



Determination of the Geological Conditions During the Formation of Kaolinite and Bentonite Deposits in NW Alborz Mountains (Pirkoh-Deylaman) of Iran and the Study of Its Practical Properties for Use in the Porcelain Industry

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Abstract

The area under study is located in northern Iran at 36° 47' latitude and 50° 12' longitude. It is 15 km from southeastern Deylaman. Petrological study of the kaolin mother rock (Eocene age) under a microscope shows that the rock is vitric tuff with a rhyolitic combination containing falcated and embowed glass shards. The thickness of the layer is approximately 20 meters, formed unconformably on a layer of conglomerate with a thickness of approximately 400 meters. Because the shards have a falcated and embowed shape and the percentage of reworked material within them is low, the tuff can be considered a type of pyroclastic airfall. The results of the study prove that ash falling occurred in the water. The stratabound layers show syngenetic deposits to be the main factor in the formation of the clay, bound as a result of alterations.

Keywords: kaolin, bentonite, volcanic ash, pyroclastic, porcelain, Guilan Province

1. Introduction

Kaolin, as clay, has been known and used for years. This group of minerals is made from the alteration of feldspar. Kaolin, an industrial mineral, is of particular importance because of its ever increasing growth in the products produced by it on a global level. Demand for the mineral and the development of industries surrounding its use, especially in Guilan province, has caused an increase in the price of kaolinite products. As a result, an increase in competition can be expected. Therefore, the exploration of kaolin deposits is highly desirable.

2. Geological Setting

The studied area is located in northern Iran at 36° 47' latitude and 50° 12' longitude. It is 15 km from southeastern Deylaman at an altitude of approximately 1,700 meters above sea level (Figure 1). The region is part of the Alborz Mountains and is located in central Alborz approximately within the boundary of the configuration zones of central and western Alborz (Figure 2). The study conducted by Anlez et. al. (1975) shows that the rocks are of Palaeogene origin consisting of three different volcanic phases. The first phase is underwater blowout most likely from the Eocene epoch.

It consists mostly of evaporated sediments including mudstone, conglomerate, shale, volcanoclastic, (tuff, tuffite) and hydroclastic breccia in a stratified shape with andesite and basaltic andesite lavas. Phases 2 and 3 contain aerial volcanic eruptions most likely from the Oligocene epoch. Phase 2 is comprised mostly of tuff, lapilli tuff, basalt and basaltic andesite lavas. Phase 3 rocks did not lie within the studied area (Figure 3-No.4 geological section). In this study, a 1:20,000 scale geology map was prepared for further investigation (figures 4-5) [1].

3. Analytical Techniques

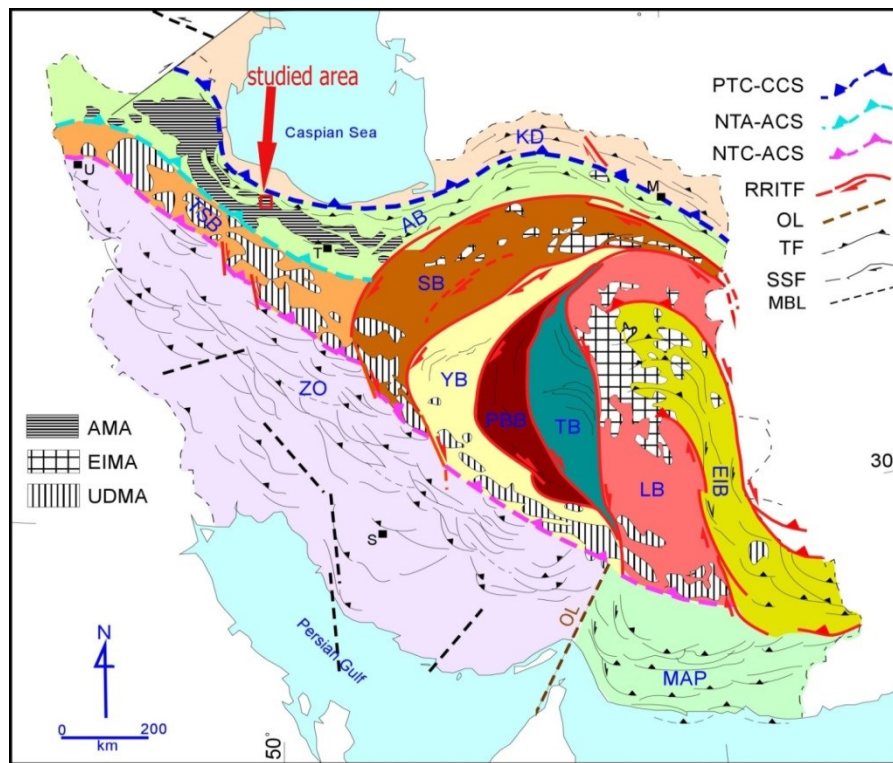
This research is part of the mining exploration doctoral thesis of the first author. The studied area consists mainly of Paleogene volcanic rocks that have been strongly influenced by tectonic forces. In this study, the lithological units were separated using aerial and satellite pictures. Geological maps (scale 1:20,000) were drawn using cartographic methods. Additionally, the different lithological units were studied using geo investigation and geological sampling. 480 samples were sent to Geological Survey of Iran and Kansaran Binaloud Company. These samples were tested using XRF and XRD analysis methods. Finally, the chemical analysis data was interpreted using computer processing. Thin sections were prepared in the laboratory of Islamic Azad University; 20 thin sections were selected and photographed under a microscope.

