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| RESEARCH ARTICLE

Investigation of the Effects of High-Grade Metamorphism on the Quality of Badakhshan-Sarsang Lapis Lazuli

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| ABSTRACT

This research was conducted to investigate the effect of metamorphism on the quality of lapis lazuli from the Sarsang mine of Karan and Manjan districts of Badakhshan province. Sarsang lapis lazuli mine is one of the most important lapis lazuli reserves in Afghanistan and the lapis lazuli stone in this region has different characteristics in terms of color, mineral composition, structure and quality. In this research, field, analytical-descriptive and laboratory methods were used and samples of lapis lazuli and adjacent rocks were collected and studied from different profiles of the mine. Geological studies show that the lapis lazuli deposits of Badakhshan are related to granitoids and metasomatosis of marbles and claspspheres has been involved in the formation of lapis lazuli rocks. The mineral composition of the samples includes minerals such as lazulite, diopside, calcite, dolomite, feldspars, scapolite, flagopite, forsterite and pyrite. The results of petrographic studies and XRF analysis show that the studied samples differ from each other in terms of mineral composition and the amount of chemical elements, and various metamorphic rocks, including micromarble, silicate marbles, pyroxene skarn, magnetite skarn and lapis lazuli, lapis lazuli and lapis lazuli, area are observed. According to the results in the paper, the processes of metamorphism and metasomatosis are closely related to the formation and characteristics of lapis lazuli host rocks and contribute to the mineral and qualitative differences of lapis lazuli.

| KEYWORDS

Lapis lazuli, metamorphism, petrography, XRF analysis, metasomatosis.

| ARTICLE INFORMATION

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1. Introduction

Since the beginning of mankind, the life and destiny of human beings has been tied to precious and semi-precious stones; Precious stones and non-ferrous metals were the first tools that humans first used in their trade. Precious and semi-precious stones were used not only in trade but also as a tool to show the power and wealth of the nobility to the common people. Rarity, beautiful effects, variety of colors and high hardness were all factors that created value, political and commercial weight in precious and semi-precious stones.For many years, the geography and towering mountains of Afghanistan have been giving the people of this country the good news of an economy based on natural resources and minerals and hope for a better and brighter tomorrow; Our beloved country has large reserves of precious and semi-precious stones in the world, which can be mentioned as the Badakhshan lapis lazuli mine, which has a high capacity to produce lapis lazuli in the world (Shigley,2020 & Omrani,2010). Lapis lazuli is derived from the Greek word Lapis Lazuli, meaning blue stone. Accordingly, it can be said that the name of this stone has gone from Persian to other cultures (Richter-Bernburg,2024). Polished lapis lazuli sheets with pyrite grains inside have been likened to the starry sky in the East (Fararu,2012). Lapis lazuli has the chemical formula Na6Ca [Al2 SiO4] (SO4 S) and its main compounds are SiO2, Al2O3, SO3, CaO, Na2O). The mineral has a cubic rock, glass polish, incomplete porosity, grade (5.5-6) specific gravity (3.4) of contact-metasomatic origin, its color is dark blue, purple and greenish blue(BenchChem,2026). From the studies of the chemical composition of the Badakhshan lapis lazuli mine, it is known that the characteristics of this mine are close to the characteristics of the Chilean and former Soviet Union mines, as well as the amount of Al2O3 and Ca and Na compounds are also close (Pajhwok, 2019). Faiz Abad is the capital of Badakhshan province. Lapis lazuli is a blue metamorphic stone that has been used by people for thousands of years as a precious stone, for sculpture, pigment production and decorative materials. This high-quality stone can be an expensive gemstone. Lapis lazuli is also found in diopside, calcite, dolomite, mostly feld9spars, scapolite, sodalite, flagopite, forsterite, glauconite and pyrite. Lapis lazuli (25-60%) also contains the mineral lapis lazuli(faryad,2012). This stone is used as ornamental and decorative sinks. It is medium-grained; Its color is blue, purple, blue-green, purple and pear-like varieties, etc. are also observed (Sahak, 2012). The stone is located deep in the Hindu Kush mountains, which is difficult to access; Because of the difficult passage and unfavorable weather during the seasons; It is only open for a few months in the summer. Lapis lazuli is found in veins containing calcite and dolomite, along with the minerals diopside, scapolite and forsterite. Pyrite is also present and its color varies depending on the inclusions in its composition (Ministry of Mines and Petroleum,2019).

