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Application of feldespar and hornblende composition to investigate the nature and thermobarometry aftabrou pluton, northwest uroumieh-dokhtar magmatic belt, Iran

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Abstract

The Aftabrou pluton, situated in the Northwest of Saveh, is a small part of the Uroumieh-Dokhtar magmatic arc of Iran in the Alpine-Himalayan orogenic belt. The arc outcrops are mainly consisted of Tertiary volcanic sequences and associated plutonic rocks typical of calc-alkaline magmatism developed at active continental margins. The arc was developed during the closure of the Neotethyan ocean between Arabia and Eurasia. This pluton is consisted of plutonic (granodiorite) and sub- plutonic (diorite) rocks, intruded into the Eocene volcanic rocks. The main minerals are plagioclase, amphibole, alkali feldspar and magnetite. In this study, composition of minerals is used to describe the nature of the granitic magma and to estimate the pressure and temperature at which Aftabrou pluton is emplaced. The chemistry of amphibole in plutonic rocks and that of clinopyroxe inclusion in plagioclase of sub- plutonic rocks show that this pluton is derived from a calc-alkalin magma. This type of magma is typically produced in the subduction environments. It means that the pluton could have formed in an orogenic suit in the subduction zone. The results obtained from amphibole and clinopyroxen chemistry are well consistent with the previous suggestions on the Uroumieh-Dokhtar belt. The average of emplacement temperatures calculated by the hornblende-plagioclase thermometer for granodiorites and dioritesare 625.5°C and 597.9°C, respectively. Aluminum-in-hornblende geobarometry indicate that the emplacement pressures for sub- plutonic and plutonic rocks of Aftabrou pluton are 1.18–0.14 Kbar and 0.08- .05 Kbar, respectively.

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Introduction

The composition of minerals provides an useful tool for evaluating P-T conditions and the nature of magma during the emplacement of granites (Stein and Diet, 2001). Amphibole is a significant ferromagnesian mineral in most acidic to basic igneous rocks (Femenias, 2006 ؛Blundy & Holland, 1990). Amphibole is stable in a wide range of pressure- temperature from 1-23 kilobar and 400-1150ºC (Femenias, 2006; Blundy & Holland, 1990). It can reflect both the nature and the physicochemical conditions of magmas from which it formed (Heltz, 1982؛ Stein & Diet, 2001؛ Leak *et al.*, 1997). Also, amphiboles are ideally used for evaluation of P-T conditions for calc-alkaline intrusions emplaced within organic belts. Hornblende-plagioclase thermometry and aluminum-in-hornblende geobarometry are ideally suited for calculation of presures and temperatures at which granites are emplaced (Blundy & Holland, 1990; Stein & Dietl, 2001).

Plutonic intrusionsspread in to volcanic rocks of Uromieh-Dokhtar belt. Determination of their emplacement P-T conditions can help to get on better perception on how magmatismevolved in this oregenic belt. So far temperature and pressure of some intrusion are determined in this belt. The dioritic rocks of Kiab pluton are evaluated 739˚C and 1Kb, respectively (Zareiei *et al.*, 2013). The temperature and pressure of the crystallization of Mehrzamin pluton are 800˚C and 1. 4 Kb, respectively (Chavideh *et al.*, 2013). Khalili and Kourang (2001) also are shown that Zafarghand pluton is formed in 700- 800˚C and 2- 5 Kb. In this research, P-T condition of Kiab, Mehrzamin and Zafargh and plutons are studied by using composition of minerals method.

Aftabrou pluton is developed within the volcanic rocks in Uroumieh-Dokhtar magmatic belt of Iran (Alavi, 1990; Berberian & King, 1981; Berberian, 1977; Mohajjel & Fergusson, 2000). Estimates of emplacement depths for this pluton provide direct evidence for the ascent or descent of exposed crustal sections through time, thus providing fundamental information about tectonic processes in the area. Aftabrou pluton is composed of plagioclase, quartz, K-feldspar, hornblende, and magnetite). Amphibole and plagioclase occur as a major minerals. This mineral assemblage is highly suitable for hornblende-plagioclase thermometry and aluminum-in-hornblende barometry (Anderson& Smith, 1995; Hammarstrom & Zen, 1986; Hollister *et al.*, 1987; Johnson & Rutherford, 1989; Schmidt, 1992, Stein & Dietl, 2001).

In this study, we present electron microprobe data, first, to estimate the pressure and temperature at which Aftabrou pluton is emplaced, secondly, recognition of environmental tectonic for former magma of this pluton.

Material and methods

Sampling and analysis techniques

After collecting and verifying the information, reports and maps of the area, check field study, petrographic studies and survey in the various stages, select 2 samplesthat have lowest degree of weathering and crystals of plagioclase and amphibole were in balance to gether of the plutonic-subplutonicrocks. The 2 samples. This samples are fromgranodiorites (sample AF- 13) and porphyric diorite (sample AF-43). All selected samples are composed of mineral assemblage of quartz, plagioclase, hornblende, K-feldspar, magnetite. Clinopyroxen is only seen in porphyric diorite rocks in to inclusion in plagioclase. This mineral assemblage is an important prerequisite for aluminum-in-hornblende barometry (Anderson & Smith, 1995, Hammarstrom & Zen, 1986; Hollister *et al.*, 1987; Johnson & Rutherford, 1989; Schmidt, 1992; Vyhnal & Mc Sween, 1990). The minerals were analyzed by using Cameca X100 electron microprobe at Iranian Mineral Processing Research Center (IMPRC). The quantitative analyses of selected minerals were performed with a 15keV accelerating voltage, a 10n A beam current and a 2-5µm beam size. The counting time at each peak was 20-30s.