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Fig1. Satellite view of Alborz Mountains and studied area [2]



Tectonic subdivisions of Iran. Abbreviations: AB - Alborz belt, AMA - Alborz magmatic assemblage, EIB - East Iran belt, EIMA - East Iran magmatic assemblage, KD - Kopeh Dagh fold belt, LB - Lut block, M - Mashhad, MAP - Makran accretionary prism, MBL - Major basement lineament, NTA-ACS - Neo-tethyan arc-arc collisional suture, NTC-ACS - Neo-Tethyan continent-arc collisional suture, OL - Oman line, PTC-CCS - Paleo-Tethyan continent-continent collisional suture, RRITF - Rotation-related intracontinental transfer fault, TF - Thrust fault, SSF - Strike-slip fault, PBB - Posht-e-Badam block, S - Shiraz, SB - Sabzevar block, T - Tehran, TB - Tabas block, TSB - Tabriz-Saveh block, U - Urumieh, UDMA - Urumieh-Dokhtar magmatic assemblage, YB - Yazd block, ZO - Zagros orogen. (After Alavi, 1991).

Fig 2. Map of tectonic subdivisions of Iran and studied area [2]

In order to study the deposits, 30 exploratory wells and 5 trenches were dug. 400 kilos of the main trench were extracted and sent to the Caspian Tile Factory lab to determine the physical properties of both raw and

oven baked samples. This produced 10 different formulations resulting from the different proportions of various minerals. The possible use of these minerals in the porcelain industry was investigated.

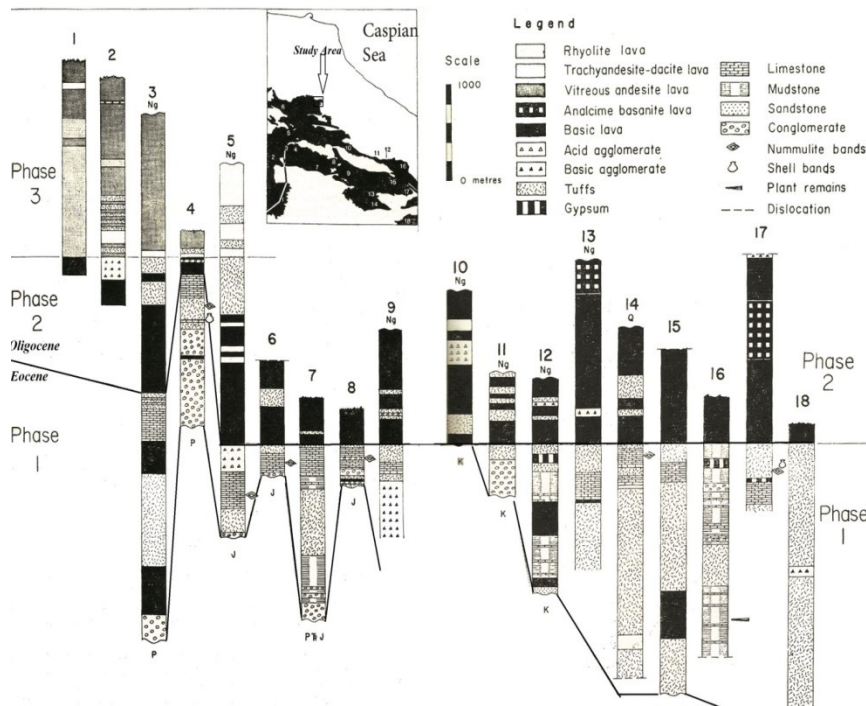


Fig 3. Generalized sections of Paleogene rocks in Qazvin and Rasht Quadrangles Map 1:250,000 scale [3]

