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Chemistry of Minerals and Geothermobarometry of Volcanic Rocks in the Region Located in Southeast of Bam, Kerman Province

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Abstract

In this paper, tectonic and geothermobarometric environments have been studied with respect to the combination of pyroxene, olivine and plagioclase in volcanic rocks in the southeast of Bam. The combination of volcanic rocks in the region consists of olivine basalt, basalt, alkaline basalt, andesite, trachyandesite and pyroxene andesite. This combination is the result of the processes of crystallization and sometimes contamination. Plagioclase, clinopyroxene, olivine, and amphibole constitute the major minerals (rock forming minerals) in these rocks. Porphyritic to mega-porphyritic textures with microlithic, glumero-porphyritic and amigdaluidal matrix are observed. Based on the thermometric calculations, plagioclase, pyroxene, and olivine minerals and the rocks of this region are crystallized at a pressure of 1.5 to 7 kb and temperatures ranging from about 700˚C to 1250˚C.

Keywords

Plagioclase, Pyroxene, Geochemistry, Thermo-Barometry, Volcanic Rocks, Bam

1. Introduction

The investigated area in 120 km southeast of Bam covering a region of approximately 800 km^2 is situated between 28˚03'E - 28˚24'E and 58˚49'N - 59˚00'N. The study area is, structurally, located in the southern sector of the Dehaj-Sarduiehmetallogenic belt as the southeastern part of the Urmieh-Dokhtar volcanic zone (**Figure 1**). Two types of tectono-magmatic models are proposed for the Urmieh-Dokhtarvolcanic zone, namely, subduction of the neo-tethys oceanic crust beneath the central Iranian continental crust from cretaceous to tertiary [1] [2] [3] [4] and/or intermittent opening and closing of intra-continental rifts [5] [6]. Sampling and microscopic studies on the volcanic rocks were carried out after the field studies, in this research. After that and given the composition of the volcanic rocks, minerals including plagioclase, clinopyroxene and olivine were used in determination of the origin, pressure and temperature of magma.

2. Study Method

About 150 microscopic sections of rock units were studied using polarizing microscope to identify the texture of the rocks, and their mineralogical composition. In order to conduct thermobarometric studies on the studied basaltic andesites, 5 thin-polished sections were selected and analyzed at the mineralogy division of the Iranian Mineral Processing Research Centre (IMPRC) using a Cameca SX-100 electron microprobe through which 90 point analysis were carried out on olivine, pyroxene and plagioclase minerals. The results obtained were used in a software called Excell software Spread sheet to determine temperature, pressure and also the type of minerals (**Tables 1-4**).

3. Geology of the Region

The area studied is located east of 1:100,000 Nagisan sheet and southeast of 1:250,000 Jahan Abad sheet, 120 km SE of Bam. Eocene alternative sequences of volcanic rocks (andesite, dacite) and volcanoclastics (tuff and ignimbrites) form

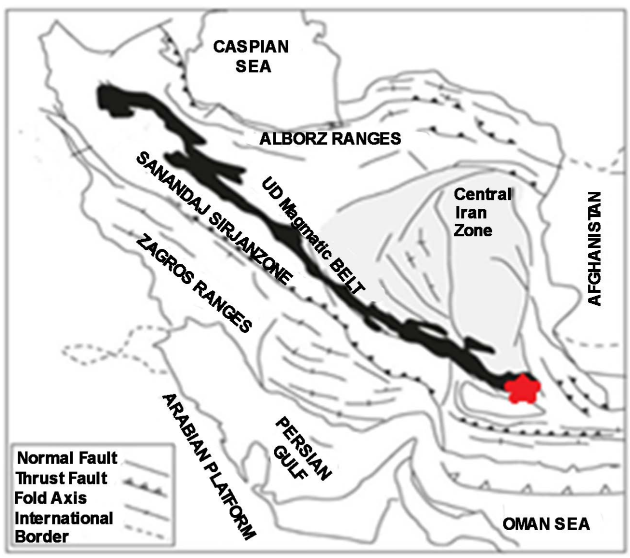


Figure 1. Sketch map showing the position of the study area on the Central Iranian magmatic zone [7].

Table 1. Determination of the type of plagioclase and pyroxene using Spreadsheet.

