Scientific Research Publishing

Open Journal of Geology, 2017, 7, 257-266
http://www.scirp.org/journal/ojg
ISSN Online: 2161-7589
ISSN Print: 2161-7570

Mineral Chemistry in Volcanic Rocks of Ore Deposit Nochun and Sarcheshmeh Copper Mine, Iran

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How to cite this paper: Riseh, M.A., Abedini, M.V., Emami, M.H. and Zakariaii, S.J.S. (2017) Mineral Chemistry in Volcanic Rocks of Ore Deposit Nochun and Sarcheshmeh Copper Mine, Iran. *Open Journal of Geology*, **7**, 257-266.
https://doi.org/10.4236/ojg.2017.73018

Received: December 28, 2016
Accepted: March 19, 2017
Published: March 22, 2017

Abstract

This paper studies on clinopyroxene, plagioclase of andesitic to dacite rocks of Nochun area to understand the geotectonic and geothermobarometry conditions. Eocene calc-alkaline volcanic rocks are exposed in Nochun that are near the Sarcheshmeh cooper mine. Volcanic rocks consist of andesitic to dacite rocks. Minerals in the volcanic rocks exhibit degrees of disequilibrium features. Plagioclase as dominant mineral in these rocks generally displays oscillatory zoning; sieves or dusty, cores are usually Ca-rich. Petrographic evidence and varying anorthite content (10% to 90%) of plagioclase and temperature estimates of clinopyroxene indicated fractional crystallization condition later than hydrothermal alteration and partial metasomatism occurred. The varying content indicates that the parent's magma was generated from subalkaline composition and then hydrothermal alteration affected phenocryst minerals and matrix of andesitic to dacite rocks. The equilibration temperatures of clinopyroxene showed (800˚C - 1200˚C). Thus, in mafic minerals development of sieve textures in plagioclase, reaction rims, zoning and heterogeneity of plagioclase phenocrysts, the resorbed and embayed phenocrysts, unique composition of clinopyroxene phenocrysts; support fractional crystallization at deep reservoir and high pressure condition as an important process in the evolution of these rocks.

Keywords

Petrography, Fractional Crystallization, Sarcheshmeh Copper Mine

1. Introduction

Kerman region where Sarcheshmeh zone is located includes end part of Uremia-

Dokhtar zone and generally petrologic units in this system (*i.e.* one of the most marvelous geological structures in Kerman region) comprises of clastic igneous and volcano clastic rocks from Eocene epoch and also in many regions, subvolcanic rocks (semi-deep plutonic) at age Oligo-Miocene and volcanic rocks of Quaternary sediments are accompanied with these formations. In this group, rocks have mainly volcanic origin. Due to lack of distinct fossil in rock units in major part of this system, age of this system has been approximated by petrologic relation and comparison with similar formations in other zones. Nonetheless, age of these sedimentary-volcanic formations has been considered from lower to upper Eocene and studied zone (Nochun) is also included as a part of this system. Sarcheshmeh mine is located 160 km distance from southwest of Kerman city, 50 km from south of Rafsanjan city, and 36 km from Pariz town. This mine is situated on geographical latitude (N: 29˚, 58') and longitude (E: 55˚, 53'). Geology of zone comprises of Eocene volcanic-sedimentary group that is one of the most interesting geological structures in Kerman region. This system has northwest-southeast trend with length 500 km and at least 15 km diameter. The major part of this system is composed of different rocks with volcanic origin. The older rocks that have created basis for these structures have no facies in Sarcheshmeh zone. Plutonic and semi-deep rocks as well as dikes have crossed this group in many points. Due to absence of fossil in Sarcheshmeh zone, age of this system has been estimated by petrologic relations and comparison with similar structures in other zones. Based on this technique, age of this system has been considered as upper Eocene including transition from middle Eocene to upper Eocene. Sedimentary deposits from third and fourth geologic periods have been spread on Sarcheshmeh zone as well.