The rims of several pairs of co-existing hornblende and plagioclase were measured for the rmobarometry studies. All measured rims of hornblende are in contact with Plagioclase, which is an important requirement for application of aluminum-in-hornblende barometry (Stein E. Dietl, 2001). Representative analytical data are listed in (Tables 1, 2, 3 & 4). BSE images of analyzed minerals are shown in (Fig. 2).

Table 1. Petrographical characteristics of AF- 13 & AF- 43 samples. M: main minerals, S: subordinate minerals, Se: secondary minerals and × :no minerals. (Qtz: Quartz; Pl: Plagioclase; Fal: Alkalifeldespar; Am: Amphibole; Zrn: Zircon; Ap: Apatite; Cal: Calcite; Chl: Chlorite; Mg: Magnetit.

Samples	**Mineralogy**									**Texture**	**Rocktype**
	Qt	*Pl*	*Kfs*	*Am*	*Zrn*	*Ap*	*Cal*	*Chl*	*Mt*		
AF-13	M	M	M	M	S	Se	Se	×	S	Granular- poieclitic	Granodiorit
AF- 43	M	M	M	M	×	Se	Se	Se	S	Granular- Graphic	Diorite

Table 2. Representative plagioclase compositions of the investigated granitoid.

Lithology	Granodiorite			Diorite	
Sample	AF-13			AF-43	
Wt %					
SiO2	61.150	61.060		60.530	58.620
TiO2	0.010	0.000		0.050	0.060
Al2O3	23.720	23.400		23.590	25.010
FeO*	0.270	0.280		0.410	0.390
CaO	6.790	6.850		6.030	8.110
Na2O	7.420	8.630		7.910	6.510
K2O	0.540	0.550		0.510	0.590
Total	99.900	100.770		99.030	99.290
Number of ion on the basis of 8 oxygens					
Si	10.915	10.869	10.904	10.904	10.583
Al	9.989	4.909	5.008	5.008	5.321
Ti	0.001	0	0.007	0.007	0.008
Fe	0.04	0.042	0.062	0.062	0.059
Ca	1.298	1.36	0.164	0.164	1.569
Na	2.568	2.978	2.763	2.763	2.279
K	0.123	0.125	0.117	0.117	0.136
Total	19.935	20.228	20.02	20.02	19.955
Mol %					
Ab	64.37	67.54		68.32	57.21
An	32.55	29.63		28.78	39.38
Or	3.08	3.83		2.9	3.41

Table 3. Representative hornblende compositions of the investigated granitoid.

Lithology	Granodiorite		Diorite	
Sample	AF-13		AF-43	
Wt %				
SiO2	50.27	51.56	54.07	54.89
TiO2	0.99	0.62	0.44	0.41
Al2O3	5.01	3.74	4.11	3.99
FeO*	17.99	18.64	11.16	10.51
MgO	10.99	11.65	17.11	18.65
MnO	0.39	0.42	0.52	0.47
CaO	11.24	10.56	12.61	11.76
Na2O	0.99	0.72	0.39	0.55
K2O	0.35	0.24	0.14	0.19
Total	98.22	98.15	100.55	101.42

Formula per Holland and Blundy (1994)				
T-sites				
Si	7.382	7.572	7.481	7.484
Aliv	0.618	0.428	0.519	0.516
Al(total)	0.867	0.648	0.670	0.641
M1,2,3 sites				
Alvi	0.250	0.219	0.152	0.125
Ti	0.109	0.068	0.046	0.042
Fe3+	0.221	0.140	0.250	0.273
Mg	2.405	2.550	3.528	3.790
Mn	0.049	0.052	0.061	0.054
Fe2+	1.967	1.970	0.963	0.716
Ca	0.000	0.000	0.000	0.000
	5.000	5.000	5.000	5.000
M4 site				
Fe	0.022	0.179	0.078	0.210
Ca	1.769	1.662	1.870	1.718
Na	0.209	0.159	0.052	0.072
	2.000	2.000	2.000	2.000
A site				
Ca	0.000	0.000	0.000	0.000
Na	0.073	0.046	0.052	0.073
K	0.066	0.045	0.025	0.033
Sum A	0.138	0.091	0.077	0.106
OH site				
O	0.000	0.000	0.000	0.000
OH	2.000	2.000	2.000	2.000
F	0.000	0.000	0.000	0.000
Cl	0.000	0.000	0.000	0.000
	2.000	2.000	2.000	2.000
Sum cations	15.138	15.091	15.077	15.106
Cation CHG	46.000	46.000	46.000	46.000
Fe#	0.479	0.473	0.268	0.240
Mg/Fe2+	1.209	1.186	3.388	4.095
Mg/Fe	1.089	1.114	2.732	3.162
XMg	0.481	0.510	0.706	0.758
XOH	1.000	1.000	1.000	1.000
cm	0.022	0.179	0.078	0.210
XSi,T1	0.846	0.893	0.870	0.871
XAl,T1	0.154	0.107	0.130	0.129
XAl,M2	0.125	0.110	0.076	0.063
Xvac,A	0.862	0.909	0.923	0.894
XNa,A	0.073	0.046	0.052	0.073
XNa,M4	0.105	0.080	0.026	0.036
XCa,M4	0.884	0.831	0.935	0.859
XK,A	0.066	0.045	0.025	0.033

Table 4. Representative clinopyroxen inclusion compositions of the investigated granitoid.

