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Chemical Composition and Coloration Genesis of Black—Black Cyan Nephrite from Margou Deposit, Qiemo County, Xinjiang, China

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Abstract: The nephrite belt in Altun Mountain-Western Kunlun Mountain region spanning approximately 1300 km in Xinjiang, NW China, constituting the world's largest preeminent nephrite deposit. The Qiemo region in the Altun Mountain is a crucial nephrite-producing area in China with demonstrating substantial prospects for future explorationl. While extant research has extensively study on secondary deposits in the Karakash River and native black nephrite deposits in Guangxi Dahua, a lacuna exists in the comprehensive investigation of black nephrite from original deposits in Xinjiang. Margou nephrite represents a recent discovery of black-toned nephrite deposits in Qiemo County, Xinjiang, warranting a comprehensive investigation into this primary source of black nephrite within the region. This scholarly inquiry deploys a suite of sophisticated analytical techniques, encompassing Polarizing microscope, electric microprobe, Backscattered Electron Image, X-ray Fluorescence, Inductively Coupled Plasma Mass Spectrometry. The rigorous experimental test is dedicated to elucidating the chemical and mineralogical composition, and further clarify the type of its genetic types of black-black cyan nephrite from Margou deposit in Qiemo, Xinjiang. Results delineate the mainly composed of tremolite-actinolite, characterized by $Mg/(Mg + Fe^{2+})$ ratios ranging from 0.86 to 1.0. Minor minerals include diopside, epidote, pargasite, apatite, zircon, pyrite and iron hydroxide. Bulk-rock rare earth element patterns exhibit distinctive features such as negative Eu anomalies (δEu=0.00~0.17), decreasing light rare earth elements, a relatively flat distribution of heavy rare earth elements, and low with total REE concentrations (1.64~38.9 μg/g), concurrently, the Cr (6~21 μg/g) and Ni (2.5~4.5 μg/g) contents are conspicuously low. The magmatic influence of granite emerges as pivotal factor in the genesis of magnesia skarn hosting the Margou nephrite. The distinctive black-black cyan colour is attributed to heightened iron content, mainly associated with FeO (0.08~6.29%). The discerned chemical composition characteristics posit the Margou nephrite as an exemplar of the magnesia skarn-type nephrite deposit.

Keywords: nephrite; chemical composition; coloration genesis

1. Introduction

The primary constituent of nephrite consists predominantly of minerals from the amphibole group, specifically belonging to the tremolite-actinolite series, characterized by the general chemical formula of Ca2(Mg, Fe)5Si8O22(OH)2. The nephrite exhibits a main microscopic structural feature is distinctive microcrystalline-cryptocrystalline structure [1]. Tremolite stands out as the predominant mineral, accompanied by minor minerals including actinolite, diopside, talc, serpentine, epidote, clinozoisite, forsterite, coarse-grained tremolite, dolomite, quartz, magnetite, and pyrite[2]. Globally, nephrite deposits are primarily found in various countries, including China, Canada, Russia, South Korea, Australia, New Zealand, Pakistan, and Poland[3,4]. Noteworthy, nephrite deposits in China are situated in Yutian County, Qiemo County, Ruoqiang County, Yulong Kashgar River, Karakashi River in Hetian Region of Xinjiang, Golmud in Qinghai Province, Xiuyan in Liaoning Province, Liyang in Jiangsu Province, Asbestos county in Sichuan Province, Luanchuan in Henan Province and Hualien in Taiwan Province[5]. Among these, the magnesium-marble-type tremolite nephrite belt in Xinjiang's Western Kunlun stands out as the world's largest and most economically valuable nephrite deposit in Xinjiang [1,3,5–8].

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Nephrite can be classified into two distinct types based on its genesis: marble type (D-type) and serpentinite type (S-type) [1,5,9–11]. Serpentinite-type nephrite primarily occurs in the contact zones between serpentinite or peridotite and siliceous rocks, such as granite, plagiogranite, and metamorphic sediments. The marble-type nephrite is predominantly found in the contact zones between magnesian marble and magmatic rocks [5–12]. In Xinjiang, nephrite deposits are attributed to the contact metamorphism of magnesium carbonate rocks adjacent to local granite bodies [13,14]. The granodiorite and granite intrusions along the Western Kunlun Mountains of the Hetian Nephrite Belt, spanning approximately 1300 km, play a pivotal role in nephrite formation [8]. Understanding the formation mechanism of nephrite provides valuable insights into the elemental migration during skarn rock formation [13].

Color serves as a crucial criterion not only for evaluating nephrite quality but also as a primary basis for its classification [15]. Nephrite exhibits approximately seven categories: white nephrite, bluish-white nephrite, green nephrite, black nephrite, brown nephrite, yellow nephrite, and jasper. Black nephrite represents the black variety of nephrite, with tremolite or actinolite as its primary mineral components [16].

Summarizing the findings from prior research, there are four potential factors influencing the coloration of black nephrite are identified: (1) High graphite content, despite a low Fe2O3 content (TFe2O3: 0.56~4.74%) [17] in the sample, a high graphite content can contribute to an overall black color [18]; (2) Some samples exhibit elevated TFe2O3 content (> 17%) and the Fe elements appearing as Fe(OH)3 in a vein-like pattern in nephrite, leading to increased density and a darker black color [5]; (3) The samples primarily composed of darker green tremolite coupled with varying quantities of Fe elements (FeO=0.48~9.55%), contributes to a specific type of black coloration [5]; (4) Samples predominantly composed of actinolite or iron-actinolite, with higher Fe content (FeO=11.67~25.75%), produce an overall black color [16–19].

In Xinjiang, the nephrite mineralization belt encompasses over 30 primary nephrite deposits, often associated with skarn and extensive hydrothermal alteration [13,15]. At present, there is limited systematic research on the black nephrite mineral composition of primary skarn-type nephrite deposits. Despite the abundance of black nephrite placer deposits in the Karakash River, there is a scarcity of reports on their occurrence in primary nephrite deposits [13]. This study focuses on Margou black-cyan nephrite samples from the primary deposits in Qiemo County, Xinjiang, offering valuable insights due to their distinctive coloration and geological context. To enhance the research content, various analytical methods, including Polarizing Microscope, Electron Microprobe Analysis (EMPA), Backscattered Electron Image (BSE) analysis, X-ray Fluorescence Spectroscopy (XRF), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), are employed to investigate the Margou nephrite from Qiemo County, Xinjiang Province. This multi-faceted approach aims to elucidate the petrographic characteristics, chemical composition, mineral constituents of Margou nephrite samples, contributing to a comprehensive understanding of its genesis.

