*

1. Introduction

Central Iran is one of the main and most complex geological zones of Iran (Fig 1). The oldest metamorphism (Precambrian) and the youngest semi-active volcanism occurred in this zone. In fact, this region is the oldest micro-continent plate in Iran which has suffered various geological processes. One of the most important and interesting geological events in Iran is the occurrence of orogenic movements comparable with the Katangan in Gondwanaland and Baikalian in the Eurasian continent. In Central East Iran the Microplate was more or less connected to the southern rim of Eurasia during the Paleozoic and early Mesozoic. A significant separation from Eurasia took place during the Jurassic [1]. As a result of Neo-Tethys subduction beneath the Central Iran Microplate (CIM) and following the collision of Iranian and Afro-Arabian plates, various structural zones developed in Iran [2-5]. However, peak of this subduction-related calc-alkaline magmatic activity is thought to have been in the Eocene age [6-13].The area under studied is located in the 115 km south of Damghan city and120 km north southwest of Shahrood with 70 square kilometers . And longitudes of 54° 30́ and 54° 45́ and latitudes 35° 15́ and 35° 30́ (Figure 1) which is part of Torud 1:250000 scale map of Central Iran micro plate. The scope of this study is to describe the geological and geochemical aspects of the Torud granidiorite in terms of mineralogy and geochemistry (whole-rock trace element analysis). These data will be used to examine the geology, geochemistry and the genetic relation of this rock

2. Regional geology

Central Iran undergone serious changes during the Mesozoic and Tertiary periods. These movements were accompanied by folding, uplift processes, metamorphism, and magmatism [15]. The magmatic activities in central Iran have occurred in several main stages include Upper Eocene-Oligoecene, Oligocene-Miocene and Pliocene[16]. Magmatic activities in the Moaleman-Troud occurred during Upper Eocene stage. After orogenesis in the Late Cretaceous, where a large amount of volcanic rocks of basalt, andesite, dacite, and rhyolite were deposited in Eocene period, which were accompanied by pyroclastic and clastic sediments in the Karaj formation in central Iran and Alborz.

2.1 Central-Iran structural zone

The Central Iranian terrene is located northeast of the Zagros-Makran Neo-Tethyan suture and its sub-parallel Cenozoic magmatic arc, between the convergent Arabian and Eurasian plates. Thus, due to the collision setting, continuous continental deformation processes affect Central Iran. The Central Iranian platform was a stable platform during Paleozoic times, but late Triassic movements caused the creation of horsts and grabens.

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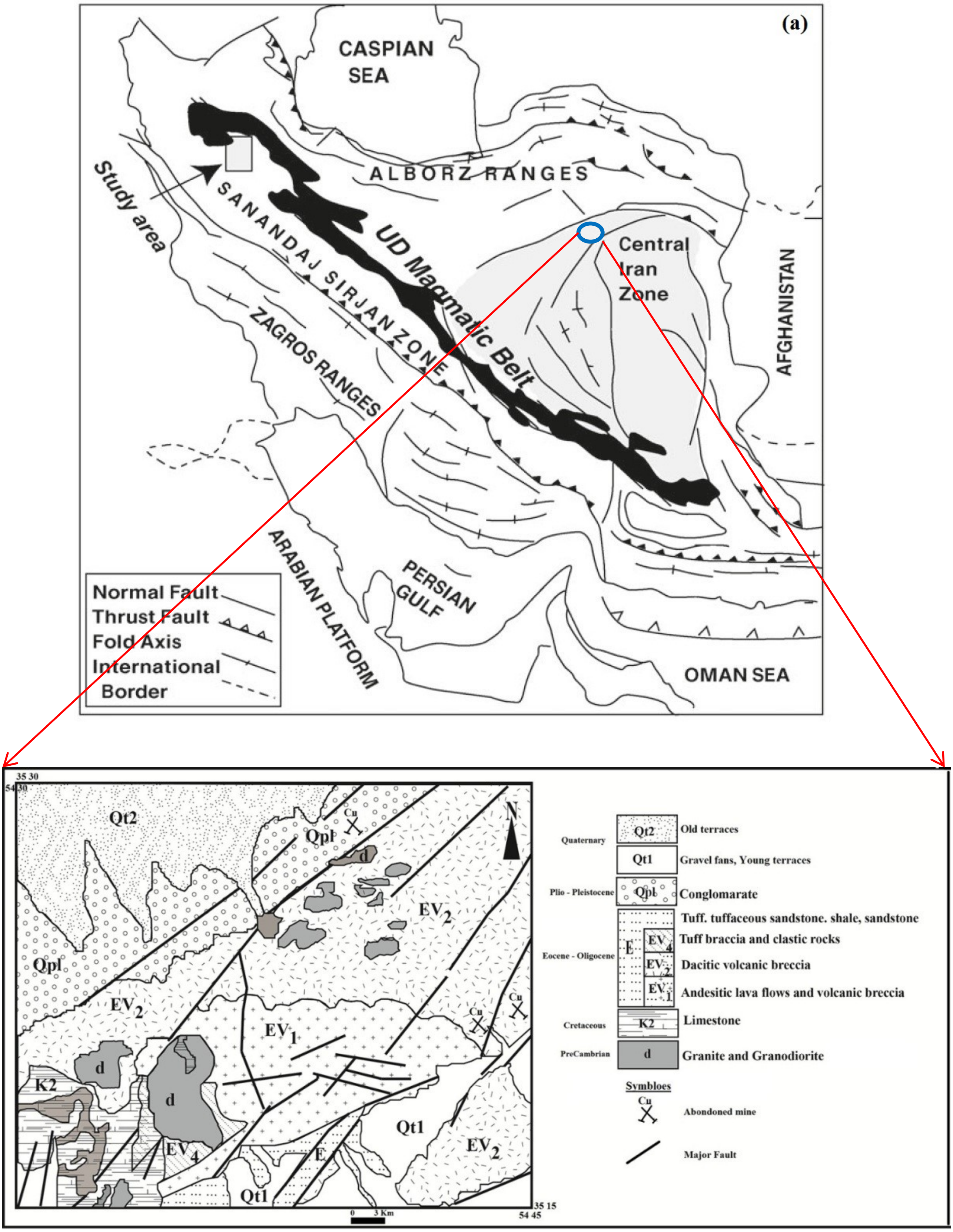

Fig. 1a. Structural subdivision map of Iran and b. Geographical location of the study area of (1:250,000) Troud map [14].

