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Study of Events and Phases in Robat-e Zengejeh Area (Southwestern Bardaskan)

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Abstract

Robat-e Zengejeh rocks affected by a variety of events began from Precambrian. This research studied preserved effects of the events. Regional metamorphism is the oldest event in this rocks include schist, amphibolite and orthogneiss, that reached up to amphibolite facies. After this regional metamorphism, it seems that mesocratic (624±5Ma) and hololeucocratic granitoides intruded respectively. Mesocratic and hololeucocratic granitoides deformed to granite-gneiss and gneiss along the northern main fault. Moreover, amphibolites show strong lineation along the faults, which as well as petrographic evidences point to the effects of dynamometamorphism in the area. Meatmorphism followed by low-grade regional metamorphism (low-greenschist facies) affected by granitoids of Robat-e Zengejeh. low-grade regional metamorphism, acted as a retrograde metamorphism for the paragenesis of the previous regional metamorphism. Finally, a sodic metasomatism affected Robat-e Zengejeh rocks which its mineralogical and geochemical evidences are significant.

Keywords: Robat-e Zengejeh granitoides; Regional metamorphism; Dynamometamorphism; Sodic metasomatism.

Introduction

The geology of Iran is immensely complicated because of the collision between the micro-continents and the overprinting of many metamorphic and tectonic events, the result of from different geological evidence will provide good knowledge on rocks history [1-7]. Therefore, in this study is foused on the magmatic, metamorphic and metasomatic events and phases in Robat-e Zengejeh area.

Robat-e Zengejeh granitoids mostly composed of granodiorite, monzogranite, syenogranite and granite, located in 85 km southwestern Bardaskan city and Zebarkouh Mountains (57º 24′- 57º 36′ E and 35 º 46′ 3″- 35 º 50′ 6″ N; Fig. 1)[8]. These rocks are exposed in a NE-SW trend along the Naiband fault. The activity of Naiband fault deformed granitoids to mylonites and granite-gneiss. Robat-e Zengejeh granitoids intruded within metamorphic rocks that mainly are phyllite, mica schist, amphibolite, and gneiss. In some parts of the granitic intrusions (particularly in the rim), mineralogy and texture is different from the primary igneous rocks which is pointing to metasomatic effect in the area. Beside these, high-grade (amphibolites facies) and low-grade (low-greenschist facies) regional metamorphic phases are affected Robat- Zengejeh rocks as well as

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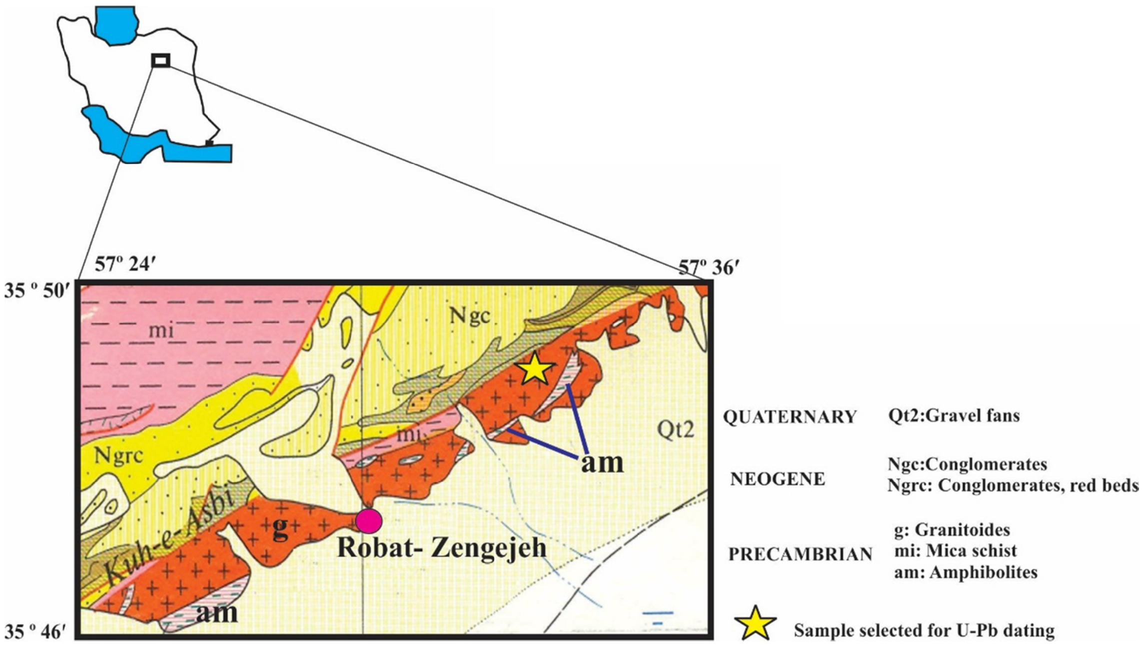

Figure 1. Location of Robat- Zengejeh granitoids shown in simplified 1:250000 Geological Map of Ferdous [8].

dynamometamorphism [9]. Since the aforementioned phases are distinguishable, focus on characteristic of each phase will help to understanding the geological history of the studied area.

