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Nephrite of Bazhenovskoye Chrysotile–Asbestos Deposit, Middle Urals: Localization, Mineral Composition and Color

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Abstract: In the Bazhenovskoye chrysotile–asbestos deposit (Middle Urals), nephrite bodies of the serpentinite type were found on the contact of after gabbro rodingites and serpentinites. The color is uniform to non-uniform, green to light green, bluish green, greyish green, and whitish. Spots, streaks, lenticules of bright bluish-green or, on the contrary, light green color are sometimes noted. The nephrite is mostly comprised of tremolite. Chromite decreases the quality of the ornamental stone, but it is replaced by chrome grossular, which gives the nephrite a brighter bluish-green color locally. Crushed grains of chromite contain increased concentrations of Zn and Mn. The quality of the nephrite is decreased by serpentine and talc, as well as by fractures due to drilling and blasting works. The specific feature of the nephrite in the Bazhenovskoye deposit is the formation of nickeline, maucherite, and uvarovite. The green color is associated with Fe^{2+} ions. The nephrite of the Bazhenovskoye deposit meets the requirements for an ornamental stone. The origin of this nephrite includes a combination of metasomatic and metamorphic processes.

Keywords: nephrite; mineralogy; ornamental stone; Bazhenovskoye deposit

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1. Introduction

Nephrite is a highly marketable piece of jewelry and ornamental stone that has long been used by humans, especially popular in China and some other countries. The most valuable nephrite is translucent white, black, and bluish green, with a minimum amount of ore minerals.

Nephrite deposits belong to two endogenous geological–industrial types: serpentinite type (after serpentinite metasomatites at ophiolites) and dolomite type (after dolomite tremolite–calcite magnesian skarns). Deposits of the first type are a source of mainly green-to-brown and black nephrite, deposits of the second type give mainly light-colored nephrite from white to green, brown and black in color. The exogenous geological–industrial type of placers, usually alluvial, is confined to the primary sources.

The most important nephrite deposits in Russia are located within the West and East Sayan, the Southwest Baikal Region, and the Middle Vitim Highland. In Russia, as of 1 January 2020, the balance sheet contains 24 deposits, including Akademicheskoye in Chelyabinsk Oblast, Kurtushibinskoye (central sector), Kantegirskoye and Stan-Taskylskoye in Krasnoyarsk Krai, Kurtushibinskoye (eastern sector) in the Republic of Tyva, Onotskoye in Irkutsk Oblast, Udokan (lode 1) in Zabaikalskiy krai, as well as 17 deposits in Buryatia.

Most of the nephrite balance reserves of the Russian Federation are located in Buryatia (92.66% of raw nephrite and 90.99% of high-grade stone on 1 January 2020). In 2019, according to official data, 1,175,150 kg of raw nephrite and 326,110 kg of high-grade nephrite were extracted in the deposits of Buryatia, which was 94.09 and 89.65% of extraction in the Russian Federation. Ospinskoye, Gorlykgolskoye, Khamar–Khudinskoye, and Ulan–Khodinskoye deposits of serpentinite type nephrite and Kavoktinskoye, Golyubinskoye, Khaytinskoye, Sergeyeva lode, and Nizhneye Ollomi of dolomite type nephrite are explored. In other regions of Russia, nephrite extraction is irregular, which increases interest in finding valuable jewelry and ornamental stone. Problems of complex use of substandard nephrite are considered in [1].

Localities of nephrite are found in the Amur region, Yakutia, Kamchatka, and the North Caucasus as well. A number of nephrite manifestations are known in the Urals [2,3]. Isolated localities were found in the area of the Muldakaevskaya dacha [4] and on the Bikilar mountain [5]. In the Polar Urals, in the ultramafic Rai-Iz massif, the manifestation Nyrdvomenshor was discovered [6]. In the Middle Urals, nephrite is known on the Listvyanaya mountain near the Pyshminskiy plant and in the alluvium of Neivo [7]. On the southern extension of the Urals, in Kazakhstan, there is the Dzhetygarskoye locality of nephrite [8]. In 2003, in the surrounding area of Miass (Chelyabinsk Oblast), Akademicheskoe deposit including Studentcheskiy and Fakultetskiy sections was discovered [2]. The Uchaly Miass potentially nephrite-bearing area was found, which can be traced from north to south from Karabash through Miass to Uchaly [3]. However, there is no nephrite extraction in the Urals.

