

Scanning electron microscopy of Pirozeh (Turquoise)-group minerals of Nishapur and Baghu (Damghan), Iran

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ABSTRACT

Pirozeh (turquoise) is a supergene mineral that forms from meteoric water along fractures which is associated with copper deposits. Although the Persian Pirozeh (turquoise) has been mined since at least the first millennium BCE, it is not a well-known gemstone for geologists. The aim of this paper is about mineralogy and mineral chemistry of the Pirozeh (turquoise) samples of Baghu (Damghan) and Nishapur areas of Iran by using of the scanning electron microscope (SEM). The samples are also analyzed by Energy-dispersive X-ray spectroscopy (EDS) for measuring the major element concentrations of Pirozeh (turquoise) group minerals as well as other mineral phases accompanying them. The results show that the origin of the Pirozeh (turquoise) samples from these areas can be determined by scanning electron microscopy due to their different mineral assemblages and textures. The EDS results suggest that by increasing the Cu content of Pirozeh (turquoise) group minerals their colors move to deeper blue while in contrast green Pirozeh (turquoise) minerals are of notable concentration of Fe. The data propose that the Cu and Fe concentrations of Pirozeh (turquoise) group minerals are not the only factors affecting the color of this gemstone. The geochemistry of Nishapur Pirozeh (turquoise) is defined by high Cu, high Al, and very low Fe/Zn. This results in its celebrated stable blue color. But the Baghu Pirozeh (turquoise) is geochemically distinct due to its higher Fe content. This acts the color from pure blue into the green-blue and green spectrum.

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1. Introduction

Turquoise, originally called Piruzeh in Persian (Ahadnejad, 2021). It is a rock (Biruni, 1048 CE; Mortimer, 1746), Gemstone (Johari Neyshaburi, 1195 CE) or mineral (Pogue, 1915) blue in color occasionally found as green and white varieties (Tousi, 13th CE; Mansour, 15th CE; Mortimer, 1746) (Akrami et al., 2021; Roohnavaz et al., 2022). Although the Persian Pirozeh (turquoise) has been mined since 2100 BCE (King, 2002) or according to Wulff (1966) the first millennium BCE, it is not a well-known gemstone for geologists (Yazdi, 2021; Shirdam et al., 2021). In modern definitions, Pirozeh (turquoise) ($\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$) is defined as a supergene mineral that forms from the meteoric water along fractures which is often associated with copper porphyry deposits (Hull, 2012).

According to Foord and Taggart (1998), the Pirozeh (turquoise) group of minerals consists of at least five end-members (Table 1). Images by Scanning Electron Microscope (SEM) are produced by scanning the beam while displaying the signal from an electron detector on a TV screen or computer monitor (Reed, 2005). It has lots of applications in geology including the mineralogy by which one can be able to study the minerals in more details by magnifying the samples up to nanometers. The first SEM images of Pirozeh (turquoise) crystals have been recorded by Murr (1979) from chalk Pirozeh (turquoise) samples of Nogales, Mexico. SEM-EDS analysis revealed that the Pirozeh (turquoise) group samples (mostly aheylite and planerite in mineralogy) collected from different



Table 1. Pirozeh (turquoise) group endmembers and their chemical formulae (Foord and Taggart, 1998).

Mineral	Chemical Formula	Color	Luster	Hardness
Aheylite	$\text{Fe}^{2+}\text{Al}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	Pale blue, green and blue-green	Vitreous, dull	5-5.5
Chalcosiderite	$\text{CuFe}^{3+}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	Apple green, dark green	Vitreous, glassy	4.5
Faustite	$(\text{Zn,Cu})\text{Al}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	Apple green	Chalky, earthy, dull	5.5
Planerite	$\text{Al}_6(\text{PO}_4)_2(\text{PO}_3\text{OH})_2(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	Green, pale blue, green and blue-green, white, olive	Vitreous, dull	5
Pirozeh (turquoise)	$\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	Pale green, blue-green, Pirozeh (turquoise) blue	Waxy	5-6
UM1981-32-PO:FeH	$\text{Fe}^{2+}\text{Fe}^{3+}_6(\text{PO}_4)_{4-x}[\text{PO}_3(\text{OH})]_x(\text{OH})_8 \cdot 4(\text{H}_2\text{O})$	No information	No information	No information

museums and universities are micro-crystalline to macro-crystalline and most of them show zoning where more green and blue colors are resulted from more iron and copper concentrations, respectively (Foord and Taggart, 1998). Krotki (2002) has used SEM for studying the Pirozeh (turquoise) crystals that were firstly reported by Schaller (1912) from the Lynch Station, Virginia. His observations resulted in finding tiny Pirozeh (turquoise) crystals up to 1 mm in diameter. Sub-microstructures of Pirozeh (turquoise) samples are studied by Yang et al. (2003) that resulted in finding slight differences between different types of Pirozeh (turquoise) samples of Maanshan area, China. Frost et al. (2006) have used SEM-EDAX analysis for acquiring the composition of Pirozeh (turquoise) samples of museum Victoria. SEM-EDS analysis has been also used for investigating the Pirozeh (turquoise) treatments and imitations (Salanne, 2009). Thibodeau (2012) has used SEM accompanied by energy-dispersive X-ray attachment (EDS) for analyzing the Pirozeh (turquoise) samples. His studies revealed the presence of Silicon (Si) and Calcium (Ca) in Pirozeh (turquoise)s. Also, he used Pb and Sr isotopic data for determining the sources of Pirozeh (turquoise). SEM analysis of Baghu Pirozeh (turquoise) samples is reported by Liaghat et al. (2008) where they have recorded alunite mineral as inclusions in Pirozeh (turquoise) samples. Albeit, they did not illustrate any SEM image but EDS analytical results in which the concentration of major elements have been measured.