Materials and Methods

In this research, 80 microscopic thin sections from granitic samples prepared. Study of microscopic thin sections was very important for detection of metasomatism evidences. For determination of granitoids chemical composition, 23 non-altered samples analyzed using XRF and ICP-AES at Kharazmi University, Tehran, Iran [Table 1]. One granitic sample (5kg) collected from northestern part of Robat-e Zengejeh granitoids) for zircon U-Pb dating. About 20 zircon grains were separated using standard heavy liquid (Bromoform) and magnetic procedures from aformentiond granitic rock. Zircons were mounted along with a zircon standard and a couple of chips of NBS 610 Trace Element Glass in epoxy and polished down to 20 µm. Zircon U-Pb dating was done in China [Sahandi, unpublished data].

Results and Discussion

So far, few studies have been done on the rocks of Robat-e Zengejeh area [e.g. 8,9]. However, these rocks affected by many different geological events from Precambrian. According to obtained results, this research studied the sequence of the events.

The Precambrian regional metamorphism of basement in Robat-e Zengejeh

Regional metamorphism in the studied area led to formation of schist, amphibolite and orthogneiss. Based on petrological evidences, the metamorphism grade reached up to amphibolite facies. The granitoids of Robat-e Zengejeh do not show evidence of such a high-grade metamorphism and non-metamorphic sediments of Infra-Cambrian overlay the metamorphic rocks [10], it can be concluded that the relative age of the metamorphic event is older than granitic magmatism and belong to Precambrian.

The granitic magmatism

In studied area, two types of mesocratic and hololeucocratic granitoides are distingushable. Hololeucocratic granitoides are younger because intruded in mesocratic types. Based on modal and chemical classifications, the mesocratic granitoides mostly plot in granodiorite and monzogranite fields, but hololeucocratic granitoides lie in syenogranite and granite regions [9]. The main textures in the granitoids are granular, microgranular porphyritic, graphic (Fig. 2a), perthitic and mylonitic (Fig. 2b). The main minerals consist of quartz, albite, microcline, perthite, orthoclase and biotite (commonly in mesocratic granitoides). Sphene (especially in metasomatic rocks), apatite,

Table 1. XRF (for Oxides) and ICP-AES (for elements) analysis results from the Robat- Zengejeh granitoieds. Presented symbols are same for all pictures.

Symbol/ Rock	▷ Hololeucocratic granites	▶ Hololeucocratic granitegneiss				● Aplite		◆ Mesocratic granitegneiss		✚ Pegmatite	◇ Mesocratic granites	
Samples	N10	F16	N39	N19	N16	F35	N54	N55	N20	F15	F49	N57
SiO_2	73.37	74.08	73.18	72.46	74.40	76.31	73.64	71.75	72.27	76.45	74.62	74.12
Al_2O_3	14.18	14.15	14.03	13.33	13.89	13.55	13.07	14.30	13.37	13.48	13.45	13.43
Fe_2O_3	2.10	3.37	3.41	3.13	3.15	0.72	2.75	3.32	3.37	0.57	1.47	1.42
MgO	0.09	0.02	0.03	0.05	0.13	0.10	0.03	0.31	0.01	0.09	0.06	0.06
CaO	0.48	0.46	1.13	0.71	0.76	1.22	1.14	0.89	1.90	0.18	0.81	0.89
Na_2O	3.70	3.32	2.11	2.84	2.18	3.46	3.98	2.60	3.42	5.44	2.91	2.60
K_2O	1.95	1.24	4.21	3.89	2.50	3.68	1.21	2.97	1.56	0.33	4.39	4.55
TiO_2	0.11	0.34	0.35	0.42	0.32	0.08	0.44	0.41	0.27	0.05	0.09	0.10
MnO	0.02	0.01	0.05	0.06	0.03	0.03	0.01	0.02	0.06	0.00	0.01	0.01
P_2O_5	0.01	0.04	0.06	0.06	0.04	0.01	0.08	0.05	0.04	0.00	0.01	0.03
Total	98.01	99.03	100.56	98.95	99.40	101.16	98.35	98.62	98.27	98.59	99.82	99.21
Rb	16.12	8.65	73.34	77.33	36.49	77.54	19.43	4.32	2.54	54.55	35.66	112.39
Sr	91.09	84.67	178.56	62.39	151.44	50.04	134.55	197.11	163.00	71.78	87.45	70.27
Ni	16.56	22.34	14.93	25.05	18.29	25.45	23.87	27.00	24.00	18.40	31.03	18.29
Y	62.87	16.83	15.50	24.20	17.40	27.04	23.45	15.56	17.37	6.39	24.04	28.97
Cr	67.09	132.50	80.45	87.50	99.41	99.04	90.09	76.02	69.91	137.51	116.49	81.72
Zr	235.34	228.34	189.60	215.45	228.38	151.12	246.81	229.44	281.76	157.93	148.29	184.02
Nb	28.45	25.12	27.56	26.56	26.29	28.25	26.15	27.48	27.22	21.39	27.33	28.06
Ba	378.44	672.78	705.02	580.03	1016.11	280.17	253.39	911.19	794.19	11.12	755.10	740.00
La	77.12	48.34	39.03	45.66	50.12	30.37	80.53	61.04	77.03	21.48	23.49	46.23
Ce	122.29	163.12	170.55	143.31	243.40	81.06	92.44	226.88	212.06	13.08	187.31	191.19
Nd	41.32	38.11	19.45	26.56	40.33	23.69	59.30	38.63	60.12	12.81	35.19	46.92
Sm	7.40	1.03	4.34	1.44	5.33	2.05	8.38	3.03	10.02	4.09	5.14	6.03
Yb	13.03	14.34	8.02	15.59	11.81	14.39	13.49	19.40	14.39	11.39	20.39	10.11
Hf	4.98	5.04	4.91	4.23	5.89	5.49	4.22	4.13	4.02	5.82	5.35	6.68
Ta	3.45	19.76	11.34	19.18	14.19	19.28	9.48	25.53	6.11	20.09	26.55	21.32
Eu	0.11	0.34	1.11	1.18	0.89	1.12	0.02	0.12	1.00	1.59	0.12	0.48
V	10.22	27.54	26.60	30.28	26.28	6.41	31.34	37.03	20.44	2.69	8.67	9.12
Pb	32.32	32.36	33.22	33.03	33.40	36.39	32.89	32.45	33.42	32.00	33.39	33.88
Cu	3.49	19.01	9.09	9.99	15.22	11.02	9.41	11.00	7.58	13.45	14.29	26.49
Co	4.21	5.12	5.34	5.23	5.21	3.21	4.11	5.00	5.39	3.94	3.01	3.49
Zn	4.30	27.76	46.76	24.39	49.07	5.29	11.34	29.56	68.50	3.73	14.24	4.11
Cs	4.09	7.54	4.03	2.00	3.49	10.39	13.28	5.23	3.22	10.12	3.44	3.30
Ga	12.43	15.34	13.65	11.03	14.12	16.29	14.43	12.12	14.19	18.93	16.19	14.00
Sn	100.45	95.39	82.51	90.11	78.21	103.08	96.03	80.59	86.95	134.56	99.71	90.12
Th	5.50	13.92	20.54	15.56	10.02	8.30	3.22	15.43	21.77	23.45	8.00	7.34
Sc	3.32	2.23	3.00	3.44	4.45	4.03	3.17	3.03	5.37	2.39	3.12	3.91