Central Iran comprises three major crustal domains: the Lut Block, the Kerman-Tabas Block, and the Yazd Block. The area of the Central Iranian terrene is surrounded and limited by faults and fold-and-thrust belts and Upper Cretaceous to lower Eocene ophiolite and ophiolitic mélange[17]. Adjoining fault separated areas and tectonical units are the Alborz and Kopeh-Dagh region, which ranges to the north, Makran and Zagros ranges to the west and south, and the East Iran Ranges, which borders this terrane to the east. The structural components (Lut Block, Kerman-Tabas, Yazd) of the Central Iranian Terrane are characterised by distinct horst (e.g. Lut block) and graben (e.g. Kerman-Tabas region) structures. The grabens are characterised by fillings of thick Jurassic sediments. However, the stratified cover rocks are largely correlatable among these blocks, but with locally significant facies and/or thickness variations across the block boundaries. The Blocks are characterised by an individual deformation style and seismicity, which makes them distinguishable from the adjacent regions[10].

2.2 Magmatic intrusions

In Mesozoic and Tertiary times tectonic activities affected particularly Central Iran. These movements were accompanied by folding, uplift processes, metamorphism, and magmatism [18]. In Late Jurassic times, the tectonic activity affected a great part of the Iranian region, which resulted in regional unconformities. In some areas, such as Central Iran, the Sanandaj-Sirjan belt and the Lut block these tectonic movements were associated with felsic intrusions[18]. The most important intrusions of the Lut block are the granodiorites of Kuh-e-Bidmeshk, Shah-Kuh, and Sorkh-Kuh, where the Shah-Kuh granite represents the largest intrusion in the Lut region. In beginning in the late Eocene or early Oligocene, the supply of previously fluxed lithospheric mantle was exhausted and the dominant source of volcanism became asthenospheric mantle, which continued to upwell in response to extension. The major and trace element compositions of the Troud granitoids indicate that they are subduction-related products. the intrusions were generated by crustal anatexis, most likely by dehydration melting of mid-crustal mafic to intermediate meta-igneous rocks followed by variable assimilation of old crustal materials. Heat for the partial melting of the mid-crustal amphibolites was produced by intraplating of hot, mantle-derived magma, in an extensional active continental margin.

2.3. Geology of the area under studied

The rock types in the are under studied are equal to-Karaj Formations. In these area, there are more than five masses of igneous bodies include Gandi, Chalou, Sosanvar, Baghou, and Zar mountains in which the Troud granodiorite is the largest with an area of 70 km^2 and is in contact with Crateciouse limestone and skarn. The rocks are ranges from acidic and basic. The sediments are mainly clastic , Schist, limestone, crystalline dolomite, marble, and metamorphic sandstone constitute this collection. The beginning of Mesozoic is accompanied by sea advancement in Triassic era and sedimentation. After tectonic stresses in the south of Anjilo fault, Cretaceous sea created with advanced transformation. This advancement began with red clastic depositions. The beginning of Tertiary is accompanied by the subsidence of the bed of sedimentary area and sea advancement. The result was a progressing conglomerate. The volcanic-sedimentary rocks of Eocene in this area are intersected by numerous intrusive rocks which rocks are in the form of domes, stocks, and dikes. These rocks are intersected by basic dikes, which are existent in almost the whole of the area. The granitoid rocks is located in the northernmost partof the Central Iran (Figure 1).The rocks of the plutonic complex vary in composition from monzonite to granite, which are exposed as stokes in the study area. In this article, we focus on the geochemical characteristics of intermediate-felsic rocks. The granitoids are associated with mafic plutonic bodies and metamorphic rocks (low to intermediate grade metamorphic rocks).

3. Petrographic studies

A total of 175 samples from the igneous rocks of the Troud complex were collected, in which 150 thin sections were studied by a polarized microscope. Based on field works and petrographic studies the igneous rocks can be classified as the following

3.1. Granitic intrusive bodies:

Monzogranite is a coarse-grained, inequigranular holocrystalline igneous rock dominated by plagioclase (30 vol%), alkali feldspar (35%), quartz (20%), biotite (10%) and hornblende with accessory titanite, zircon and apatite. Plagioclase and microperthite occur as large subhedral crystals up to 5 mm in size. Plagioclase is present as laths, often with well developed Carlsbad twins and is partly replaced by sericite giving it a cloudy appearance in PPL. Microperthites have oscillatory zoning and some have simple twins, lamella exsolution are small and indistinct. Plagioclase, quartz, microcline occur as smaller anhedral intergranular phases. Quartz often has well developed undulose extinction. Poorly developed myrmekite is present on the margins of some felspar crystals. Hornblende and biotite occur in clots of subhedral crystals up to 4 mm in size. Some hornblende contains abundant opaque inclusions that trace growth zones. Titanite is present as euhedral rhombs up to 1.5 mm in size and as small rounded anhedral grains. Apatite and zircon are present as inclusions in other phases.

3.2.Granodioritic bodies:

Granodiorites, volumetrically, form the largest amounts of the intrusive bodies intruded in to the Eocene volcanic rocks. In hand specimen, these rocks are hollo crystalline, grey or greenish grey colored with medium- to course-grained textures. In microscopic view, rocks show a variety of textures of mostly granular with subordinate graphitic, porphyritic and poikilitic textures (Figure 2-b). The rocks incorporated parts of earlier-solidified magma as autoclaves. The rock forming minerals include plagioclase, quartz, k-feldspar and amphibole. Biotite, pyroxene, apatite, sphene and opaques minerals form the minor and accessory minerals. Chlorite, epidote, sericite, sphene and clay minerals are the alteration products of the original minerals. The characteristic features of the granodiorites are their medium- to coarse-grained granular textures, absence of moscovite, absence of metamorphic effects, and their association with more mafic rocks like diorite, quartz-diorite and gabbro-diorite. The major minerals in these rocks are plagioclase (~40%), quartz (~20 %), orthoclase (15–20 %) and biotite (10–15 %).

3.3. Monzonitic intrusive bodies:

The inteusive body in the north of the Gandi village is the largest body in this area compositionally ranges from monzonite to quartz monzodiorite. The monzonite rocks intruded the upper Cretaceous impure carbonate rocks which host the Skarn zones and a series of Oligocene dacitic breccias, tuffs and trachy-andesitic lavas. The results of this intrusion, in addition of the skarnification, and mineralization, are the recrystallization of Cretaceous limestone along with pronounced preserve alteration produced. This is almost the same happened in the Mazraeh skarn deposit[19]. The predominant minerals are, garnet and epidote. In addition of exoskarn towards the country rocks ,a thin endo skarn also developed toward the igneous rcks and change the colour of this rock in to grat–green color. These colors are due to loss of mafic mineral and addition of epidote respectively. In terms of texture the minerals are coares to medium grains with granular texture. In microscopic scales, the texture is granular. Sometimes graphic, porphyries, and poieklitic textures are also observed. In some parts, they have a large amount of mafic micro-granular enclaves. The main minerals are plagioclase, quartz, orthose and hornblend. The minor minerals are biotite, pyroxene, apatite, sphene, and opaque minerals. Chlorite, epidote, sericite, sphene, and clay minerals are the alteration products (Figure 2-e).