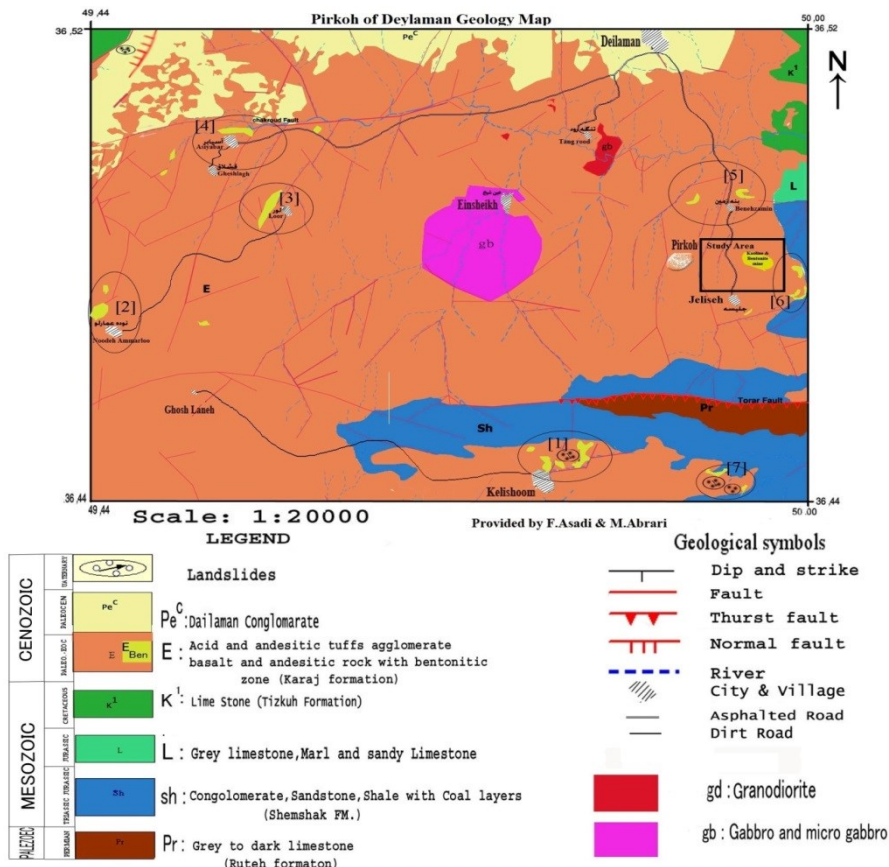


Fig 4. Geological Map of Pirkoh- Deylaman Area



Fig 5. Prospect of studied area, the layer of bentonite being formed unconformably on a layer of conglomerate (J.Sh) with a thickness of approximately 400 meters

4. Petrographic Studies

Petrological study of the kaolin mother rock under the microscope indicated that it is vitric tuff with a rhyolitic combination, containing falcated and embowed glass shards (Figure 6). The thickness of the layer is approximately 20 meters formed unconformably on a layer of conglomerate with a thickness of approximately 400 meters [1] (figure 5). The color of the ore's surface is bright buffy, changing to white in the lower parts, with more density and stability toward the upper side. Because the shards have a falcated and embowed shape and the percentage of reworked material within them is low, the tuff can be considered a type of pyroclastic airfall (Figure 7-8). The results of the study show that ash falling occurred in the water. Stratabound layers show that syngenetic deposits are the main factor in the formation of the clay, bound as a result of alterations [4] (Figure 9).

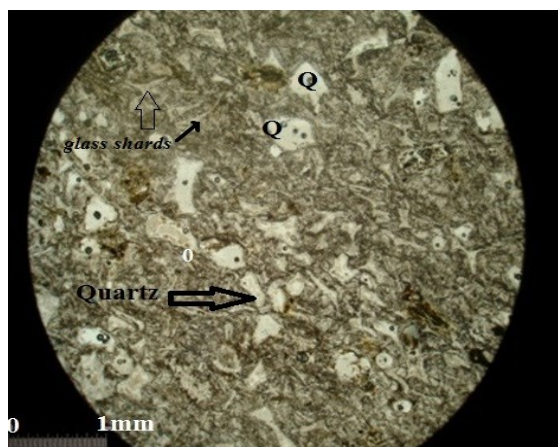


Fig 6. Vitric tuff with egnemberite containing glass shards (PPL)

5. Geochemistry

In this area two different vertical mineralization zones are recognizable: the deeper zone which consists mainly of bentonite and the surface zone which consists mainly of kaolin.

Bentonite Zone: x-ray analysis revealed that the most frequently occurring minerals include: *crystalite, quartz, montmorillonite, kaolinite and vermiculite*.

The results of XRF are illustrated in Table 1. According to the above analysis, it can be concluded that this deposit is calcite bentonite. A comparison of the chemical composition of Pirkoh and other established bentonite mines is represented in Table 2.

Kaolin Zone: x-ray analysis revealed that the most frequently occurring minerals include: *crystalite, kaolinite, tridymite, montmorillonite and quartz*.

The results of XRF are illustrated in Table 3. A comparison of the chemical composition of Pirkoh and other kaolin mines is represented in Tables 4 and 5.

According to the above mentioned results, the low percentage of iron oxide and alkaline oxide as well as the nonexistence of harmful minerals such as sulphur, makes the kaolin desirable for use in the porcelain industry.