1.1. Nochun Area

The Nochun area is located near the Sarcheshmeh, a world class porphyry copper mine. The major towns close to the Nochun district are Rafsanjan, 60 km to the north, and Kerman, 90 km to the east-northeast. The morphology of the Nochun area includes a steeply incised mountainous terrain ranging in altitude between 2600 to 3040 m. The region has an arid climate with a highest average temperature of 45˚C during hot days in summer, but is cold to −10˚C during cold days in winter [1]. The dry season lasts from May to December and the wet season is between December and April. The total annual rainfall is 300 mm during the wet season.

1.2. Literatures Review

The geology of the Sarcheshmeh area was first studied by NICICO. The granodiorite dikes are commonly silicified and argillites. Siliceous veins are found within the granodiorite dikes and volcanic wall rocks. Pyrite, chalcopyrite, and chalcocite appear at shallow depth, where the siliceous veins are in contact with volcanic rocks [2].

Stresses the necessities of the present work are:

- Study the primary and altered minerals, creating a detailed petrographic classification of the different rock types.
- Analyze the major and trace elements of rock types to find the geochemical signatures associated with the different rock types.
- Compare the lithogeochemistry and diagnostic mineral compositions of the Nochun area with the Sarcheshmeh porphyry copper deposit.
- Develop a genetic model for the Nochun area.

2. Material and Methods

120 samples were selected with respect to lack of iteration and given strength and thin section. In order to identify composition of constituent minerals in these rocks, 14 samples of regional rocks were selected. Electron-Probe Micro Analysis (EPMA) was done on 120 points at Iranian researcher centers for processing of minerals by camera (model: SX-100). Composition of constituent minerals on regional rocks was determined according to the given results from Electron-Probe Micro Analysis (EPMA) by diagrams for determination of mineral compositions presented by different researchers.

Most accepted values are within one standard deviation of the average. Backscattered electron (BSE) images of olivine, Clinopyroxene and Feldspar grains were taken to document zoning patterns. Element maps of Mg, Fe, Al, and Cr of two zoned Cr-spinel grains were also obtained to document zoning patterns. The mineral analyses were processed with the program PET. Nomenclature of amphiboles and estimation of their Fe^{3+} contents follow the recommendations [3]. Mineral abbreviations are after Kretz [4].

The massive volcanic complex occurs through the east of the Sarcheshmeh cooper mine, Nochun area and corresponds to an Eocene volcanogenic eruption in the Urumieh-Dokhtar magmatic arc [2] [3]. This Eocene volcanic complex is the oldest rock unit cropping out at the Nochun area and mainly consists of fine-grained, dark-gray andesite to trachy-andesite. The trachy-andesite is particularly well developed at the contact with intrusive dikes, while the andesite is found to an extent beyond the intrusions through the east of the Nochun area. The volcanic complex is formed by steeply beds towards the northeast dipping. The volcanic complex covers 1.6 km^2 of the Nochun area and shows a green alteration at the contact with the porphyritic intrusion. The copper carbonate veins developed through the volcanic rocks which are in contact with the intrusion. Several fragments (xenoliths) of volcanic rocks were found within the intrusion dikes. The western border of volcanic rock ends by breccia dikes, along the contact with porphyritic intrusion through the eastern portion of the Nochun area.

3. Discussion

3.1. Petrography

The dark gray, porphyritic andesite consists of fine to medium-grained phenocrysts. The phenocrysts consist of plagioclase, pleochroic green amphibole, rarely clinopyroxene grains. Commonly, the amphibole phenocrysts are surrounded by a fine rim of Fe-oxide. The groundmass is dark gray containing variable amounts of plagioclase microliths, amphibole, cryptocrystalline material, magnetite, traces of opaque minerals. Commonly, the plagioclase phenocrysts crystallized early, followed by amphibole. (Figure 1(a) and Figure 1(b)).

The trachy-andesite is composed of abundant plagioclase, rare amphibole. The amount and crystal size of plagioclase increases in the trachy-andesite relative to the andesite rocks.

The dacite consists of phenocrysts set in a glassy matrix. They are accompanied by biotite, green hornblende and K-feldspar. The glassy groundmass is dark and contains plagioclase microliths, quartz and feldspar fragments. The trace minerals include apatite, sphene, and fine-magnetite. (Figure 1(c) and Figure 1(d)).