2. Literature Survey

Afghan lapis lazuli was exported to ancient civilizations such as Greece, Persia, India, and China in the past. Badakhshan lapis lazuli was mined here 6,500 years ago. The discovery of Afghan lapis lazuli in the Egyptian pyramids in the Dushor area testifies to the trade disputes between Afghanistan and Egypt (4,400) years ago, which took place at a distance of 3,220 km (Bariand, 1979).
Cleopatra (Egyptian pharaoh who ruled Egypt in 50 BC) used lapis lazuli powder to paint her eyes on her face because lapis lazuli was considered very important (Bariand, 1972).
Alexander the Great visited the lapis lazuli area of Badakhshan and increased its fame and expanded it. Afghan lapis lazuli was also famous in China in 800 BC and was used in the engraving industry. In 1273, Marco Polo traveled to China to find trade routes through Central Asia and Badakhshan, and wrote about Badakhshan lapis lazuli: "The mountains of Badakhshan have lapis lazuli veins, and this stone is blue, which is the most beautiful stone in the world" (Rustai, 2017). The Badakhshan Stone Mine has been published, which is more focused on crystals and deposits of lapis lazuli and The Ministry of Mines and Petroleum has also conducted studies on lapis lazuli mines with Russian experts since the 1950s, preparing maps at 1:500,000.Global Witness conducted two years of research in the geological and economic sectors of lapis lazuli in 2015-2014(Shigley,2020 & Omrani,2010).

2.1 Geology and geography of the region

The lapis lazuli mine areas, which belong to Karan and Manjan districts, are located at an altitude of (800) to (1500m) above sea level in Kokcheh and at an altitude of (3500-4000m) above sea level.The area has a temperate and pleasant climate, that is, the summer is relatively cold, the winter is cold, the weather is cold, it rains days and nights, and its high altitude is covered with snow. They are and make a living from it. It should be noted that along the route of about (15 km) from the south of the area called the project is a village and to the area of Rabat to the north of the sea route Kokcheh no residential neighborhood except a small village that about (10) families lived in it does not seem to be a residential area(Firooz,1978 & .tolonews,2011)
During the years (1963-1964) in the upper basin of the Kokcheh Sea in the Sarsang mine, geological research was carried out by former Soviet experts, who made a geological, schematic map of the upper part of the Kokcheh Sea on a scale of (1:20,000). The studied mine area, which is very simple in terms of geological structure, is located in the southern part of Badakhshan and generally consists of Sakhi Suite formations. Orthoamphibolites are formed in the form of dykes. The lapis lazuli mines of Badakhshan are spread among the Archaic (AR) formations and are structurally related to the granitoids, which have caused the metasomatosis of marbles and calcifers. These metasomatites, which are mostly composed of diopside, flagopite and feldspathoid minerals (gauin, sodalite, calcite and other colorless minerals probably belonging to the sodalite group), contain lapis lazuli, which is of fundamental industrial importance(Musazai,2017 & Rahmani,2017).
Large lapis lazuli fragments, sometimes weighing up to 100 kg, are inhomogeneous, while smaller fragments up to 10 kg are relatively homogeneous (Bariand, 1972).