3.4. Gabbro

These rocks have small outcrops in the studied area (outcropping for an area of about 2 square kilometers). Based on petrographic studied, the main minerals are plagioclase, clinopyroxene (mostly, augite or Ti-augite in composition) and olivine. Biotite, apatite and opaque minerals constitute the accessory minerals. The textures range from granular to micro granular and porphyroid. Chlorite and sericite are the secondary minerals. Plagioclases occur as subhedral to euhedral crystals. Samples taken from the marginal parts of the intrusive body exhibit finer-grained textures containing mostly rounded plagioclases showing traces of zoning but the plagioclases from the inner parts of the intrusive body show elongated forms and well preserved. The extinction angles of plagioclases indicate a composition ranges of andesine to labradorite(base on the Levi method).

4. Geochemistry

Fourteen representative samples were then selected for whole-rock chemical analysis (Table 1). Samples weighed between 1 and 1.5 kg before crushing and powdering. Whole-rock major elements were determined by an X-ray fluorescence (XRF) spectrometer and trace and rare earth elements (REEs) were determined by lithium metaborate fusion ICP-MS at the GSI laboratory in Thran, Iran.:

We used the diagram of [20] for nomenclature and showed a composition in the range of quartz-monzonite, granodiorite, monzonite, quartzmonzo-diorite and granite (Fig. 3a). Based on alkalis versus silica (TAS) diagram [21] (Fig. 3b), the investigated granitoids are classified as granite, granodiorite, quartz monzonite and monzonite. The rocks dominantly plot in the subalkaline field of the diagram of [22] (Fig. 3b). Plots of La/sm vs La [23], Th/Sm vs Th/Yb, and Rb/Th vs Rb [24] and Y/Zr [25,26] are utilized to differentiate between fractional crystallization and partial malting processes. An ascending linear pattern is indicated by these plots testifying to the occurrence of fractional crystallization processes (Fig4 A to D).

The following diagrames are used to determine the magmatic series and Aluminum saturation index(ASI). The granitoid rocks plot in the field of metaluminus rocks in diagram[27] and calc-alkaline rocks with low to medium Fe content on diagrams [28,29] (Fig. 5A and B). The studied granitic samples plot in the fields of OGT granites on the Zr+Nb+Ce+Y vs $Na_2O+K_2O)/CaO$ diagram [30]. The diagram of Y vs SiO_2 [31] verifies the distinct I-type nature of theses rocks. (Fig. 5C and D).

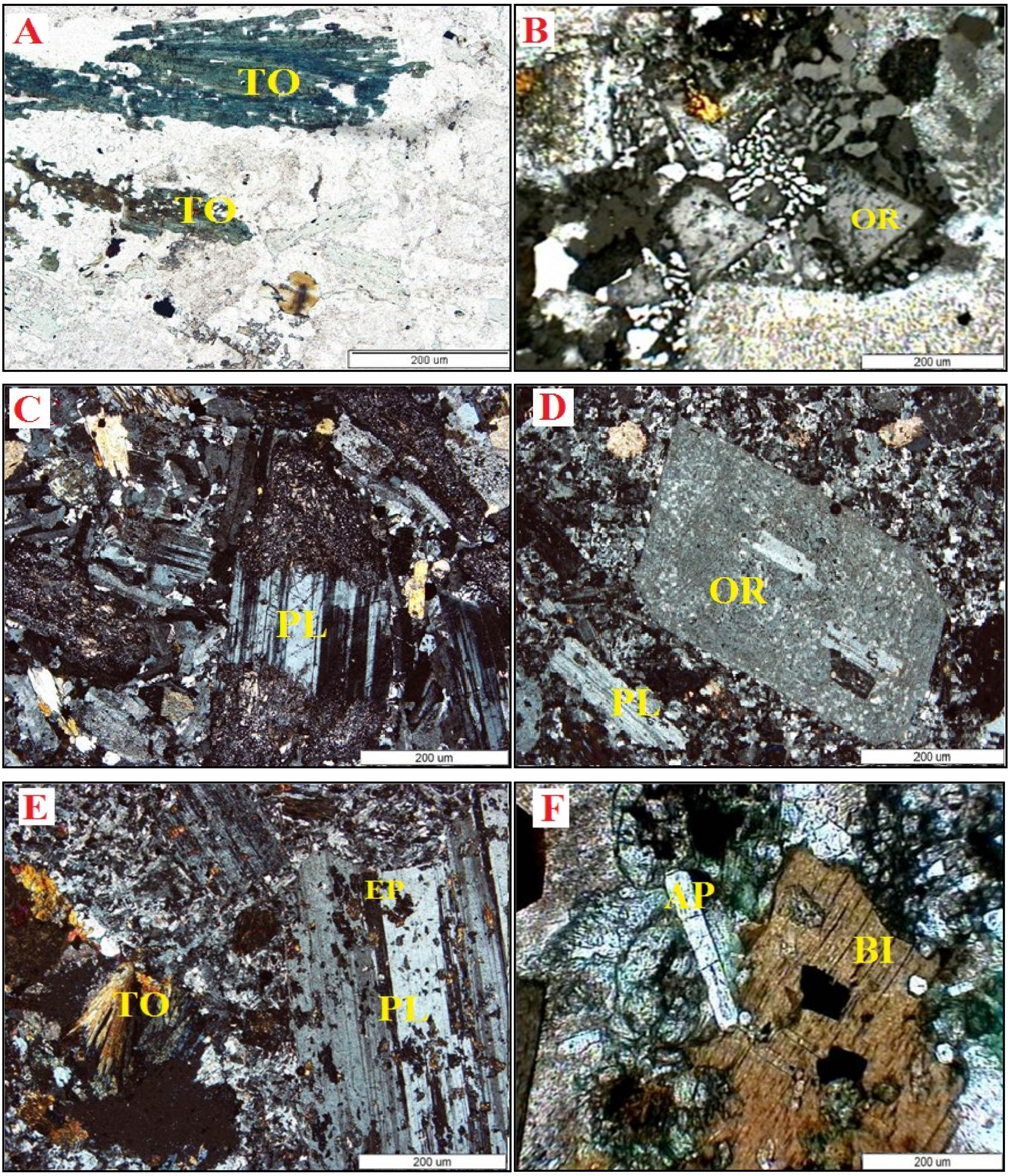

Fig. 2-A. large grains of tourmaline within the granite (ppl). B-graphictexturein the granodiorite (xpl). C-corrosion margin which indicates a distribution of plagioclase and opaque mineral in the monzogranite (xpl).D-alkali feldspar, plagioclase surround, in the granodiorite (xpl). E- prophytic texture in the tourmaline-bearing granite of Zar Mountains (xpl).F-biotite crystals containing inclusions of magnetite with elongated apatite in the monzogranite(xpl).