Lithology	Diorite			
Sample	AF- 43			
Wt %				
SiO2	55.25	55.31	55.2	55.39
TiO2	0.31	0.12	0.18	0.8
Al2O3	2.08	3.58	3.26	3.78
Cr2O3	0	0	0	0
FeO	10.94	10.55	10.72	10.36
MnO	0.4	0.49	0.48	0.51
MgO	16.8	16.9	16.82	17
CaO	12.93	10.9	11.48	10.5
Na2O	0.23	0.39	0.32	0.44
K2O	0.07	0.3	0.16	0.4
Total	99.01	98.54	98.62	99.18
Number of ion on the basis of 8 oxygens				
Si	2.03	2.026	2.025	2.014
Ti	0.009	0.003	0.005	0.022
Al	0.12	0.18	0.165	0.176
Cr	0	0	0	0
Fe	0.342	0.33	0.336	0.322
Mn	0.012	0.015	0.015	0.016
Mg	0.92	0.923	0.92	0.921
Ca	0.509	0.428	0.451	0.409
Na	0.016	0.028	0.023	0.031
K	0.003	0.014	0.007	0.019
Total	3.932	3.921	3.922	3.916

Software

The results of analysis using software Min pet 2. 2for draw the diagrams. Abbreviations of minerals were adapted from Kretz (1983).

Geological Setting

The study area (Fig. 1a) consists of volcanic rocks and Aftabroupluton , recognized with a tectonic contact (Fig. 2). Two main Cenozoic geological units (Emami *et al.*, 2000) include: (1) Middle-Upper Eocene andesite to andesitic basalt (Emami *et al.*, 2000), (2) Eocene-Oligocene acidic plutonic and sub plutonic rocks (Sabzian *et al*, 2015) corresponding to subduction of central Iran sub- continental plate under the Arabian plate (Ghasemi & Talbot, 2005; Mohajjel & Fergusson, 2000; Berberian & King, 1981).

Result and discussion

Aftabrou Pluton

Aftabrou pluton with a E- W trend occurs as an elongate body exposed in the andesite to andesitic basalt rocks (Fig. 2) in 2 km eastern of Gheshlagh-e-Aftabrou village (Fig. 1).

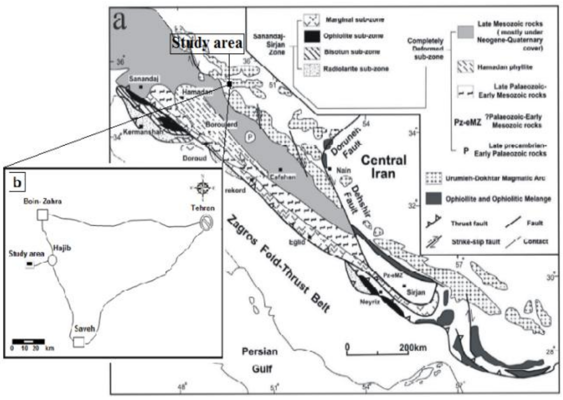

Fig. 1. Location (a) and Road access (b) of study area in the Uroumieh- Dokhtar belt in Iran (after Mohajjel & Fergusson, 2000).

Plagioclase (51- 54 vol. %), quartz (5- 21 vol. %), Kfeldspar (9- 16 vol. %), hornblende (12- 14 vol. %) are the main minerals of this pluton. Common accessory minerals are titanite, apatite, magnetite, chlorite and sericite. Geochemical analyses of the major elements show that the plutonic rocks are cal-alkaline, metaluminous type and sub plutonic rocks are alkaline, metaluminous to peraluminous. Genetic parameters for Aftabrou pluton are compatible with I-type granite (Amini Harooni, 2014 ;Sabzian *et al.*, 2015).

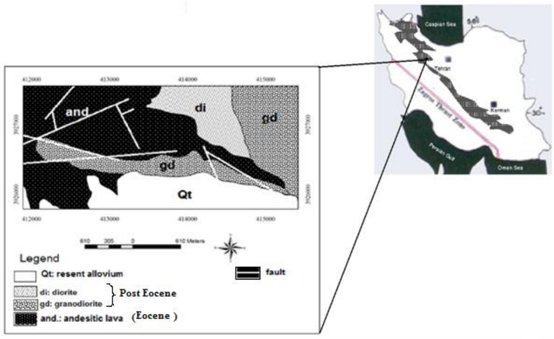

Fig. 2. The simplied 1: 25000 geological map (in scale) of study area location on the Uroumieh-Dokhtar belt.

Aftabrou pluton is formed in a volcanic arc related to granitoids (VAG) (Sabzian *et al.*, 2015). Some times, tabular plaioclase is altered to very fine -grained of sericite. K-feldspar is subhedral to unhedral. Quartz occurs in amorphous grains with highly variable size. Amphibole is prismatic and tabular in shape and its composition is mainly hornblende (Fig. 2- B). Ilmenite and magnetite are commonly associated with hornblende. Based on petrographical studies, plagioclase and amphibole crystals are euhedral to subhedral (Fig. 2) and are in equilibrium without reaction rim, that is an important prerequisite for aluminum-in-hornblende barometry (Anderson & Smith, 1995; Hammarstrom & Zen, 1986; Hollister *et al.*, 1987; Johnson & Rutherford, 1989; Schmidt, 1992; Stein E. Dietl, 2001; Vyhnal & Mc Sween, 1990,Blundy& Holland, 1990; Ernst, 2002; Holland & Blundy, 1994; Stein & Dietl, 2001).

Mineral Chemistry

As mentioned before, for determining of plagioclase, alkali feldspar, amphibole and clinopyroxenecom positions of the Aftabrou pluton, 2 samples were selected and 56 points were analyzed by using EPMA. This result is shown in table 2, 3 and 4.

