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| RESEARCH ARTICLE

Mineralogy and Geochemistry of Nephrite from Wolay Deposited, Kunar, East Afghanistan

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| ABSTRACT
This research deals with the study of geochemical, petrographic and mineralogical properties of Wolay Nephrite Occurrences in Kunar Province. Nephrite is a relatively silicate mineral, Cyclosilicate, with a chemical composition of $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$ and has a monocline crystal shape. It is found in metamorphic rocks in many parts of the world. Wolay nephrite area is related to the tectonic zone of Jalalabad. Jalalabad zone is located in the eastern part of Afghanistan and south-east of the Nuristan zone. Correspondingly, this zone is related to the upper Cambrian or younger Cambrian. In this area, the age of rocks is related to Archean- Middle Proterozoic AR-PR_2. This contribution presents the first systematic mineralogical and geochemical studies on the Wolay nephrite deposit. Electron probe microanalysis, X-ray fluorescence (XRF) spectrometry, inductively coupled plasma mass spectrometry (ICP-MS), and isotope ratio mass spectrometry was used to measure the mineralogy, bulk-rock chemistry, and stable (O and H) isotopes characteristics of samples from Kunar. Field investigation shows that the Kunar nephrite ore body occurs in the dolomitic marble near the intruding granitoids. Petrographic studies indicate that the nephrite is mainly composed of fine-grained actinolite with Schist and dolomite. Geochemical studies show that all nephrite samples have low bulk-rock Fe/(FeO + MgO) values (4.72–21.34%), as well as SiO_2 (72.75%), Al_2O_3 (2.01), CaO (14.58%) and NiO (0.05%) contents. The chemical data analysis and interpretation of F=Mg/Mg+Fe percentages show that the Nephrites type is actinolite. The deposit of nephrite mineral has been formed in hydrothermally veins and lens shape in contact with serpentinite and carbonate (dolomite marble) rock in the under study area. The color and its clarity have a direct effect on the economy and its price. The Nephrite from the Khas Konur district is found in green color due to the existence of iron elements.

| KEYWORDS

Actinolite, Geochemistry, Mineralogy, Nephrite, Schist and Tremolite.

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1. Introduction

Nephrite is one of the two distinct minerals commonly known as jade. While nephrite doesn't match the variety or the fine green "imperial jade" colors found in jadeite, it does occur in attractive colors, including green, and is even more durable as a gem material for jewellery and carved art objects. (Liu, Y. et al., 2012)

Nephrite Ca2(Fe,Mg)5Si8O22(OH)2 is a Fe-Mg bearing Ca-silicate mineral with a doublechain structure, which is classified in the group of amphiboles (clino-amphiboles). It has a massive variety with an intermediate composition in the tremolite-ferroactinolite series, known mainly with a pale green or dark green colour, but can also be white, yellowish, brownish, or rarely with some other colours. In some cases, small black inclusions can be found in the fine green aggregates, which are attributed to magnetite and other spinel-type minerals. Its genesis is attributed mainly to metamorphic (metasomatic) processes in ultrabasic (serpentinite) or carbonate (dolomite marble) host rocks. The main genetic types of deposits of this gemmological material are related to the contacts of gabbroids, acid igneous or metamorphic rocks with ultrabasic rocks or to their contacts with dolomite marbles (Kostov, 2013).

There are two kinds of jade stones associated with serpentinites in mountain belts at convergent plate boundaries. One is nephrite jade, enriched in Ca and Mg, and the other is jadeite jade (or jadeitite), enriched in Na and Al. Both kinds of jade result from metasomatic reactions between serpentinites and country rocks/tectonic blocks taking place, presumably, within convergent environments (Kristensena, 2016).

In this regard, Afghanistan is also one of the richest countries in the world in terms of having various metallic, nonmetallic and oil and gas resources. Based on surveys and investigation, Afghanistan is unique in owning mineral deposits in the region, having some of the most valuable mines in the mountainous areas. Afghanistan is considered the unique country in the world due to a complex geologic and tectonic setting that causes different mineral deposits in it. In addition to other mineral deposits in the country, nephrite deposits are also distributed abundantly in which these deposits have not been studied in detail and has been remained unknown. In this study, the geologic structure, chemical analysis, mineral observation and petrographic properties of nephrite deposits in Kunur province are were studied. The results of this study somehow affect in country's economy.