3.2. Mineral Chemistry

3.2.1. Plagioclases

Composition of this mineral is very sensitive to temperature, pressure, and the existing water content in molten material [5] [6]. Plagioclase is present as one of the major minerals in composition of volcanic rocks in Sarcheshmeh zone. Sur-

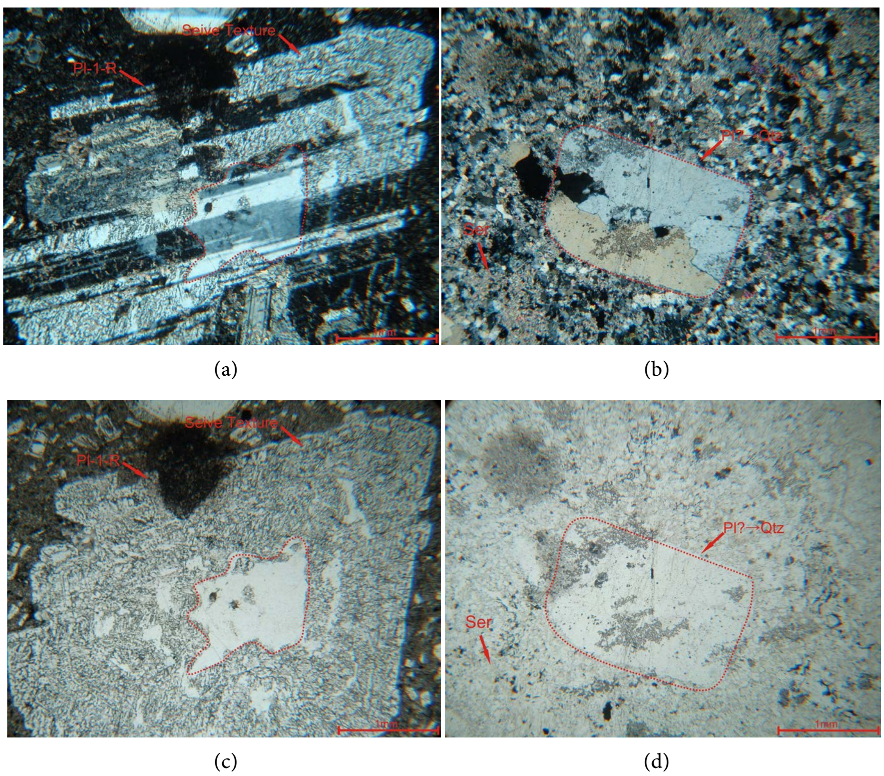


Figure 1. A view from thin sections of lavas. (a) Plagioclase phenocrysts in a and esite (XPL); (b) Plagioclase in andesite (PPL); (c) Plagioclase phenocrysts with microcrystalin texture in dacite (XPL); (d) Reaction and sieve-textured in Plagioclase phenocrysts, resorption-generated zone in dacite lavas (PPL).

veying and study of microprobe analysis on plagioclase mineral in regional rocks shows that some of plagioclase minerals indicate wet calcic compounds so that the quantities of calcium is more increased from margin to margin in these minerals. We utilized triangular diagram of Or-Ab-An to determine composition of plagioclase minerals in regional rocks. Based on these diagrams, existing plagioclases in regional rocks show wide composition from albite to bitonit. Plagioclases with bitonit composition indicate compounds belonging to wet calcic crystals. Likewise, results of conducted analyses on a pyroclastic sample indicate that plagioclase minerals in this sample possess calcic property and show composition of labradorite to bitonit. The most An-rich plagioclase phenocrysts occur in the Andesitic rocks, while the most An-poor crystals are from the dacite porphyritic rocks.

Sieve texture and zonation of plagioclase is noticeable in these volcanic rocks (**Figure 2**). This may be interpreted as resulting from either partial dissolution during the magma process [7], or a decompression effect [8]. Tsuchiyama [9] concluded from experimental data that "these textures were closely related to temperature and chemical compositions)" [10]. Plagioclase phenocrysts in lavas develop a resorption zone in response to different temperature and composition of surrounding melt. Then the outer rim crystallizes with composition of new magma [11] **Table 1**.