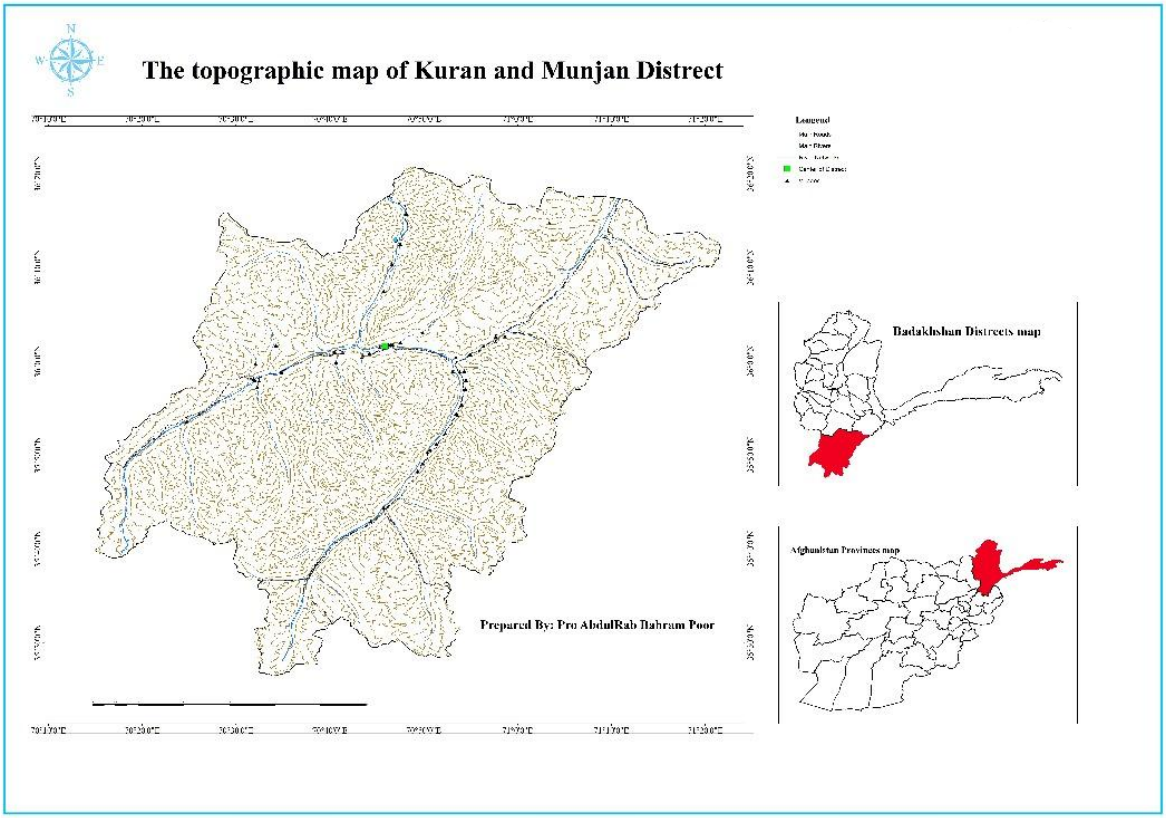

Figure1. Topography map of Sarsang lapis lazuli mine in Badakhshan

3. Methods

Field, data collection (analytical-descriptive) and laboratory methods were used in writing the article. In the field method, the Sarsang mine was visited. During the visit, the necessary parameters were measured and several samples of different profiles were taken from the selected mine area of lapis lazuli and adjacent rocks to study the effects of metamorphism on the quality of lapis lazuli; National and international reports and books have also been used and the samples have been analyzed. After analyzing the above method, the effects of metamorphism on the quality of lapis lazuli have been discussed in detail.

4. Results and Discussion

4.1. Results of Petrographic Studies of Samples 1 and 2

According to Table 1, microscopic studies of samples 1 and 2 show significant differences in mineral composition, structure, texture, grain size and rock type. Sample No. 1 is composed of carbonates, quartz and pyrite. The presence of carbonates alongside quartz and pyrite indicates a different mineral composition of this sample compared to other samples examined. Structurally, the sample has a microgranoblastic structure and mass texture, and its grain size is recorded to be about 0.01 to 0.1 mm. According to petrographic classification, sample No. 1 is placed in the group of metamorphic rocks and is named micromarble.

Sample No. 2 differs from sample No. 1 in terms of mineral composition. The minerals olivine, lazulite, calcite, quartz and pyroxene were identified in this sample. The presence of lazulite in the composition of the sample is of special significance, as this mineral is one of the main components associated with the lapis lazuli stone. The composition of olivine and pyroxene also indicates the mineralogical difference of this sample with the micromarble of sample No. 1. The structure of sample number 2 is reported to be nematogranoblastic and its texture is massive and petrographically introduced as metamorphic rock and silicate marble of the grain bed. Therefore, the results of Table 1 show that even in rocks within the same mineral range, the mineral composition and petrographic characteristics can be different. The presence of carbonate, quartz and pyrite in one sample and olivine, lazulite, calcite, quartz and pyroxene in another sample indicates the diversity of metamorphic rock composition in the study area.