2. Geological Setting

2.1. Mergou nephrite Deposit

The Margou nephrite mine, a recently discovered black cyan nephrite deposit situated in Qiemo county, Xinjiang province, presents a distinct geological profile. The strata in the mining area encompasses hornblende biotite gneiss and medium-thick coarse-grained white marble. Magmatic rocks in the region include light gray medium-grained monzonitic granite and diorite (Figure 1C). Stratigraphically, the direction of strata is north-northwest, the tendency is north-east, and the dip angle is 70-80 degrees. Notably, the diorite exhibits veining at the contact between marble and gneiss. Black cyan nephrite mineralization occurs predominantly along the contact zone or bedding in the outer contact zone of monzonitic granite and dolomite marble. The associated alteration related to mineralization processes include potassic feldspathization, epidotization, tremolite, serpentinization and phlogopite.

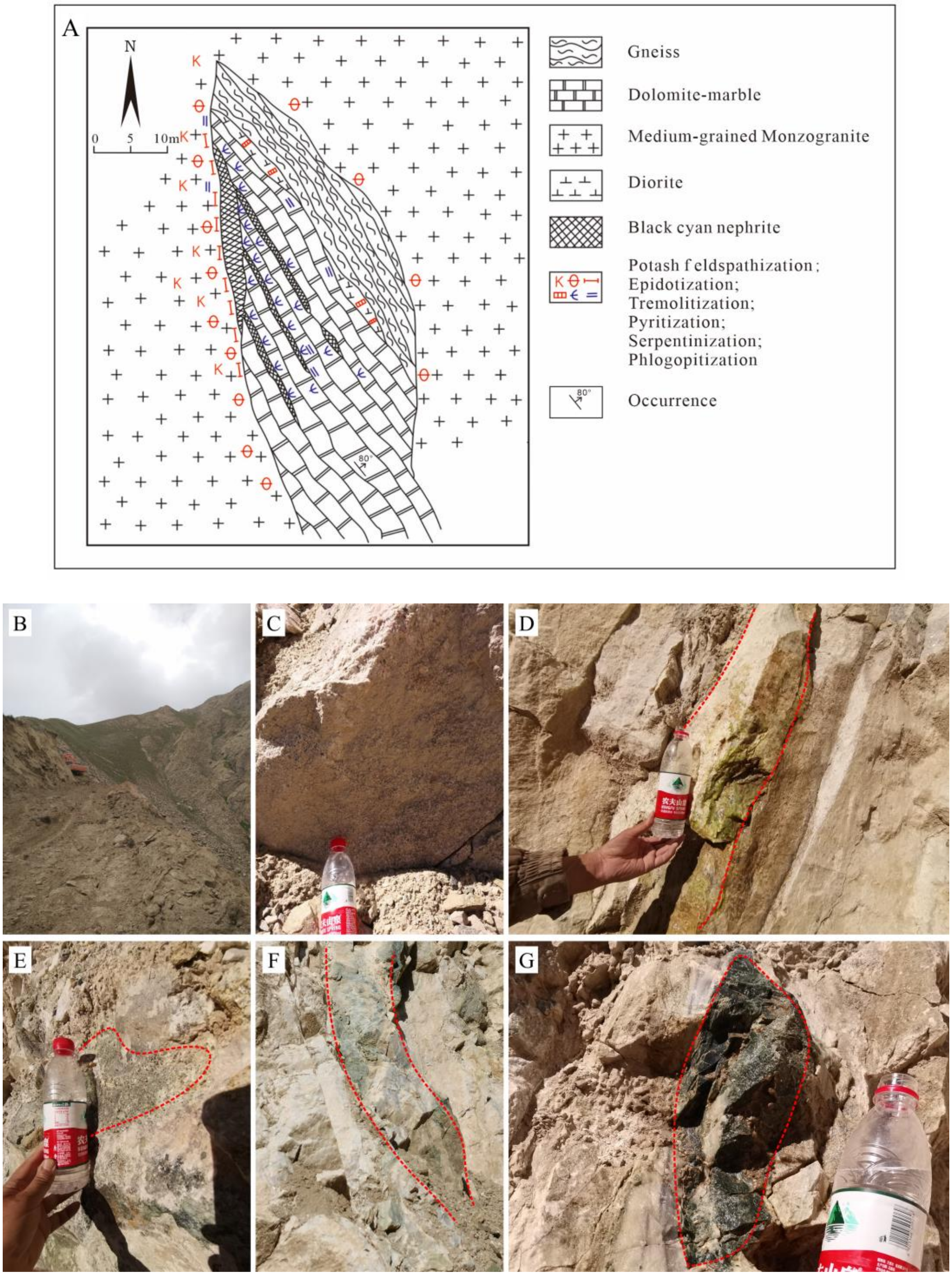

Figure 1. (A) Plane geological sketch of the black cyan nephrite in Margou, Qiemo Country, Xinjiang, China; (B) Field photographs of the Margou nephrite mine; (C) Medium-grained monzonitic granite; (D) Serpentinization; (E) Phlogopite; (F-G) Margou Nephrite.

The ore body, oriented nearly north-south, thickness ranging from 1 to 4 meters and extends for 25 meters. It exhibits a lenticular shape, with thick a thicker middle section that tapers and eventually disappears at both ends towards the north and south, after reaching a depth of 15 meters, the ore body gradually pinch out. Currently, the upper thickness has been largely mined out, leaving only three downward-extending branches. These three branches, characterized by a thickness of 20-40 centimeters and a length of 20-30 meters, follow a north-north-east trend. Mineralization is well-developed along these layers, exhibiting a nearly upright and steep orientation, extending in a layered, stratified, and lenticular manner. The three branch veins intersect upward, forming the main

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vein in the deposit. From the vertical point of view, the magmatic hydrothermal fluid gives rise to a substantial ore body near the contact zone with dolomite marble, subsequently migrating along the marble layer to form three distinct branches.

Potassium feldspathization is predominantly observed in the monzonitic granite of the inner contact zone. Epidotization mainly occurs on the side of the granite within the inner contact zone. Tremolite, closely associated with mineralization, is generated on the side of the marble in the outer contact zone. Serpentine formation is evident in both the outer contact zone and the marble bedding alteration zone (Figure 1D). Phlogopite production occurs in proximity to the contact zone and diorite vein (Figure 1E). The diorite vein commonly exhibits disseminated and agglomerated pyrite alteration.

The black cyan nephrite ore displays a significant large block size, with approximately 30% of the texture exhibiting delicacy and high quality (Figure 1F,G). This observation underscores the distinctive geological characteristics and promising quality of the ore at the Margou nephrite mine.