zircon and muscovite are the accessory minerals in Robat-e Zengejeh granitoids. In this area, alteration process cause to form some secondary minerals such as sericite, epidote, calcite and clay minerals. Robat-e Zengejeh granitoids are peraluminous (based on [11] diagram; Fig. 3a) and belong to calc-alkaline series (e.g. based on [12] diagram; Fig. 3b). According to microscopic and geochemical characteristic introduced by Chappell and White [13] (Fig. 3c) and ACF diagram (Fig. 3d) the source of studied granitoids is I-type. They plot in volcanic arc granites (VAG) area [14] (Figs. 3e and f) and belong to post collision magmatism zone [e.g. 15 and 16] (Figs. 4a and b). the Robat- Zengejeh granitoids intruded in older regional metamorphic rocks, their composition tend to granodiorite in their contact, the existence regional metamorphic xenoliths in granitoids and aplite apophysis in metamorphic rocks, it can be concluded that granitic magmatism occurred after regional amphibolite facies metamorphism.

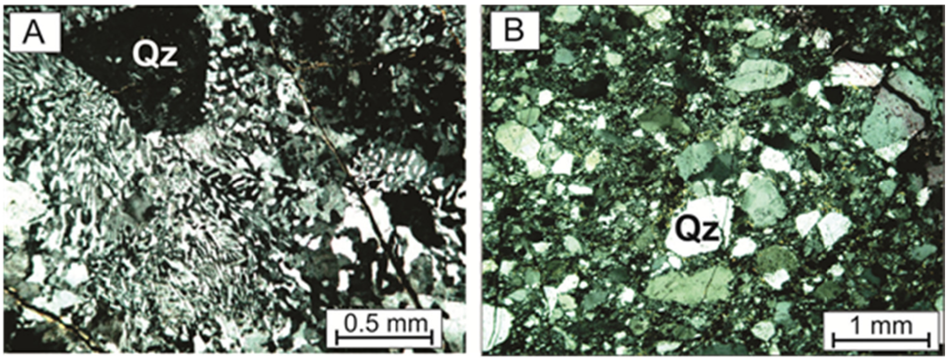

Figure 2. A) Graphic texture in Robat- Zangijeh granitoids (XPL; sample N37); B) mylonitic texture in granitoides next to fault zone (XPL; sample F16).