Table 1. Specifications of Samples 1 and 2

Mineral composition	(1)Carbonates, quartz and pyrite	(2)Oluvine, lazulite, calcite, quartz and pyroxene
Structure	Microgranoblastosis	Nematogranuloblasty
Texture	Cattle	Cattle
Grain size	0.1-0.01mm	
Petrographic class	Metamorphic rock	Metamorphic rock
Stone name	Micromarble	Silicate marbles give grains

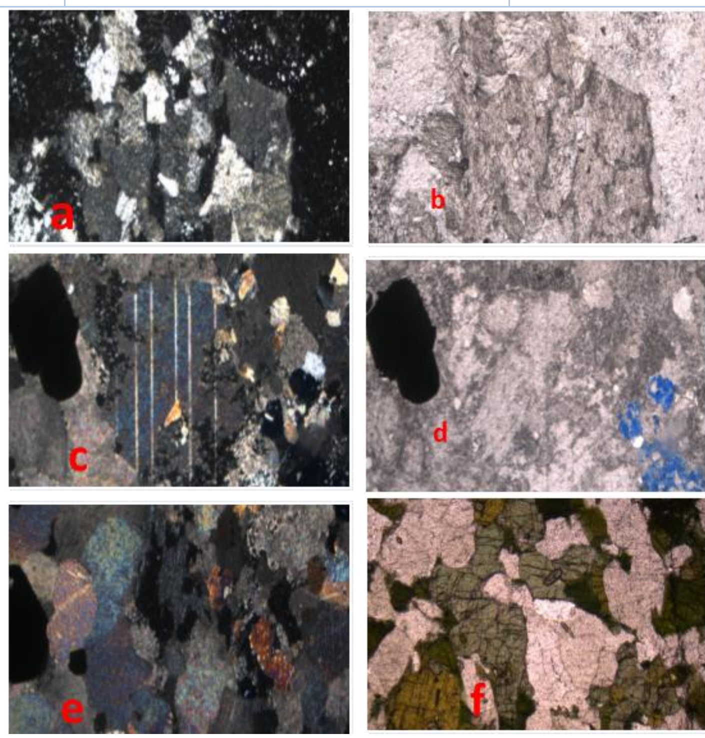

Figure 2. Microscopic images of samples 1 and 2

4.2. Results of microscopic studies of samples 3, 4 and 5

According to Table 2, microscopic studies of samples 3, 4 and 5 also show significant diversity in mineral composition and petrographic characteristics. Minerals such as tremolite, feldspar, lazulite, carbonate, actinalite, pyroxene, magnetite and calcite were identified in these samples. This mineral diversity indicates that the rocks associated with lapis lazuli in the Sarsang mine do not have the same composition. In the examined samples, nematogranoblastic and granoblastic structures were observed. Nematogranoblastic structure was recorded in two samples and granoblastic structure in one sample. The texture of the samples is mainly mass and in one sample the texture of the floor is reported. The size of the mineral grains is also in the range of about 0.05 to 0.5 mm and 0.2 to 0.5 mm. These features indicate differences in the texture and organization of the minerals that make up the rocks studied.

In terms of petrographic nomenclature, the samples studied include lazulite and trimalite, pyroxene skarn and magnetite skarn with lapis lazuli. Therefore, the results of Table 2 show that in the studied area, in addition to marble and silicate rocks, there are also skarni rocks and some of these rocks are directly associated with lapis lazuli.

Table 2. Microscopic characterization of samples (3.4.5).

Mineral composition	Trimalite, feldspar, lazulite and carbonate	Trimolite, actinalite, pyroxene, magnetite and calcite.	Contains tremolite, lazulite and carbonate
Structure	Nematogranuloblasty	Nematogranuloblasty	Granoblasty
Texture	Cattle	Cattle	Floor
Grain size	(0.05-0.5) millimeters	(0.2-0.5) millimeters	
Petrographic class	Metamorphic rock	Metamorphic rock	Metamorphic rock
Stone name	Lazulite and Trimalite Minerals	Pyroxene skarne	Magnetite shield with lapis lazuli