2.2. Materials

This article presents a comprehensive examination of the mineralogical and geochemical characteristics of Margou nephrite samples from the Qiemo Formation in the Qiemo area, Xinjiang, China. The nephrite metallogenic belt in the Xinjiang region is primarily distributed in three areas: Shache-Yecheng, Hetian-Yutian, and Qiemo-Ruoqiang. Despite variations in deposit types, all nephrite deposits share similar geological backgrounds, predominantly occurring within the contact zones between Precambrian dolomitic marble and medium-acidic magmatite [6,20]. The samples under investigation in this study were procured from the Qiemo area, characterized by a consistent distribution of black and black cyan tone. They exhibit an overall glossy appearance, greasy luster, blocky structure, dense texture, and minimal fissures. Remarkably, some black samples even resemblance to pure lacquer, as depicted in Figure 2C.

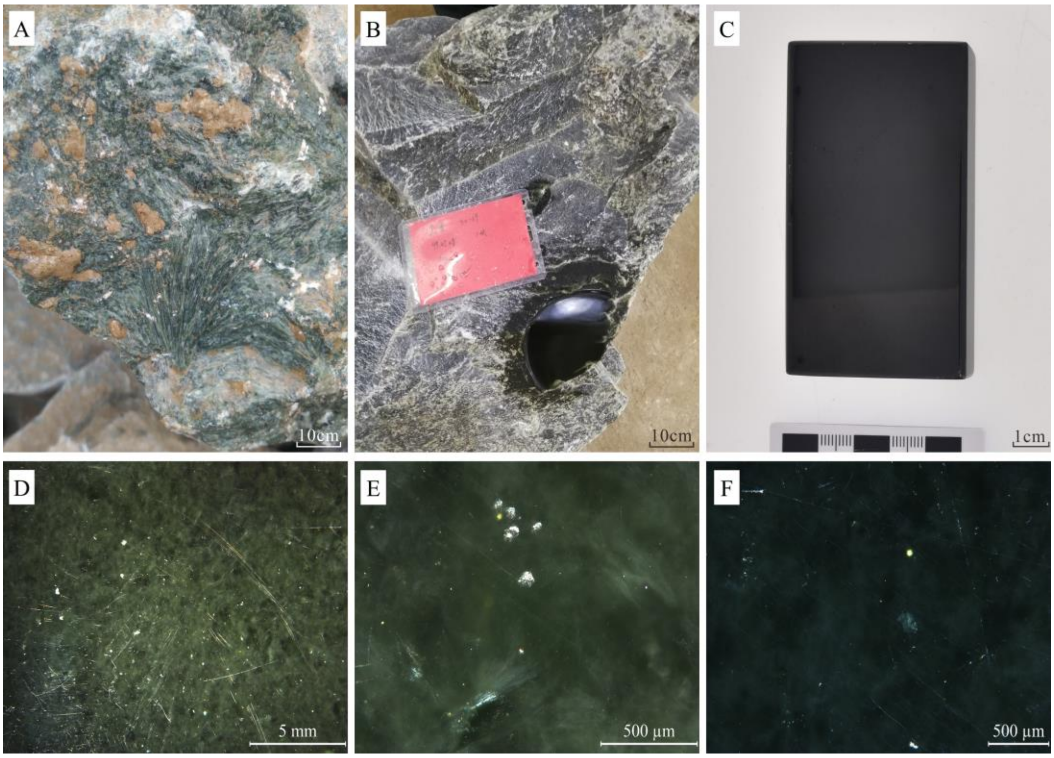

Figure 2. Nephrite samples from the Margou nephrite mine in the Qiemo Country, Xinjiang, China. (A) Picture of hand specimens of Margou nephrite; (B) Picture of hand specimens of partial polished Margou nephrite sections; (C) Picture of hand specimens of polished Margou nephrite; (D-F) Ultra-Depth Three-Dimensional Microscope images of Margou nephrite sample surface.

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3. Methods

(1) Polarizing Microscope [21]: Sample observation under both orthogonal and single polarized light respectively was conducted using the BX51 model polarizing microscope in the laboratory of the Gemology Institute, China University of Geosciences (Beijing).

(2) Major Elemental Composition Analysis [22,23]: Elemental compositions and concentrations of main and accessory minerals in Margou black-black cyan nephrite were analyzed using the JXA-8230 electron probe microanalysis at the Institute of Mineral Resources, Chinese Academy of Geological Sciences. Backscattered Electron Images (BSE) and mineral components were obtained using the JSM-IT500 series Scanning Electron Microscope under the following test conditions: voltage 15 kV, current 20 mA, wavelength 5 μm. Standard minerals, both natural and artificial, were employed for calibration, and the ZAF correction program provided by the manufacturer was utilized to correct gangue minerals.

(3) Bulk-Rock Major and Trace Element Testing[24]: Bulk-rock geochemical analysis was conducted at the ALS Minerals Laboratory, Guangzhou. The procedure involved mixing 0.7g of powdered bulk-rock samples with 5.3g of Li2B4O7, 0.4 g of LiF, and 0.3 g of NH4NO3 in a 25 mL porcelain crucible. The resulting powder mixture was transferred to a platinum alloy crucible, and 1 mL of LiBr solution was added, followed by drying. The sample was then slowly melted in the automatic flame melting machine. Finally, X-ray Fluorescence (XRF) analysis of major elements was carried out in the cold glass, with an analysis error below 2%. For trace elements analysis, 50 mg of bulk-rock powder was dissolved in 1 mL of pure HF and 0.5 mL of HNO3, dried in a 15 mL of Savillex Teflon screw cap capsule in a 190°C environment for one day, then mixed with 0.5 mL of HNO3, dry again to ensure complete mixing. After that, the sample was mixed with 5 mL of HNO3, sealed in a 130°C furnace for 3 hours, cooled, transferred to a plastic bottle, and diluted to 50 mL before analysis. The trace elements in the sample solution were analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) with an analytical accuracy of 5%.

4. Results

4.1. Petrological Characteristics

4.1.1. Mineral components characteristics

This study presents a comprehensive analysis of the petrological and geochemical characteristics of Margou black-black cyan nephrite from Qiemo County, Xinjiang. Utilizing microscopic examination and Backscattered Electron Imaging, the mineralogical composition was elucidated, revealing remolite-actinolite as the dominant bases minerals, complemented by minor minerals including diopside, epidote, pargasite, apatite, zircon, pyrite, and ferric hydroxide. The identified mineral assemblage bears a striking similarity to that of Hetian nephrite sourced from the Karakashi River in the Hetian region [5].

Microscopic and BSE analyses of Margou black cyan nephrite from Qiemo County, Xinjiang, indicate a predominant composition of fine-grained felted tremolite [25].The tremolite particles exhibit an exceptionally fine texture, making challenges to distinguish their contours under the microscope (Figure 3A,C). Additionally, second-stage tremolite is observable (Figure 3B), displaying a sequence of formation from gray-white fine-grained tremolite to gray coarse-grained tremolite. The optical characteristics of tremolite from different periods remain roughly consistent, presenting a second-order blue-blue-green interference color under orthogonal crossed polarizers, appearing colorless under a single polarizer. The texture is characterized by a cryptocrystalline and microcrystalline fibrous structure, with semi-directional to directional distribution (Figure 3A). The presence of tremolite with different grain sizes indicates that the formation of the Margou nephrite sample has undergone multiple stages of hydrothermal metasomatic mineralization. Epidotes are relatively common and are mostly distributed within the tremolite matrix or at the periphery of tremolite particles. The images illustrate that epidotes often undergo replacement by tremolite,

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exhibiting a metasomatic residual structure (Figure 3D). Apatite appears as elongated columnar crystals with a fracture length of up to 600 μm (Figure 3D).