Therefore, the discovery of nephrite in the developed Bazhenovskoye chrysotile–asbestos deposit in Sverdlovskaya Oblast is of great interest. The first data refer to 2009 (oral report by B. A. Tochilin). Brief information was published by Loskutov and Novgorodova [9].

2. Bazhenovskoye Deposit

The Bazhenovskoye deposit of chrysotile–asbestos is located 60 km to the northeast of Yekaterinburg on the eastern side of the Middle Urals. The geology and mineralogy of the deposit are well studied; it was discovered in 1885 and has been developed since 1889 [10–13].

It lies in the massif of ultrabasic rocks of the same name, which are referred to as the middle-upper Ordovician, elongated in the meridional direction for 28 km with a width of 1 to 4 km; the area of the massif on the surface is about 75 km^2. Harzburgites with subordinate role of dunites, clinopyroxenites, olivine websterites, lherzolites and wehrlites predominate in the composition of the Bazhenovskiy hyperbasite massif. At the same time, pyroxenites and wehrlites compose significant volumes of the northern part of the massif (Figure 1). In the west, it is adjacent to the gabbronorites of the Asbestovskiy massif, composing its hanging side, and in the east and south, it is limited by the Reftinsky and Kamensky granite massifs of younger age.

Vein bodies of basic and acidic composition with numerous apophyses permeate the body of ultrabasic rocks, fixing variously oriented faults up to 12–15 km long. These faults divide the ultrabasic rocks into a number of blocks. In their central parts, the blocks are composed of relatively fresh harzburgites (serpentine content from 30 to 70 vol.%). Along the periphery, closer to the fault zones, harzburgites are replaced by serpentinites and talc–chlorite rocks, and in the axial parts of the faults, by talc–carbonate rocks. Dikes that fix faults are represented by gabbroids, diorites, and plagiogranites, mostly rodingitized. The thickness of the dikes is small—from 0.1 to 1–2 m. The age of plagiogranite dikes cutting through the body of ultrabasic rocks is Early Silurian, 428 $\pm$ 33 Ma [14].

In the area of the Bazhenovskiy ultrabasic massif, 24 asbestos lodes were explored. They are located in the middle part of the ultrabasic massif and elongated in the meridional direction. The length of the lodes varies from 200 m to 4.5 km and the thickness from 20 to 300 m. The adjacent deposits are combined into industrial areas. Five sections are distinguished (from north to south): Okunevsko-Reftinsky, north, central, south, and Trudovoy otdykh. The total length of the industrial asbestos-bearing zone is about 10 km. Industrial asbestos-bearing property is traced to a depth of up to 1000 m.