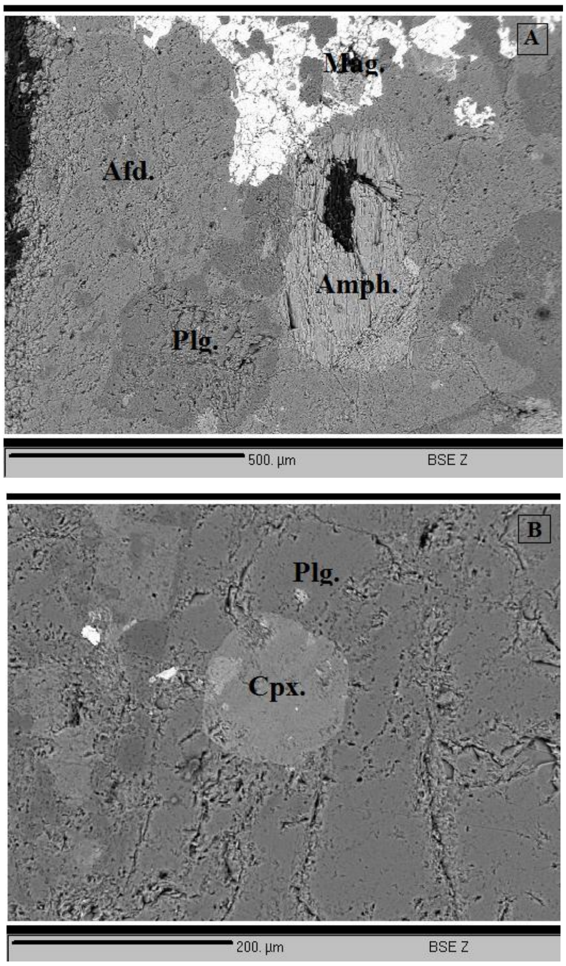

Fig. 2. BSE of mineral assemblages in analyzed sample, A: Granodiorite (AF- 13), B: Diorite (AF- 43). Plg= Plagioclase, C.px.= Clinopyroxen, Afd= Alkali feldspar, Amph= Amphibole, Mag.= Magnetite.

Using the Minpet 2.02 program designed by Richard (1995), structural formulae of plagioclase were calculated on the basis of 8 oxygens and 5 cations. Chemical composition of plagioclase are determined by using Albite- Orthose- Anorthite ternary diagram. Anorthite content ranges between 28.78- 49.05% in diorite, while that of in granodiorite is 29.17- 34.77% (Table 2). Plagioclase, with a variable composition from oligoclase to andesine, is the most common mineral occurred in all phases of the Aftabrou pluton. In diorites, plagioclase is andesine in composition, which is consistent with the EPMA analysis.

Chemical formulae and mineral name for clinopyroxene inclusion were determined following the method of Morimoto *et al.* (1988). In this method, clinopyroxene compositions, including sodic, sodiccalcic and calcic, need to be distinguished (Table 4).

Structural formula and mineral name for amphibole were calculated on the basis of 23 oxygens following the method outlined in Holland & Blundy (1994). Based on the nomenclature of Leake *et al.* (1997), the amphibole of Aftabrou pluton is classified as calsicamphibole (Table 3) and hornblende, mostly.

Discussion will deal first with the significance of amphibole chemistry in Aftabrou pluton. Three amphibole crystals of granodiorite and diorite were analyzed for determining the magma type and tectonic setting (Table 3). The P-T conditions of granitoids generations were calculated based on their mineral composition.

Table 5. Results of microprope analyze of amphiboles.

Lithology	Granodiorite						Diorite			
Texture	core	rima	rima	rima	rim	rim	core	rima	rim	rima
Sample	AF-13	AF-13	AF-13	AF-13	AF-13	AF-13	AF-43	AF-43	AF-43	AF-43
Specimen	A24	A24a	A24b	A24c	A25	A26	A27	A27a	A27b	A27c
SiO2	49.74	49.98	50.27	50.98	51.56	51.68	53.39	53.85	54.51	54.99
TiO2	1.09	1.04	0.99	0.79	0.62	0.34	0.36	0.39	0.39	0.36
Al2O3	5.67	5.14	5.01	4.75	3.74	3.67	4.18	4.13	3.99	3.81
FeO*	17.72	17.81	17.99	18.14	18.64	17.15	10.13	10.89	10.99	10.55
MgO	10.76	10.81	10.99	11.13	11.65	12.66	20.13	18.96	17.54	18.01
MnO	0.34	0.36	0.39	0.40	0.42	0.21	0.48	0.50	0.49	0.46
CaO	11.95	11.63	11.24	10.09	10.56	11.95	11.28	12.01	12.05	11.88

Lithology			Granodiorite						Diorite	
Texture	core	rima	rima	rima	rim	rim	core	rima	rim	rima
Na2O	1.20	1.12	0.99	0.85	0.72	0.67	0.57	0.42	0.40	0.41
K2O	0.56	0.52	0.35	0.29	0.24	0.24	0.18	0.16	0.14	0.13
Total	99.03	98.41	98.22	97.42	98.15	98.57	100.70	101.31	100.50	100.60