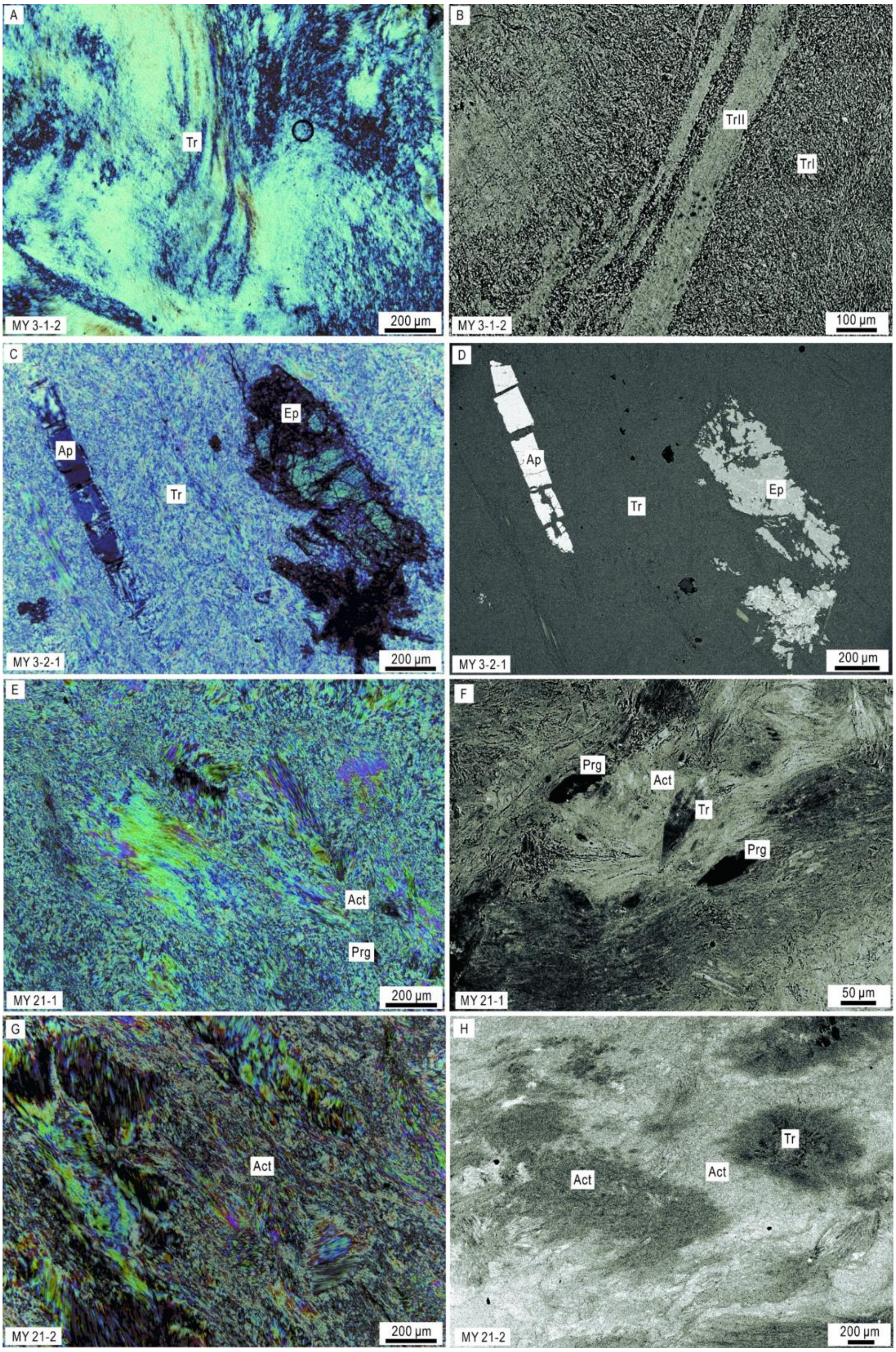

Figure 3. Photomicrographs and Backscattered electron (BSE) images of Margou nephrite. (A) Different periods of tremolite and brownish dissemination; (B) Two periods of tremolite, TrI and TrII; (C) Distribution of epidote and apatite in fine-grained tremolite aggregates; (D) Irregularly outlined epidote and columnar apatite replaced by tremolite; (E) Visible patchy porphyroblastic texture of actinolite and some actinolite fibers arranged in a radial pattern; (F) Actinlite replacement tremolite and pargasite; (G) Semi-directional to directional distribution of actinolite; (H) Tremolite altered by

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actinolite, exhibiting metasomatic relict texture. (Tr=tremolite Act=actinolite Prg=pargasite Ep=epidote Ap=apatite).

In black Margou nephrite, actinolite displays a first-order orange-second-order blue-green interference color, and some actinolite crystals exhibit a radial arrangement (Figure 3E,G). Coexisting tremolite, actinolite, and pargasite are observed, with actinolite ractively replacing tremolite and pargasite, resulting in a metasomatic relict texture for tremolite and pargasite (Figure 3E,F). The replacement sequence indicates that the formation of tremolite and pargasite predates that of actinolite. Furthermore, actinolite can also replace tremolite, with tremolite forming metasomatic relict texture (Figure 3H).

In summary, metasomatism phenomena are prevalent in Margou black-cyan nephrite and black nephrite from Qiemo County. The replacement of diopside and epidote by actinolite snd tremolite indicates that the anhydrous minerals of diopside and epidote formed earlier than tremolite and actinolite, occurring in different stages of metamorphic and hydrothermal mineralization. The presence of apatite, zircon, and other minerals suggests that a close association between the formation of black-black cyan nephrite and granite.