Samples	Wo	En	Fs	Ac	An	Ab	Or
Ol Ba-A123-1	3.8	77.6	18.5	0.1	63.66	35.34	1.00
Ol Ba-A123-2	34.5	52.9	12.0	0.6	76.95	22.45	0.60
PX An-A25-1	20.0	54.6	24.8	0.5	68.28	31.22	0.50
PX An-A25-2	14.4	58.4	26.8	0.3	65.25	34.24	0.51
Ba-A29-1	38.8	51.8	8.5	0.9	80.81	19.00	0.19
Tr An-A77-1	19.7	54.2	26.0	0.1	79.85	19.83	0.32
Tr An-A77-2	45.0	41.8	12.0	1.2	61.98	37.83	0.19
Tr An-A77-3	46.2	41.4	11.4	1.0	82.05	17.95	0.00
Tr An-A77-4	44.4	43.8	11.0	0.9	77.59	21.41	1.00

Table 2. The results of Thermobarometry of samples using clinopyroxene.

	Putirka *et al.* (1996) [12]					Putirka *et al.* (2003) [13]		
	Eqnation (T1)		Eqnation (T2)		Eqnation (P1)			
	T(K) P-ind	T(C) P-ind	T(K) P-dep	T(C) P-dep	P(kbar)	T(K)	P(kbar)	T(C)
Ol Ba-A123-1	0	0	0	0	0	0	0	−273.15
Ol Ba-A123-2	0	0	0	0	0	0	0	−273.15
Tr An-A25-1	0	0	0	0	0	0	0	−273.15
Tr An-A25-2	0	0	0	0	0	0	0	−273.15
Ba-A29-1	1416.35	1143.20	1411.58	1138.43	0.28	1363.80	−0.08	1090.65
Px An-A77-1.	1240.35	967.20	1234.23	961.08	−16.40	1258.95	−14.41	985.80
Px An-A77-2	1317.87	1044.72	1332.08	1058.93	−1.23	1281.63	−2.76	1008.48
Px An-A77-3	1307.95	1034.80	1320.70	1047.55	−2.69	1274.76	−3.88	1001.61
Px An-A77-4	1303.93	1030.78	1316.39	1043.24	−3.21	1271.30	−4.28	998.15

Table 3. The results of Thermobarometry of samples using plagioclase.

	Plagioclase-Liquid Thermometers, hygrometer and "barometer"				
	Putirka (2008) [14] RiMG equations				
	Putirka (2005)			Putirka (2005)	
	Eqnation (23)	2005	Eqn (24a)	Eqnation (25a)	Eqnation (26)
	T(C)	T(C) sat	T(C)	P(kbar)	T(C) sat
Ol Ba-A123	1244.038	1278.540	1215.609	18.549	1272.555
OLBa-A141	1228.184	1267.235	1198.370	21.067	1252.361
Tr An-A25-1	1219.644	1274.388	1192.483	23.558	1274.378
Tr An-A25-2	1224.612	1274.388	1198.023	27.298	1274.378
Ba-A29	1161.942	1199.108	1140.432	27.186	1193.803
Px An-A77-1	1189.609	1259.380	1144.545	31.984	1212.784
Px An-A77-2	1204.052	1259.380	1162.325	28.615	1212.784
Px An-A77-4	1218.052	1239.093	1179.121	13.892	1178.799

Table 4. The results of Thermobarometry of samples using olivine.

	Equation (13)	Equation (14)	Equation (15)	Helz & Thornber (1987) [15]	Helz & Thornber (1987) [15]
	PutirkaRiMG '08	PutirkaRiMG '08	PutirkaRiMG '08	Mg-thermometer	Ca-thermometer
	T(C)	T(C)	T(C)	T(C)	T(C)
Ol Ba-A123-1	1192.48	1196.24	1252.65	1165.38	1153.49
Ol Ba-A123-2	1192.48	1196.24	1252.65	1165.38	1153.49
Ol Ba-A123-3	1192.48	1196.24	1252.65	1165.38	1153.49
Tr An-A25	1065.63	1043.28	1122.57	1068.44	1127.04
Ba-A29-1	1068.06	1051.77	1145.61	1070.29	1089.74
A29-2	1068.06	1051.77	1145.61	1070.29	1089.74
A29-3	1068.06	1051.77	1133.86	1070.29	1089.74
A92-1	1229.54	1241.85	1274.29	1193.70	1140.48
A92-2	1229.54	1241.85	1274.29	1193.70	1140.48
A92-3	1229.54	1241.85	1223.39	1193.70	1140.48
A92-4	1229.54	1241.85	1223.39	1193.70	1140.48
A92-5	1229.54	1241.85	1223.39	1193.70	1140.48
Ol Ba-A141-1	1212.48	1224.67	1209.84	1180.67	1139.83
Ol Ba-A141-2	1212.48	1224.67	1209.84	1180.67	1139.83