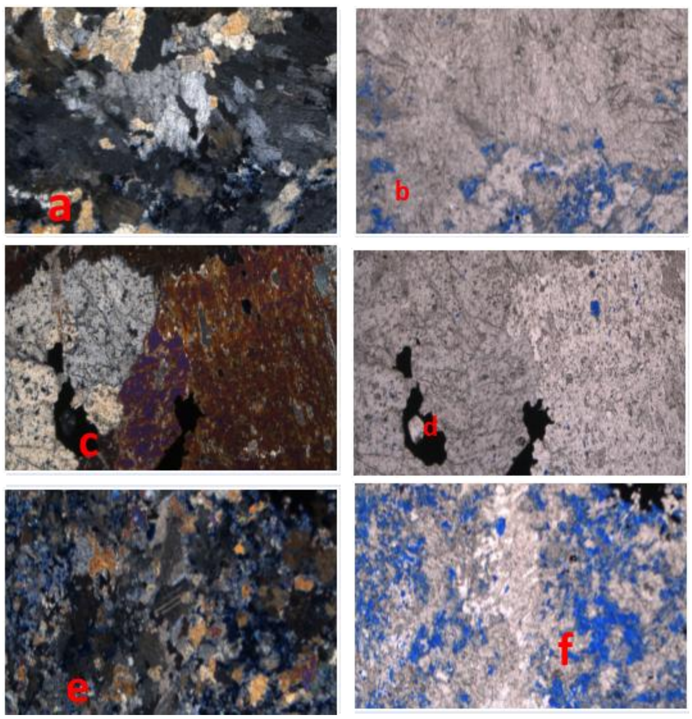

Figure 3. Microscopic images of samples 3.4.5

4.3. XRF analysis results of samples

Table No. 3 shows the XRF analysis results of the studied samples. In this analysis, various chemical elements in the samples were measured, among which Ca, Mg, Si, Al and S are prominent in the main results table. The amount of these elements is not the same in different samples and significant differences are observed between samples. The amount of calcium (Ca) in samples 1 to 8 was recorded as 144396, 241681, 216182, 146144, 157141, 140578, 277903 and 266721 respectively. According to these figures, the highest amount of Ca is observed in sample number 7 and the lowest amount is observed in sample number 6. The difference in Ca content between the samples could be related to the difference in their mineral composition; Because the petrographic results also report the presence of carbonates and various calcium-containing minerals. The amount of magnesium (Mg) in different samples also varies. The highest amount of Mg was recorded in sample No. 7, about 67055, and the lowest was recorded in sample No. 1, about 30487. Samples 6 and 8 also have about 41429 and 61487 Mg, respectively. This difference in Mg content is related to the presence of magnesium-containing minerals, including olivine and some silicate minerals; The article also introduces Mg-rich olivines among the index minerals of the samples.

Silicon is one of the elements that shows a very large variation in samples. The amount of Si in sample number 1 is about 201543, in sample number 2 about 105175 and in sample number 3 about 130151, while in samples 4, 5 and 6 its amount is about 190264, 193364 and 21960 respectively. In samples 7 and 8, the Si content decreases to about 19,976 and 20,686, respectively. Therefore, the very large difference in Si content between samples is one of the most characteristic results of XRF analysis. Aluminum (Al) also varies significantly in the samples. The Al content in different samples varies from about 5882 to 48009. The highest amount of Al is observed in sample number 3 and the lowest amount is observed in sample number 8. These changes are related to differences in the mineral composition of the samples, especially the presence of feldspars and other aluminum-bearing minerals. Sulfur (S) also has different amounts in different samples. The value of S ranges from about 2319 to 53978. The highest sulfur content was observed in sample No. 3 and the lowest was observed in sample No. 7. The presence of pyrite in some samples reported in petrographic studies can be related to the presence of S element in XRF results.

Table 3. Results ofXRF analysis of samples

Elements	M1	M2	M3	M4	M5	M6	M7
Ball	636909.938	650582.500	474667.938	512530.656	494731.438	512529.250	543627.063
Ca	266722.906	277902.844	140577.875	157141.063	146143.688	216181.578	241681.219
Mg	61487.148	67055.250	41429.426	44664.828	36712.813	42644.633	30982.881
Yes	20685.723	19976.033	196401.641	193363.000	190263.703	130150.984	105174.953
Al	5881.646	7082.482	48008.809	35630.656	45941.738	28161.103	32309.238
S	3139.595	2318.454	53977.910	30216.758	45924.148	31670.098	22810.443
K	1934.029	2113.118	5358.777	7713.891	7637.778	10112.735	6637.442
Fe	929,662	771,916	26511.195	15875.187	18806.451	22285.732	12207.534
Cl	693.926	599.393	4871.811	1812.943	4181.102	1391.596	2107.190
Cr	426,647	423.819	1878.841	//	4086.773	442,792	//