4.1.2. Chemical Composition

Electron Probe Microanalysis was conducted on selected samples of Margou black-black cyan nephrite from Qiemo County, and the specific results are outlined in Table 1. The analysis revealed that the main chemical component include SiO2 (56.11%~57.90%), MgO (20.01%~24.30%), and CaO (12.13%~14.13%), with average values of 56.95%, 21.82%, and 13.17%, respectively. Notably, these values are significantly lower than the theoretical value of tremolite (58.18%, 24.16%, and 13.18%, respectively) [26]. According to the nomenclature rules set by the International Mineralogical Association for amphibole, samples with Mg/(Mg+Fe2+) >0.9 are categorized as tremolite, whereas those with Mg/(Mg+Fe2+) <0.9 are designated as actinolite. The calculated Mg/(Mg+Fe2+) ratios range from 0.86 to 1.0, and the Si and Mg/(Mg+Fe2+) binary diagrams affirm the main minerals composition of black-cyan nephrite as tremolite-actinolite (Figure 4). In comparison with the composition of SiO2 (43.59%~58.46%), MgO (18.89%~26.55%) and CaO (10.20%~23.21%) in white and green nephrite from Hetian nephrite at the Alamas deposit in the Mrble-type deposit, the results indicate overlapping values [3]. The FeO content exhibits a wide variation (0.08%~6.29%), while Cr2O3 content ranges from 0.00% to 0.04%, the NiO content varies between 0.00% and 0.07%. These values are comparable similar to typical magnesian marble-origin tremolite, being notably lower than serpentine-type tremolite of the corresponding type (Cr2O3=0.07%~0.43%, NiO=0.08%~0.36%) [6,14,27].

Table 1. Chemical compositions of main minerals in Margou nephrite by EPMA. (wt.%).

Sample No.	21-1-A1	21-1-A2	21-1-A3	21-1-A4	21-2-A1	21-2-A2	21-2-A3	21-2-A4	21-3-A1	21-3-A2	21-3-A3
SiO_2	57.67	56.68	56.54	57.74	57.9	56.71	56.11	56.41	57.28	56.51	56.86
TiO_2	0.03	0.00	0.00	0.03	0.00	0.03	0.00	0.08	0.00	0.00	0.00
Al_2O_3	1.99	2.18	0.59	0.20	0.83	0.41	0.40	0.65	0.64	0.54	0.36
Cr_2O_3	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00
FeO	0.43	0.17	5.56	3.03	4.29	4.91	5.29	6.29	5.26	4.71	4.66
MnO	0.00	0.06	0.14	0.02	0.20	0.20	0.23	0.22	0.05	0.08	0.10
MgO	23.44	24.30	21.21	21.53	21.63	22.06	20.01	21.05	22.58	21.03	21.14
CaO	14.13	13.85	13.38	13.77	13.1	12.73	13.05	13.55	12.82	12.13	12.4
Na_2O	0.21	0.14	0.11	0.05	0.13	0.10	0.07	0.13	0.15	0.13	0.12
K_2O	0.02	0.00	0.04	0.04	0.04	0.04	0.06	0.06	0.06	0.07	0.05
P_2O_5	0.01	0.02	0.01	0.03	0.03	0.00	0.03	0.00	0.01	0.00	0.09
BaO	0.00	0.00	0.02	0.03	0.02	0.01	0.00	0.06	0.04	0.04	0.00
NiO	0.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.68	0.80	0.65	0.31	0.00	0.09	0.00	0.42	0.69	0.51	0.19

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Cl	0.02	0.01	0.01	0.01	0.01	0.02	0.00	0.01	0.01	0.01	0.02
Total	98.72	98.25	98.31	96.77	98.17	97.30	95.25	98.96	99.62	97.75	96.24
T-Si	7.81	7.73	7.88	8.03	7.95	7.90	7.99	7.83	7.85	8.00	8.01
T-Al	0.19	0.27	0.10	0.00	0.05	0.07	0.01	0.11	0.10	0.00	0.00
Sum-T	8.00	8.00	7.98	8.03	8.00	7.97	8.00	7.94	7.95	8.00	8.01
C-Al	0.13	0.08	0.00	0.03	0.09	0.00	0.06	0.00	0.00	0.09	0.06
C-Cr	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.00	0.00	0.00
C-Mg	4.73	4.92	4.41	4.46	4.43	4.58	4.25	4.36	4.62	4.44	4.44
C-Fe^{2+}	0.05	0.00	0.59	0.35	0.48	0.42	0.63	0.64	0.38	0.47	0.50
C-Ti^{4+}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
C-Mn^{2+}	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
C-Ca	0.09	0.00	0.00	0.16	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Sum-C	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.01	5.00	5.00	5.00
B-Mg	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
B-Fe^{2+}	0.00	0.02	0.06	0.00	0.01	0.15	0.00	0.09	0.22	0.09	0.05
B-Mn	0.00	0.01	0.02	0.00	0.02	0.02	0.00	0.03	0.01	0.01	0.01
B-Ca	1.96	1.95	1.92	1.89	1.93	1.83	1.96	1.88	1.77	1.84	1.87
B-Na	0.04	0.00	0.00	0.01	0.04	0.00	0.02	0.00	0.00	0.04	0.03
B-K	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01
Sum-B	2.00	2.00	2.00	1.91	2.00	2.00	1.99	2.00	2.00	1.99	1.97
A-Ca	0.00	0.07	0.08	0.00	0.00	0.09	0.00	0.13	0.11	0.00	0.00
A-Na	0.02	0.04	0.03	0.00	0.00	0.03	0.00	0.04	0.04	0.00	0.00
A-K	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00
Sum-A	0.02	0.11	0.12	0.00	0.00	0.12	0.00	0.18	0.16	0.00	0.00
Sum-Cat	15.02	15.11	15.10	14.94	15.00	15.09	14.99	15.13	15.11	14.99	14.98
Mg/(Mg+Fe^{2+})	0.99	1.00	0.87	0.93	0.90	0.89	0.87	0.86	0.88	0.89	0.89
Mineral	Tremolite	Tremolite	Actinolite	Tremolite	Tremolite	Actinolite	Actinolite	Actinolite	Actinolite	Actionlite	Actinolite
Nephrite Name	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite	Black-Cyan Nephrite

Note: Amphibole formulae were recalculated on the basis of 23 oxygen atoms; 0.00—concentration below the detection limit. T, C, B, and A represent the occupation of cations in tremolite.