6. Discussion

6.1. The genesis and determination of kaolin and bentonite deposits

The conditions existing during the formation of the kaolin can be described as follows: As a result of phase 2 aerial blowout eruptions during the Oligocene epoch, along with the formation of horst and graben in the region, lakes ranging in size from small to relatively large were created. Volcanic ash fell in the sedimentary environment. Very small ash particles were suspended in the basin over a long period of time after which precipitation slowly occurred. During this period, these particles changed to argillaceous minerals due to the

process of alteration and the Ph and Eh conditions of the environment. What is significant about the findings in this mine is that sub-conglomerate contact at the deepest depth of the sedimentary minerals are formed more than kaolinite minerals. A reduction in the depth of this sedimentary basin, caused by the accumulation of sediments, changed the proportions causing an increase in kaolin and a gradual decrease in

montmorillonite minerals. It can therefore be deduced that the longer the suspension of ash particles takes, the more the particles are changed into montmorillonite as a result of hydration and alteration. However, gradual filling of a sedimentary basin along with a decrease in the suspension time will decrease this hydration and alteration [5].

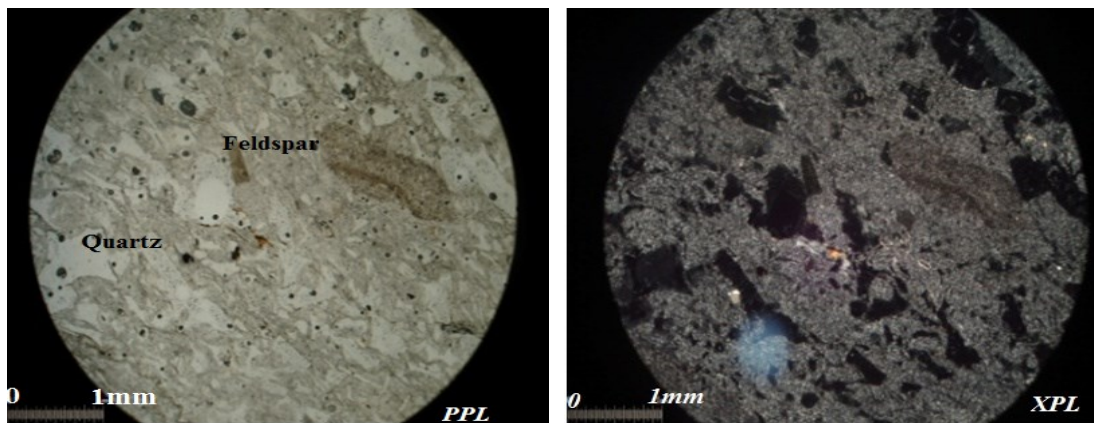


Fig 7. Littik breccia tuff in which feldspar and quartz can be seen

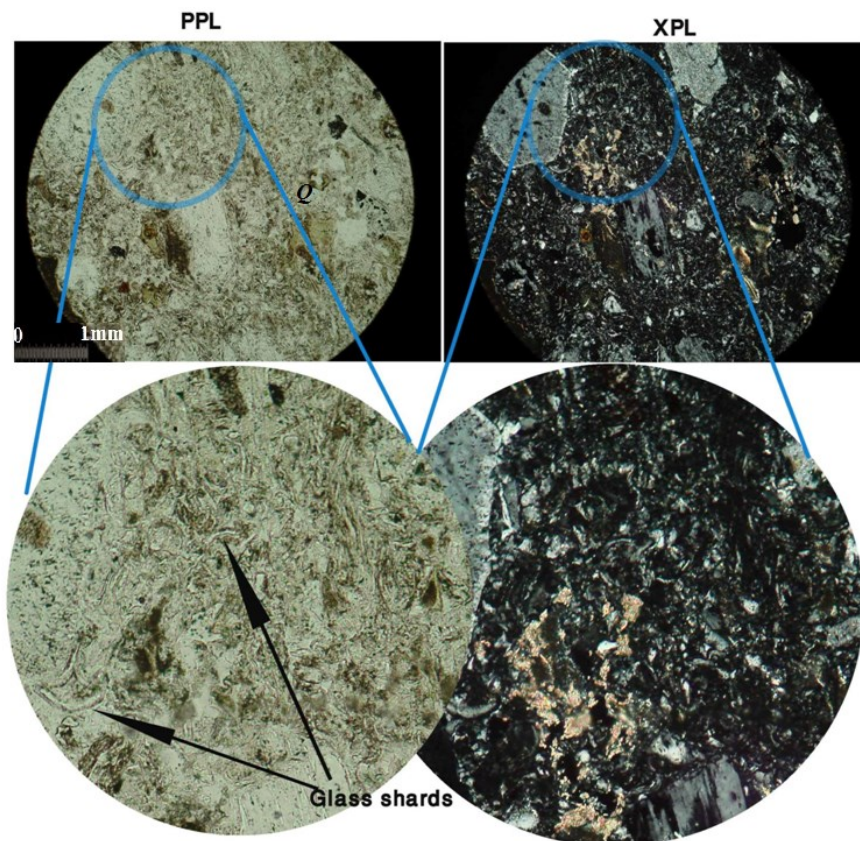


Fig8. Vitric tuff in which falcated and embowed glass shards can be seen



Fig 9. Stratabound ore body in the study area

Table 1. Chemical combination of bentonite samples using XRF analysis [1, 2]