the oldest geological units in the area (**Figure 2(a)**). Intrusion of a multistage Batolithic mass with the combination of diorite, tonalite and granite is the result of the Miocene magmatic activity. From Oligocene to Pliocene, various sediments consist of conglomerate, silty and marl sandstones with gypsum and lava deposits in bright gray to black color are formed. In the southeastern part of the Nagisan region, quaternary magmatic phases, especially the Pliocene-Pleistocene, are volcanic blocks that discontinuously cover all conglomerate deposits or Neogene time andesites and subordinate units. Quaternary deposits are mostly of olivine-bearing basalts with associations of pyroclastic rocks. The lava flows of these rocks have distinct compression blades. One of the characteristics of the quaternary lava is the relative preservation of the cone and its volcanic crater (**Figures 2(b)-(d)**).

4. Petrography

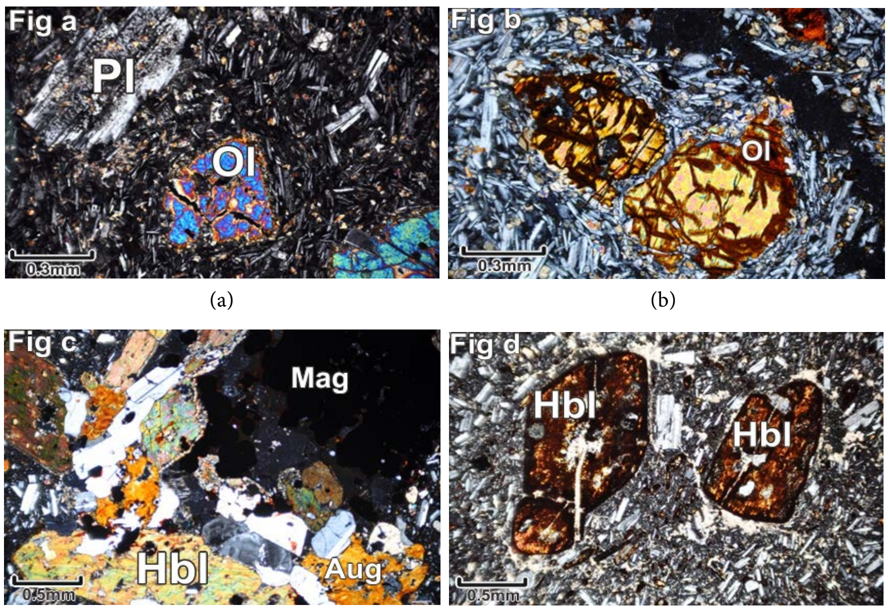
In terms of petrography, the volcanic rocks of the region have an olivine basalt, basalt, alkaline basalt, trachybasalt, andesite, trachyandesite and pyroxene andesite mineralogy.

4.1. Olivine Basalts, Basalts

These rocks show porphyritic textures with microlithic to vitreous matrix, however, glumero-porphyritic, amigdaluidal and afitic textures are sometimes observed (**Figure 3(b)**). The rock-forming minerals are plagioclase, clinopyroxene and olivine, which are hosted by a matrix of plagioclase, clinopyroxene (augite),

(c) (d)

Figure 2. A view of the sediments and lava in the area. (a) Pyroclastic rocks, mostly ignimbrite, with a mixture of Eocene andesite in east of Mil Farhad village; (b) A view of the eroded lava block with olivine basalt composition; (c) A view of semi-prismatic lava in the Siah-Gar region; (d) Layering in the quaternary basaltic lava in the Sorkh-Gabor region.