The Baghu and Nishapur Pirozeh (turquoise) mines are located at Nishapur and Binalud structural zones, respectively (Fig. 1). The Nishapur Pirozeh (turquoise) mine is a part of Cenozoic continental magmatic arc of northern Sabzevar ophiolitic zone which is extended in a NW-SE trend (Karimpour et al., 2011). It is located at northwestern Nishapur city and

southern Quchan volcanic belt. The most important rock units of area include lavas and andesitic-dacitic pyroclastics of Eocene age (Ovissi et al., 2017). Diorite porphyry to syenite porphyry sub-volcanic intrusions have pierced the area. The alteration zones can be divided into four major zones: silicic, argillic, carbonate and propylitic (Karimpour et al., 2011). The Pirozeh (turquoise) mineralization is occurred as veins and veinlets controlled by structural units. The Pirozeh (turquoise) veins cut all previous sulfide-oxide mineralization phases (Karimpour et al., 2011).

The Fig. 2 illustrates the geological map of the Nishapur Pirozeh (turquoise) mine. The Baghu area located at Toroud-Chahshirin volcanic belt is confined between Anjilu fault in north and Toroud fault in south (Keynezhad et al., 2010). The Pirozeh (turquoise) deposit is hosted by Toroud-Chahshirin intrusive-volcanic belt (middle Eocene). Lithological units comprise andesite, rhyolite, granodiorite and dacite (Fig. 3). The ore minerals occur as disseminated grains and veinlets in granodioritic to dacitic units (Liaghat et al., 2008). Liaghat et al. (2008) assumed the interaction of Cu-P-Fe bearing solutions (resulted from supergene conditions) and Al-bearing minerals such as alunite as the main proposal for the Pirozeh (turquoise) mineralization. The aim of this paper is to describe the Pirozeh (turquoise) samples of Baghu (Damghan) and Nishapur areas by the use of scanning electron microscope (SEM). The samples are also analyzed by EDS for measuring the major element concentrations of Pirozeh (turquoise) group minerals as well as other mineral phases accompanying them. The EDS will provide a semi-quantitative result by which we were able to identify the mineral phases. The results show that the origin of the Pirozeh (turquoise) samples from these areas can be determined by scanning electron microscopy due to their different mineral assemblages and textures.

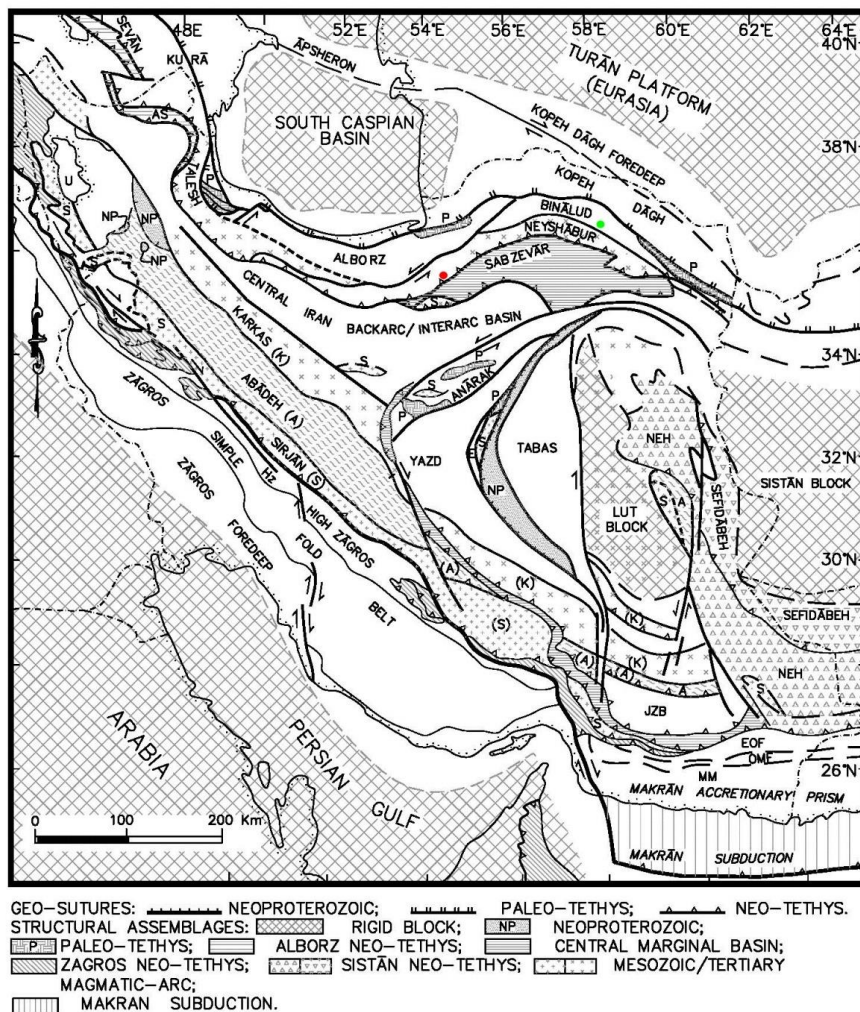


Fig. 1. The structural zones of Iran (Berberian, 2014). The Baghu (red circle) and Nishapur (green circle) Pirozeh (turquoise) mines are shown.