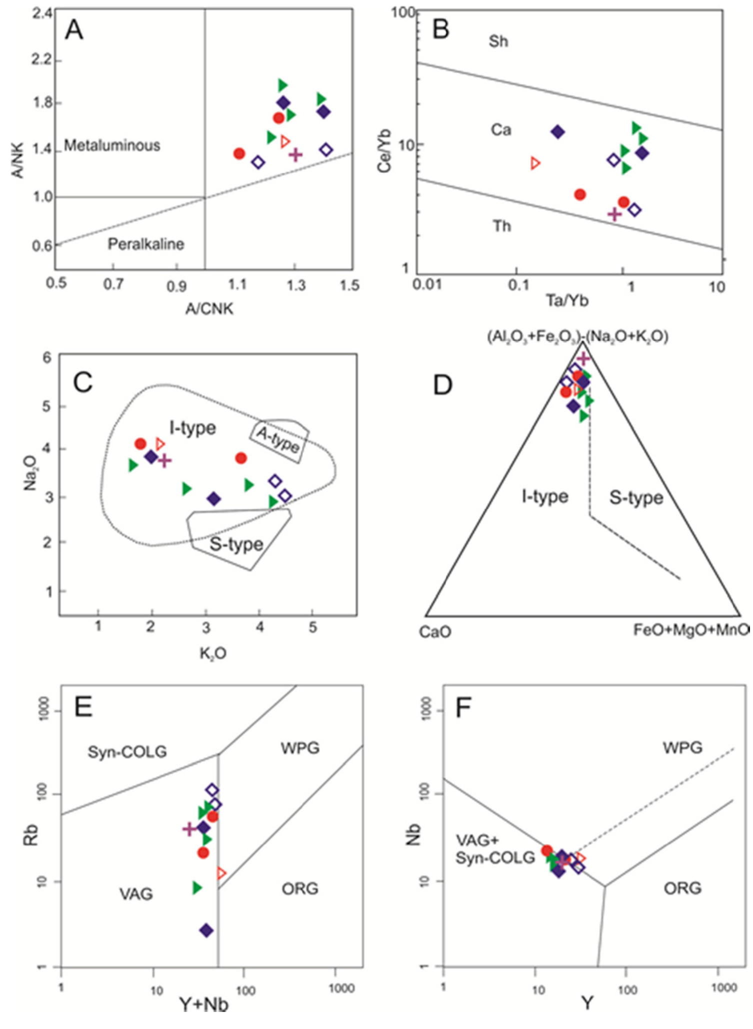

Figure 3. A**)** ploting samples in peraluminous area in Shand [11] diagram; B) ploting samples in Calc-alkaline area in Yb /Ce vs. Yb /Ta diagram [12]; C) ploting samples in I-type area in Na_2O vs. K_2O diagram [13]; D) ploting samples in I-type area in ACF diagram; E and F) The most samples are plot in volcanic arc related granites Rb vs. Y+Nb and Nb vs. Y diagrams [14]. Sign of Symbol are presented in Table 1.

U-Pb Zircon dating

Zircon not only is frequent as an independent mineral in mesocratic granites of Robat-e Zengejeh area, but also as inclusions in biotites (Fig. 5a). The existence of

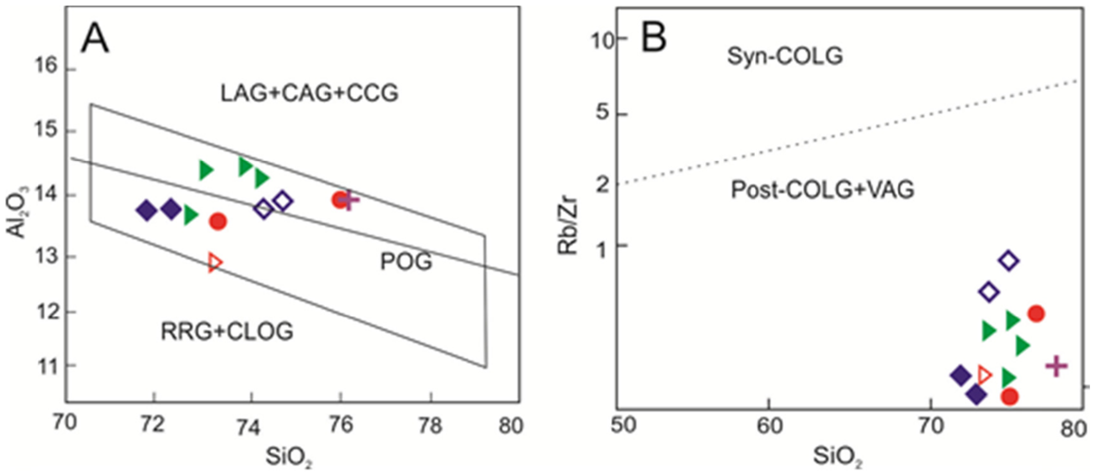

Figure 4. A**)** samples ploted in Post-Orogenic granites in Al_2O_3 vs. SiO_2 diagram [15]; B) All samples lie within post-collision (post-COLG) and volcanic arc related granites area in Rb/Zr vs. SiO_2 diagram [16].