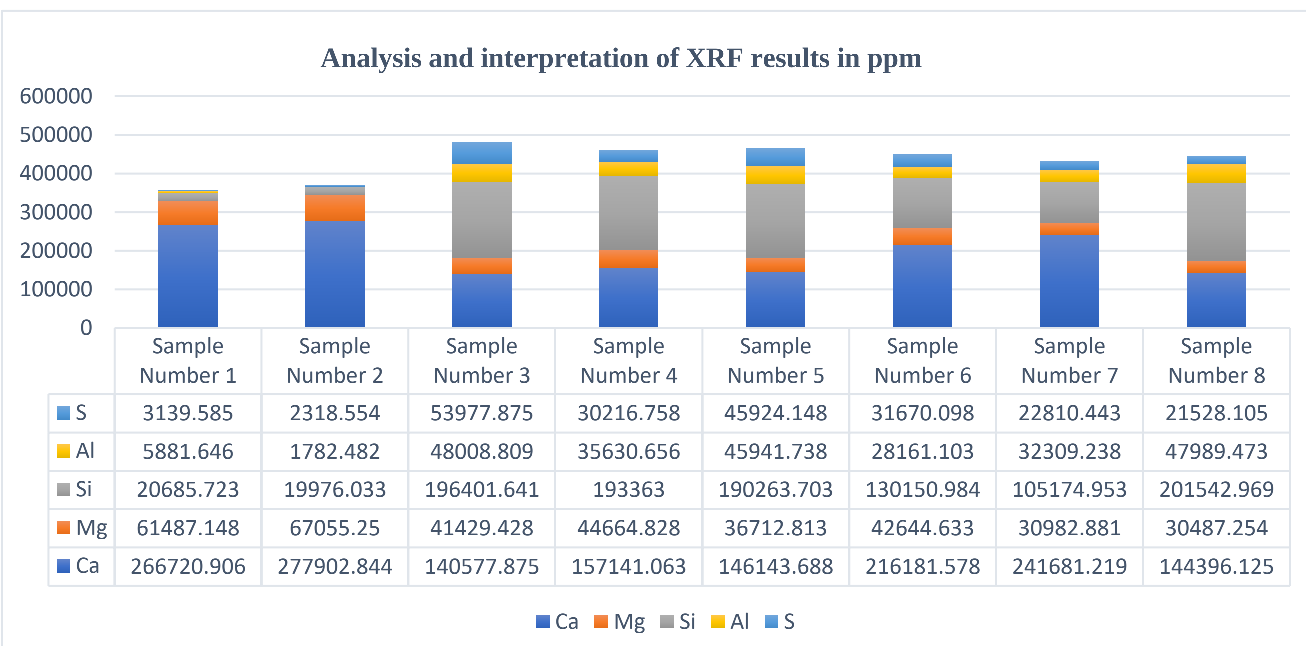

Figure 4. Analysis graph and interpretation ofXRF analysis results

5. Conclusion

Based on the results of field studies, petrography, and XRF analysis, the Sar-e-Sang Badakhshan lapis lazuli mine exhibits significant diversity in terms of mineral composition, texture, structure, and chemical composition. Examination of the samples revealed that the rocks in the area primarily belong to the metamorphic group; identified types include micromarble, silicate marbles, pyroxene skarn, magnetite skarn containing lapis lazuli, as well as lazulite and tremolite-bearing rocks. This diversity in mineral composition and petrographic characteristics indicates that metamorphic conditions and processes were not uniform across different sections of the mine. XRF analysis results also demonstrate distinct differences in the chemical composition of the samples. Variations in the levels of Ca, Mg, Si, Al, and S, along with the presence of K, Fe, Cl, and Cr, reflect the chemical heterogeneity of the studied rocks. These results align with the petrographic findings, indicating a correlation between variations in chemical composition and differences in mineralogy and metamorphic rock types. Furthermore, geological assessment of the region suggests that the Badakhshan lapis lazuli deposits are associated with granitoids, and that metasomatic processes drove the alteration of marbles and calciphyres, leading to the formation of lapis lazuli-bearing rocks. Thus, it can be concluded that metamorphism and associated metasomatic processes played a significant role in shaping the mineral composition, petrographic characteristics, and—consequently—the quality of the lapis lazuli from the Sar-e-Sang mine. Overall, the research results indicate that the quality and characteristics of Sar-e-Sang lapis lazuli cannot be evaluated solely based on color and appearance; rather, mineral composition, host rock type, metamorphic conditions, and variations in chemical composition also contribute to its properties. The findings of this study can be utilized to better understand the geological origin of Sar-e-Sang lapis lazuli and to examine its relationship with the metamorphic and skarn rocks of the region.

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