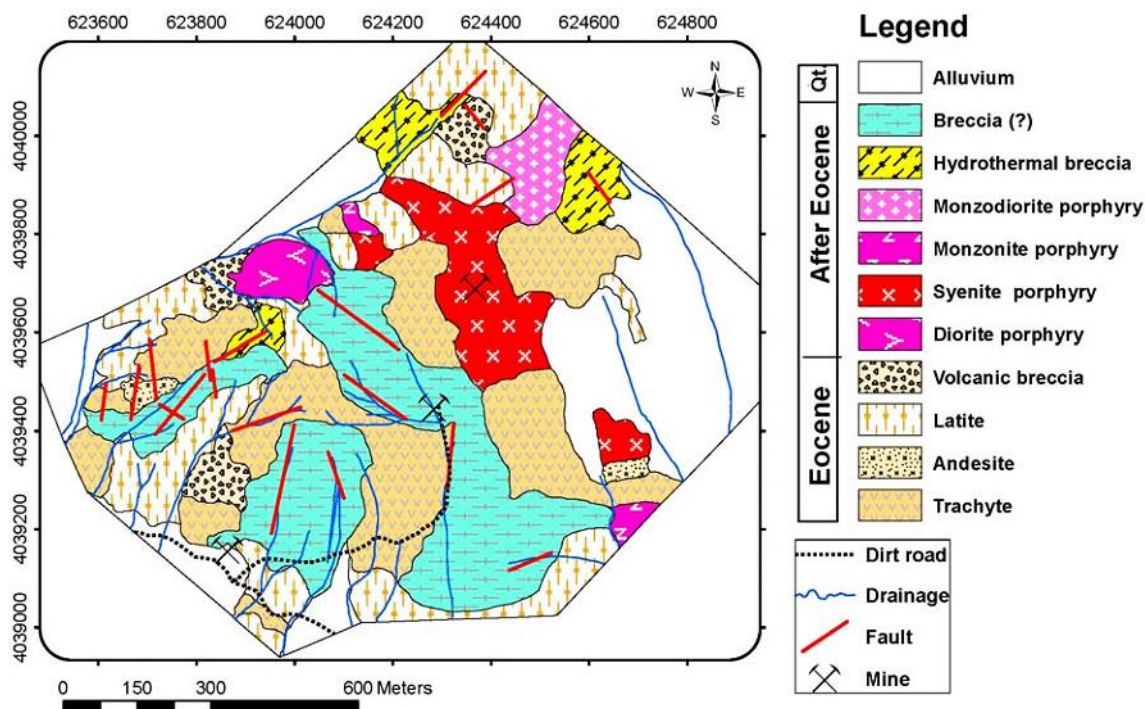


Fig. 2. The geological map of Nishapur Pirozeh (turquoise) mine (Karimpour et al., 2011).

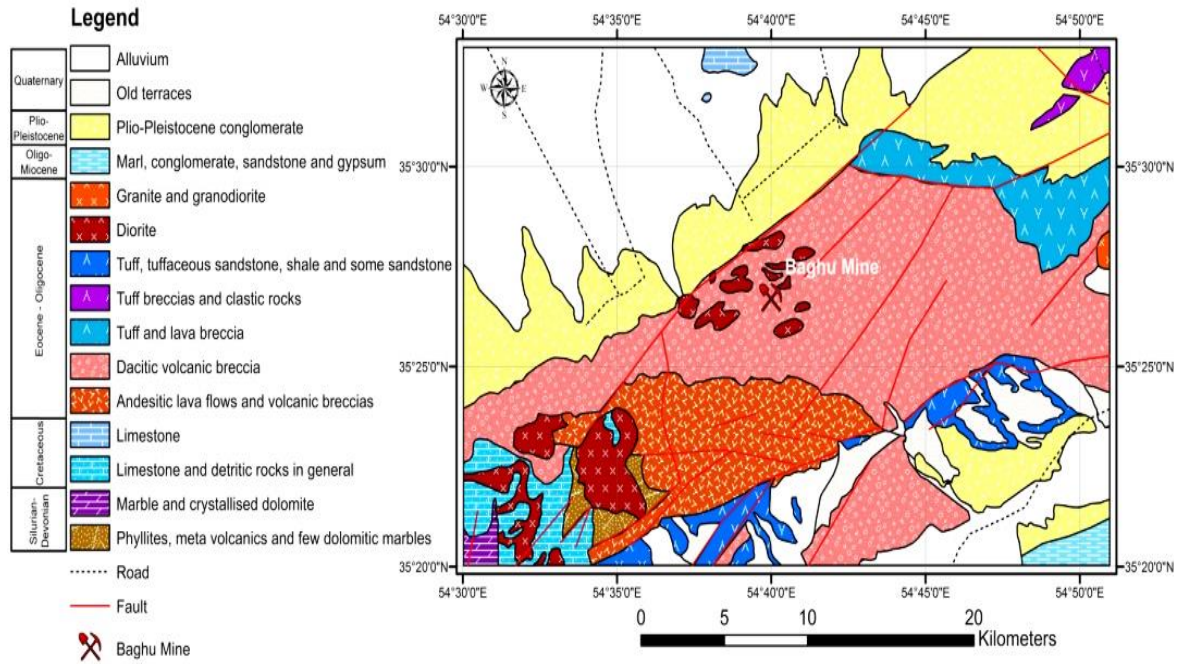


Fig. 3. The geological map of the Baghu area (Liaghat et al., 2008).