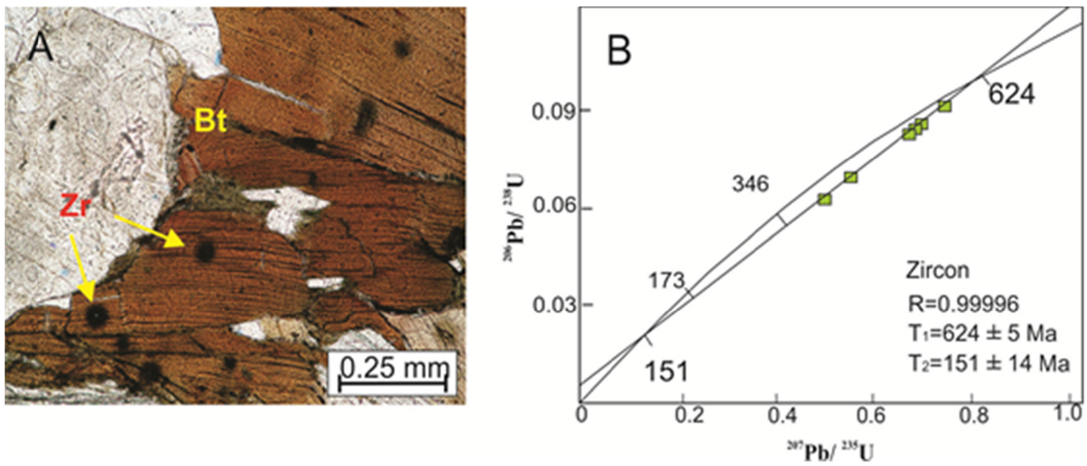

Figure 5. A**)** Zircon inclusions (with distinctive dark halos formed by radioactive decay) in biotites of mesocratic granites, (PPL, sample F49); B) Concordia and discordia diagram showing zircon U-Pb data from mesocratic granites of Robat- Zengejeh area [Sahandi, unpublished data].

two 'parallel' uranium-lead decay routes (^{238}U to ^{206}Pb and ^{235}U to ^{207}Pb) of zircons leads to dating mesocratic granites within the U–Pb system [Sahandi, unpublished data] (Fig. 5b). In this approach, the upper intercept of the concordia and the discordia line reflect the original age of zircon crystallization, while the lower intercept reflect the age of the event that led to open system behavior and therefore the lead loss (although there has been some disagreement regarding the meaning of the lower intercept ages; [17]). The analysis of zircon from Robat-e Zengejeh mesocratic granites show concordant U–Pb age of 624±5 Ma (Neoproterozoic) which refer to age of the granite crystallization. Moreover, the lower intercept reflect the age of 151±14 Ma which is contemporaneous with late Cimmerian Orogeny. This event could be considered as a main factor causing the low grade (greenschist facies) metamorphism of Robat-e Zengejeh rocks as well as their dynamometamorphism.

Results obtained from recent studies [e.g.18-21] show that Late Neoproterozoic to Early Cambrian granitoids and granitic gneisses are present in all continental structural zones of Iran. Although the U-Pb age of the granodiorites of northeastern Bardaskan (553 ±11 Ma) [22] or dacite-porphyries from the Cambrian Volcano-Sedimentary Unit (CVSU) in the southern Saghand region (528±1 Ma) [19] demonstrate the younger ages, all rocks are belong to the Neoproterozoic-Early Cambrian and confirm above interpretation.

Dynamometamorphism (mylonitized granitoids and granite-gneiss)

Robat-e Zengejeh granitoids deformed to mylonitized granites and granite-gneiss along the northern major and minor faults. Moreover amphibolites show strong lineation along the faults. In microscopic thin sections, presence of single myrmekite, perthitic texture (Fig. 6a), mylonitic texture, irregular twinning, wedge-shaped twinning and interfingering growth in plagioclase (Fig. 6b), bending in biotite cleavages and plagioclase twinning (especially in mylonitized augen granite-gneisses; Fig. 6c) as well as lineation in amphiboles along the brecciated zones (Fig. 6d) are the results of dynamometamorphism in Robat-e Zengejeh rocks.

The dynamometamorphism occurred in some Robat-e Zengejeh granitoids is as high as medium-grade (mylonitization). The following evidence confirm that the event:

A- It is clear that quartz experiences ductile deformation at lower temperatures than feldspar [23]. The observed ductile deformation in quartz and brittle deformation in feldspars of studied mylonitic granitoids demonstrate mylonitization occurred at tempretures as high as 300-400 ºC which is related to medium-grade dynamometamorphism [24](Fig. 6a).

B- Mylonitic granitoids of Robat- Zengejeh show linear mylonitic fabrics which is characteristic of medium-grade dynamometamorphism. This fabric has not seen in cataclastic or other low temperature dynamo-metamorphic rocks.

C- Lack of pseudotachylite (which form within the depth with the range of 5–10 km and belong to high-grade dynamometamorphism) in deformed Robat-e Zengejeh granitoids indicating mylonitization occurred at medium-grade dynamometamorphism.