Table 1. Chemical composition Major elements (wt.%) compositions of rocks from thefor Troud granitoide rocks area.

Sampl.	**E70-MG**	**E77-MG**	**E72-QM**	**E82-QM**	**E91-QM**	**E118-QM**	**E73-GR**	**E99-MO**	**E83-QMG**	**E62-GA**	**Km2-GA**	**Km 16-GA**	**Km 24/4-GA**	**Km 23/1-GA**
SiO2	62.95	63.92	65.55	64.27	63.29	60.61	62.24	64.59	58.63	49.24	49.18	49	50.04	50.81
Al2O3	19.14	17.53	18.23	16.14	15.98	15.77	17.8	15.51	16.99	19.25	15.57	18.84	17.51	15.83
Fe2O3	1.58	2.6	1.95	2.12	2.11	2.77	2.56	2	2.73	3.66	3.08	2.79	3.33	3.5
FeO	2.49	3.47	2.28	2.54	2.74	3.56	3.41	2.5	3.94	7.65	6.03	4.87	6.33	6.13
CaO	3.23	1.55	0.41	2.94	3.84	4.81	2.98	3.88	5.28	6.94	7.58	7.3	6.87	7.84
MgO	3.43	2.58	2.36	2.84	3.42	3.48	2.57	2.86	4.35	6.73	8.77	9.74	7.42	7.27
Na2O	4.06	2.89	2.97	3.25	3.53	3.07	3.09	3.16	3	2.84	4.62	4.16	4.68	4.82
K2O	1.66	4.23	5.22	4.67	3.94	4.5	4.12	4.39	3.73	1.37	1.85	1.07	0.8	0.58
P2O5	0.52	0.31	0.2	0.3	0.42	0.51	0.31	0.41	0.41	0.42	0.93	0.29	0.26	0.27
MnO	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.21	0.18	0.14	0.25	0.3
TiO2	0.73	0.72	0.61	0.61	0.42	0.51	0.72	0.51	0.73	1.47	1.52	1.22	1.78	1.95
SrO	0.1	0.1	0.1	0.2	0.21	0.2	0.1	0.1	0.1	0.21	0.01	0.03	0.03	0.03

Table 2. Chemical composition Trace, and rare earth element (ppm) for Troud granitoide rocksTrace, and rare earth element (ppm) compositions of rocks from the Troud area.QM= Quartz monzonite, MG=Monzogranite,Gr=Granodiorit, QMG=Quartz monzogabro, GA= Gabbro

Sampl.	E70-MG	E77-MG	E72-QM	E82-QM	E91-QM	E118-QM	E73-GR	E99-MO	E83-QMG	E62-GA	Km2-GA	Km 16-GA	Km 24/4-GA	Km 23/1-GA
Be	1.81	2.06	1.69	2.53	1.99	2.65	2.06	2.78	1.3	0.82	1	1	1	1
Bi	0.5	0.58	0.5	0.5	0.5	0.5	0.57	0.5	0.5	0.78	0.75	0.65	0.78	0.77
Ce	51.55	55.25	28.34	55.14	30.45	41.85	58.34	58.06	38.82	32.67	60.1	25.5	26.4	29.7
Co	10.95	20.03	23.24	13.82	13.6	12.63	20.02	9.56	17.62	32.27	32.5	26.9	33.6	37.9
Cr	34.95	73.25	94.84	96.06	67.04	76.12	82.78	73.25	64.64	167.16	165	163	164	166
Cu	3.33	31.21	130	56.05	39.5	56.37	68.21	38.45	80.61	9.1	333.1	42.9	76.3	96.6
Dy	6.65	3.96	2.42	7.57	0.97	0.08	7.51	0.08	2.99	69.11	3.57	3.43	4.85	5.7
Er	1.56	1.31	0.66	2.24	1.7	1.39	2.38	2.07	2.39	2.24	1.71	1.9	2.8	3.34
Eu	1.44	1.21	0.45	1	0.74	1.17	1	1.96	1	4.7	1.88	1.29	1.5	1.72
Ga	23.22	21.54	27.95	25.43	13.23	25.24	20.73	22.93	19.36	1.69	18.4	18.8	18.4	17.5
Gd	3.8	5.1	3.43	5.22	3.43	4.14	5.11	4.82	4.9	25.11	5.51	3.65	4.74	5.6
Ge	0.9	1.91	1.18	1.19	1.26	1.04	1.7	0.77	1.42	7.26	7.2	7.5	7	7.14
Hf	5.33	8.91	5.89	8.06	5.66	7.13	7.72	9.5	8.87	2.42	3.4	2.3	4.1	4.2
Ho	0.48	0.61	0.3	0.62	0.4	0.62	0.62	0.75	0.61	0.04	0.62	0.69	1	1.2
La	27.07	27.94	12.89	29.3	18.68	25.13	30.89	29.43	19.99	13.21	27.8	11.5	11.9	12.1
Li	29.71	25.01	18.58	11.49	9.5	10.29	25.76	9.46	12.19	96.45	0.95	0.97	0.89	0.95
Lu	0.23	0.37	0.24	0.35	0.21	0.31	0.33	0.41	0.8	0.72	0.22	0.27	0.4	0.47
Mn	285	605	354	445	684	865	477	1459	601	1520	1500	1450	1400	1420
Mo	15.73	6.39	6.94	25.61	25.75	34.78	11.06	7.48	7.88	2.56	0.3	0.7	0.8	1
Nb	20.02	23.26	19.66	25.59	14.19	17.58	26.16	23.42	24.3	66.75	17.1	11.4	7.2	8.2
Nd	30.12	24.39	15.37	24.99	19.43	28.48	54.56	32.84	18.81	24.73	36.3	15.1	18	21.2
Ni	16.9	39.61	55.66	28.41	29.29	27.72	43.51	25.59	19.26	44.47	45	45.5	44	43
P	1277	825	567	883	1072	1082	803	1567	1243	996	990	985	978	988
Pb	4.82	16.83	11.21	22.83	45.65	17.79	16.49	21.83	15.9	6.57	5.2	1.5	2.3	4.4
Pr	8.34	8	5.66	10.14	6.37	12.5	8.38	6.76	5.58	9.58	8.49	3.51	3.87	4.42
Rb	116	114	44.54	134	173	223	85.57	238	157	319	30.4	17.7	19.3	15.1
Sc	11.13	11.33	9.14	10.2	8.27	10.62	9.14	14.39	14.97	32.51	33	32.5	33.45	32
Se	0.08	0.12	0.11	0.19	0.13	0.05	0.08	0.06	0.06	0.13	0.12	0.11	0.13	0.15
Sm	4.69	4.66	2.21	4.71	2.53	3.6	5.3	4.87	3.64	5.26	6.48	3.54	4.37	5.13
Sn	1.97	3.02	2.09	2.9	1.91	2.64	2.79	3.22	3.09	4.49	1	1	2	2
Sr	397	392	158	435	516	766	295	822	488	1095	1157	752.9	857.6	893.6
Ta	1.23	2.74	1.77	2.63	1.53	1.78	3.11	1.62	2.85	3.82	0.9	0.8	0.5	0.6
Te	0.18	0.28	0.21	0.27	0.19	0.24	0.26	0.31	0.29	0.49	0.5	0.55	0.54	0.56
Th	9.71	14.49	9.26	17.41	9.49	12.87	15.7	16.51	14.46	22.43	3.6	1.1	1.7	2
U	2.71	5.01	3.61	3.42	3.32	3.1	5.22	2.76	4.4	238	0.9	0.4	0.6	0.7