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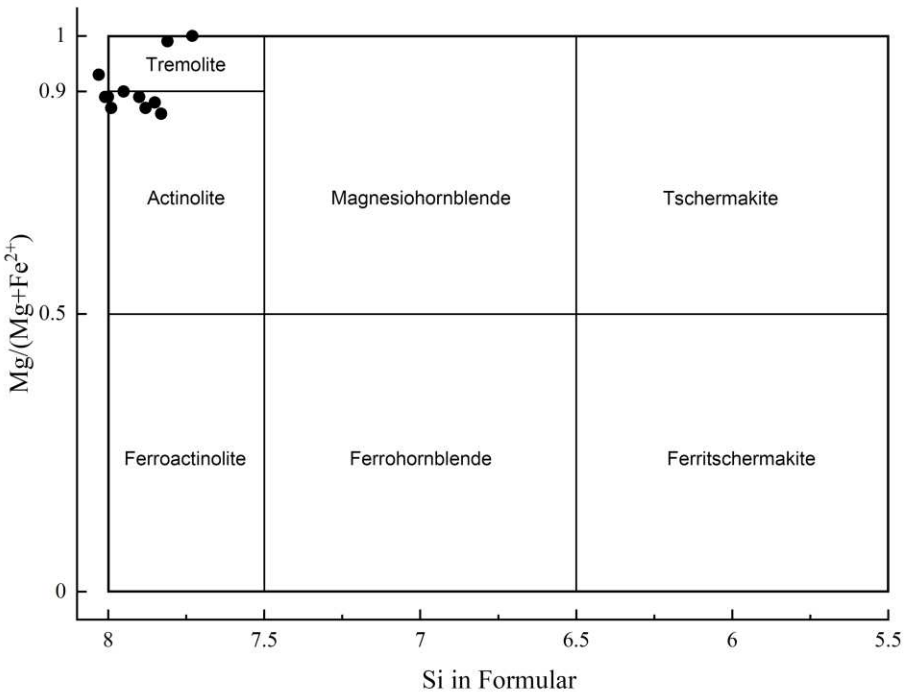

Figure 4. Classification map of Amphibole in Margou nephrite.

- Tremolite - Actinolite: Tremolite in Margou black-black cyan nephrite exhibits 7.73-8.03 a.p.f.u. Si at the T site, 4.43-4.92 a.p.f.u. Mg at the C site, and 1.89-1.96 a.p.f.u. Ca at the B site. This is slightly lower than the Xinjiang Hetian area sample of nephrite, which features 8.00-8.08 a.p.f.u. Si at the T site, 4.61-4.73 a.p.f.u. Mg at the C site, and 1.88-2.0 a.p.f.u. Ca at the B site [5]. The characteristics of actinolite component of Margou black-black cyan nephrite, actinolite exhibits 7.83-8.01 a.p.f.u. Si at the T site, 4.25-4.62 a.p.f.u. Mg at the C site, and 1.77-1.96 a.p.f.u. Ca at the B site, with Ca exceeding 1.50 a.p.f.u. at the B site. The FeO content ranges from 0.08% to 6.29 wt.%, higher than white nephrite (FeO=0.07~1.09 wt.%) and green nephrite (FeO=0.17~4.93 wt.%), but similar to Xinjiang black nephrite (FeO=4.11~14.39 wt.%) and lower than Guangxi black nephrite (FeO=11.67~25.75 wt.%) [19].
- Epidote: In Margou black-cyan nephrite from Qiemo County, epidote exhibits a relatively high FeO content (11.43%~12.04%), with SiO2 and CaO contents of 40.72%~41.67% and 23.57%~23.69%, respectively. The atomic composition of each unit of epidote has the following geochemical characteristics (a.p.f.u): Si=3.15~3.21, Al=2.05~2.09, and Ca=1.95~1.96 (Table 1).
- Pargasite: Pargasite in the black nephrite has almost the same composition, with SiO2 content ranging from 46.69% to 46.73%, MgO from 20.21% to 21.18%, and CaO from 13.80% to 13.99%. The atomic composition of each unit of pargasite has the following geochemical characteristics (a.p.f.u) : Si=6.50~6.53, Al=1.97~2.12 and Ca=2.07~2.09 (Table 1).
- Diopside: Diopside commonly exists in magnesian silicate skarn deposits, is considered one of the primary material sources for the formation of Xinjiang nephrite [10,14]. The main chemical component of diopside are SiO2 (54.43~54.49%), MgO (11.24~17.95%), and CaO (24.02~26.02%).

Table 2. Chemical compositions of trace minerals in Margou nephrite by EPMA. (wt.%).

Sample No.	21-1-1A1	21-1-1A2	21-1-2A3	3-2-1-1C	3-2-1-2A	3-2-1-2B	3-1-2-3A	21-2-1A1	3-1-2-3B
SiO_2	46.69	46.73	54.49	54.43	41.67	40.72	0.09	27.98	0.16
TiO_2	0.74	0.65	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Al_2O_3	12.93	11.97	0.28	0.50	22.58	22.92	0.00	15.32	0.02

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Cr_2O_3	0.00	0.03	0.00	0.00	0.01	0.02	0.00	0.05	0.05
FeO	0.36	0.39	0.13	4.96	11.43	12.04	0.08	14.39	55.52
MnO	0.00	0.03	0.06	2.99	0.15	0.20	0.00	0.37	0.24
MgO	20.21	21.18	17.95	11.24	0.28	0.14	0.03	21.74	0.01
CaO	13.99	13.8	26.02	24.02	23.69	23.57	54.93	0.30	0.03
Na_2O	2.22	2.10	0.00	0.11	0.00	0.03	0.00	0.01	0.00
K2O	0.32	0.27	0.01	0.00	0.01	0.00	0.00	0.02	0.00
P_2O_5	0.00	0.00	0.00	0.00	0.00	0.00	41.19	0.00	0.00
F	0.63	0.93	0.00	0.00	0.00	0.00	3.36	0.21	0.00
Total	98.13	98.20	99.12	100.38	99.87	99.71	99.85	80.52	56.03
Si	6.50	6.53	1.99	2.09	3.21	3.15	0.01	3.07	-
Ti	0.08	0.07	0.00	0.00	0.00	0.00	0.00	0.00	-
Al	2.12	1.97	0.01	0.02	2.05	2.09	0.00	1.98	-
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Fe^{2+}	0.04	0.05	0.00	0.16	0.74	0.78	0.01	1.32	-
Mn	0.00	0.00	0.00	0.10	0.01	0.01	0.00	0.03	-
Mg	4.20	4.41	0.98	0.64	0.03	0.02	0.00	3.55	-
Ca	2.09	2.07	1.02	0.99	1.96	1.95	5.01	0.04	-
Na	0.60	0.57	0.00	0.01	0.00	0.00	0.00	0.00	-
K	0.06	0.05	0.00	0.00	0.00	0.00	0.00	0.00	-
P	0.00	0.00	0.00	0.00	0.00	0.00	2.97	0.00	-
Total	15.69	15.72	4.00	4.00	7.99	8.00	8.00	9.90	-
Mineral	Pargasite	Pargasite	Diopside	Diopside	Epidote	Epidote	Apatite	Chlorite	Ferric hydroxide

Note: Amphibole formulae were recalculated on the basis of 23 oxygen atoms; 0.00—concentration below the detection limit.