Late Cimmerian low-grade regional metamorphism

Robat-e Zengejeh rocks metamorphosed up to greenschist facies (e.g. the formation of phyllite and gneissic foliation in some granitoids). The low-grade (greenschist facies) metamorphism act as retrograde metamorphism on the previous regional high-grade (amphibolite facies) metamorphic rocks. In the studied area, the Infra-Cambrian dolomites and the limestones of Bahram Formation (Devonian) show recrystallization evidence. Sahandi et al. [10] believe that Carboniferous rocks of Zebar-Kouh (e.g. phyllites) show a low-grade regional metamorphism, therefore it could be concluded that the low-grade regional metamorphism occurred after Carboniferous. On the other hand, Davoudzadeh and Schmidt [25] confirmed that the Jurassic sandstones

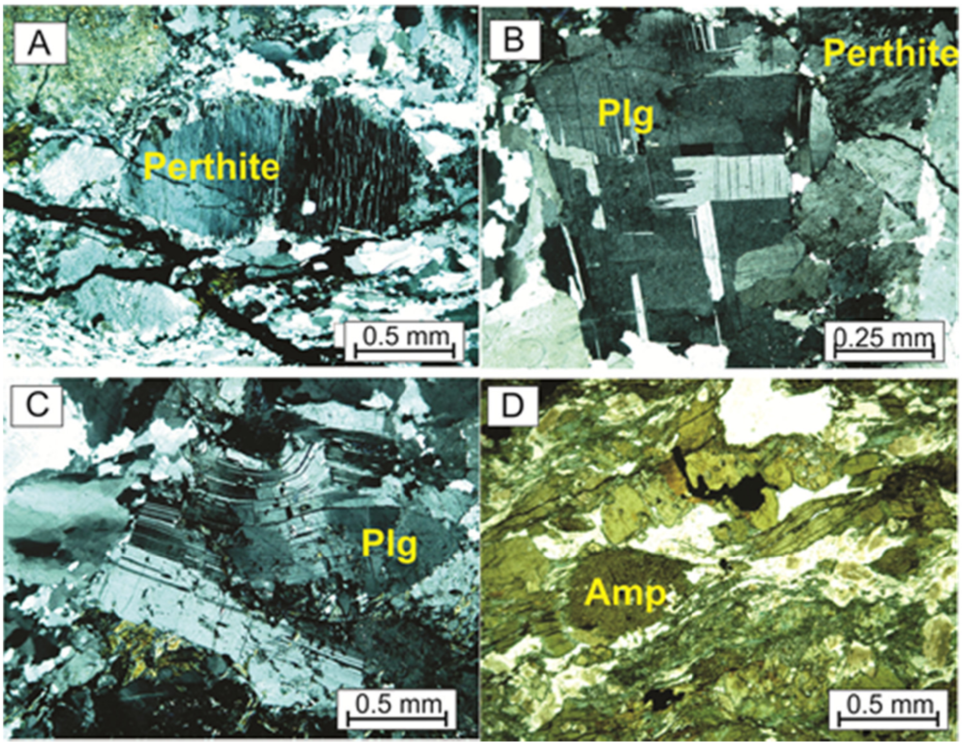

Figure 6. A) Perthite texture in augen gneiss (XPL; sample N27); B) Wedge-shaped twinning and interfingering growth in plagioclases of brecciated granites (XPL; sample N19); C) Bending of plagioclase twinning due to stress (XPL; sample N55); D) lineation in amphiboles along the brecciated zones (XPL; sample F63).

and shales from northeastern Robat-e Zengejeh granitoids show low-grade regional metamorphism which could be indicating such a metamorphism has occurred a thermal event in middle Jurassic (late Cimmerian). Based on results and our new interpretation of the lower intercept age obtained by Sahandi (151± 14 Ma; this paper) the late Cimmerian Orogeny could be responsible for the low-grade (greenschist facies) metamorphism as well as dynamometamorphism in Robat-e Zengejeh rocks.

Metasomatism effects on Robat-e Zengejeh rocks

Evidencefor the presence of metasomatism are:

A- The existence of mylonitic texture:

Mylonitic texture which is common in Robat-Zengejeh rocks, provide a condition for metasomatism process and the most evidence of this metasomatism are distinguishable in mylonitic granites (Fig. 7a).

B- The formation of single or wart-like myrmekite:

Single or wart-like myrmekite form due to metasomatism in an active tectonic condition [26]. All myrmekites in studied granitic rocks are single or wart-like. On the other hand, myrmekites are anhedral which is characteristic for those form due to metasomatism in an active tectonic condition. However, in myrmekite bearing samples, evidence such as preservation of