1.1. Objectives of the Research

This study aims to study the geological structure, geochemical analysis, and determine the mineralogical composition, petrographic properties and physical characteristics of the Nephrite occurrences in Wolay of Konur province.

1.2. Importance of Research

This study was conducted by extensive field works and sampling from the main veins of nephrite. The interpretation and findings of this study can effectively be used as an authorized reference for the Afghanistan Geological Survey (AGS) and relevant research entities.

1.3. Research Questions

1) What are the adjacent rocks in the Wolay Nephrite field?
2) What is the bulk chemistry of nephrite?
3) What are the mineralogical and petrographic properties of Nephrite in the study area?
4) Does the Wolay Nephrite area have economic value?
5) What is the first origin of Kunar Province's nephrite?

1.4 Research Limitations

Every research has its own constraints and challenges. In this study, due to the security problems, lack of geological work in this area, and lack of previous excavation work by the government, geological information was not enough prior to research. One of the big challenges was the pandemic coronavirus. In order to analyze and make thin sections of the specimen in AGS and other private companies, enough facilities and standard laboratories in Kabul Polytechnic University were not available, which can be counted as a major constraint for in-depth.

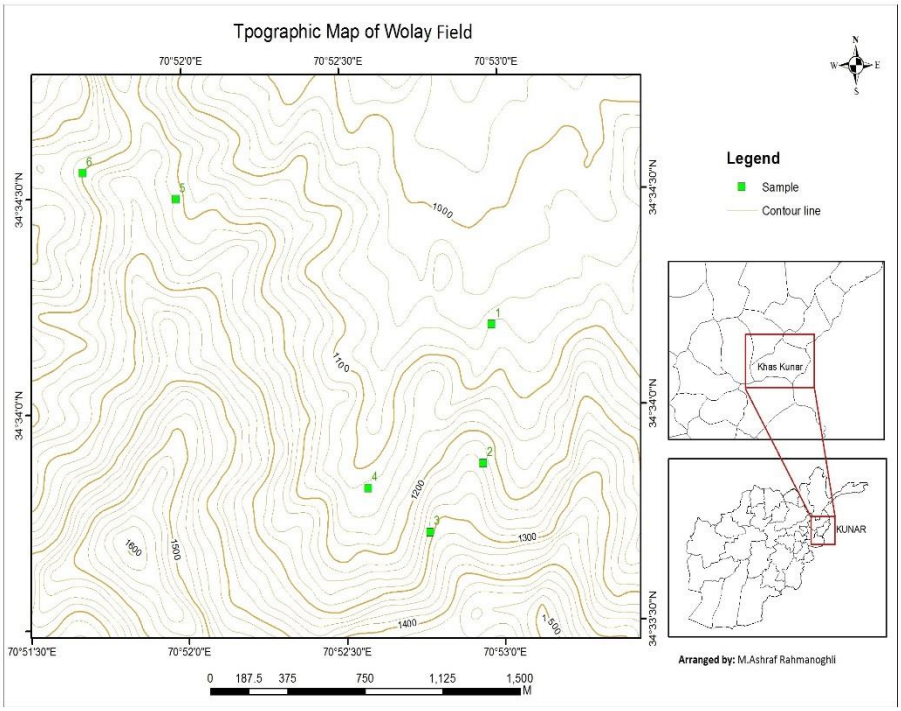
2. Study area

The specimens for this research have been collected from the Wolay area located in the Khas-Kunar district of Kunar province and has a common border with the Goshta District of Nangarhar province in Jalalabad city. The geographic coordinate of this area depicts that its latitude is 34°33′42.7′′ N, and its longitude is 70°52′ 46′′ E. This area is one of the areas which has several Nephrite veins and lenses. These veins and lenses have been identified due to the excavation of land by locals for construction purposes in the Wolay Nephrite field (Figure 2.1) (Bohannon, 2010).

The absolute elevation from the sea level in the aforementioned area varies from 787 to 1,200 meters, and the relative elevation of the area is about 250 meters. Kunar Province is mountainous and rugged terrain have been relatively flat-lands, the climate is almost Mediterranean, with warm summer and mild and slightly cold winter. The temperature is 47c° in summer and 3c° in winter. As stated before, the study area is located in the Jalalabad zone in eastern Afghanistan. This zone was separated in 1969 by Prof. Slavin to Jalalabad tectonic zone for the first time. The basement metamorphic rock can be seen in the Spinghar Mountains, in the part of the aforementioned eastern zone in Jalalabad, left side of Kabul River, as outcrops. (Karapetov, 1979–1981).