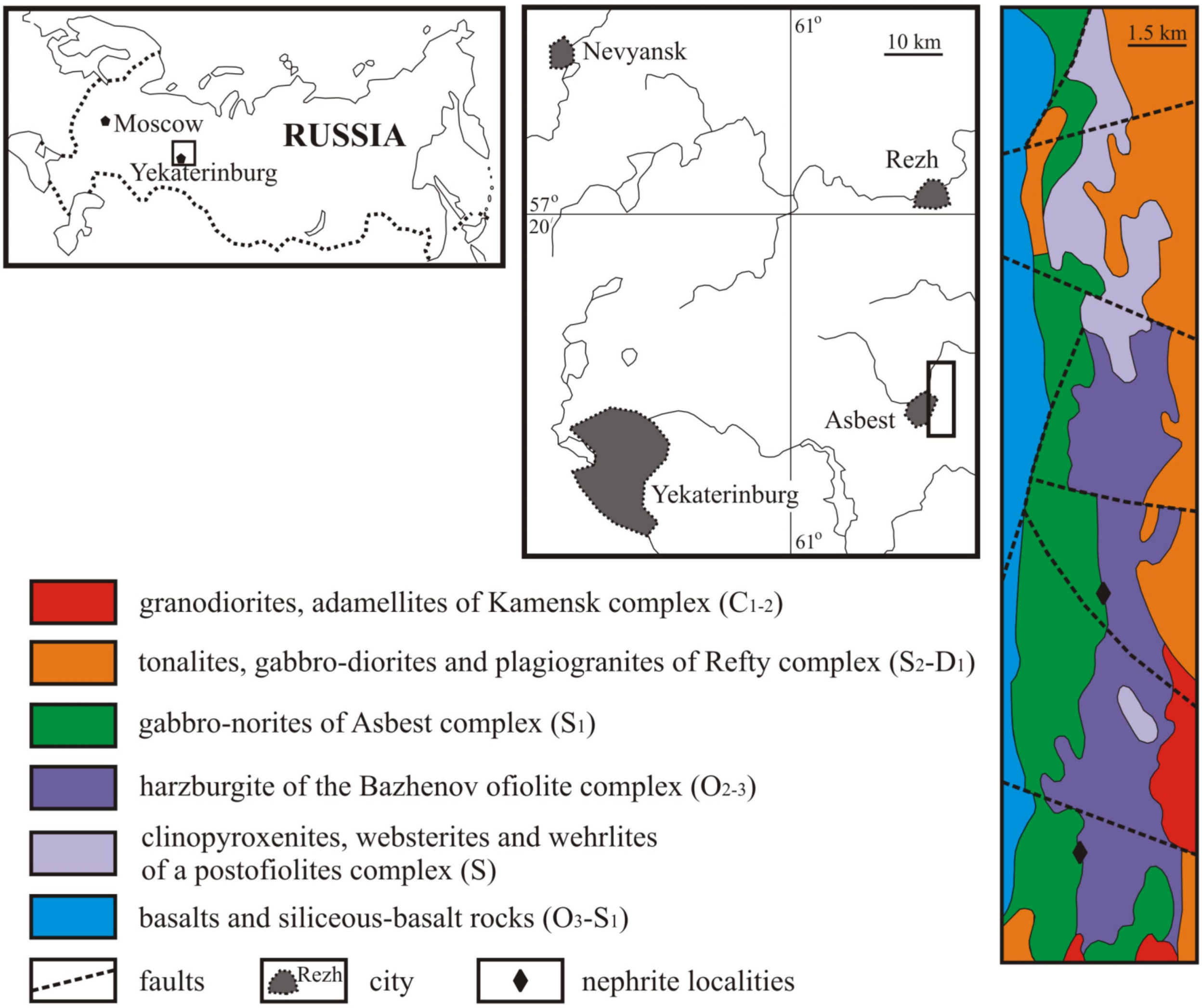

Figure 1. Location and geological map of the Bazhenovskiy ophiolite complex after [10] with our simplifications and additions.

3. Methods

Visual petrographic and mineralogical study of nephrite was carried out in natural light using a camera. Ornamental features (color, shade, pattern, presence of edges, degree of roughness) were determined through wetting, using a binocular microscope MBS-10 and a CYZ-B05 special flashlight. Plates, from 5 cm × 10 cm to 10 cm × 15 cm in size, from 1cm to 3 cm thick were made and polished to determine translucency, polishing acceptance, and shagreen. Thin sections were studied on a polarizing microscope POLAM L-213.

The chemical composition of the rocks was determined by X-ray Fluorescence spectroscopy on an XRF-1800 wave X-ray fluorescence spectrometer (Shimadzu, Kyoto, Japan) at IGG UB RAS (Yekaterinburg, Russia) after the methodic [15]. The current is 1–1000 μA, the voltage is 5–50 kV, the collimator width is 3.10 mm, and the measurement time is 100 s. The device is equipped with a vacuum system to increase the sensitivity of light element detection (Na, K, Mg, Al, Si, etc.). Qualitative and quantitative analyses of the samples were carried out; measurements were performed in two ranges—from Na to Sc and from Ti to U; optimal conditions for measuring the spectra were selected for each of them. As a result, the spectrum of the sample and information on the presence of elements in the sample were obtained. After smoothing the spectra by 25 points using Savitzky–Golay method and manual background correction, intensities of the element lines were calculated, and calibrations were constructed to determine the oxide contents of the studied elements through calibration graphs. Calculation of the contents was performed by the method of fundamental parameters (FP) since the construction of graduations using powder standard rock samples is not applicable in the case of samples of arbitrary size and shape.