3.2.2. Pyroxenes

Clinopyroxene mineral is one of the paramount minerals in determining position of formation and geodynamic environment in igneous rocks, especially types of volcanic rocks. Approximation of temperature and pressure of volcanic

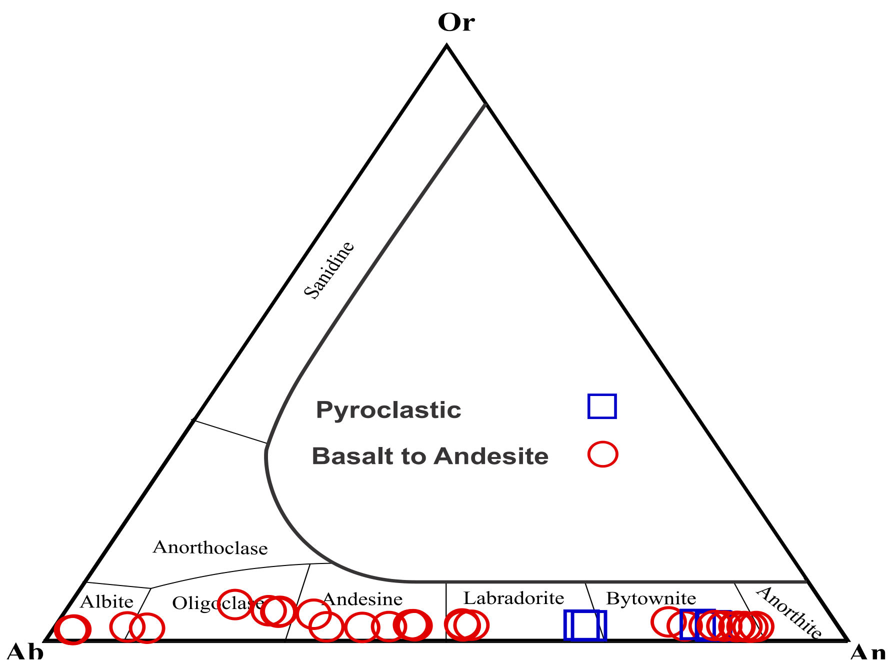


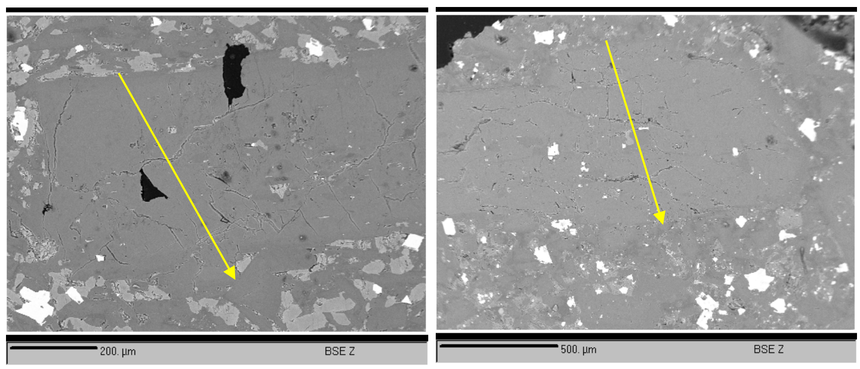
Figure 2. Diagram of determination of plagioclase composition in rocks of the zone: Plagioclase composition in rocks of this zone covers wide range from albite to bitonit.

Table 1. The results of microprobe analysis on plagioclase in Nochun zone.