In the central parts of this zone, Neogene formation has deposited new tectonic troughs. In the tectonic map prepared in 1976 in this region, the sub-zone was separated into three sub-zones are named Kunar subzone, Spinghar and depression of Jalalabad trough (Treloar, 1993).

Figure 2.1: Location of the study area in the topographic map.



3. Geological Setting

3.1 Tectonic

Jalalabad tectonic zone is located in the eastern part of Afghanistan and SE part of Nuristan block. It was first identified in 1969 by Prof. Slavin called Tectonic Zone of Jalalabad, which are located and named Block of Nuristan. Correspondingly, the zone is related to the upper Cambrian or younger Cambrian. The basic metamorphic rocks are exposed in Spinghar Mountains. They can also be observed in the eastern part of that zone, southeastern parts of Jalalabad city left bank of Kabul and Kunar River. In the central part of this zone, the Neogene sediments have been positioned in the new tectonic depression. In the tectonic map of 1976, in this area, sub-zones are isolated, which are called Kunar, Spinghar and Jalalabad depressions (Figure. 2.2). (Peters, USGS, 2011)

The Nephrite of mineralization includes a group of actinolite and tremolite deposits that have formed as a result of the contact-metasomatic impact of ultra-acidic mafic rocks with adjacent rock, such as phyllite and serpentinite metamorphic rock, upon Precambrian carbonate rocks in the Nurestan block. The nephrite occurrences are confined to a unit of calcite _ dolomitic marble beds occurring in serpentinite and phyllite. A group of unique nephrite deposits is located in the Nuristan Block. Nephrite deposits and occurrences have been found in the areas that extend in veins and lens shapes for more than a few meters and 10 meters. And underlain by phyllite, calcite and dolomitic marbles and hornblende and biotitegarnet schists, garnet amphibolite and skarns. Nephrite is subdivided into Jade which is a semi-precious gemstone that is further classified into two categories named Jadeite and Nephrite that divided into two groups of actinolite and tremolite deposits (AGS, 2017).

The stratigraphy of the Jalalabad zone is different in terms of age and composition; the oldest sediments are related to the Archean (Proterozoic) period and the youngest to the Quaternary period, which means that there are sediments of all periods in this zone. Magmatic rocks are vastly developed in the Jalalabad zone, and they are outcropped along Kunar Valley and the Spinghar Mountain series. In the Jalalabad zone, the following magmatic complexes can be separated:

- Granites and gabbro amphibolite complex, Upper Proterozoic (PR3)
- Granite and granodiorites complex, Upper Paleogene (PZ) (Figure. 2.2).
  (Feroz, 1975)