2. Material and methods

Ten Pirozeh (turquoise) samples from Neyshabur (NT) and Baghu (BT) areas (Figs 4-6) are studied using a scanning electron microscope (TESCAN, VEGA II, XMU, Czech Republic) at a beam voltage of 20 kV equipped with an EDS analyzer. Selected samples from Neyshabur Pirozeh (turquoise) include NT02,

NT05, NT08, NT11, NT12 and from Baghu Pirozeh (turquoise) include BT01, BT02, BT04, NT05, NT08. The samples were firstly coated by gold and then each sample was studied carefully where backscattered (BSE) images of all samples were provided. While studying the samples, wherever different mineral phases were identified, EDS analysis have been performed for analyzing the chemical composition of the unknown phase.



Fig. 4. The location of NT02, NT05, NT08, NT11, NT12 samples in andesite host rock. The main extraction tunnel in Nishapur turquoise mine.



Fig. 5. The location of BT01, BT02, BT04, NT05, NT08 samples in andesite host rock. The main extraction tunnel in Baghu turquoise mine. The turquoise associated with chlorite and Fe-oxides in the silicified veinlets.

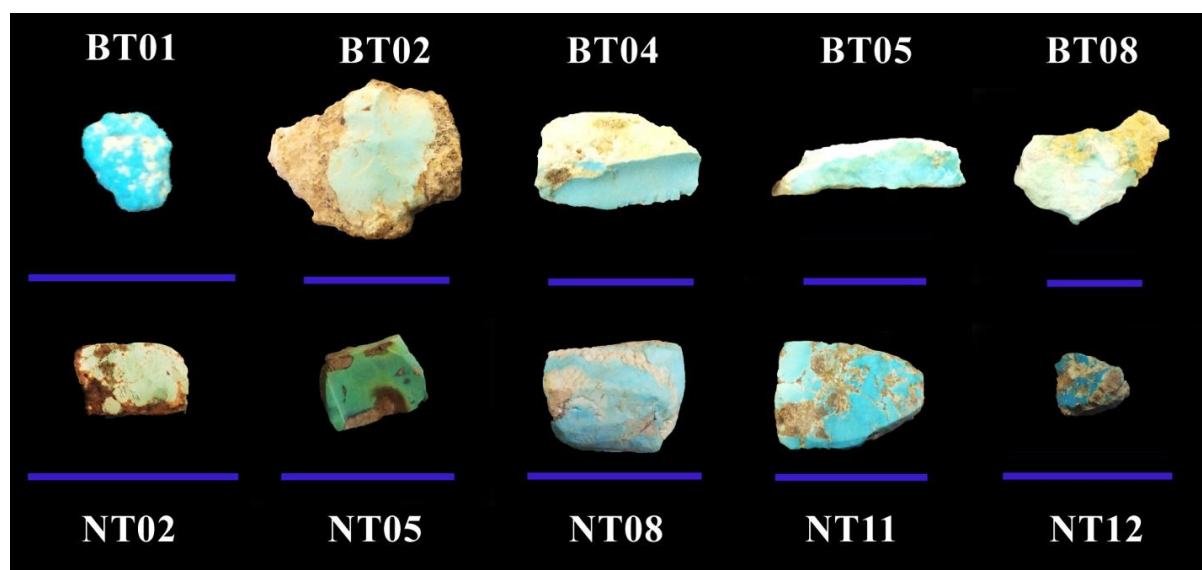


Fig. 6. The Pirozeh (turquoise) samples of Baghu (BT) and Neyshabur (NT) areas studied by SEM-EDS. The color bar below each sample comprises the scale (1 cm for Baghu and 3 cm for Neyshabur samples).

3. Results and Discussion

Different color shades of Pirozeh (turquoise) samples were chosen in order to identifying their different mineral phases (Fig. 6 and Table 2). The colors include different shades of blue (from pale Pirozeh (turquoise)

blue to royal blue) and green. Each sample is carefully studied under the SEM in BSE mode where we were able to distinguish different mineral phases. Firstly, the texture of samples is illustrated and afterwards the chemical compositions of different mineral phases in each sample will be presented.

3.1. Backscattered Scanning Electron (BSE) Imaging

Backscattered scanning electron microscopy (BSE) reveals the minerals, textures, and fabrics of sediments and rocks in much greater detail than is possible with conventional optical microscopy (Kransley et al., 2005). In this study BSE imaging is used for distinguishing different mineral phases and textures of the Pirozeh (turquoise) samples. The results show that BSE is a powerful tool for studying Pirozeh (turquoise) mineral and its accompanied mineral assemblages. The Fig. 7 shows BSE images of Pirozeh (turquoise) samples of Baghu and Nishapur areas in a magnification ratio of 100x.

Pirozeh (turquoise) under a microscope reveals clear texture and color but under the features in BSE image differs completely. In all samples, matrix appears as dark brown to black, pattern and composition of the matrix are different also. Without analyzing it is difficult to reveal the matrix and other components. For

example, in samples of BT05, matrix has an integrated texture. Hard Pirozeh (turquoise) such as sample No. NT05 appears relatively solid and non-porous. Samples such as BT02 has microcrystalline aggregate texture. It seems all samples have uneven color and texture distribution.