V	144	137	110	130	107	136	140	176	186	238	293	214	223	240
Y	14.93	16.49	7.34	20.65	9.49	12.68	20.39	16.37	18.16	29.73	15.5	18.4	26.3	28.8
Yb	1.47	1.78	1.08	2.23	1.1	1.39	2.09	1.9	2.04	3.42	1.48	1.72	2.59	3.07
Zn	23.95	20.14	23.56	25.06	56.54	50.45	31.66	63.56	25.06	67.52	54	41	51	60
Zr	40.48	13.12	9.46	43.84	54.66	44.91	13.12	22.98	38.7	288	130.8	86.7	141.2	169.3

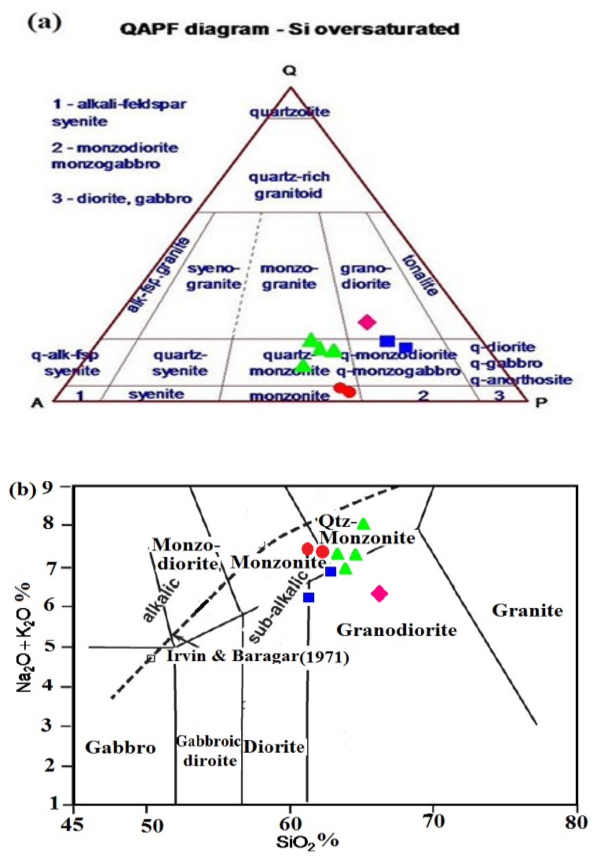

Fig 3. a-Rocks classification diagram[20]. b-Geochemical classification of intrusive rocks using Na_2O+K_2O vs SiO2 [21]. Signs: Monzogranite, Quartzmonzonite, Granodiorite, Quartz-monzogabbro

The compositions of granitoid rocks normalized to lower continental crust and chondrite (Fig. 6A and B) show depletion of HREE relative to LREE. The source rocks underwent partial melting process instead of whole rocks melting. Due to partial melting of the lower crustal rocks, the LREE are partitioned in to the partial melts and therefore the resulting rocks are enriched in LREE. By contrast, the HREE tend to be retained in the source rocks and are not preferentially partitioned into the partial melts resulting in the generation of a magma with HREE-depleted pattern relative to LREE. The rocks show a depleted pattern relative to Zr, Ba and Ti. Zr can replace for Ti in the host Ti-bearing minerals show no tendency to this rock [als.32].Thus, Zr anomalies can be related to the crystal fractionation of Titaniume rich minerals like titanite and titanomagnetite. Ba replaces K in feldspars. Positive anomalies of some elements like K and Th can be related to their higher crustal abundances. In I-type granites, P behaves as a compatible element and enters the early crystallizing phases resulting in negative P anomaly in the initial stages of magma differentiation. Slab-derived magmas and fluids brought about negative anomalies of Nb and Ti due to metasomatic processes in the mantle wedge [33]. the positive Sr anomaly is the first approximation of a function of the amount of plagioclase and abundances of Ce and Sm to estimate depth is limited by the differential effects of fractional crystallization in variably evolved magmas, whereas REE ratios such as Ce/Yb offer sensitive indicators of changing lithospheric thickness because they will not be radically affected by fractional crystallization[34]. The LILE could be enriched in the mantle wedge source rocks by fluid derived from the leading edge of the sub ducting plate [35].

P enrichment can be attributed to the presence of apatite. Apatite can also control the U, Th, Y, Zr , P and REE enrichments[36]. MREE depletion can be related to the fractionation of sphene or hornblende[37,38]; since hornblende is the main mineral hosting the MREE, but depleted in HREE, the fractionation of hornblende causes a decrease of MREE residual melt but has no effect on HREE amounts[39]. The granitoid samples plot in a VAG (Volcanic Arc Granitoid) tectonic setting on [40,41] diagrams(Fig. 6C and D). The Rb/Y vs Nb/Y and Nb/Zr discrimination diagrams were used to examine the crustal source of these rocks and their affinity to eductions environments. The samples contain high concentrations of Sr which on the discrimination diagram of [42] plot in the field of subduction-related rocks originated from continental crust(Fig 7A). The granitoids similarly plot on a subduction-related environment using the tectonic setting discrimination diagram of [43] confirming the previous notions about the tecotnic setting of the rocks (Fig. 7B).

Two ways for the generation of felsic magmas in continental arc and back-arc environments are as following:

1-Fractionation of an original basaltic magma by assimilation and fractional crystallization (AFC) [44,45]. This model was described as MASH (melting, assimilation, storage and homogenization) model by [46].