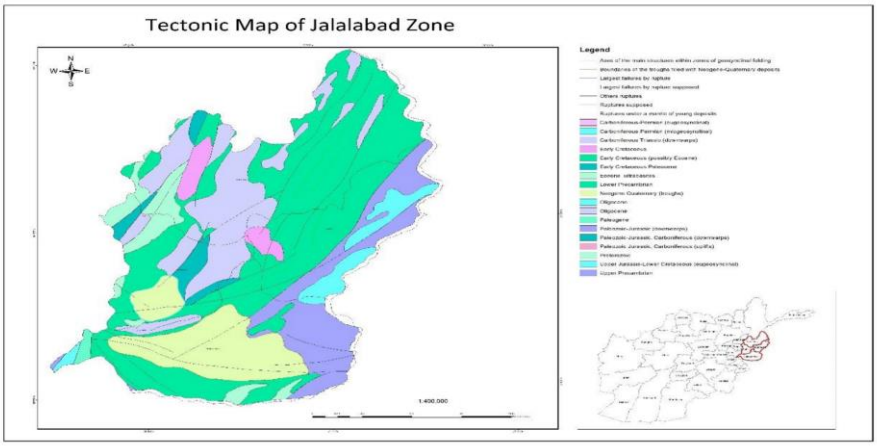


Figure 2.2: Tectonic Map of Jalalabad Zone

3.2 Mineral Deposit

From the point of view of mines, the Jalalabad zone is not that much rich in mines. In this zone, the Achin and Ghunday magnesite and talc deposits occur within the east-west trending Spinghar Zone; the Spinghar Zone consists mainly of Early Proterozoic metamorphic rocks. The largest portion of this zone consists of middle Paleoproterozoic marble, biotite and garnet-staurolite-biotite gneiss and schist, quartzite, and amphibolites. Smaller portions of this zone consist of early Paleoproterozoic 2-mica, biotite, biotite-amphibole, garnet, garnet sillimanite biotite, pyroxene-amphibole, plagioclase, and cordierite gneisses, along with schist, quartzite, marble, and amphibolite. Other Proterozoic rocks consist of granite-gneiss, granite, and Plagiogranite and a minor amount of middle Proterozoic Meta volcanic lava. Early Cretaceous rocks consist of gabbro, monzonite, diorite, and granodiorite intrusions. The rock unit codes noted above are those from (Abdullah and Chmyrinov 2008; King & Partners 2011).

The northern part of the Ghunday-Achin magnesite and talc is covered mainly by Pliocene, and Quaternary conglomerate and sandstone Rocks of the Spinghar Zone may extend under the Pliocene and Quaternary cover. Detailed maps of the individual deposits are available (Figure. 3.1). In addition to surface geologic maps, audit maps, cross-sections, and long sections contain important information regarding the geology and geochemistry of these deposits. In the eastern parts of the Jalalabad tectonic zone, there are Nephrite veins and lens shape interlayered serpentinites and dolomite marble rock {Peters & Partners, King & Partners (USGS) 2007, 2011}.

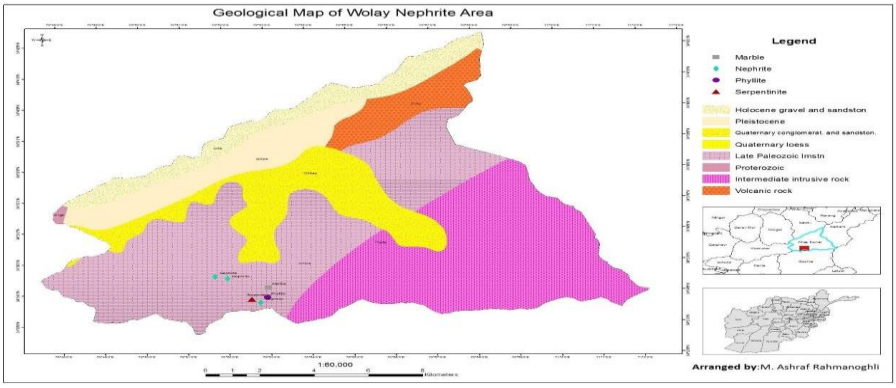


Figure 3.1: Geological Map of Nephrite Area in Khas Kunar District of Kunar Province.

4. Material and Methods

This study was carried out using the three following methods:

1. Library Method: The method is considered the initial part of the study; the related literature using research and review articles, thesis, textbooks, authorized websites were reviewed. This method aimed to find out the unrevealed and weak points of previous studies on the wolay nephrite deposits and to select the proper analysis being used for the mineralogical, petrographic and geochemical properties nephrite. The general information, including the geologic and tectonic setting of the study area, was provided by this method.

2. Field Observation Method: Fieldwork and sampling make a critical part of such studies. Therefore, field works in this study were carried out through several geologic transverses to study the macroscopic properties and to collect the samples from the selected points. The sample collection for lab analysis was conducted within the two phases of field works in the study area. The samples were collected randomly and based on the physical, morphological, and structural changes of nephrite. 14 samples were collected, including 8 samples during the first phase and 6 samples through the second phase as shown in (Table 4.1) with their associated coordinates (Figure. 2.1) and can also be shown more clearly as a satellite image in (Figure. 4.1).

3. Laboratory Method: The purpose of this method was the mineralogical, chemical, petrographic analysis of the collected samples to reveal the selected properties of nephrite. The samples were sent to the Mineralogical Laboratory of Afghanite Engineering Services and the Afghan Geological Survey in Kabul, Afghanistan, for reliable results. The samples were subjected to X-ray fluorescence and mineralogical analysis for chemical and mineralogical composition.