Lithology			Diorite			
Texture	rima	rim	core	rima	rim	rim
Sample	AF-43	AF-43	AF-43	AF-43	AF-43	AF-43
Specimen	A28	A30	A30a	A39	A40	A41
SiO2	54.07	55.28	54.89	55.83	56.39	54.82
TiO2	0.44	0.30	0.41	0.46	0.29	0.53
Al2O3	4.11	3.70	3.99	1.83	2.52	2.53
FeO*	11.16	10.23	10.51	11.29	11.11	11.32
MgO	17.11	18.62	18.65	15.59	17.58	16.74
MnO	0.52	0.41	0.47	0.55	0.51	0.46
CaO	12.61	11.70	11.76	12.58	12.24	12.60
Na2O	0.39	0.43	0.55	0.26	0.41	0.36
K2O	0.14	0.15	0.19	0.06	0.08	0.08
Total	100.55	100.82	101.42	98.45	101.13	99.44

Amphibole and Clinopyroxen Inclusion Composition and Magma Type

The clinopyroxeninclusion isoccurred in the sub-plutonic phase of Aftabrou pluton, but it is not seen at the plutonic phase. Aanalyzedclinopyroxeneis classified as calcic clinopyroxenes (augite) (Fig. 2- A, B). Based on Mg/ (Mg+Fe2) vs. Si binary diagrams, all of the analyzed amphiboles from the porphyricdiorite and granodiorite of the Aftabrou pluton are classified as calcic amphiboles and hornblende (Fig. 2. A, B). Amphibole and clinopyroxene composition has been used to describe the nature and tecthonic setting of magma (Chapple and White, 1974; after Jiang and An, 1984; Lundgaard & Tegner, 2004; Le Bas, 1962); Leterrier *et al.*, 1982; Sun & Bertrand, 1991; Jakes & White, 1972). Fig. 4-B shows the subduction zone for amphiboles. The magmatic nature of clinopyrox-eninclusion, based on Fig. 4. A, C is subalkaline and calcalkaline.

Aluminum-in-Hornblende Thermometry

Hornblende and plagioclase are commonly coexisting minerals in calc-alkaline igneous rocks, so they are usually used for thermometry (Blundy and Holland, 1990; Ernst, 2002; Holland and Blundy, 1994; Stein and Dietl, 2001). Based on hornblende solid-solution models and well constrained natural and experimental systems, two hornblende-plagioclase geothermometers (thermometer A and B) were calculated by Holland & Blundy (Holland and Blundy, 1994).

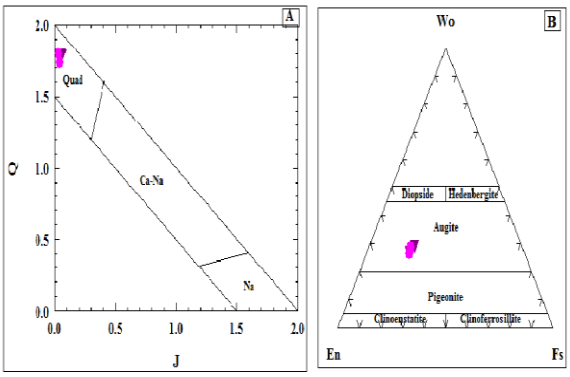

Fig. 2. (A) Location of the analyzed clinopyroxenes on the Q-J diagram of Morimoto *et al.*, 1988; (B) Classifying of the analyzed clinopyroxenes based on Wo-En-Fs triangular diagram (Morimoto *et. al.*, 1988).

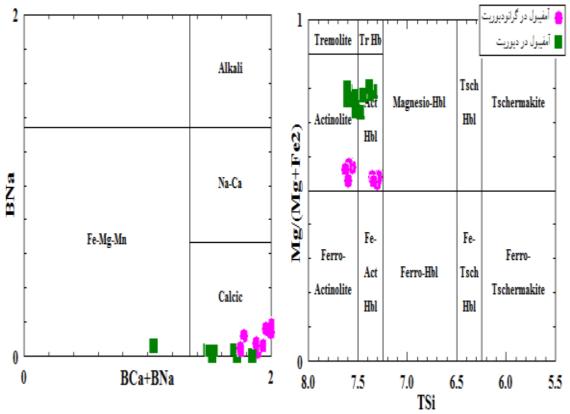

Fig. 2. (A) Classification of the analyzed amphiboles (Leak *et al.*, 1997), (B) Classifying of the analyzed amphiboles based on Mg/(Mg+Fe2) vs. Si binary diagram (Leak *et al.*, 1997).

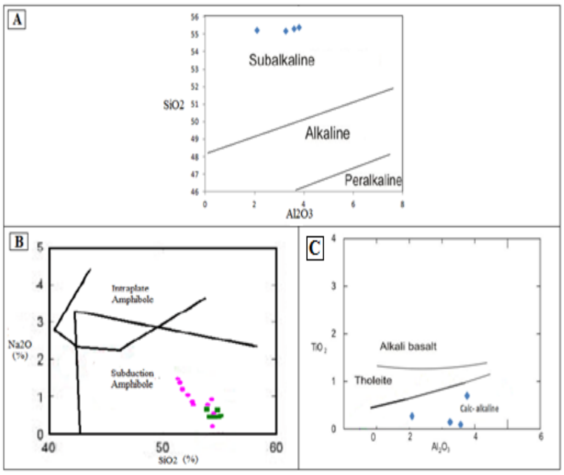

Fig. 2. Diagrams showing the classification of magmas on the basis of mineral chemistry analyze. A. SiO2- Al2O3 clinopyroxen diagram (Le Bas, 1962). B. Na2O- SiO2 amphibole discrimination diagram (Coltorti *et al.*, 2007). C. TiO2- Al2O3 clinopyroxen discrimination diagram (Le Bas, 1962).