As it can be observed in Fig. 5, the Nishapur samples are of more uniform texture compared to those of Baghu area. In this scale of view, at least two mineral phases can be distinguished in Baghu samples (BT01, BT02, and BT05) while apparently the Nishapur samples are showing just one mineral phase. In next lines we will zoom on each sample to see what other mineral phases can be identified. In the meanwhile, it can be suggested that due to their more uniform texture, the Nishapur Pirozeh (turquoise) samples are of more quality. Having other mineral phases than Pirozeh (turquoise) can extremely cause lower qualities of gemstone and color. It should be noted that the BSE images are taken from those parts of samples where a uniform texture was expected.

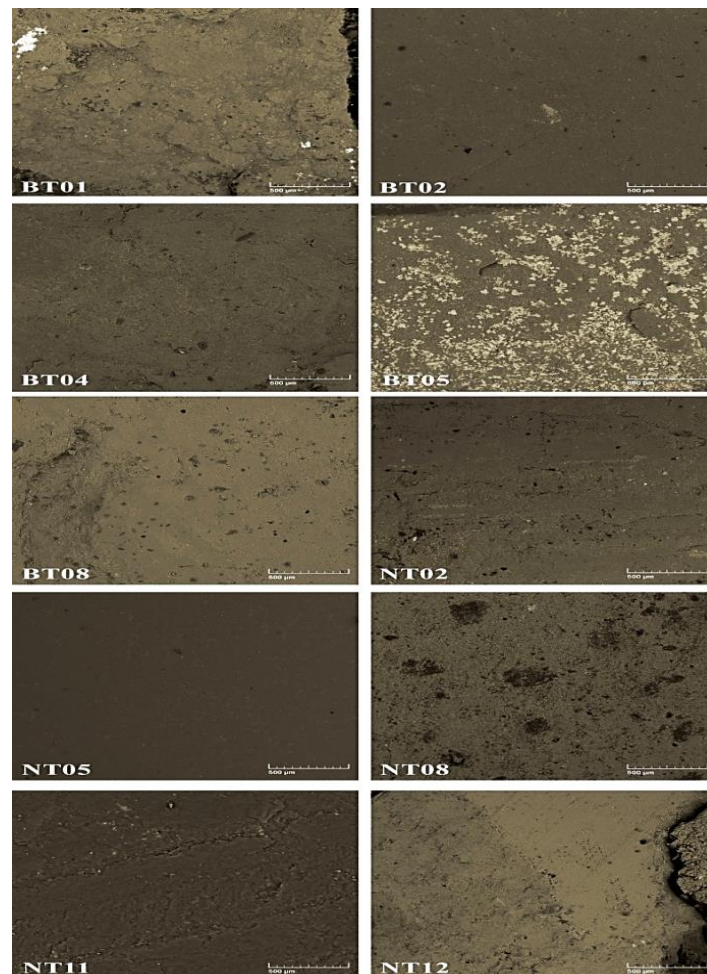


Fig. 7. The BSE images of Pirozeh (turquoise) samples from Baghu (BT) and Nishapur (NT) areas in a magnification ratio of 100x.

3.2. EDS Analysis of mineral phases

Each sample is studied in details in order to define the mineral phases and their textural relationships. For this purpose, the samples are studied in higher magnification ratios up to 5.00 kx. Wherever a different mineral phase is identified, an EDS analysis is performed for measuring the major element concentrations. Initially, the Baghu samples and afterwards the Nishapur samples will be discussed in next lines.

3.2.1. Baghu samples

Five samples from Baghu area are chosen for this research. These samples include the following minerals such as BT01 (A turquoise, B barite), BT02 (A barite, B iron oxides, C turquoise), BT04 (A turquoise, B turquoise, C iron oxides), BT05 (A turquoise, B barite, C

barite, D apatite), BT08 (A quartz, B turquoise, C turquoise). The BT01, BT02, and BT05 samples showed a completely different mineral phase in their BSE images (Fig. 8). The mineral phases are analyzed by EDS and the results suggest that the unknown bright mineral phase is barite. Well-formed barite blades identified in sample BT05 up to 15 μm in diameter. The EDS analytical results are available at Table 2. The sample BT02 is of another mineral phase that is identified as iron oxides that due to its irregular form it is suggested to be the product of supergene environments after iron sulfides oxidization. As it can be observed in BSE image of sample BT02 (Fig. 6), the barite mineralization is as veinlets cutting the Pirozeh (turquoise) mineral. So, it can be concluded that in despite to what is reported by Liaghat et al. (2008), the Pirozeh (turquoise) mineralization is not the last mineralization phase of Baghu area.