(c) (d)

Figure 3. (a) Porphyritic texture with vitreous to fluvial vitreous microlitic matrix. Corrosion of the margin of plagioclase and pyroxene crystals in alkali olivine basalts (xpl light, 10×); (b) Fluvial porphyritic texture and converting the olivine margin to iddingsitein olivine basalt (xpl light, 10×); (c) Glumeroporphyry texture (plagioclase, pyroxene and hornblende) and magnetite in hialo-trachyandesite (xpl light, 5×); (d) Porphiritic texture with vitreous and microlitic matrix. Opacitic rims of hornblend in hornblend pyroxene andesite (xpl light, 5×).

olivine, and opaque minerals or glass. Opaque minerals are of accessory minerals while iddingsite (or bulangite), epidote, serpentine and chlorite form the main secondary minerals. Matrix is formed from glass, plagioclase microlites, opaque minerals and secondary minerals.

4.2. Alkali Olivine-Basalt

These rocks are dark green to black in color (**Figure 3(a)**). microlitic-porphyric and porphyritic-amigdaluidal are dominant textures in these rocks. Ca-plagioclase (labradorite-bitonite) forms course phenocrysts. Plagioclase founds also as fine grain microlites within the vitreous matrix. Olivine and, to a lesser extent, clinopyroxene are among the other rock components found either as phenocrysts or microlite. Chlorite, calcite, iddingsite, serpentine and iron oxides, as the result of alteration of various minerals, are also found within these rocks. Opaque minerals are among the accessory minerals. Cavities are often filled with calcite.

4.3. Trachybasalts

These rocks have generally porphyritic texture with microlithic to vitreous matrix and in some parts show glomero-porphyritic to trachytic texture. Phenocrysts include plagioclase, clinopyroxene and olivine. Matrix is made of glass, plagioclase, clinopyroxene, olivine and opaque minerals (magnetite and titanomagnite). Chlorite, iddingsite and iron oxides are also found in these rocks. opaque minerals are among the accessory minerals in these rocks.

4.4. Andesites

The andesitic rocks of the area include basaltic andesite, andesite, hornblende-pyroxene andesite, pyroxene andesite and trachy-andesite. These rocks represent a variety of porphyrytic, flow, glomeru-porphyrytic, and sieve textures.The rock forming minerals of these rocks are plagioclase and one or more mafic minerals such as hornblende and pyroxene (**Figure 3(c)**). Plagioclase is often crystallized in the form of zoned phenocrysts, oligoclase-andesinein composition. In all of these rocks, plagioclase has been decomposed into sericite, chlorite, and clay minerals. Secondary quartz crystals are also seen as fine grains in the matrix and sometimes as phenocrysts. The secondary minerals in the andesitic rocks of the area are mostly magnetite, titanumgentite (opaque minerals) and apatite. Trachy-andesites exhibit porphyritic texture with microlithic and trachytic and in some cases mega-porphyritic matrix. The mineralogy of these rocks contains plagioclase crystals and one or more mafic minerals such as hornblende and pyroxene. One of the most prominent features of these rocks is bay-like corrosion at the margin of plagioclase and clinopyroxene, thieve texture in coarse and fine grain plagioclase, and also longitudinal and transversal sections of auto-morph hornblende with burned margins. There are inclusions of opaque and apatite minerals in these crystals. In some samples, limited occurrences of olivine are also observed (**Figure 3(d)**).

5. Determination of Plagioclase, Clinipiroxone and Olivine Minerals Based on Chemical Composition

a) Plagioclase

On Or-Ab-An diagram [8], plagioclase minerals in the igneous rocks of the region are within the boundaries of labradorite and bitonite (Figure 4(a)). Chemical composition of Coarse plagioclase crystals differs from $An_{61.98}$ $Ab_{37.83}Or_{0.19}$ to $An_{79.85}$ $Ab_{19.83}Or_{0.32}$, in trachy andesites, from $An_{65.22}$ $Ab_{34.24}Or_{0.51}$ to $An_{68.28}$ $Ab_{31.22}Or_{0.5}$ in pyroxene andesites, $An_{80.81}$ $Ab_{19}Or_{0.19}$ in basalts, and from $An_{63.66}$ $Ab_{35.34}Or_{1.00}$ to $An_{76.95}$ $Ab_{22.45}Or_{0.6}$ in olivine basalts (Table 1).