2-Partial melting of crustal volcanic rocks[47-49]. The rocks originated from partial melting of crustal rocks show higher contents of Rb, Th, U, K, La (LREE) and Pb. Such rocks are depleted in Ta, Ti and Nb but enriched in mobile trace elements and show a slight fractionation regarding the HREE.

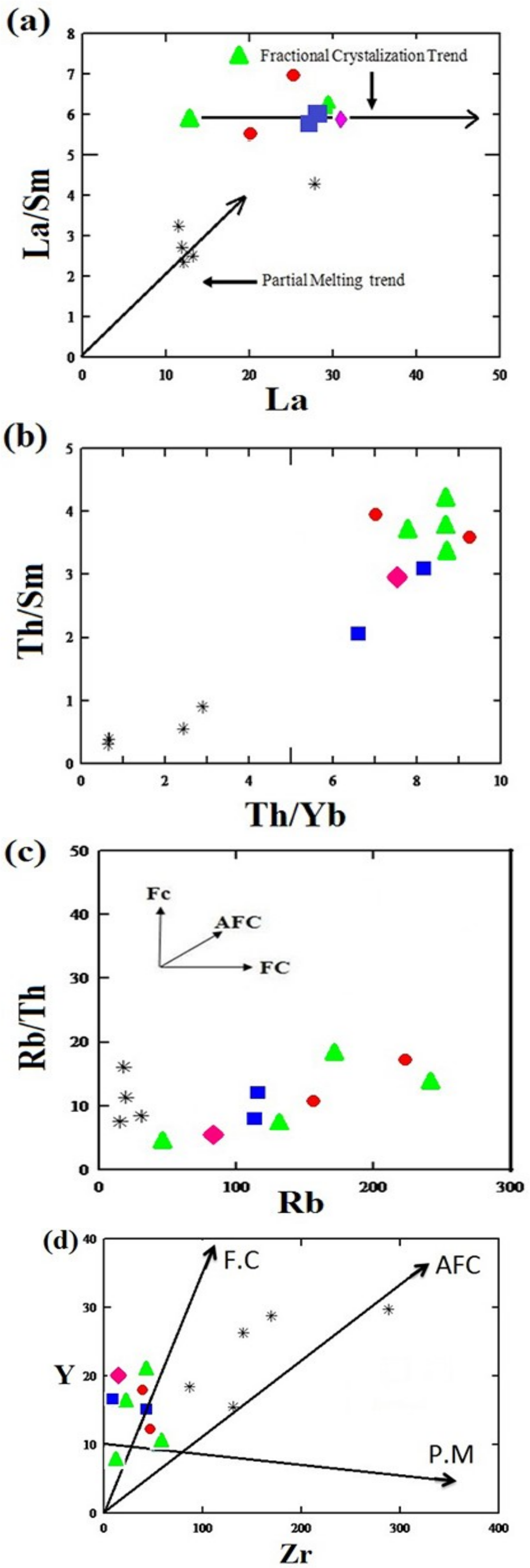

Fig. 4. Determine the fractional crystallization and partial melting of granitoid rocks. Mineral accumulation and/or fractional crystallization appear to have played an important role in the magma evolution. A-[22], B-[23], C- [24], D-[25]. CC: crustal contamination, AFC: Assimilation ± Fractional Crystallization, FC: Fractional Crystallization. P.M: Partial melting.

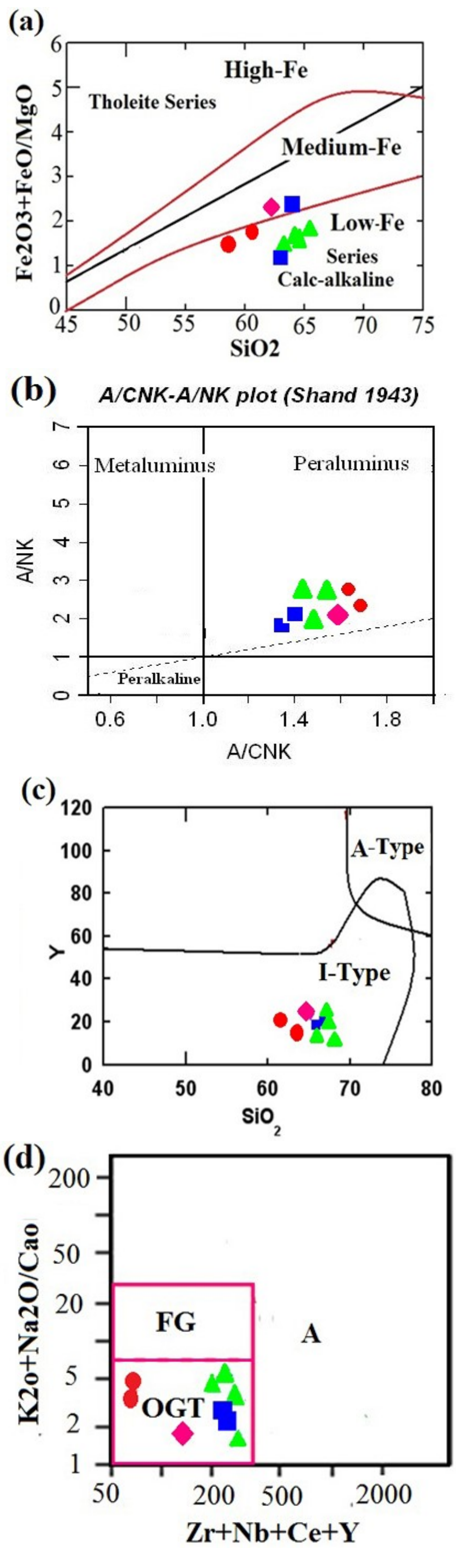

Fig. 5A- diagram Feo_t+Mg/SiO_2 to determine the magmatic series [26]. B-Troud granitoides on the A/NK versus A/CNK diagram to Aluminum saturation index (ASI) [27]. C-diagram Y/SiO_2 [28] and D diagram [Na_2O + K_2O) /CaO] vs.[Zr + Nb + Ce + Y] [29] discriminating I-and A-types granitoids from S-type rocks. or highly fractionated. FG: Fractionated felsic granites; OGT: unfractionated M-, I- and S-type granites.