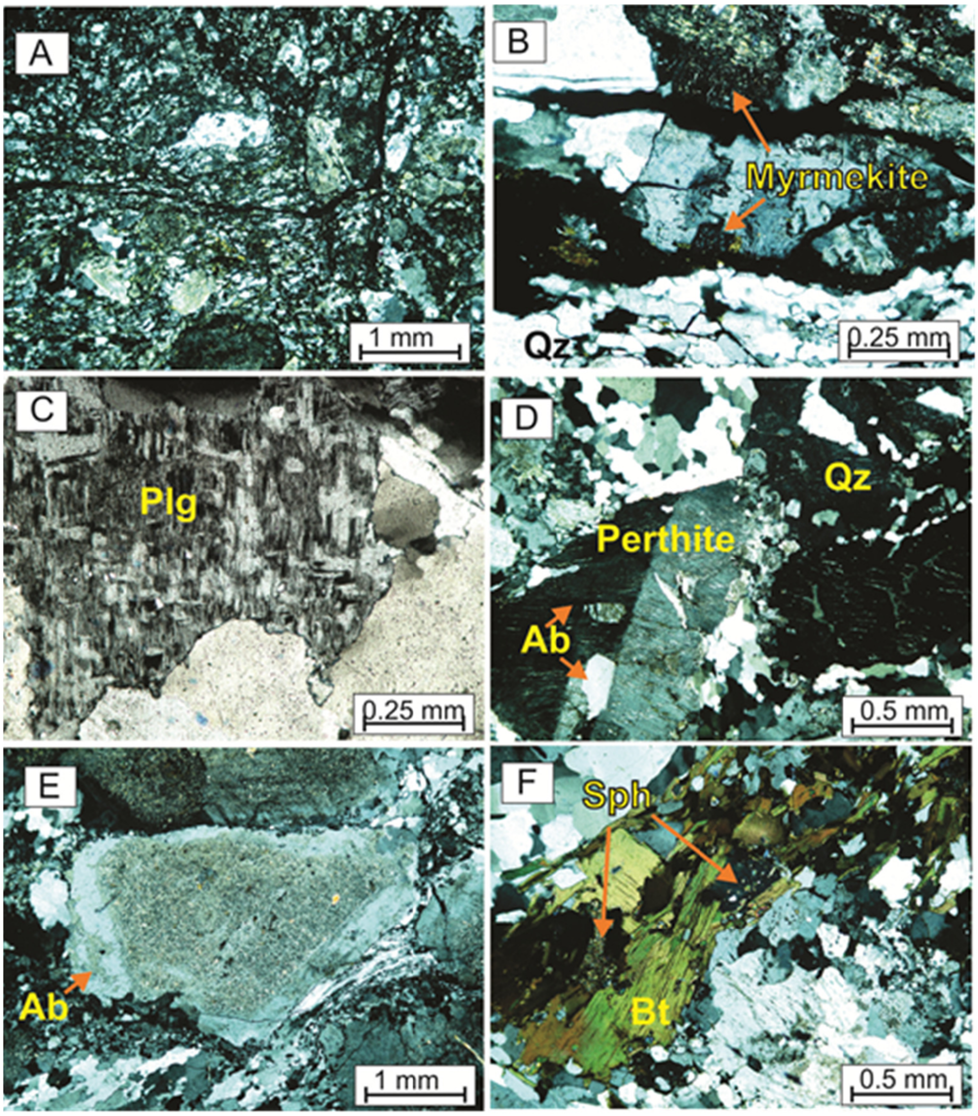

Figure 7. A) Mylonitic texture in granites within the fault zone. (XPL; sample N39); B) Single or wart-like myrmekite in metasomatic granite (XPL; sample N39); C) Chess-board texture in plagioclase indicating interaction of shearing stress and sodic metasomatism (XPL; sample F49); D) Albitization in alkali feldspars from studied mylonitic and metasomatic granites (XPL; sample N39); E) Neoform albite rim around K-feldspars in mylonitic granites indicating Na-metasomatism in Robat- Zengejeh area (XPL; sample F16); F) The frequency of sphene in a mylonitic granite (XPL; sample F49).

original texture (e.g. pertite and granophyric) not only decline their exsolution origin but also demonstrate the role of fluids in metasomatism as well as myrmekite formation (Fig. 7b).

C- The formation of chess-board texture in plagioclase and alkali feldspar albitization:

Chess-board texture in plagioclase form during repeated crystallization result from the interaction of shearing stress and sodic metasomatism [27] (Fig. 7c). On the other side, the albitization of plagioclase and alkali feldspars, which is one of the most frequently observed metasomatic evidences, is common in studied mylonitic and metasomatic granites (Fig. 7d).

D- The occurrence of neoform albite rim around K-feldspars:

Neoform albite rim occurs at the borders of K-feldspars during Na-metasomatism [19]. Such a rim is frequently seen around K-feldspars in Robat-e Zengejeh mylonitic granites (Fig. 7e).

E- Sphene's abundance:

Sphene suggests important implications for large-scale K- and Na-metasomatism and mobility of Ti [28-33]. The frequency of sphene in mylonitic granites containing myrmekite and its absence in intact granitic rocks of Robat-e Zengejeh can be evidence for the metasomatism process (Fig. 7f).

F- The crystallization of large albite minerals in fine-grained groundmass of mylonitic granites:

Usually, large albite minerals are rare in non-metasomatic granites of the studied area so their crystallization can be due to the existence of Na-bearing fluids cause metasomatism (Fig. 8a).