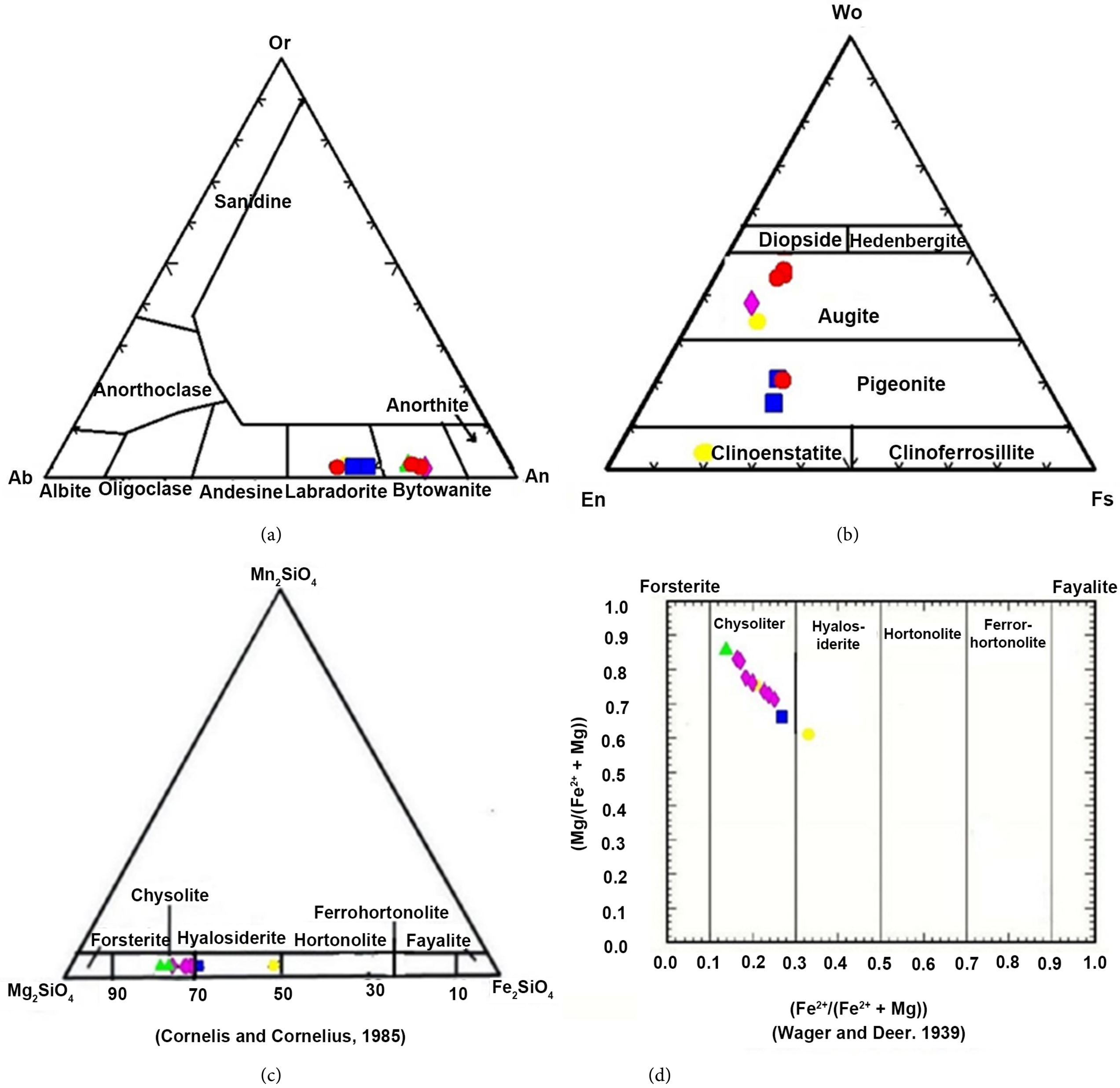


Figure 4. In diagrams (a) and (b): ●: pyroxene andesite, ■: trachy andesite, ◆: basalt, ●: olivine basalt; (c) and (d): ▲: Alkali olivine-basalt, ■: trachy andesite, ◆: basalt, ●: olivine basalt.