Point. No	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	An	Ab	Or
HH1	46.87	0.04	32.82	0.6	0.01	0.1	17.33	1.97	0.05	82.7	17	0.3
HH2	47.75	0.03	32.62	0.63	0.01	0.13	16.91	2.31	0.05	80	19.8	0.3
HH3	55.19	0.06	27.85	0.7	0	0.05	11.13	5.65	0.23	51.5	47.3	1.3
HH4	44.77	0.01	33.57	0.57	0.01	0.07	18.82	1.17	0.03	89.7	10.1	0.2
HH5	44.71	0.02	33.58	0.65	0.01	0.07	18.64	1.26	0.01	89.1	10.9	0.1
HH6	50.13	0.05	29.31	0.94	0.01	0.16	14.92	2.28	0.15	77.6	21.5	0.9
HH7	65.5	0	21.21	0.18	0	0.01	2.76	10.93	0.1	12.2	87.3	0.5
HH8	66.12	0	20.36	0.1	0	0	2.2	11.36	0.14	9.6	89.7	0.7
HH9	68.1	0	19.84	0.02	0	0.01	0.21	12.63	0.08	0.9	98.7	0.4
HH10	67.45	0	20.08	0.03	0.02	0	0.16	13.02	0.09	0.7	98.9	0.4
HH11	67.99	0	19.78	0.07	0.01	0	0.22	12.43	0.11	1	98.5	0.6
HH12	62.45	0.02	23	0.15	0	0	4.67	9.11	1	20.9	73.8	5.3
HH13	60.87	0.01	24.13	0.15	0	0	5.86	8.22	0.76	27.1	68.7	4.2
HH14	60.87	0	23.62	0.18	0.01	0	5.67	8.56	0.8	25.6	70.1	4.3
HH15	59.7	0	25.1	0.13	0	0	7	7.9	0.61	31.8	64.9	3.3
HH16	60.93	0.03	24.04	0.16	0.01	0	5.92	8.37	0.76	26.9	68.9	4.1
HH17	60.49	0.02	24.22	0.16	0	0	5.91	8.36	0.75	26.9	69	4.1
HH18	57.11	0.09	26.33	0.8	0	0.08	9.76	6.43	0.28	44.9	53.5	1.5
HH19	54.78	0.09	26.96	0.84	0	0.15	11.24	5.44	0.19	52.7	46.2	1.1
HH20	56.72	0.08	26.49	0.7	0.01	0.08	9.96	6.44	0.25	45.5	53.2	1.4
HH21	59.14	0.02	21.05	0.11	0.01	0	8.65	8.93	0.25	34.5	64.4	1.2
HH22	57.41	0.05	26.35	0.36	0	0	9.1	6.71	0.22	42.3	56.5	1.2
HH23	54.77	0.05	27.93	0.43	0.01	0	11.14	5.63	0.17	51.7	47.3	0.9
HH24	56.06	0.04	26.94	0.4	0	0.03	9.76	6.36	0.28	45.2	53.3	1.5
HH25	57.7	0.05	25.76	0.31	0.01	0	8.45	7.17	0.2	39	59.9	1.1
HH26	50.33	0.05	29.13	1	0.01	0.06	14.06	3.78	0.14	66.7	32.5	0.8
HH27	46.33	0.02	32.13	0.72	0.02	0.05	17.24	1.85	0.05	83.5	16.2	0.3
HH28	46.9	0.02	31.65	0.68	0	0.1	16.93	2.07	0.09	81.5	18	0.5
HH29	45.85	0.02	31.79	0.64	0	0.05	17.34	1.84	0.04	83.7	16.1	0.2
HH30	50.3	0.04	29.25	0.94	0.01	0.09	14.15	3.65	0.12	67.7	31.6	0.7
HH31	46.02	0.02	32.33	0.62	0.02	0.05	17.48	1.84	0.06	83.7	15.9	0.3
HH32	45.01	0.03	32.74	0.63	0.01	0.04	18.24	1.55	0.03	86.5	13.3	0.2
HH33	45.36	0	33.09	0.59	0.01	0.02	18.18	1.41	0.03	87.5	12.3	0.2
HH34	45.77	0.02	32.65	0.67	0	0.03	17.63	1.7	0.04	84.9	14.8	0.2
HH35	45.81	0.05	32.76	0.61	0.03	0.06	17.5	1.47	0.03	86.7	13.2	0.2