Thermometer A is based on the edenite-tremolite reaction (edenite + 4 quartz → tremolite + albite), which is applicable to quartz-bearing igneous rocks: and thermometer B is based on the edenite-richterite reaction (edenite + albite → richterite + anorthite), which can be applied to both quartz-bearing and quartz-free igneous rocks (Holland and Blundy, 1994; Stein and Dietl, 2001). According to Anderson (1996), thermometer B (edenite-richterite) is successfully used rather than other igneous thermometers.

Thus, the thermometer B is selected to calculate the emplacement temperatures and pressures of Aftabrou pluton. However, the temperatures calculated by thermometer A are also listed in Table 2.

Equilibration temperatures for hornblende-plagioclase assemblages are calculated based on Anderson & Smith method. The calculated temperatures (edenite-richterite thermometers) for granodiorit (plutonic) and dioritie (sub- plutonic) range from 622.1 to 639.6°C and 604.8 to 662.6°C, respectively (Table 3).

Otten (1984) used of Ti (apuf) for thermometery.
Accordingly, if Ti (apuf) < 0.345, then:
T (min) = 1204* Ti (apuf) + 545 (Otten, 1984)
T (max) = 273* Ti (apuf) + 877 (Otten, 1984)

The calculated average of temperature for granodiorites and diorites, by using the Otten method, are 652°C 597.9°C, respectively.

Aluminum-in-Hornblende Barometry

Empirical studies suggest that, in the presence of an appropriate buffer assemblage, the Al content of calcic amphibole may show an linear relationship of pressure during pluton crystallization (Hammarstrom and Zen, 1986; Anderson and Smith, 1995; Hollister *et al.*, 1987; Johnson and Rutherford, 1989; Schmidt, 1992; Thomas and Ernst, 1990).

Subsequent experimental studies (Johnson and Rutherford, 1989; Rutter *et al.,* 1989; Schmidt, 1992; Thomas and Ernst, 1990) provided general confirmation of crystallization, and to constrain the emplacement depths of batholiths or vertical displacements of crust (Ernst, 2002; Mc Causland *et al.*, 2002; Moazzen and Droop, 2005; Stein E. Dietl, 2001).

There are several calibrations for aluminum-in-hornblende barometry, including:

P (±3 kbar)= −3.92 + 5.03 Al total, r2= 0.80 (Hammarstrom and Zen, 1986);

P (±1 kbar) = −4.76 + 5.64 Al total, r2 = 0.97 (Hollister, 1987);
P (±0.5 kbar) = −3.46 + 4.23 Al total, r2 = 0.99 (Johnson M.C. and Rutherford, 1989);
P (±0.6 kbar) = −3.01 + 4.76 Al total, r2 = 0.99 (Schmidt, 1992).

The last two calibrations have been more commonly used because of their experimental derivation. Anderson & Smith (Anderson and Smith, 1995) developed a temperature-corrected Al-in-hornblende barometer calibrated using the Schmidt experiments (Schmidt, 1992) at approximately 655°C and 700°C and a pressure range of 2.5 to 13 Kbar. The schmidt calibration is as follows:
P (± 0.6 kbar)= - 3.01 + 4.76 Al_{tot}

Considering to the temperature (and oxygen fugacity) effect on the pressure calculation, the calibration of Anderson and Smith (1995) is used to calculate the crystallization pressures of the plutons. Temperature is calculated based on coexisting hornblende and plagioclase using the thermometry of Holland & Blundy (1994). Pressures are also calculated by the Johnson & Rutherford (Johnson and Rutherford, 1989) and Schmidt methods (Schmidt, 1992) and are compared with results obtained from the Anderson & Smith (1995) calibration.

Calculated pressures from aluminum-in-hornblende barometry are listed in Table 6. The temperature - corrected pressures calculated using Anderson & Smith method (1995) for granodiorite (plutonic) and diorite (sub- plutonic) rocks are1.18–0.14 kbar and .08- .05 kbar, respectively.

Regional Implications
The Aftabrou pluton, which is dominantly composed of hornblende and plagioclase, is a part of Uroumieh-Dokhtar volcanic belt in central Iran zone. Hornblende compositions can determine the tectenomagmatic subduction environmental (Chapple & White, 1974؛ White, 1979؛ Petro *et al.*, 1979؛ White & chapple, 1983 ؛John & Wooden, 1990؛ Barton, 1990 ؛Barbarian, 1990؛Alther *et al.*, 2000) for magmas, clearly, from which they have crystallized. The average of emplacement temperatures calculated by the hornblende-plagioclase thermometer for granodiorite and porphyricdiorite are 625.5°C and 597.9°C, respectively. However, it seems that crystslization of porphyric diorite is occurred in subsolidous stage. Aluminum-in-hornblende geobarometry indicate that the emplacement pressures for sub- plutonic and plutonic rocks of Aftabrou pluton are 1.18– 0.14 Kbar and 0.08- .05 Kbar, respectively. According to P= ρ . g. h, average of emplacementdept for granodiorite and porphyric diorite is obtained 3. 32 Km and 1.88 Km, respectively.

Table 6. Results of geothermobarometry, Plag Ab- the atomic ratio [Na/(Na+Ca+K)]; Amph Al (Total)- the number of Al cations calculated in the structural formula of hornblende (Table3); P-Sch-pressure calculated using Schmidt (Schmidt, 1992); T(ed-tr) temperature calculated using plagioclase-hornblende geothermometer A(edenite-tremolite) of Holland &Blundy (Holland and Blundy, 1994); T (ed-ri)-temperature calculated using plagioclase-hornblende geothermometer B (edenite-richterite) of Holland &Blundy (Holland and Blundy, 1994) ; P-A&S- the temperaturecorrectedpressure, calculated using Anderson & Smith (Anderson J. L and Smith, 1995) ; T=T(ed-ri).