b) Pyroxene

According to the nomenclature [9] pyroxenes fall mainly in the clino-enstatite and augite fields (**Figure 4(b)**). Chemical composition of Coarse pyroxene crystals differs from $En_{41.4}$ $Fs_{11.4}$ Wo_{46} to $En_{54.2}$ Fs_{26} Wo_{19} in trachy andesites, from $En_{54.6}$ $Fs_{24.8}$ $Wo_{2.0}$ to $En_{58.4}$ $Fs_{24.8}$ $Wo_{14.4}$ in pyroxene andesites, $En_{51.8}$ $Fs_{8.5}$ $Wo_{38.8}$ in basalts, and from $En_{52.94}$ Fs_{12} $Wo_{34.5}$ to $En_{77.6}$ $Fs_{18.3}$ $Wo_{3.8}$ in olivine basalts (**Table 1**).

c) Olivine

Olivines, on different discrimination diagrams, [10] [11] for example, lie within the field of hyalosiderite and crysolite rather than fyaliteindicating low Fe contents (**Figure 4(c)** and **Figure 4(d)**). Primary olivine minerals certainly have a higher magnesium content but the edingzitation and oxidation of these minerals has led to the stabilization of Fe in place of Mg and the placement of Olivine's to the Faylite pole.

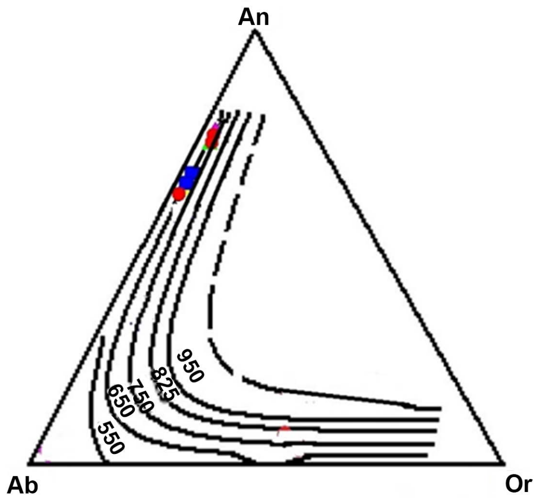
6. Thermobarometry

In this section, using the total analysis of the rock and analyzing the plagioclase, pyroxene, and olivine samples, temperature and pressure using the excel spreadsheet used by several researchers are estimated for rocks in the region. In these tables, temperature (TC) and pressure (kbr) are approximately estimated and Eqn refers to the equations used in the spreadsheets. The results of thermobarometry of clinopyroxene in basalt and andesite rocks, the temperature is estimated to be about 967.20˚C to 1143.20˚C and the pressure is estimated about 0.28 kb (**Table 2**) and based on the results thermobarometry of plagioclase,the temperature and pressure is estimated to be about 1162˚C and 31.98 kb in andesite, but in basalt, temperature and pressure is 1244˚C and 27 kb (**Table 3**). The results of thermobarometry of olivines also indicate a temperature of about 1089˚C to 1270˚C.

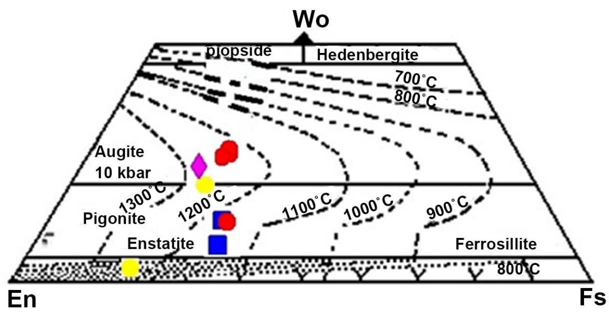
In the following, various models have been used to measure the temperature of the rock in the area. Using the Or-Ab-An ternary system, the temperature was estimated to be around 650˚C to 750˚C for different rocks (**Figure 5(a)**). Clinopyroxene thermometer was also used for rock in the region. Based on this thermometer, the formation temperature estimated was about 1100˚C to 1250˚C (**Figure 5(b)**).

7. Conclusion

The Quaternary volcanic rocks of the area include olivine basalt, basalt, alkali basalt, hialopyroxene andesite, pyroxene andesite and trachy andesite. The main minerals of these rocks are plagioclase, olivine and pyroxene. According to the chemistry of these minerals, the composition of the plagioclase minerals in these igneous rocks lies within the field of Andesin and Labradorite. The composition of clinopyroxenes is of augite type and some of pyroxenes are Ca-poor minerals. Similarly, the combination of olivine is of chrysolite-hyalociderite type. According to thermobarometry calculations of plagioclase, pyroxene and olivine



(a)



(b)

Figure 5. (a) Orb Ab-An diagram for temperature estimation [16]; (b) Wo-En-Fs diagram of pyroxene for temperature estimation [17].

minerals, the rocks of the region have been crystallized in a temperature ranging from 650˚C to 1250˚C and a pressure between 1.5 to 7 kb.