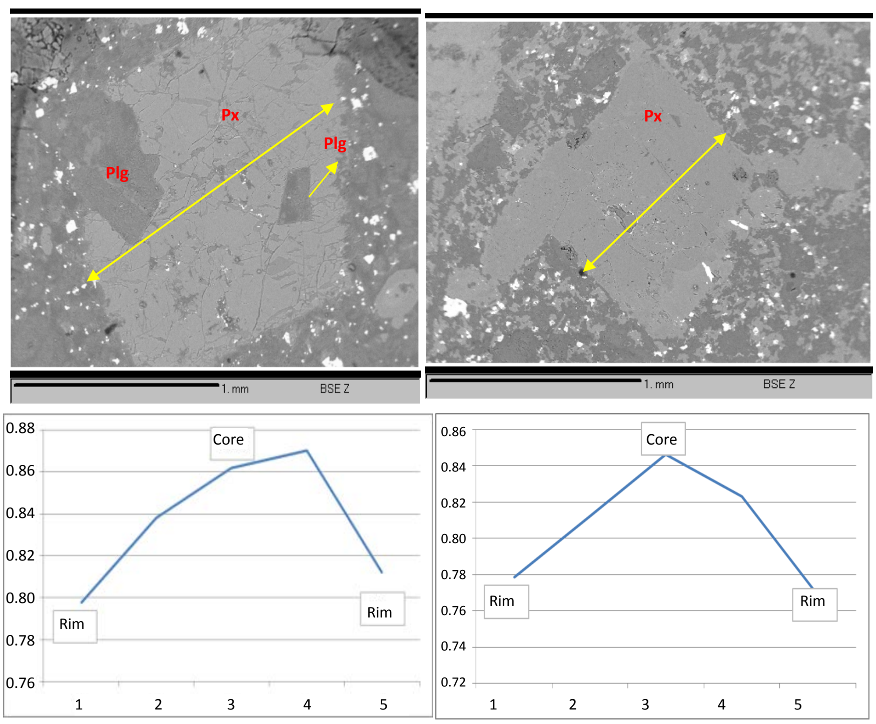
rocks is also one of other cases that indicate importance of pyroxene minerals. In addition, composition of clinopyroxene minerals is a function of chemical compound and ambience to form builder of their magma and it can propose valuable information about tectonic environment in formation of rocks to us [12].

Based on results of microprobe analysis, all of analyzed pyroxene minerals are located within calcic limit in diagram of Q-J classification. Similarly, according to triangular terminological chart for pyroxenes, the pyroxene mineral is composed of diopside and augite types in these rocks (**Figure 3**). Generally, mineralography composition of this mineral is almost fixed in regional rocks and it varies approximately from $Wo_{27.65}$ $En_{40.16}$ $Fs_{8.82}$ to $Wo_{47.27}$ $En_{47.01}$ $Fs_{29.04}$. According to diagram, most of samples have move away from territory of alkaline rocks due to shortage of TiO_2 and they have been located within range of calc-alkaline rocks. Likewise, based on triangular diagram of TiO_2-SiO_2/100-Na_2O, the studied clinopyroxene minerals show property of magmatic arcs in terms of tectonomagmatic environment (**Figure 4**). The low quantity of TiO_2 in structural formula of the studied pyroxenes on the one hand and high rate of SiO_2 on the



(a) (b)

Figure 3. Plagioclase chemistry: (a) Backscatter image showing the traverse points that were analyzed, and (b) Compositional zoning of plagioclase.



(a) (b)

Figure 4. Clinopyroxene chemistry: (a) Backscatter image showing the traverse points that were analyzed; and (b) Compositional zoning of clinopyroxene.

other hand may indicate property of the existing pyroxenes in igneous rocks in volcanic arcs [13]. Microprobe analytical results for pyroxene are listed in Figure 5 and Table 2.

Table 2. The results microprobe analysis on pyroxene at Nochun zone.