4.2. Bulk-rock major and trace elements

Results of major elements analysis (Table 3) indicate a generally consistent chemical composition for Margou black-cyan nephrite, with relatively stable component contents. The SiO2 content ranges from 56.38% to 56.91%, MgO content from 21.3% to 22.20%, and CaO content from 13.10% to 13.45%. These values overlap with the major elements chemical composition of black nephrite from the Yulong Kashgar River and the Karakashi River, with SiO2 content ranges from 51.09% to 57.01%, MgO content from 14.24% to 24.80%, and CaO content from 10.86% to 13.88% [13]. The average values for SiO2, CaO, and MgO are 56.65%, 13.25%, and 21.8%, respectively. Importantly, these values are significantly higher than the chemical composition of actinolite (SiO2=53%, CaO=13.80%, MgO=14.42%) [16]. Previous studies have suggested that with an increase in FeO content in nephrite, the crystal form transitions from tremolite to actinolite [28]. In Xinjiang Qiemo Margou black cyan nephrite, the main mineral is tremolite, with FeO content in the bulk-rock chemical composition ranging from 3.97% to 5.09%, and TFe2O3 content from 4.68% to 6.11%. These values overlap with the content of FeO (0.48% to 9.55%) and TFe2O3 (0.56% to 16.23%) in black nephrite from the Karakashi River [16].

Table 3. Analysis of major elements in Margou black cyan nephrite from Qiemo Xinjiang.

Sample	Content（wt%）		
	MY 2021-3-1	MY 2021-3-2	MY 2021-3-3
SiO_2	56.65	56.38	56.91
Al_2O_3	0.62	0.89	0.53
CaO	13.10	13.20	13.45
TFe_2O_3	5.40	6.11	4.68
FeO	4.54	5.09	3.97
K_2O	0.08	0.08	0.05
MgO	21.90	21.30	22.20
MnO	0.28	0.33	0.30
Na_2O	0.05	0.04	0.05
TiO_2	0.02	0.02	0.00
BaO	0.00	0.01	0.01
Cr_2O_3	0.01	0.01	0.00
Fe^{3+}	0.00	0.25	0.32
LOI	2.52	2.44	2.75
Total	105.17	105.90	104.90

Note: T—Total; LOI—Loss on ignition.

Trace elements analysis were conducted on black cyan nephrite, and detailed results are presented in Table 4. Crucial elements in nephrite genesis, such as Cr, Ni, and Co, were examined, commonly utilized for classifying nephrite genesis types [12,29]. In Xinjiang Qiemo Margou black cyan nephrite, the Cr and Ni content ranges are 6 to 21 μg/g and 2.5 to 4.5 μg/g, respectively. These values overlap with the content in nephrite materials from the Alamas deposit and Hetian nephrite placer deposit, which are Cr (8.95 to 178.7 μg/g) and Ni (0.05 to 3.95 μg/g), and Cr (5.44 to 28.1 μg/g) and Ni (9.44 to 18.2 μg/g) [30]. The Cr and Ni content in the bulk-rock trace elements of Qiemo Margou black cyan nephrite also suggest its classification as Hetian nephrite related to marble, exhibiting content consistent with marble-type nephrite. In this context, Cr ranges from 2 to 29 μg/g and Ni ranges from 0.05 to 471 μg/g. These values are notably lower than the Cr (900 to 2812 μg/g) and Ni (959 to 1898 μg/g) [12] content in serpentinite-type nephrite.

Table 4. Bulk-rock trace elements compositions of Margou black cyan nephrites from Qiemo Xinjiang.

Sample	Content（μg/g）			
	MY 2021-3-1	MY 2021-3-2	MY 2021-3-3	Average
Li	4.80	4.10	4.40	4.43
Be	18.2	15.05	12.90	15.38
Cr	14.00	21.00	6.00	13.67
Mn	2010.00	2400.00	2100.00	2170.00
Co	34.60	36.90	30.60	34.03
Ni	3.50	4.50	2.50	3.50
Cu	4.40	4.30	2.70	3.80
Zn	105.00	127.00	135.00	122.33

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Ga	1.10	1.50	1.30	1.30
Rb	5.30	4.40	1.90	3.87
Sr	7.00	20.50	6.00	11.17
Mo	2.01	1.58	0.55	1.38
Cd	0.04	0.06	0.06	0.05
In	0.006	0.007	0.069	0.03
Cs	1.75	1.93	1.06	1.58
Ba	3.70	5.70	<0.50	3.13
Ti	0.01	0.02	<0.01	0.01
Pb	5.30	10.30	7.60	7.73
Bi	0.03	0.04	0.03	0.03
Th	0.51	1.54	0.05	0.70
U	0.52	0.69	0.29	0.50
Nb	8.60	1.70	10.30	6.87
Ta	0.20	<0.05	0.76	0.32
Zr	4.00	10.00	<2.00	4.67
Hf	0.10	0.30	<0.10	0.13
Sn	0.40	0.50	2.30	1.07
Sb	0.23	0.16	0.33	0.24
TI	0.04	0.04	0.02	0.03
W	0.80	0.20	1.20	0.73
As	<0.20	<0.20	0.40	0.13
V	11.00	14.00	11.00	12.00
La	0.10	8.00	<0.10	2.70
Ce	0.10	16.50	<0.10	5.53
Pr	0.03	1.96	<0.02	0.66
Nd	0.10	7.80	0.10	2.67
Sm	0.05	1.41	0.03	0.50
Eu	<0.02	0.07	<0.02	0.02
Gd	0.09	1.02	0.08	0.40
Tb	0.02	0.15	0.02	0.06
Dy	0.16	0.72	0.16	0.35
Ho	0.05	0.13	0.06	0.08
Er	0.25	0.38	0.28	0.30
Tm	0.07	0.08	0.09	0.08
Yb	0.61	0.59	0.72	0.64
Lu	0.10	0.09	0.10	0.10
Sc	0.50	0.70	0.20	0.47
Y	1.90	4.00	2.6	2.83
δEu	0.00	0.17	0.00	0.06
$[La/Yb]_N$	0.12	9.73	0.00	3.28
LREE	0.38	35.74	0.13	12.08
HREE	1.35	3.16	1.51	2.01
∑REE	1.73	38.9	1.64	14.09

4.3. Rare Earth Elements Characteristics

The Margou black cyan nephrite samples display a negative Eu anomaly (δEu=0.00~0.17), potentially arising from a certain degree of separation crystallization during the mineralization process of Xinjiang nephrite [31]. This finding overlaps with data showing negative Eu anomalies (δEu=0.03~0.21) in the Alamas deposit, a typical deposit associated with marble [3]. The LREE enrichment (LREE: La~Eu) exhibits right deviation, and the HREE flatness (HREE: Gd~Lu) shows flat characteristics in Margou black cyan nephrite, consistent with the rare earth distribution pattern of

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Hetian nephrite in the Alamas deposit (Figure 5A). This pattern reflects typical granite characteristics. Furthermore, the ∑REE total abundance in Margou black cyan nephrite is low, ranging from 1.64 to 38.9 μg/g (∑REE average 14.09 μg/g) (Table 4), similar to the rare earth elements content in magnesian marble-type Hetian nephrite deposits, such as the Alamas Hetian nephrite rare earth element content (2.84 μg/g to 84.81 μg/g) [14,27]. This suggests that nephrite formation involves hydrothermal fluids evolving from intrusive pyrolith (granodiorite) and replacing local surrounding rocks [13]. There is a significant depletion of Ti, a lack of Ba and Th, however, high-field strength elements (Zr, Hf, and Nb) are high or almost not depleted (Figure 5B), resembling the rare earth elements characteristics of black samples from the Karakashi River.