References

[1] Takin, M. (1972) Iranian Geology and Continental Drift in the Middle East. *Nature*, **235**, 147-150.

[2] Alavi, M. (1994) Tectonic of the Zagros Orogenic Belt of Iran; New Data and Interpretations. *Tetonophysics*, **229**, 211-238.

[3] Berberian, M. and King, G.C.P. (1981) Towards a Paleogeography and Tectonic Evolution of Iran. *Canadian Journal of Earth Sciences*, **18**, 210-265.

[4] Berberian, F. (1981) Petrogenesis of Iranian Plutons: A Study of the Natanz and Bazman Intrusive Complexes. Ph.D. Thesis, Cambridge University.

[5] Amidi, S.M. (1975) Contribution a letudestratigraphique et Petrochimique des rochesmagmatiques de la region Natanz-Nain-Surk (Iran Central). Universite Scientifique et Medical de Grenoble, France, 316.

[6] Emami, M.H. (1981) Geologie de la reigon de Qom-Aran (Iran) contribution a l'etudedenamique et geochemique du volcanisme Teriaire de l'Irancentaral. Unpubl. Ph.D. These, University Sc. Et Medical de Grenoble, 489.

[7] Gile, H.A., Boni, M., Balssone, G., Allen, C.R., Banks, D. and Moore, F. (2006) Marble-Hosted Sulfide Ores in the Angouran Zn-(Pb-Ag) Deposit, NW Iran: Interaction of Sedimentary Brines with a Metamorphic Core Complex. *Mineralium Deposita*, **41**, 1-16. https://doi.org/10.1007/s00126-005-0035-5

[8] Deer, W.A., Howie, R.A. and Zussman, J. (1991) An Introduction to Rock Forming Minerals. Longman, 528 p.

[9] Morimoto, N., Fabries J., Ferguson, A.K., Ginzburg, I.V., Ross, M., Seifert, F.A., Zussman, J., Akoi, K. and Gottaridi, G. (1988) Nomenclature of Pyroxenes. *Mineralogical Magazine*, **65**, 1-28.

[10] Wager, L.R. and Deer, W.A. (1939) The Petrology of the Skaergaard Intrusion, Kangerdlugssuak, East Greenland. *Meddel. om Grenland*, **105**, 1-352.

[11] Cornelis, K. and Cornelius, S.H. (1985) Manual of Mineralogy. John Wiley and Sons, New York.

[12] Putirka, K., Johnson, M., Kinzler, R., Longhi, J. and Walker, D. (1996) Thermobarometry of Mafic Igneous Rocks Based on Clinopyroxene-Liquid Equilibria, 0-30 kbar. *Contributions to Mineralogy and Petrology*, **123**, 92-108.

[13] Putirka, K.D., Mikaelian, H., Ryerson, F. and Shaw, H. (2003) New Clinopyroxene-Liquid Thermobarometers for Mafic, Evolved, and Volatile-Bearing Lava Composition, with Application to Lavas from Tibet and Snake River Plain, Idaho. *American Mineralogist*, **88**, 1542-1554. https://doi.org/10.2138/am-2003-1017

[14] Putirka, K.D. (2008) Thermometera and Barometers for Volcanic Systems. *Reviews in Mineralogy and Geochemistry*, **69**, 61-120. https://doi.org/10.2138/rmg.2008.69.3

[15] Helz, R.T. and Thornber, C.R. (1987) Eothermometry of Kilauea Iki Lava Lake, Hawaii. *Bulletin of Volcanology*, **49**, 651-668. https://doi.org/10.1007/BF01080357

[16] Seck, H.A. (1971) Koexistierende Alkalifeldspate and Plagioklase in System $NaAlSi_3O_8$ $KAlSi_3O_8$-$CaAl_2Si_2O_8$ bei Temperaturen 650 c bis 900 c. *Neues Jahrbuch für Mineralogie Abhandlungen*, **115**, 315-345.

[17] Lindsley, D.H. (1983) Pyroxene Thermometry. *American Mineralogist*, **68**, 477-493.