Sample	Spots	Plg. Ab.	Amph Al (Total)	T(ed- tr) °C	T(ed- ri) °C	T (Otten)	P Sch (kb)	P-A&S (Kbar)
AF- 13	21b	64.37	0.867	302	662.1	676.6	1.12	1.18
AF- 13	22	67.54	0.648	292	639.6	627.4	0.07	0.14
AF- 43	32b	68.32	0.67	299.4	585.2	600.1	0.18	0.05
AF- 43	33a	57.21	0.641	307.3	662.6	595.6	0.04	0.08

Conclusion

The Aftabrou pluton, situated in the Northwest of Saveh, is a small part of the Uroumieh- Dokhtar magmatic arc of Iran in the Alpine-Himalayan orogenic belt. The arc outcrops are mainly consisted of Tertiary volcanic sequences and associated plutonic rocks typical of calc-alkaline magmatism developed at active continental margins. The arc was developed during the closure of the Neotethyanocean between Arabia and Eurasia. This pluton is consisted of plutonic (granodiorite) and sub- plutonic (diorite) rocks , intruded into the Eocene volcanic rocks. The main minerals are plagioclase, amphibole, alkali feldspar and magnetite. In this study, composition of minerals is used to describe the nature of the granitic magma and to estimate the pressure and temperature at which Aftabrou pluton is emplaced.

The chemistry of amphibole in plutonic rocks and that of clinopyroxe inclusion in plagioclase of sub-plutonic rocks show that this pluton is derived from a calc-alkalin magma. This type of magma is typically produced in the subduction environments. It means that the pluton could have formed in an orogenic suit in the subduction zone. The results obtained from amphibole and clinopyroxen chemistry are well consistent with the previous suggestions on the Uroumieh-Dokhtar belt. The average of emplacement temperatures calculated by the hornblende-plagioclase thermometer for granodiorites and dioritesare 625.5°C and 597.9°C, respectively. Aluminum-in-hornblende geobarometry indicate that the emplacement pressures for sub- plutonic and plutonic rocks of Aftabrou pluton are 1.18–0.14 Kbar and 0.08- .05 Kbar, respectively.

References

Alavi M. 1994. Tectonic of Zagros orogenic belt of Iran: New data and interpretations. Tectonophysics **229,** 211-238.

Amini Haroni I. 2014. Mineralogy and geochemistry of the Aftabrupoly metal prospect, Markazi Province. (MSc Thesis), Geology Department, Isfahan University, Isfahan, Iran (127 pp. in Persian).

Anderson JL. 1996. The Nature and Origin of Cordilleran Magmatism. Geological Society of America, Memoir **174,** 71-98.

Anderson, JL, Smith DR. 1995. The effects of temperature and fO2 on the Al-in-hornblende barometer. Am. Mineral **80,** 549–559.

Barbarin B. 1990. Granitoids: main petrogenetic classification in relation to origin and tectonic setting. Geological Journal **25,** 227-238.

Barbarin B. 1999. A review of the relationships between granitoid types, their origins and their geodynamic environments. Lithos **46**, 605-626.

Blundy JD, Holland TJB. 1990. Calcic amphibole equilibria and a new amphibole-plagioclase geothermometer. Contrib mineral petrol **104,** 24- 208. 24.

Chappell BW, White AJR. 1974. Two Contrasting Granite Types. Pacific Geology **8,** 173-174.

Chavideh M, Kananian A, Ahmadian J, Sarjoughian F. 2013. 1stcoference on Iranian applied geochemistry (CIAG), Damghan university.

Coltoriti M, Bonadiman C, Faccini B, Gregori M, O'reilly SY, Powell W. 2007. Amphiboles from suprasubduction and intraplate lithospheric mantle. Lithos **99,** 68–84.

Emami MH. 2000. Magmatism in Iran. published by the Geological Survey and Mineral Exploration Iran.

Ernst WG. 2002 Paragenesis and thermobarometry of Caamphiboles in the Barcroftgranodioritic pluton, central White Mountains, eastern California .Am. Mineral **87,** 478-490.

Femenias OC, Mercier JC, NKono C, Diot H, Berza T, Tatu M, Demaiffe D. 2006. Calcic amphibole growth and compositions in calc-alkaline magmas: Evidence from the Motru Dike Swarm (Southern Carpathians, Romania). American amaineralogist Journal **91,** 73- 81.

Ghasemi A, TalbotC J. 2005. A new tectonic scenario for the Sanandaj- Sirjan Zone (Iran). Journal of Asian Earth Science **26(6),** 683-693.

Hammarstrom JM, Zen EAN. 1986. Aluminum in hornblende: An empirical igneous geobarometer, American Mineralogist **71,** 1297- 1313.

Helz RT. 1982. Phase relations and compositions of amphiboles produced in studies of the melting behavior of rocks, Mineralogical Society of America Reviews in Mineralogy **9B,** 279-346.

Holland T, Blundy J. 1994. Non-ideal interactions in calcic amphiboles and their bearing on amphibole-plagioclase thermometry. Contrib Mineral Petrol **116**, 433-447.

Hollister LS, Grissom GC, Peters EK, Stowell HH, Sisson VB. 1987. Confirmation of the empirical correlation of Al in hornblende with pressure of solidification of calc-alkaline plutons. Am. Mineral **72**, 231-239.

Jakes P, White AJR. 1972. Major and trace element abundances in volcanic rocks of orogenic areas, Geological Society of America Bulltein **83,** 29-40.