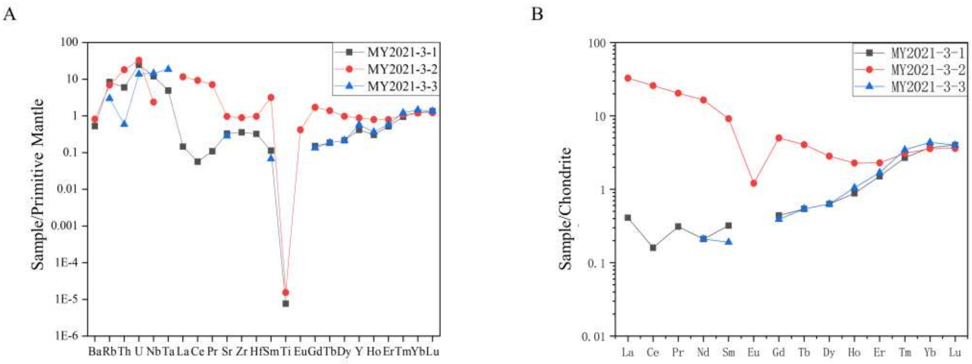

Figure 5. (A) Rare earth distribution curve of Qiemo black-cyan nephrite in Xinjiang; (B) The spider diagram of trace elements in Qiemo black-cyan nephrite in Xinjiang (Digitized standard value data Sun and McDonough, 1989).

Previous studies have indicated that in magnesian marble-type skarn Hetian nephrite deposits, magmatic rocks exhibit a rare earth distribution pattern with high rare earth content: Eu negative anomaly, LREE right deviation, and HREE flat rare earth distribution pattern, while magnesian marble is characterized by relatively stable rare earth distribution pattern and low rare earth content [3]. The rare earth distribution pattern and rare earth content characteristics of Qiemo Margou black cyan nephrite primarily inherit the geochemical characteristics of magmatic rocks and magnesian marble surrounding rocks, indicating that Qiemo Margou black cyan nephrite belongs to the magnesian marble skarn-type Xinjiang nephrite deposit.

5. Discussion

5.1. Genetic Types of Qiemo Margou black cyan and Black nephrite

In general, Cr, Ni, and Co are crucial elements in the formation of nephrite and are commonly used to classify their origin types [29]. They are employed to distinguish nephtite associated with dolomite marble (related to dolomite) from nephrite associated with serpentinite [32]. The serpentinite-type nephrite exhibits higher bulk-rock concentrations of Cr (900~2812 μg/g), Ni (959~1898 μg/g), and Co (42~207 μg/g), while marble-type nephrite has lower concentrations of Cr (2~79 μg/g), Ni (0.05~471 μg/g), and Co (0.5~10 μg/g). The bulk-rock trace elements analysis of Qiemo Margou black cyan nephrite reveals Cr and Ni concentrations (6~21 μg/g and 2.5~4.5 μg/g, respectively) consistent with other dolomite marble-type nephrite, significantly lower than serpentinite-type nephrite, indicating that Qiemo Margou black cyan nephrite belongs to nephritee which is related to marble.

Bulk-rock analysis of rare earth elements in Qiemo Margo black cyan nephrite suggests its association with magnesian dolomite marble-type nephrite. The rare earth distribution pattern curve of Qiemo Margou black cyan nephrite shows a negative Eu anomaly (δEu=0.00～0.17), a decrease in LREE, and a flat HREE, with low total REE abundance ranging from 1.64 to 38.9 μg/g (average ∑REE 14.09 μg/g). The rare earth element distribution pattern and rare earth content of Qiemo Margou black cyan nephrite mainly inherit the geochemical characteristics of magmatic rocks and marble rocks, indicating that Qiemo Margou black cyan nephrite belongs to the magnesian marble-type skarn nephrite deposit.

5.2. Coloration Factors of Qiemo Margou black cyan and black nephrite

A previous study has highlighted that the color of nephrite can be differentiated based on the w(FeO) content, indicating a connection between nephrite color and Fe content. The color-causing elements Fe in the tremolite structure of nephrite mainly originates from granite, which typically lacks Cr and Ni elements in the crystal structure of tremolite [5]. Qiemo Margou black cyan and black nephrite exhibit higher FeO (3.97~5.09%) and TFe2O3 (4.68~6.11%) content. The FeO content of Gobi material nephrite is 0.36~1.83% [3,33], Alamas deposit white nephrite and green nephrite ranges from 0.41% to 1.96% [3], nephrite FeO content of Karakax River green is 0.67% to 3.18% and black nephrite is 0.48% to 9.55%. White nephrite with TFe2O3 ranges from 0.33% to 1.42%, bluish-white nephrite with TFe2O3 ranges from 0.43% to 0.96%, and green nephrite with TFe2O3 ranges from 0.77% to 3.97%. The content of green nephrite with TFe2O3 is 0.77% to 3.97 % and black nephrite with TFe2O3 is 0.56% to 16.23% in Kalakash River. Overall, the FeO and TFe2O3 content of Qiemo Margou black cyan and black nephrite samples align with black nephrite from the Karakax River. The contents of Cr and Ni in Qiemo Margou black cyan and black nephrite samples are irregular and consistently below 25 μg/g and 5 μg/g, respectively, all lower than the Cr and Ni content in marble-type nephrite [5], white nephrite to bluish-white nephrite from Xinjiang Hetian area. The limited distribution of graphite in the samples suggests that the Margou black cyan and black color of Qiemo nephrite were caused by higher iron content, and related to coloration through Fe content, and unrelated to Cr and Ni.

6. Conclusions

This paper provides insights into the mineral component and chemical composition of Qiemo Margou black cyan and black nephrite. The study reveals that these nephrite samples are predominantly composed of tremolite-actinolite, with minor minerals such as diopside, epidote, pargasite, apatite, zircon, pyrite, and ferric hydroxide. Comparative analysis of Cr and Ni element concentrations and rare earth elements distribution patterns with other nephrite worldwide conclude that Qiemo Margou black cyan and black nephrite belong to the typical magnesian skarn-type nephri te. The geochemical characteristics of these nephrite samples are consistent with those of Yutian nephrite, Pishan brown nephrite, Baiyu River nephrite placer and Moyu River nephrite placer material deposits, indicating that the material sources and deposits type of Qiemo Margou black - black cyan nephrite are consistent with these area deposits. The Margou nephrite appears black cyan and black color because of the high iron content

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