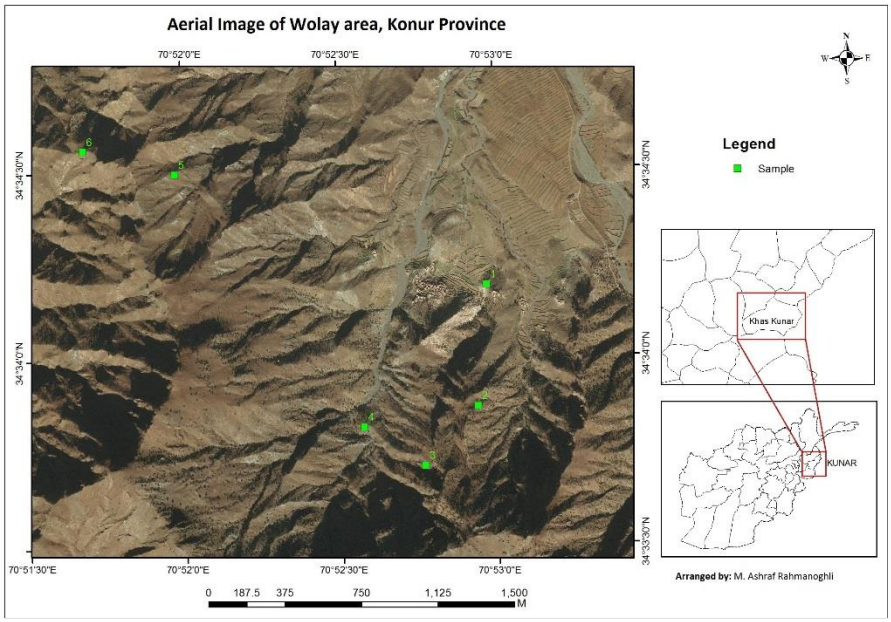


Figure 4.1: Satellite image of Wolay area, Khas Konur District, Konur Province.

Table 4.1: Associated coordinates and altitudes of the collected samples.

No	Name of rocks	Sample	Elevation	E	N
				DMS	DMS
1	Marble	1	1091	70 52 58	34 34 11.4
2	Phyllite	2	1281	70 52 56	34 33 52.1
3	Nephrite	3	1306	70 52 46	34 33 42.7
4	Serpentine	4	1164	70 52 34	34 33 49
5	Nephrite	5	1295	70 51 59	34 34 29.7
6	Nephrite	6	1238	70 51 41	34 4 33.6

5. Results

5.1 Petrographic analysis

The petrographic analysis identifies the origin, where igneous, sedimentary, or metamorphic, and the mineral content for the classification of rock. Analysis usually comprises the description of the macroscopic aspects of the rock, such as fabric, color, grain size, and other relevant characteristics that may be visually observed in hand specimen or in outcrops, and chiefly the identification

and description of microscopic characteristics of the studied material in thin sections such as mineral composition, texture, grain size, and evidence of alteration and/or deformation (Maria, 2018). Dolomite marble adjacent to Nephrite has been studied under the petrographic microscope. The following results are obtained from it; #1: Its texture is massive and structure is granoblasty, and its name is marble, as shown in (Figure. 5.1 (1, 2)). Also, the analyses of sample #2 under the petrographic microscope showed: the texture is schist, and its structure is lepidoblastic, and this is a metamorphic rock, and also its crystal system is monoclinic that, as shown in (Figure. 5.1 (3, 4)).