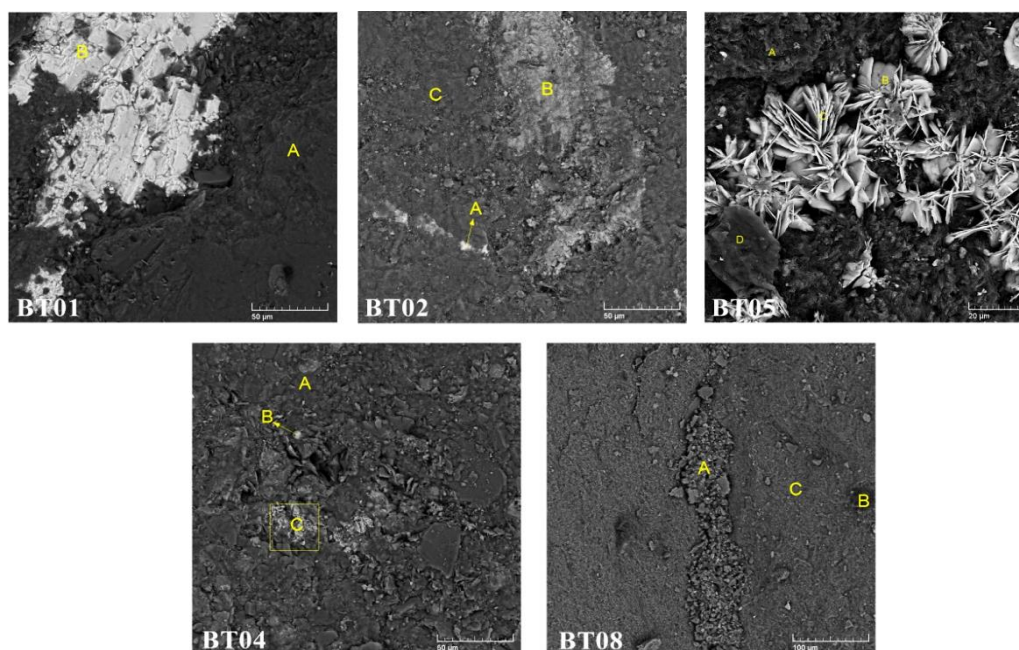


Fig. 8. BSE images of Baghu Pirozeh (turquoise) samples and the points on which EDS analysis are performed.

The sample BT04 has a different story in which the EDS results suggest just one mineral phase. The atomic percentages of its elements propose an Al-bearing silicate such as K-feldspar or kaolinite. The copper and iron concentrations accompanied by phosphorus content can lead to Pirozeh (turquoise) mineralization. According to Liaghat et al. (2008) the Pirozeh (turquoise) mineralization is occurred after alunite where the Pirozeh (turquoise) is growing from the marginal to central parts of alunite nodules. Since sulfur is not reported in the sample BT04,

so alunite cannot be the parent phase of Pirozeh (turquoise) mineralization in this case. London (1992) has reported the feldspars as a source of P where they can participate in aluminum phosphate and sulphate mineralization. So, Pirozeh (turquoise) mineralization after alkali-feldspars can be one possibility. Albeit, proving this needs more data including EPMA analysis on alkali-feldspars of host rocks of area and more detailed petrographic studies. Apatite is observed as individual grains in BT05 sample (Table 2) that can be one of the main sources of

P in Pirozeh (turquoise) mineralization. The BT08 sample is composed of Pirozeh

(turquoise) group minerals where quartz can be found as veinlets.

Table 2. The EDS analytical results of Baghu Pirozeh (turquoise) samples.

Sample Code	Point	Elemental Concentrations (W%)												Mineral	
		O	Al	Si	P	K	Fe	Cu	Ba	S	Ca	Sr	Mg		Ce
BT01	A	56.29	19.07	4.85	14.73	0.52	0.51	3.32	0.72	-	-	-	-	-	Pirozeh (turquoise) Group
	B	21.72	-	-	0.00	-	0.24	0.47	62.95	14.62	-	-	-	-	Barite
BT02	A	37.98	6.44	2.25	5.87	-	0.31	2.04	33.14	11.97	-	-	-	-	Barite
	B	44.34	1.32	4.04	1.74	-	47.15	1.40	-	-	-	-	-	-	Iron Oxides
	C	56.60	18.56	4.39	14.99	-	1.38	4.07	-	-	-	-	-	-	Pirozeh (turquoise) Group
BT04	A	53.63	18.40	23.10	0.59	2.16	1.46	0.65	-	-	-	-	-	-	Pirozeh (turquoise) Group
	B	57.90	7.12	15.47	17.70	0.49	0.66	0.67	-	-	-	-	-	-	Pirozeh (turquoise) Group
	C	49.45	9.66	8.94	1.70	1.08	28.63	0.53	-	-	-	-	-	-	Iron Oxides
BT05	A	58.30	18.85	-	16.17	-	1.20	5.48	-	-	-	-	-	-	Pirozeh (turquoise) Group
	B	47.60	3.54	-	-	-	-	1.10	18.78	13.49	0.82	14.67	-	-	Barite
	C	34.53	0.82	-	-	-	-	0.77	28.66	16.65	0.98	17.59	-	-	Barite
	D	55.36	0.69	-	15.79	-	-	0.59	-	-	25.69	-	1.16	0.72	Apatite
	A	60.03	4.98	18.68	2.74	0.93	3.25	0.91	-	-	8.48	-	-	-	Quartz
BT08	B	62.83	17.50	1.03	12.92	-	0.85	4.86	-	-	-	-	-	-	Pirozeh (turquoise) Group
	C	62.13	17.34	0.90	14.46	-	0.95	4.21	-	-	-	-	-	-	Pirozeh (turquoise) Group