Oxide (%)	BJ.100	BJ.110	BJ.120	BJ.130	BJ.140	BJ.150	BJ.160	BJ.170	BJ.180	BJ.190
Al_2O_3	15.55	17.15	16.53	15.34	15.64	14.89	16.13	17.05	15.37	16.25
MgO	1.05	1.03	1.08	1.11	1.02	1.12	1.17	1.23	1.03	1.12
SiO_2	66.39	65.49	65.76	66.41	63.52	67.21	65.89	64.56	66.67	68.12
K_2O	0.87	0.75	0.82	0.56	0.13	0.76	0.86	0.79	0.74	0.95
Na_2O	0.10	0.07	0.09	0.10	0.06	0.09	0.11	0.08	0.09	0.08
CaO	1.33	1.71	1.09	1.41	1.10	1.03	1.09	1.01	1.23	1.39
TiO_2	0.39	0.20	0.25	0.37	0.33	0.32	0.27	0.12	0.37	0.39
Fe_2O_3	1.03	1.01	0.28	1.13	0.74	1.28	0.73	0.69	1.08	1.04
ZrO_2	0.05	0.04	0.06	0.03	0.03	0.06	0.07	0.05	0.02	0.04
LOI	13.29	12.41	13.48	11.89	16.70	12.09	13.42	13.02	11.72	11.26
Oxide (%)	BJ.200	BJ.210	BJ.220	BJ.230	BJ.240	BJ.250	BJ.260	BJ.270	BJ.280	BJ.290
Al_2O_3	16.75	18.19	16.75	18.53	15.24	15.64	14.99	16.40	17.15	15.34
MgO	1.00	0.22	1.06	0.18	1.15	1.02	1.14	1.83	0.21	0.83
SiO_2	68.32	70.15	69.01	68.46	65.71	63.52	62.81	62.89	66.50	64.60
K_2O	0.85	0.41	0.73	0.32	0.96	0.13	0.26	0.83	0.89	0.58
Na_2O	0.10	0.08	0.12	0.09	0.12	0.17	0.14	0.16	0.09	0.14
CaO	1.29	0.47	2.01	0.19	1.15	1.10	1.14	2.01	1.24	1.89
TiO_2	0.491	0.56	0.18	0.35	0.30	0.33	0.35	0.20	0.37	0.31
Fe_2O_3	0.94	1.68	1.18	0.98	0.98	0.74	1.08	0.89	0.96	1.28
ZrO_2	0.04	0.05	0.03	0.03	0.04	0.03	0.03	0.02	0.02	0.02
LOI	10.29	8.25	10.41	11.12	12.89	16.70	14.59	12.19	13.56	13.72

Table 2. Chemical composition diagrams comparing Pirkoh and other well-known bentonite mines [1, 2]