G- Petrographical evidences:

Based on microscopic studies and modal calculation of minerals, it is clear albite crystals in mylonitic and those granites which show evidences of metasomatism are significantly more than K-feldspars. Geochemical data confirm petrological evidence.

H- Geochemical evidences:

Some geochemical evidences such as increase in Na_2O content in mylonitic granites, decreasing trend in K_2O-Na_2O (Fig. 8b) and Rb-SiO_2 (Fig. 8c) diagrams as well as non-linear trend in Na_2O-SiO_2 (Fig. 8d) diagram [34] can be resulted from Na-metasomatism of Robat-e

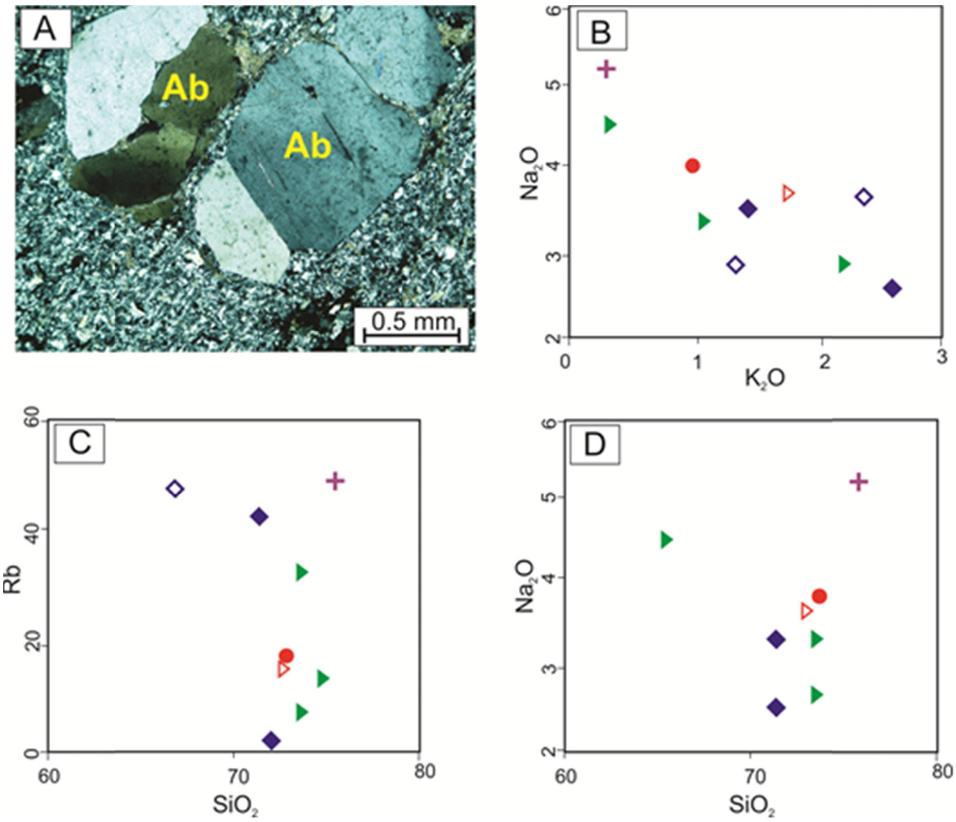

Figure 8. A) The crystallization of two large albite minerals in fine-grained groundmass of mylonitic granite (XPL; sample F16); B) Downward slope in K_2O-Na_2O diagram show an increase in Na versus K; C) Downward slope in Rb-SiO_2 diagram demonstrating the role of metasomatism; D) Non-linear trend in Na_2O-SiO_2 diagram confirm Na-metasomatism in Robat-Zengejeh area.

Zengejeh granites.

Conclusion

Based on the new interpretation of U-Pb age data (this paper), the field observations as well as petrological and geochemical evidences, it's possible to determine geological events occurred in Robat-e Zengejeh area. It seems that the amphibolite facies metamorphism occurred before 624±5 Ma. In 624±5 Ma ago, mesocratic granites intruded in older regional metamorphic rocks and shortly afterwards hololeucocratic granites intruded in mesocratic units. Both mesocratic and hololeucocratic granites show similar petrological and geochemical characteristics, it can be concluded that they are similar and derived from a same magmatic source. After Robat-e Zengejeh magmatism, a dynamometamorphism overprinted the rocks. Deformation of granites to mylonite and granite-gneiss with mineralogical evidences as well as the occurrence of strong lineation in amphibolites along the northern faults are consequences of this event. Based on petrographic studies, Robat-e Zengejeh dynamometamorphism estimated as high as medium-grade (mylonitization). Then Robat-e Zengejeh rocks metamorphed in greenschist facies (e.g. phyllite). According to field study, the second age obtained by U-Pb geochronology (151±14 Ma) and previous results, it can be concluded that the late Cimmerian orogeny could be responsible for the low-grade (greenschist facies) metamorphism as well as dynamometamorphism in Robat-e Zengejeh rocks. Finally, sodic metasomatism overprinted some parts of Robat-e Zengejeh granites.

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