Jiang CY, An SY. 1984. On chemical characteristics of calcic amphiboles from igneous rocks and their petrogenesis significance. J. Mineral. Petrol **3,** 1–9.

John BE, Wooden J. 1990. Petrology and geochemistry of the metaluminous to peraluminous Chemehuevi Mountains Plutonic suite, southeastern California.

Johnson MC, Rutherford MJ. 1989. Experimental calibration of the aluminum-in-hornblende geobarometer with application to Long Valley Caldera (California) volcanic rocks. Geology **17,** 837-841.

Kaya O. 1978. Paleozoic basement structure of northwest Anatolia (an approach). In: ZAPFE, H. (ed), Scientific Results of the Austrian Projects of the International Geological Correlation Programme (IGCP), SterreichischeAkademie der Wissenschaften Schriften der ErdwissenschaftlichenKommissionen Band. **3,** 223- 234.

Khlili M, Kuorangi M. 2001. Investigation of geology, petrology, petrography and geochemistry of plutonics mass of south and south and north- western of Zafarghand. Thesis of Ph. D.

Leake BE, Woolly AR, Arps CES, BirchWD, Gilbert MC, Grice JD, Hawthorne FC, Kato A, Kisch HJ, Krivovichev VG, Linthout K, Laird J, Mandarino J, Maresch WV, Nickel Eh, Rock NMS, Schmucher JC, Smith DC, Stephenson NCN, Unungaretti L, Whittaker EJW, Youzhi G. 1997. Nomenclature of Amphiboles. Report of the Subcommittee on Amphiboles of the International Mineralogical Association Commission on New Minerals Names. Europian Journal of Mineralogy **9,** 623-651.

LeBas NJ. 1962. The role of aluminium in igneousclinopyroxenes with relation to their parentage. Am. J. Sci **260**, 267-88.

Leterrier J, Maury RC, Thonon P, Girard D, Marehal M. 1982. Clinopyroxene composition as a method of identification of the magmaticaffinities of paleo-volcanic series. Earth. Planet. Sci. Lett **59**, 139-54.

Lundgaard KL, Tegner C. 2004. Partitioning offerric and ferrous iron between plagioclase and silicate melt. Contributions to Mineralogy and Petrology **147,** 470- 483.

Mc Causland PJA, Symons DTA, Hart CJR, Blackburn WH. 2001. Paleomagnetism and geobarometryofthe Granite Mountain batholith, Yukon: Minimalgeotectonic motion of the Yukon-Tanana Terranerelativeto North America. Yukon Exploration and Geology, 163- 177.

Moazzen M, Droop GTR. 2005. Application of mineralthermometers and barometers to granitoid igneous rocks:theEtive Complex, W Scotland. Mineral Petrol **83**, 27- 53.

Mohajjel M, Fergusson CL. 2000. Dextral transpression inLate Cretaceous contatinetal collision, Sanandaj-SirjanZone, western Iran. Journal of Structural Geology **22**, 1125-1139.

Morimoto N, Fabries J, Ferguson AK, Ginzburg IV, Ross M, Seifert FA, Zussman J, Aoki K, Gottardi G. 1988. Nomenclature of pyroxenes. Mineral Petrol **39**, 55–76.

Petro WL, Vogel TA, Wilband JT. 1979. Major-elementchemistry of plutonic rock suites from compressional andextensional plate boundaries. Chemical Geology **26**, 217- 235.

Rutter MJ, Van der Laan SR, Wyllie PJ. 1989. Experimental data for a proposed empirical igneousgeobarometer: Aluminium in hornblende at 10 kbar pressure. Geology **17**, 897-900.

Sabzian A, Masoudi F, Emami MH, Nezafati N. 2015. The study of dual entity of alkaline - calcalkaline magma origin in plutonic rocks in Aftabrou area, North West of Saveh, Arak. Journal of Biodiversity and Environmental Science (JBES) **6(6),** 428- 437.

Schmidt MW. 1992. Amphibole composition in tonalite as afunction of pressure: An experimental calibration of theAl-in-hornblende barometer. Contrib Mineral Petrol **110**, 304-310.

Sun CM, Bertrand J. 1991. Geochemistry of clinopyroxenes in plutonic and volcanic sequences from the Yanbian Proterozoic ophiolites (Sichuan Province, China) Petrogenetic and geotectonicimplications. Schweizerische Mineralo-gischeund Petrographische Mitteilungen **71**, 59- 243.

Thomas WM, Ernst WG. 1990. The aluminium content ofhornblende in calc-alkaline granitic rocks: A mineralogicbarometer calibrated experimentally to 12kbar: In:Spencer RJ , Chou IM (Eds.), Fluid-mineralinteractions: A tribute to HP Eugster, The GeochemicalSociety Special Publication **2**, 59-63.

Vyhnal CR, Mc Sween HY, JR. 1990. Constraints on Alleghanian vertical displacements in the southern Appalachian Piedmont, based on aluminum-inhornblendebarometry. Geology, **18**, 938-941.

White AJR, Chappell BW. 1983. Granitoid types andtheir distribution in the Lachlan Fold Belt, southeastern Australia. In: Roddick JA (Ed.) Circum-Pacific Plutonic Terranes. Geological Society of America, Memoi **159**, 21-34.

Zareie T, Kananian A, Sarjoughian F, Ahmadian J. 2013. Chemistry of minerals and stimate of tempreture and pressure of Kiabdioritic mass, north- western of Ghom. 1stcoference on Iranian applied geochemistry (CIAG), Damghan university.