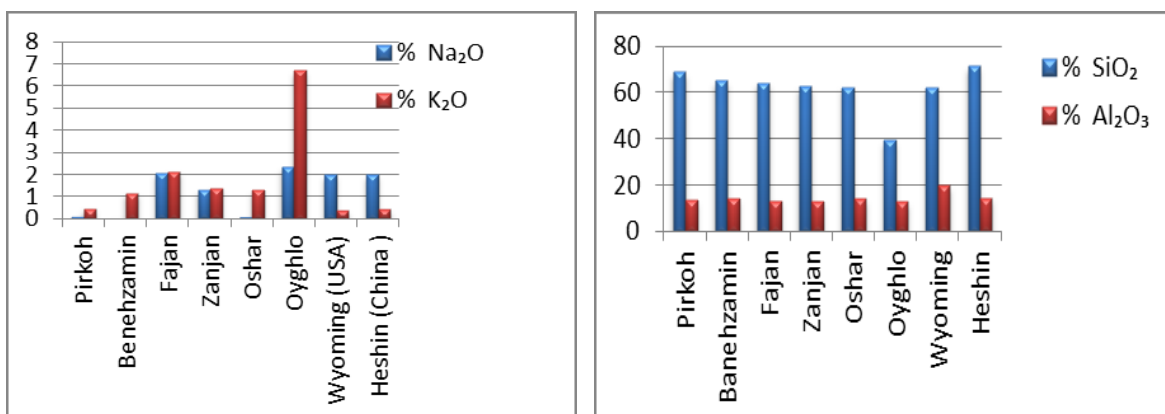


Table 2: Continued

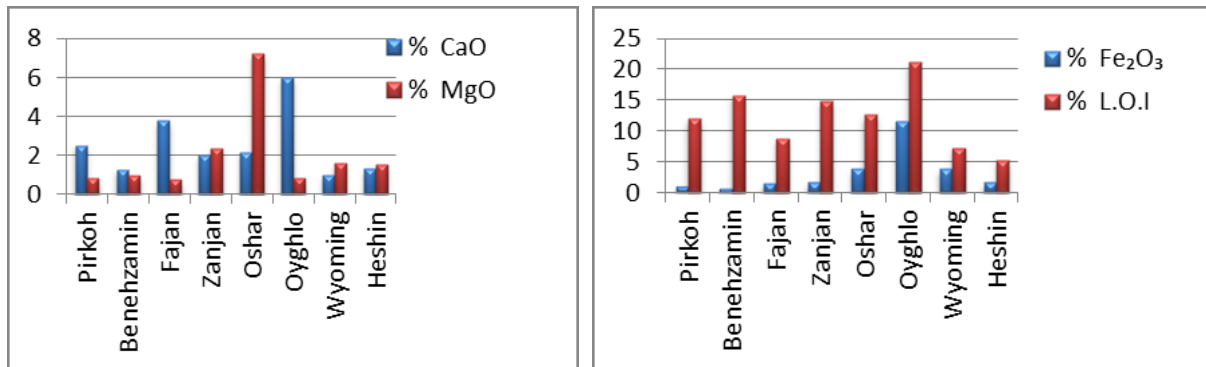


Table 3. Results of XRF analysis of kaolin samples [1, 2]

	Unit	KJ.S	KJ.105	KJ.120	KJ.135	KJ.150	KJ.160	KJ.170	KJ.180	KJ.190	KJ.195	
SiO ₂	%	72.93	71.34	73.43	71.89	71.98	72.84	72.68	72.72	72.92	72.88	
Al ₂ O ₃	%	19.26	19.96	18.24	19.96	20.12	19.11	19.35	19.46	18.98	19.23	
Fe ₂ O ₃	%	0.60	0.86	0.91	0.83	0.89	1.02	1.15	0.62	0.59	0.86	
CaO	%	0.25	0.27	0.43	0.26	0.32	0.29	0.31	0.29	0.43	0.21	
Na ₂ O	%	0.01	0.02	0.04	0.06	0.03	0.07	0.02	0.08	0.10	0.09	
K ₂ O	%	0.18	0.20	0.25	0.37	0.33	0.32	0.27	0.12	0.17	0.19	
MgO	%	0.07	0.06	0.07	0.03	0.09	0.07	0.07	0.10	0.11	0.07	
TiO ₂	%	0.31	0.28	0.22	0.32	0.35	0.29	0.31	0.28	0.34	0.36	
MnO	%	0.001	0.002	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001	
P ₂ O ₅	%	0.038	0.010	0.022	0.021	0.031	0.030	0.038	0.033	0.028	0.029	
SO ₃	%	0.003	0.001	0.003	0.002	0.001	0.001	0.003	0.002	0.001	0.001	
LOI	%	5.94	5.83	6.12	5.86	5.79	6.05	6.12	5.81	5.63	6.19	
Cl	ppm	25	35	23	26	28	31	36	36	25	26	
Ba	ppm	554	510	534	489	496	531	562	498	553	561	
Sr	ppm	49	38	42	49	36	45	51	41	40	46	
Cu	ppm	52	58	46	30	59	62	39	59	61	51	
Zn	ppm	21	23	20	15	29	31	16	29	30	25	
Pb	ppm	14	17	13	8	15	21	17	20	23	15	
Ni	ppm	18	17	13	18	19	17	12	13	11	10	
Cr	ppm	11	8	6	12	13	19	7	16	8	11	
		KJ.210	KJ.220	KJ.230	KJ.240	KJ.250	KJ.260	KJ.270	KJ.280	KJ.290	KJ.300	KJ.210
SiO ₂		72.81	72.12	69.89	73.04	67.72	70.58	69.92	70.26	73.17	71.38	72.81
Al ₂ O ₃		19.63	19.83	21.18	18.49	23.42	21.39	22.01	20.85	19.37	20.02	19.63
Fe ₂ O ₃		0.31	0.36	0.76	0.53	0.99	0.83	0.75	1.03	1.12	0.62	0.31
CaO		0.18	0.17	0.35	0.12	0.38	0.19	0.41	0.28	0.15	0.31	0.18
Na ₂ O		0.01	0.02	0.01	0.01	0.02	0.06	0.01	0.03	0.09	0.05	0.01
K ₂ O		0.17	0.10	0.16	0.21	0.21	0.19	0.16	0.19	0.21	0.17	0.17
MgO		0.07	0.07	0.05	0.04	0.03	0.08	0.09	0.02	0.13	0.06	0.07
TiO ₂		0.33	0.31	0.32	0.30	0.32	0.27	0.36	0.31	0.29	.27	0.33
MnO		0.001	0.001	0.001	0.002	0.003	0.003	0.001	0.002	0.001	0.002	0.001
P ₂ O ₅		0.001	0.013	0.012	0.001	0.001	0.020	0.008	0.003	0.013	0.007	0.001
SO ₃		0.003	0.002	0.001	0.001	0.003	0.001	0.001	0.003	0.003	0.001	0.003
LOI		6.07	5.89	6.06	6.39	6.23	5.66	5.98	5.38	6.11	5.83	6.07
Cl		15	89	101	48	59	63	25	84	73	77	15
Ba		504	610	320	376	577	439	489	380	621	536	504
Sr		49	28	33	69	72	37	38	53	48	42	49
Cu		32	64	54	62	43	65	29	86	73	47	32
Zn		21	38	28	32	21	76	25	41	37	23	21
Pb		57	33	28	78	25	43	76	31	34	39	57
Ni		59	51	43	74	61	28	776	35	26	64	59
Cr		101	82	6	18	57	78	19	29	31	8	101