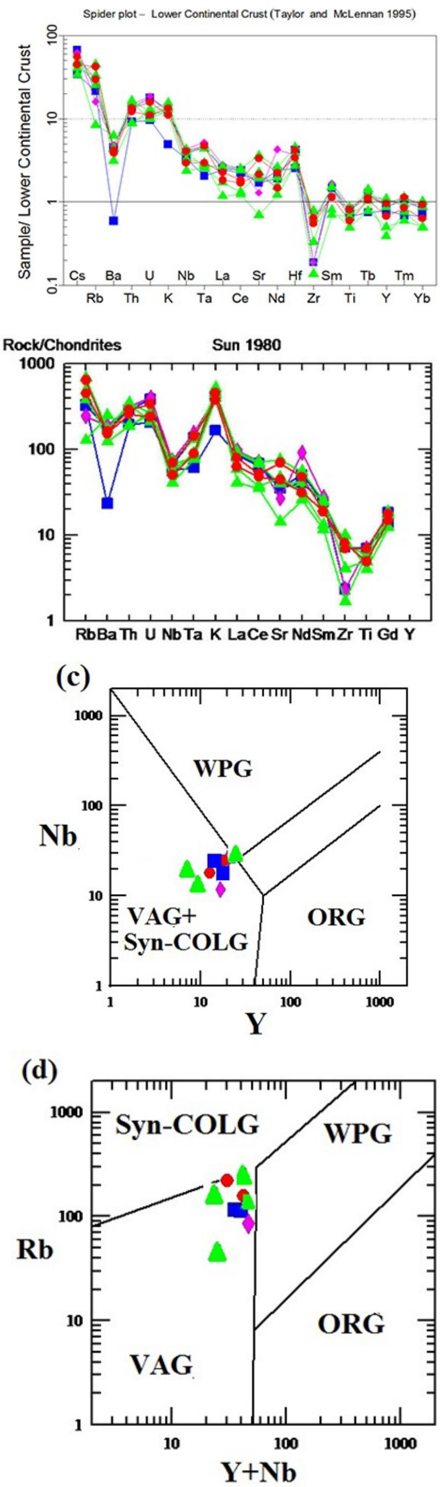

Fig. 6-A. lower continental crust -normalized element patterns for the granitoids from the Torud area.[50,51]. B-Chondrite-normalized rare earth element abundances for the Tourd granitoids [52], C and D- Discrimination diagrams of Y v. Nb and Nb+Y versus Rb [41] classify the Torud granitoids as volcanic arc and syn-collisional rocks. VAG – volcanic arc granitoids; COLG – collisional granitoids; syn-COLG –syn-collisional granitoids; ORG – ocean ridge granitoids; WPG – within-plate granitoids. The Torud granites plot in the volcanic arc granite (VAG) field.

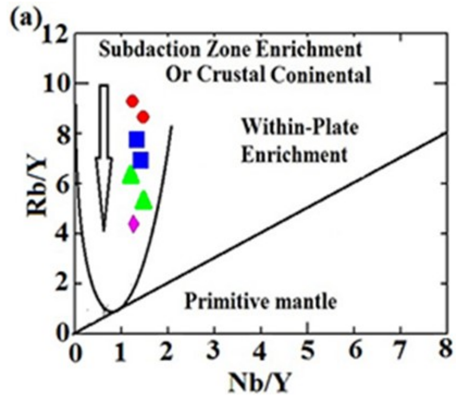

Fig. 7a. Nb/Y diagram vs Rb/Y and samples plot in the crustal continental associated with subduction field, [43].

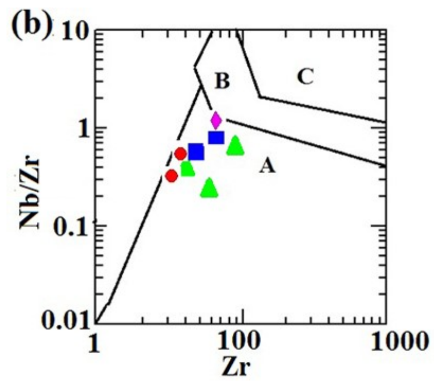

Fig. 7b. Zr, vs Nb/Zr diagram, [42]. The data are normalized using [51] method. A: subduction-related magmatic rocks; B: collision-related magmatism; C: Alkaline rocks related to intraplate magmatism

[52] stated that peraluminous granitoids have mainly been created by partial melting of crust rocks. The granitoids rocks of Troud contain a high content of potassium and are cal-alkaline. They are I- type granite. These rocks are enrichment in the Rb, La, Ce, K, Nd, Th and negative anomaly of Ba, Sr, Nb, Ta, P and Ti., The ratio of Rb/Sr and Sr/Y is high (in the majority of samples, more than 20) and Sm/Nd are low. In order to identify the origin of constituent magma of the rocks, the proportions of various PM[1], N-MORB, and continental composition on average (Cont.C.average) have been compared with each other (table3). In table 3, it can be seen that the ratios of Th/La, Ba/Th, La/Nb, Zr/Nb, and Ba/La in the area of the study are close to the average of continental composition . This shows the originating role of some compositions, which are close to continental compositions on average, in the formation constituent magma of these rocks. The analytical and field studies have revealed the generation of various magmas which are resulted from the melting crust compositions. Metapelites, amphibolites and gneisses are common

[1] composition of primitive mantle

rocks in this area. As figure 8A-C shows, the melted of mafic crust (compared to the melted metagrewackes and felsic plites) has a lower proportions of $Al_2O_3/FeO_t+MgO+TiO_2$and $Na_2O+K_2O/FeO_t+MgO+TiO$. In contrast, the proportion of $CaO/FeO_t+MgO+TiO_2$ is higher. Based on these proportions the Troud granitoid (figure8A-C) with the high level of Mg≠ (45-70) (Mg≠ molar $[Mg/(Mg+Fe^{+2})\times 100]$), suggested that it has originated from a lower crust.

The higher abundances of CaO, negative anomaly of Eu, Sr, and depleted of REE elements indicate the existence of plagioclase in the source.

The presence of amphibole in the source rocks is implied by the lower TiO_2, Rb/Sr and K/Rb contents in the resulting igneous rocks[51]. The magmas originated from an amphibole-bearing source show significant amounts of Ba and high Ba/Rb ratio [53]. Therefore, dehydration melting of mafic rocks in lower crustal conditions (pressures 1-2.2 GP and temperatures of 850-1100 ^{0}C) produces huge amounts of magma with compositions ranging from quartz-diorite to tonalite with unmelted rocks enriched in plagioclase, amphibole and garnet providing the heat conductance would be high enough in the source area [54-60].

The heat required for partial melting of the crustal rocks may have been supplied from two possible sources. (1) The first is upwelling of mantle plume and adjectives heating of the crust by deep-seated magma chambers. This can occur in an extensional system with lithospheric thinning (breaking-off of a downward oceanic slab) or may be related to delaminating events in the area [e.g. 61]. Such a model requires crystallization of an unreasonably large volume of mafic magma generated after cessation of subduction and crustal thickening, which is in disagreement with the scarcity of exposed mafic suites in the study area and so is ruled out on the basis of field and lithological evidence in the Tourd area.(2) The heat required for partial melting of the crust has been provided by the continental collision causing crustal thickening[62].