3.2.2. Nishapur samples

Five samples from Nishapur area are chosen for this research (Fig. 9). These samples include the following minerals such as NT02 (A turquoise, B iron oxides, C magnetite, D turquoise, E free gold grain), NT05 (A turquoise, B turquoise), NT08 (A turquoise, B turquoise, C pyrite), NT11 (A turquoise), NT12 (A turquoise, B free gold grain). The Nishapur samples are of more uniform texture but in a closer view they show different mineral phases including iron oxides, pyrite, free iron and occasionally barite. Another important identified mineral phase in Nishapur samples is free gold which is observed in two samples (NT02 and NT12). The Pirozeh (turquoise) group minerals are surrounding all these mineral phases and this can be concluded that the Pirozeh (turquoise) mineralization is the last mineralization phase of area. In samples NT02 and NT08 the Pirozeh (turquoise) is of high contents of silicon (up to 7.19 w%). The samples NT05 and NT11 have shown just Pirozeh (turquoise) as the only identified mineral phase. The EDS analytical results of

Nishapur samples can be found in Fig. 9 and Table 3.

3.3. Comparison of Iran Pirozeh (turquoise) whit USA and China turquoises

Comparing the Iranian, American, and Chinese turquoise provides a scientific basis for their differing in geological conditions, host rocks, geochemistry, appearances, texture and color. The basic formula for all these turquoises is $\text{CuAl}_6(\text{PO}_4)_4(\text{OH})_8 \cdot 4\text{H}_2\text{O}$. Copper (Cu) is responsible for the blue color. Aluminum (Al) is core structural component. Phosphorus (P) is phosphate ions in structural component. Water (H_2O) is another major component of the crystal structure. The variations in color and texture arise from elemental substitutions within this crystal structure. For example, iron (Fe^{3+}) can substitute for aluminum (Al^{3+}). This is the most important substitution, shifting the color from blue to green. Zinc (Zn^{2+}) can substitute for Copper (Cu^{2+}). This creates the bright apple-green mineral known as faustite, which is often intermixed with turquoise. Chrome (Cr) or Vanadium (V) can also cause green color but are less common.

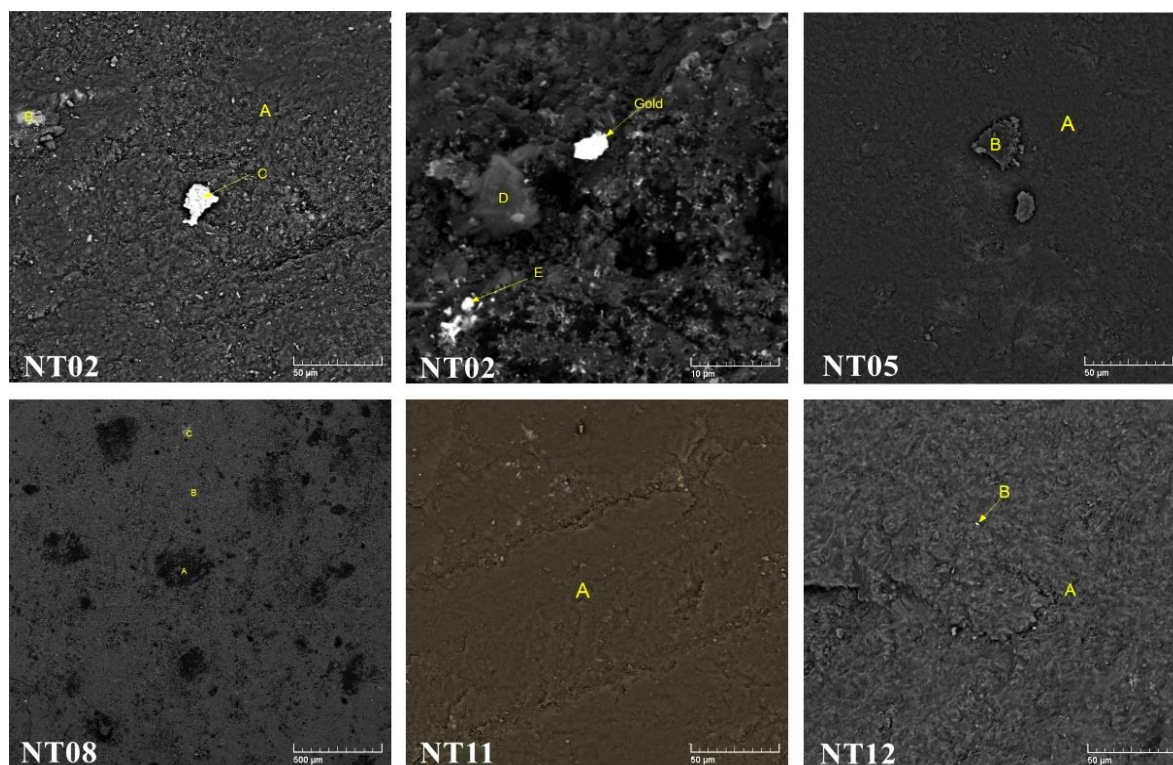


Fig. 9. BSE images of Neyshabur Pirozeh (turquoise) samples and the points on which EDS analysis are performed.

Table 3. The EDS analytical results of Nishapur Pirozeh (turquoise) samples.