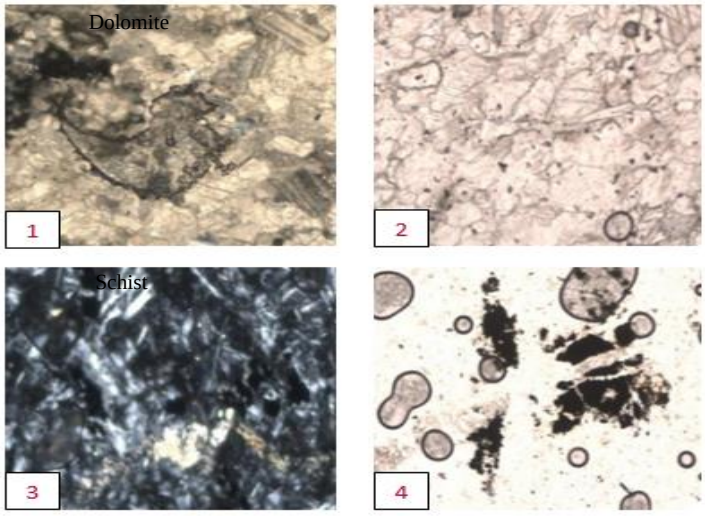


Figure 5.1: Photographic images **($XPL-40X, PPL-40X$).**

5.2 Chemical analysis

The chemical analysis of samples as follows; #1: Bal 93.45%, Si 0.45%, Mg 0.0%, Ca 5.87%, Fe 0.01%, Cl 0.48%, Ba 0.0%, Ti 0.01% and its name is Marble. #2: Bal 38.02%, Si 33.86%, Mg 12.16%, Ca 10.44%, Fe 3.56%, Cl 0.16%, Ba 0.03%, Ti 0.03% and its name is Nephrite. #3: Bal 51.07%, Si 22.41%, Mg 0.85%, Ca 8.26%, Fe 7,97%, Cl 0.00%, Ba 0.03%, Ti 0.7% and i's name is Phyllite. #4: Bal 58.50%, Si 19.04%, Mg 13.38%, Ca 1.9%, Fe 5.56%, Cl 0.06%, Ba 0.01%, Ti 0.01% and its name is Serpentinite. #5: Bal 34.53%, Si 34.90%, Mg 13.71, %, Ca 10.38%, Fe 4.69%, Cl 0.13%, Ba 0.02%, Ti 0.02% and its name is Nephrite. #6: Bal 38.91%, Si 33.26%, Mg 12.74%, Ca 10.44%, Fe 2.75%, Cl 0.16%, Ba 0.02%, Ti 0.03% and its name is Nephrite. The chemical composition of all them is shown in (Table. 5.1).

Table 5.1: Chemical composition of all samples.

Element	Bal	Si	Mg	Ca	Fe	Cl	Ba	Ti	Name of rock
Value of #1	**93.45**	**0.45**	**0.00**	**5.87**	**0.01**	**0.48**	**0.00**	**0.01**	Marble
Value of #2	**38.02**	**33.86**	**12.16**	**10.44**	**3.56**	**0.16**	**0.03**	**0.03**	Nephrite
Value of #3	**51.07**	**22.41**	**0.85**	**8.26**	**7.97**	**0.00**	**0.03**	**0.70**	Phyllite
Value of #4	**58.50**	**19.04**	**13.38**	**1.90**	**5.65**	**0.06**	**0.01**	**0.01**	Serpebtinite
Value of #5	**34.53**	**34.90**	**13.71**	**10.38**	**4.69**	**0.13**	**0.02**	**0.02**	Nephrite
Value of #6	**38.91**	**33.26**	**12.74**	**10.44**	**2.75**	**0.16**	**0.02**	**0.03**	Nephrite
Analysis Method	XRF								
Specimen Collected Date	12/05/2021								
Specimen Analysis Date	20/12/2021								

In addition as for the proper recognition based on a study (Barnes, 2018), the three specimens collected from different points of Wolay field in Khas Kunar district, the result below, which is obtained from chemical analysis, shows the comparison with the oxides of Jadeite, Nephrite - Actinolite, Nephrite-Trimolite, Serpentine Chrysotile, Serpentine - antigorite and Vesuvianite (Table. 5.2).

Table 5.2: Comparison of oxidized samples.

Oxides	SiO_2	NiO	Al_2O_3	Na_2O	CaO	MgO	Fe_2O_3	FeO
Averaged Value of (3) Nephrite Samples	**72.75**	**0.05**	**2.01**	**0.00**	**14.58**	**21.34**		**4.72**
Jadeite	**58.61**	**0.00**	**22.38**	**15.11**	**0.00**	**0.00**		**0.00**
Nephrite-Actinolite	**54.68**	**0.00**	**0.00**	**0.00**	**12.03**	**16.11**		**10.61**
Nephrite-Trimolite	**59.2**	**0.00**	**0.00**	**0.00**	**13.8**	**24.8**		**0.00**
Serpentine-Clinochrysolite	**43.36**	**0.00**	**0.00**	**0.00**	**0.00**	**43.63**		**0.00**
SerpentineAntigorite	**39.9**	**0.00**	**0.00**	**0.00**	**0.00**	**30.15**	**17.92**	**0.00**
Vesuvianite	**38.03**	**0.00**	**14.34**	**0.00**	**39.43**	**5.67**	**0.00**	**0.00**

Jadeite is the Jade silicate of Sodium and Aluminum, whereas Nephrite is the Jade of calcium silicate, magnesium and iron (Campbell, 2008; Harlow, 2005).