5. Tectonomagmatic Setting

The subduction of the Neotethys oceanic crust beneath the central Iran microplate and the collision between Arabian and Iran plates are the most important events during Cenozoic. These events are manifested by the occurrence of three volcano-plutonic belts (Central Iranian volcanic belt, Lut volcanic belt and Alborz volcanic belt) and emplacement of multiple intrusive bodies. The stratigraphy and location of the studied granitoids in Iran indicates that such rocks are probably formed during orogenic events related to subduction of Neotethys oceanic crust beneath the Central Iran continental crust. The heat from underplating basaltic magmas generated above the subducting plate caused partial melting of lower crustal rocks and generation of parent magmas for Torud granitoids. The paleomagnetic[1] and geological [63] studies all indicate a rupture in Iran plate had occurred during the Triassic-Jurassic period. Towards the end of middle Triassic time, the East Iran microplate separated from the Central Iranian plate resulting in a rupture between the East Iran microplate and the Central Iran plate. The East Iranian microplate rotated 65°in a counterclockwise manner during Triassic times. The counterclockwise rotation has been repeated by as much as 35° during Jurassic and cretaceous period.

Table 3. Comparing the ratios of Ba / Ca Th / La, Zr / Nb, La / Nb, Ba / Th in granitoides rocks with primitive mantle (PM), normal Morb (N-MORB) and the average composition of the continental crust (Cont.C. average) [64].

sample	Zr/Nb	Ba/La	La/Nb	Ba/Th	Th/La
E70	2.02	3.266	1.352	9.105	0.359
E77	0.56	24.409	1.201	47.067	0.519
E73	0.48	72.847	0.656	101.404	0.718
E72	1.71	22.082	1.145	37.163	0.594
E82	3.85	25.161	1.316	49.526	0.508
E91	2.55	23.080	1.429	45.066	0.512
E99	0.50	23.406	1.181	46.051	0.508
E118	0.98	22.290	1.257	39.733	0.561
E83	1.59	30.815	0.823	42.600	0.723
E62	4.31	44.058	0.198	25.947	1.698
HIMU-mini	2.7	6.2	0.66	39	0.1
HIMU-max	5.5	9.3	0.77	58	0.2
EM1-mini	3.5	11.3	0.86	80	0.1
EM1-max	13.1	19.1	1.19	204	0.2
EM2-mini	4.4	7.3	0.89	57	0.1
EM2-max	7.8	13.5	1.09	105	0.2
P.M	14.8	4.3	0.94	77	0.1
N-MORB	30	9	1.07	60	4
Cont.cav	16.2	54	2.2	124	0.2

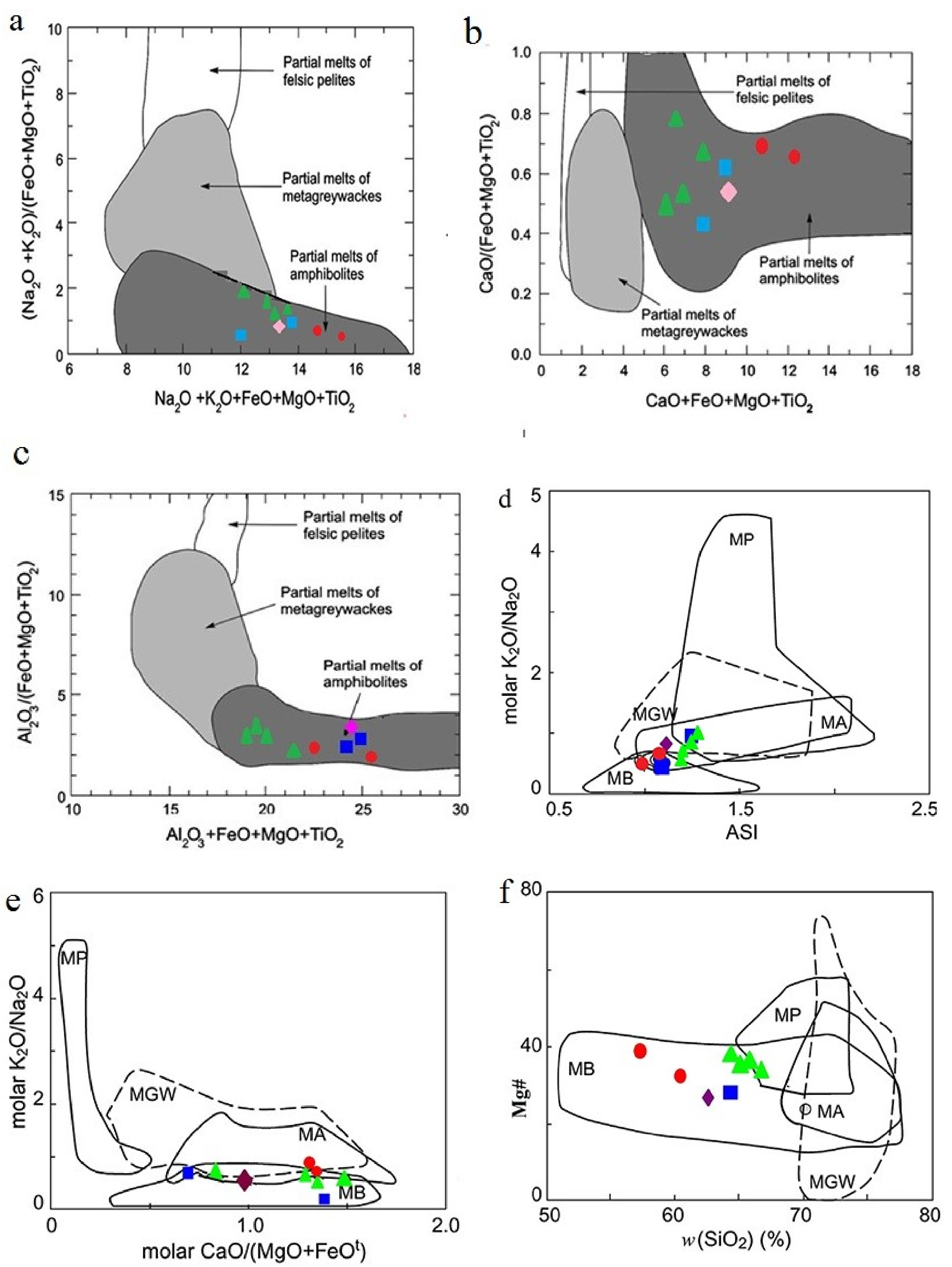

Fig. 8. The fields on the diagram are chemical composition of melts from experimental studies of dehydration melting.MA=Meta andesite, MB=Meta basalt, MP= Meta pelites, MGW= metagreywacke : [65-75]

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