Sample Code	Point	Elemental Concentrations (W%)									Mineral
		O	Al	Si	P	K	Fe	Cu	S	Au	
NT02	A	61.14	18.41	1.23	14.81	-	1.37	3.04	-	-	Pirozeh (turquoise) Group
	B	49.33	3.95	2.31	2.82	-	40.93	0.66	-	-	Iron Oxides
	C	9.31	1.47	2.31	1.93	-	84.08	0.90	-	-	Iron
	D	63.51	17.53	7.19	8.59	0.13	0.74	2.31	-	-	Pirozeh (turquoise) Group
	E	35.37	6.80	1.26	5.05	0.70	-	2.15	0.66	48.00	Free Gold
NT05	Gold	26.54	5.22	1.09	4.21	-	-	2.31	0.59	60.04	Free Gold
	A	56.72	19.10	0.55	18.02	-	2.11	3.49	-	-	Pirozeh (turquoise) Group
NT08	B	58.32	17.62	0.89	19.44	0.43	1.38	1.91	-	-	Pirozeh (turquoise) Group
	A	49.80	23.34	1.89	17.89	-	-	7.09	-	-	Pirozeh (turquoise) Group
NT11	B	50.65	21.86	6.15	16.38	-	-	4.97	-	-	Pirozeh (turquoise) Group
	C	47.81	6.32	2.15	5.94	4.91	19.80	1.92	11.14	-	Pyrite
NT12	A	55.01	20.41	1.43	17.62	-	0.62	4.92	-	-	Pirozeh (turquoise) Group
	A	56.42	20.62	0.98	16.95	0.19	0.36	4.48	-	-	Pirozeh (turquoise) Group
	B	34.50	8.43	1.03	5.71	0.43	0.18	2.15	0.42	47.14	Free Gold

Iran's Pirozeh (turquoise) is perfect blue, low-iron, high-aluminum and by volcanic host rock. America's turquoise is green-blue, high copper, iron, zinc and its geochemistry are a direct fingerprint of the parent copper porphyry system. China's turquoise is green-black-blue and its geochemistry is defined by an iron-rich, carbonaceous sedimentary environment. Iran's

unique volcanic geology created a perfect storm for ideal Pirozeh (turquoise). America's numerous copper deposits create a diverse spectrum of turquoise. China's sedimentary deposits produce abundant but geochemically compromised material that requires significant treatment to mimic the qualities of the finest Persian and American turquoises (Table 4).

Table 4. Comparison of Iran turquoise whit USA and China turquoise (Staples, 2021 and Yiheng et al., 2023).

Feature	Iran	China	USA
Famous source	Nishapur and Baghu	Hubei	Colorado
Host rocks	Trachyte and andesite	Sedimentary copper	andesite
Composition	Low Fe, High Al Fe-oxides	High Fe, Organic C & P	Highly Variable Fe & Zn Fe-oxides (brown/red), Mn-oxides (black),
Matrix Composition	(limonite/hematite - brown), Mn-oxides(black)	sharp black spider-webbing	Jasper (red), Pyrite (metallic), Green-blue
Color	intense sky-blue	yellow-green hues	Green-blue
Trace Elements	Cu	Zn	Ba

4. Conclusion

The Pirozeh (turquoise) from the Baghu (also commonly spelled Bāghū) and Nishapur (Nishapur) mines in Iran are among the most famous and historically significant in the world. While they originate from the same geological province, their geochemistry and resulting appearance have distinct characteristics. They are classified as supergene hydrothermal ore deposits, formed by the action of circulating heated meteoric water. Selected samples Pirozeh (turquoise) samples from Nishapur and Baghu Pirozeh (turquoise) mines used in this research for studying their mineral assemblages and textures by using of the SEM-EDS. The BSE images show that the Nishapur samples have generally of uniform uneven color and texture while those of Baghu area show different mineral assemblages as veinlets and/or individual crystals. The identified mineral phases in Baghu area include Pirozeh (turquoise) group minerals, barite, iron oxides, apatite and quartz. The Baghu Pirozeh (turquoise) samples are characterized by the occurrence of well-formed barite blades that have microcrystalline intergrowth on Pirozeh (turquoise) group minerals. The occurrence of barite as veinlets in Pirozeh (turquoise) group minerals of Baghu area shows that the Pirozeh (turquoise) mineralization is not the last mineralization phase of area. By observing apatite as one of the mineral phases accompanying the Pirozeh (turquoise) group minerals, it can be suggested that apatite is one of the main sources of P in area. On the other hand, due to elemental composition of sample BT04, K-feldspar can be one of the possible sources of P in Baghu area acting as the parent mineral of Pirozeh (turquoise) mineralization. Quartz is identified as veins and veinlets in Baghu samples. The Nishapur samples are characterized by the occurrence of free gold inclusions as individual grains up to 4 μm in diameter. Iron-oxides, iron and pyrite are other

mineral phases identified in Nishapur Pirozeh (turquoise) samples. The EDS results suggest that by increasing the Cu content of Pirozeh (turquoise) group minerals their colors move to deeper blue while in contrast green Pirozeh (turquoise) minerals are of notable concentration of Fe. For instance, the higher Cu/Fe ratio can be found in sample NT12 where it shows the deeper blue color among all studied samples. Anyway, the data propose that the Cu and Fe concentrations of Pirozeh (turquoise) group minerals are not the only factors affecting the color of this gemstone. The geochemistry of Nishapur turquoise is defined by high Cu, high Al, and very low Fe/Zn. This results in its celebrated stable blue color. But the Baghu turquoise is geochemically distinct due to its higher Fe content. This acts the color from pure blue into the green-blue and green spectrum.

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