Table 4. Chemical composition comparison between Pirkoh and other famous kaolin mines in Iran [1, 2]

Oxide (%)	Pirkoh	Zenoz	Ghazandaghi	Maki	Koshknosrat	Esteghlal	Robatkhan	Doplan
SiO ₂	72.81	73	53	63	64	50	54	42
Al ₂ O ₃	19.63	17	29	28	25	27	32	34
Fe ₂ O ₃	0.31	0.3	3.7	0.51	0.42	7.8	1.45	6.7
TiO ₂	0.33	0.05	1.4	0.8	0.46	1.2	1.44	1.7
CaO	0.18	1.2	0.42	0.42	0.18	1.3	-	-
MgO	0.07	0.32	0.36	0.25	0.68	1	-	-
K ₂ O	0.17	0.2	2.5	0.72	2.04	2.1	0.88	-
Na ₂ O	0.01	0.3	0.49	0.11	0.52	0.77	0.46	-
L.O.I	6.07	7	8.6	5	7	8.6	10.98	14

Table 5. Chemical composition diagrams comparing Pirkoh and other kaolin mines in Iran

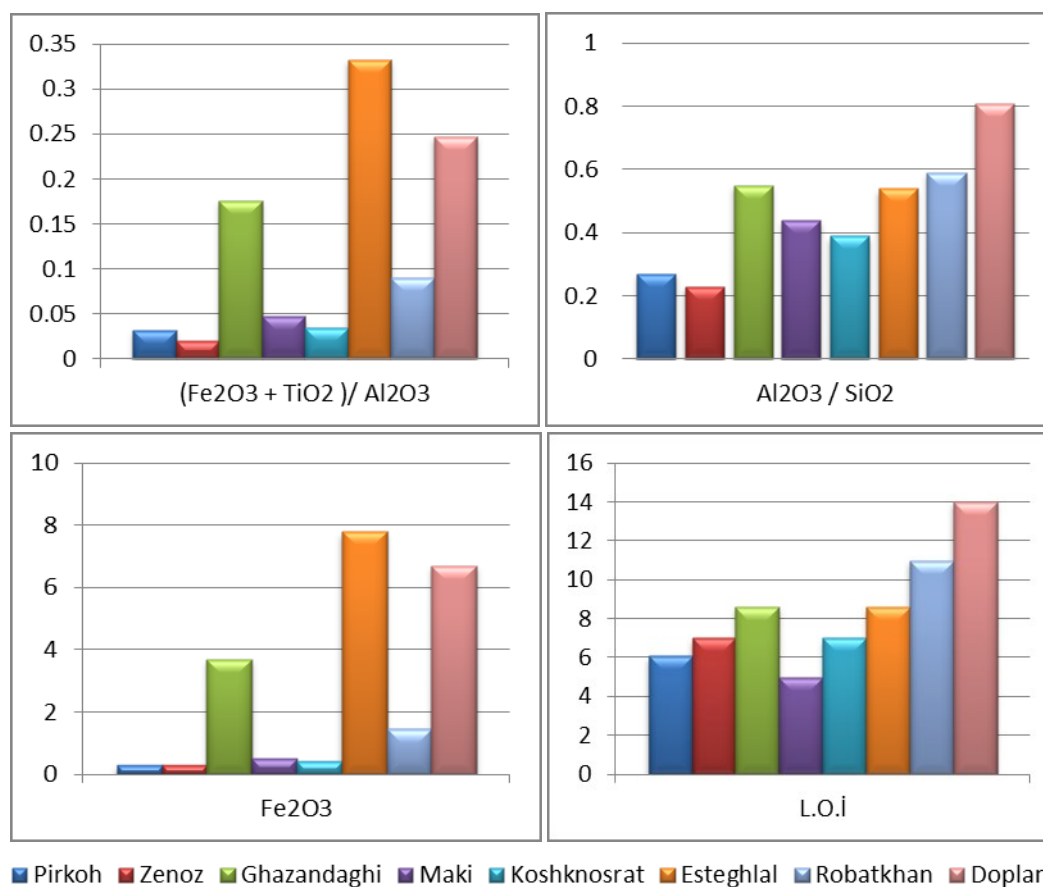


Table 6: Results of baking test for Pirkoh and other major clay deposits [6]