Point. No	SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	MgO	CaO	Na2O
HS1	49.61	0.56	5.68	0.012	6.04	0.13	15.17	22.75	0.42
HS2	49.96	0.48	5.63	0.14	5.82	0.11	15.25	23.09	0.45
HS3	50.77	0.48	4.65	0.32	5.52	0.15	15.65	22.74	0.33
HS4	49.72	0.55	5.48	0.2	5.89	0.13	15.45	22.67	0.47
HS5	51.66	0.64	1.86	0.05	9.47	0.28	15.68	20.34	0.43
HS6	51	0.49	3.63	0	7.45	0.2	15.34	22.29	0.3
HS7	49.41	0.85	5.9	0	8.25	0.23	13.84	22.23	0.4
HS8	50.05	0.88	5.4	0	8.02	0.15	14.11	22.35	0.46
HS9	49.24	0.81	5.12	0	8.22	0.18	14.07	22.76	0.4
HS10	49.28	0.85	6	0	8.05	0.2	14.09	22.22	0.44
HS11	51.34	0.75	1.85	0.01	13.78	0.41	15.89	16.6	0.26
HS12	52.55	0.47	1.95	0.13	9.38	0.34	16.35	18.93	0.51
HS13	51.52	0.6	2.72	0.33	8.81	0.25	15.94	19.79	0.44
HS14	52.23	0.55	1.72	0.05	9.98	0.28	16.74	18.47	0.55
HS15	51.99	0.48	1.89	0.02	10.2	0.61	14.16	21.17	0.52
HS16	52.05	0.49	1.87	0	10.75	0.62	14.81	20.33	0.38
HS17	51.57	0.44	1.54	0	10.25	0.63	15.44	20.66	0.43
HS18	51.62	0.54	2.25	0	10.64	0.54	14.96	19.87	0.4
HS19	48.98	0.7	4.39	0	15.86	0.66	13.27	11.79	1.02
HS20	49.04	0.68	4.38	0.06	8.62	0.25	14.3	21.19	0.36
HS21	50.16	0.51	3.4	0.17	7.3	0.18	15.17	22.23	0.28
HS22	50.42	0.62	2.58	0.04	9.59	0.27	15.46	19.95	0.17
HS23	50.48	0.57	2.56	0.08	9.76	0.28	15.71	19.76	0.36
HS24	49.39	0.68	4.26	0.03	8.61	0.21	14.62	21.3	0.2

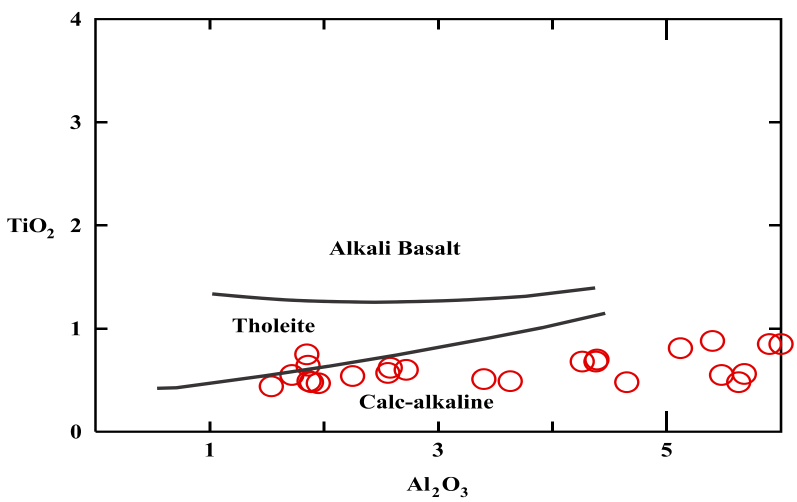


Figure 5. TiO_2 v. Al_2O_3 binary diagram for pyroxene.

4. Conclusion

The studied rocks in Nochun zone include extrusive and intrusive igneous rocks. The major ores in studied sections of Nochun zone consist of pyrite, chalcopyrite, and magnetite. The subsidiary minerals also include chalcocite, covellite, bornite, and hematite. We may find it by comparing mineralization of magnetite and hematite in Nochoon with Sarcheshmeh zone that magnetite mineral is less spread in background rock in Nochoon. Alternately, rate of conversion of magnetite to hematite is higher in Nochoon than in Sarcheshmeh zone and magnetite is more under influence of hydrothermal solutions in Nochoon. It is characterized by comparison of pyrite and chalcopyrite mineralization in Nochoon versus Sarcheshmeh that mineralization is different in these two ores with each other in terms of paragenetic sequence and various generations. Minerals in the volcanic rocks exhibit degrees of disequilibrium features. Plagioclase as dominant mineral in these rocks generally displays oscillatory zoning; sieves or dusty, cores are usually Ca-rich. Petrographic evidence and varying anorthite content of plagioclase and temperature estimates of clinopyroxene indicated fractional crystallization condition later than hydrothermal alteration and partial metasomatism occurred. The varying content indicates that the parent's magma was generated from subalkaline composition and then hydrothermal alteration affected phenocryst minerals and matrix of andesitic to dacite rocks.

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