According to the following graph, the amount of magnesium and aluminium of samples from Khas Kunar district is compared, shown in percentage (Figure. 5.2).

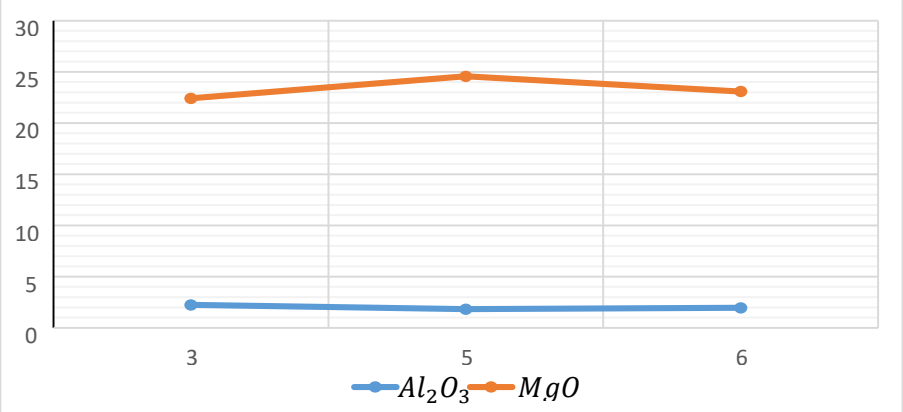


Figure 5.2: Contents comparison of magnesium and aluminium in the specimens.

Considering the graphical chart illustration, the contents of (Mg) in the collected specimens are more than (Al), which infers that the specimens are not Jadeite.

According to the comparison of different oxide contents described in tables (5.5, 5.6, 5.7, 5.8, 5.9), the averaged oxide contents of the specimen from Khas-Kunar district with Jadeite oxide total difference is (94.22%), and the average difference is (11.78%), Nephrite Actinolite total difference is (33.8%), and the average difference is (4.8 %), the total difference of Trimolite is (24.52), and the average difference is (3.5) the total difference of Serpentine Clinochrysotile is (73.05%), and the average difference is (10,11%) the total difference of Serpentine Antigorite is (80.95 %), and the average difference is (10.11%), and the total difference of Vesuvianite is (92.36%), and the average difference is (11.54%) (Table. 5.3).

Table 5.3: Total and averaged differences between the oxide compound of specimen and other minerals oxide compounds

Type of jewel	Total difference to %	Average difference to %
Jadeite	**94.22**	**11.78**
Nephrite-Actinolite	**33.80**	**4.82**
Nephrite-Trimolite	**24.52**	**3.50**
Serpentine-clino Chrysotile	**73.05**	**10.43**
Serpentine-Antigorite	**80.94**	**10.11**
Vesuvianite	**92.35**	**11.54**

In the above table, the least differences of the specimen from KhasKunar's district belongs to Nephrite Trimolite (3.5%) and Nephrite Actinolite (4.82%) (Table. 5.3). We separately compare the oxide compounds of the specimen shown in the following (Table. 5.4).

The other characteristic for identifying the type of Nephrite is Fe and Mg. The Trimolite mineral, if the f=Mg/ (Mg + Fe)>0.9 and the Actinolite mineral if F is (0.5-0.9) (Table. 5.4). (Barnes, 2018)

Table 5.4: Total and averaged differences between the Oxide compound of Specimen for nephrite Actinolite and nephrite Trimolite also the ratio calculation of Mg and Fe Specimen from Khas-Kunar district.

Specimen #	#3	#5	#6
The total difference with Nephrite Trimolite	25.50	26.11	21.95
The total difference with Nephrite Actinolite	32.65	35.51	33.09
The average difference with Nephrite Actinolite	5.45	5.92	5.52
The average difference with Nephrite Trimolite	4.25	4.35	3.66
Magnesium Percentage	12.16	13.71	12.74
Iron Percentage	3.57	4.69	2.75
F=Mg/(Mg+Fe)	0.77	5.92	5.52

Based on the results shown in Figure 5.3. All the Specimen are from (0.745) up to (0.822), so all the Specimen from Khas-Kunar district are Actinolite-Nephrite.