Clay Name	Cheskin	Chobar	SP400	Zenoz	Pirkoh
Water (cc)	650	650	650	550	550
Liquid Maker (gr)	3.5	3.5	3.5	0.4	3
Density (gr/cm ³)	1.6	1.57	1.58	1.59	1.63
Viscosity	37	15	57	37	23
+100#	--	--	--	--	--
Baking Temperature	1105	1105	1105	1105	1105
Baking Cycle	52	52	52	52	52
Pressure	1-100 2-300	1-100 2-300	1-100 2-300	1-100 2-300	1-100 2-300
Heating Waste%	4.5	5.9	3.36	3.79	4.68
Baking Contraction	1.45 mm	5.2 mm	4.03 mm	0.17 mm	0.41 mm
Moisture %	5.02	4.4	5.65	5	5.5
Expansion%	0.319	0.4	0.39	0.65	0.17
Pre-baking Resistance (kg/cm ²)	9.75	8.3	10.1	6.89	5.92
Water Absorption %	10.92	6.4	8.35	14.2	17.21

Table 7: Khazar Tile Factory results showing best formulation of clay for use in baking [6]

		%	Formulation Compound
Test 1	Body Code	20	Pirkoh Kaolin
10.2. 88	Baking Data	16	SP400- (Shiraz – Abadeh)
5.2	Mustier %	22	Cheskin Kaolin
0.4	Expantion %	10	Chobar- Shaft Kaolin
6.8	Pre-Baking Resistance (kg/cm ²)	12	Hamedan Dolomaite
14.7	Water Absorption %	15	Zenoz Kaolin
195	Post-Baking Resistance (kg/cm ²)	5	B.T
8.5	Heating Waste %		
1.3	Baking Contraction (mm)		
White – chocolate	Post-Baking Color		

Even with a change in the Ph and Eh of the environment, kaolinite ores are mostly formed. As the process goes on, the alteration will decrease as long as the ash particles precipitate in the air and tuff layers remain. This condition is unlike that existing in the theory proposed by Anlez and other researchers who studied the region. They claim that as a result of volcanic eruptions during the Oligocene along with particular geochemical and geophysical conditions of the subsea during formation, the dispersed feldspar in the sea, affected by the appropriate chemical and physical conditions, became altered precipitating into a stratabound shape [7]. Numerous glassy shards show signs of blowout in the landmass along with a lack of large expansions and dispersions of kaolinite ores in the area. This invalidates the theory proposed by Anlez et. al. If bentonite first began to form in the subsea, bentonites containing sodium ions should have been

formed as a result of the abundances of sodium ion in the environment. This is the case in most other bentonite zones in central Iran. However, bentonite formed in this mine is of a calcic type.

The results show the amount of sodium oxide present to be less than 0.1%. Chemical analysis of the ore body shows a very low percentage of sulphur, less than 1 ppm, while the amount of Cl is less than 22 ppm. Because of the slender bedding in the mine and the other abovementioned reasons, we can conclude that the kaolin ore is autochthonous and sedimentary. Exploratory operations showed the amount of recoverable reserve to be nearly 8 million tons and the amount of mineable bentonite to be 450,000 tons. Based on the results obtained in this study, several geological indexes in this region were identified as promising areas and marked on the geological map. (Figure 4).

6.2. Application of Pirkoh Kaolin in Porcelain Industry

One of the main uses of kaolin is in the porcelain industry; therefore, its usability has been widely studied by this industry. Particular properties and characteristics have been determined desirable for the raw materials in order to ensure the quality of products produced. The measurement of water absorption, drying and baking temperatures, parameters of shrinkage and dilation during baking and drying and measurement of brightness after baking (baking color), are all among laboratory experiments conducted in order to identify baking characteristics (Table 6). The amount of alkali material present has a considerable effect on the vitrescent properties because it is able to change the porosity of a ceramic body. The kaolin used in the ceramic industry must have less than 1.5% potash along with the lowest amounts possible of titanium and free silica. All the above experiments were conducted on samples from the Pirkoh kaolin mine.

7. Conclusions

Petrological study of kaolin mother rock under a

microscope shows that the rock is vitric tuff with a rhyolitic combination, containing falcated and embowed glass shards. The thickness is approximately 20 meters, formed unconformably on a layer of conglomerate with a thickness of approximately 400 meters. Because the shards have a falcated and embowed shape and the percentage of reworked material within them is low, the tuff can be considered a type of pyroclastic airfall. The results of the study prove that ash falling occurred in the water. The stratabound layers show syngenetic deposits to be the main factor in the formation of the clay, bound as a result of alterations.

Based on the results obtained in this study, several geological indexes in this region were identified as promising areas and marked on the geological map. (Figure 4). The results of physical testing of the deposits show a level of quality necessary for use in the porcelain industry to be present (Table 7). The mineral processing of kaolin results in a reduction of its free silica, iron oxide and other gangue minerals. The resulting concentration can be used in the porcelain and ceramic industries as well as in the production of mucilage.

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