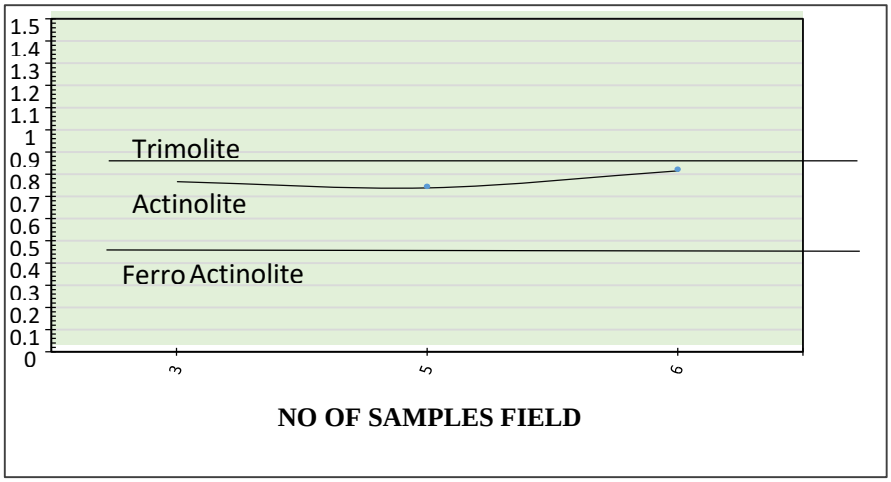


Figure 5.3: Diagram showing the $[F = Mg/(Mg + Fe)]$ of a specimen from Khas-Kunar.

6. Discussion

This research made efforts to study the geochemical, petrographic and physical properties of Wolay nephrite occurrences in Konur province. Nephrite is mostly located in metamorphic rocks (serpentines) and some contact metamorphic rocks. Based on chemical analysis, Nephrite from the Khas Kunar district contains various kinds of other minerals such as chromite.

As a result of this research, the nephrite from Khas Kunar district is revolutionized and composed (serpentines) that it's in contact rock are in total created from schist.

Nephrite is one of the decorative rocks whose physical characteristic greatly affects its quality and price, and it plays a key role. The major physical characteristics of nephrite are hardness, color, clarity, and to be free of inclusion, the quality of nephrite is specified according to these characteristics.

The color and its clarity directly affect the economy and its price. The Nephrite from Khas Konur district is found in green color due to the existence of chrome and iron elements.

7. Conclusions

Taking into account the objectives of this study, the following conclusions were made:

1. The deposit of nephrite mineral has been formed in hydrothermally veins and lens shape in contact with Serpentinite and carbonate (dolomite marble) rock in the under study area.
2. The geological structure of adjacent rocks, including Serpentinite and marble, has a low inclined angle, further reasoning whether change resulted from physical erosion to adjacent rocks formed from Diluvia sedimentary.
3. The reason behind the green color of nephrite is due to the existence of Iron and chromium elements in its crystal form.
4. The microscopic observation shows that the inclusion of chromite elements in nephrite crystal form has a negative impact on nephrite's color.
5. The chemistry data analysis and interpretation of $[F = Mg/(Mg + Fe)]$ percentages show that the mineral type is Actinolite.
6. The findings of chemistry data analysis, interpretation and comparison with oxides of Jadeite, serpentine chrysotile, serpentine - antigorite and Vesuvianite, shows that the considered mineral is Nephrite.

9. Recommendation

Upon the completion of this thesis on geochemical, petrographic and mineralogical- characteristics of Wolay nephrite occurrences in Kunar province. The following points are recommended:

1). For research, evaluation and mapping of the Wolay nephrite area Afghan government take serious action.
2). Currently, Nephrite is being mined illegally exported to the global market by the name of other countries, it is necessary to establish a center to collect, Categorize, Marketing and sell the Mined Nephrite ores.
3). It is recommended that the Director of Kabul Polytechnic University provide the geologic instruments and devices for the fieldwork to resolve the problems of students of this department and also establish an equipped petrographic lab, slide preparation lab, and spectrometry analysis lab.
4). For the purpose of precise consolidation of mineralization and economic importance, a geologic mapping should be plotted having the scale of 1:100000.
5). As we all know that the major parts of revenue come from mining and smuggling of gems and others minerals going to terrorist groups, the government is required to take some practical steps towards the legalization of mining activities around the country.

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