The composition of the minerals was determined on a Cameca SX 100 electron probe microanalyzer (IGG UB RAS, Yekaterinburg), equipped with five wavelength spectrometers. Standards for sulfides: Ag–Ag; S, Cu, Fe–$CuFeS_2$; As–InAs; Hg–HgTe; Pb–PbS; Ni–Ni; Au–Au; Bi–Bi; Zn–ZnS; Sb–GaSb; Cd–CdS; Co–FeNiCo. Standards for silicates and oxides: Mg, Ca, Si–diopside; Na, Al–jadeite; Fe–Fe_2O_3; Cr–Cr_2O_3; K–orthoclase; Mn–rhodonite; Ni–Ni; V–V; Co–FeNiCo; Zn–ZnS; Ti–TiO_2.

X-ray diffraction analysis was conducted on an XRD-7000 (SHIMADZU) diffractometer (IGG UB RAS, Yekaterinburg) equipped with polycapillary optics and an Anton Paar HTK-1200N high-temperature attachment for operation in the temperature range 25–1500 °C. Cu Kα rays were used, and the operating mode of the X-ray tube is 40 kV, 30 mA. A diffractogram was obtained for the sample in the area of angles 2Θ from 4 to 70 degrees. The determination of the quantitative content of minerals by this method of analysis is limited to 5%.

The color of the nephrite was studied by optical absorption spectroscopy (KFU, Kazan, Russia). Optical absorption spectra were recorded on a specialized SHIMADZU UV-3600 spectrophotometer in the wavelength range of 185–3300 nm and on a standardized MSFU-K spectrophotometer in the wavelength range of 400–800 nm, with a step of 1 nm. The method of calculating chromaticity coordinates according to the international colorimetric system XYZ was used for objective measurement and description of the nephrite color. All colorimetric results on the interpretation of optical absorption spectra of minerals were submitted to the standard color triangle of the International Commission on Illumination CIE-1931. Colorimetric parameters of the studied minerals (x, y, z—chromaticity coefficient; λ—dominant wavelength, P—density of the main color tone) were calculated using specialized software "Spectra". Optical absorption spectra were recorded from plane-parallel samples; the color of nephrite is green, of varying intensity.

In order to further analyze the crystal–chemical features of nephrite, Raman scattering spectroscopy studies were carried out. Photos of the samples were taken using an inVia Qontor confocal Raman microspectrometer. Mode control and data processing were performed using Wire 5 application. A laser with a wavelength of 532 nm (laser power—500 mW) was used in the work. All experimental studies were conducted at room temperature.

4. Results

4.1. Nephrite Bodies

In the Bazhenovskoye deposit, nephrite was discovered in an operating quarry of the "Uralasbest" plant in the central and south sections. Nephrite forms a contact zone between rodingite after fine-grained gabbro and serpentinite.

In the central section, nephrite forms outcrops on the western side between horizons +2 and +17. A large block, 1 m × 1.5 m in size, composed of light green nephrite, was studied (Figure 2). The structure is massive, the stone is fractured due to drilling and blasting works. Occasionally, small voids with tremolite crystals were observed in the nephrite, less often—there is prehnite. On the contact of nephrite bodies and serpentinites, talc forms. On the gabbro side, quartz veins are usually traced lying subparallel to nephrite bodies. The nephrite block contacts gabbro through a transitional zone—A bright green opaque tremolite rock with inclusions of ore minerals—its thickness is 15 cm. The contact between all the zones is distinct and fractured. The block trends 200° to the southwest, the dip is 260°–270° to the west, the dip angle is 70°. The nephrite zone was traced 35 m up the side of the quarry and cut at +32 horizon.

At the center it is a green block of nephrite in the center of Figure 2, the central part of the block is wetted with water. On the left, i.e., lower left part of this block, contact of gabbro (1) transitional rock (2) and nephrite (3) are shown; the image on the right is the block of nephrite in the south section. In the upper part is gabbro (1), in the lower part, serpentinite (3), and between them, a zone of nephrite (2). The central part of the block is wetted with water.

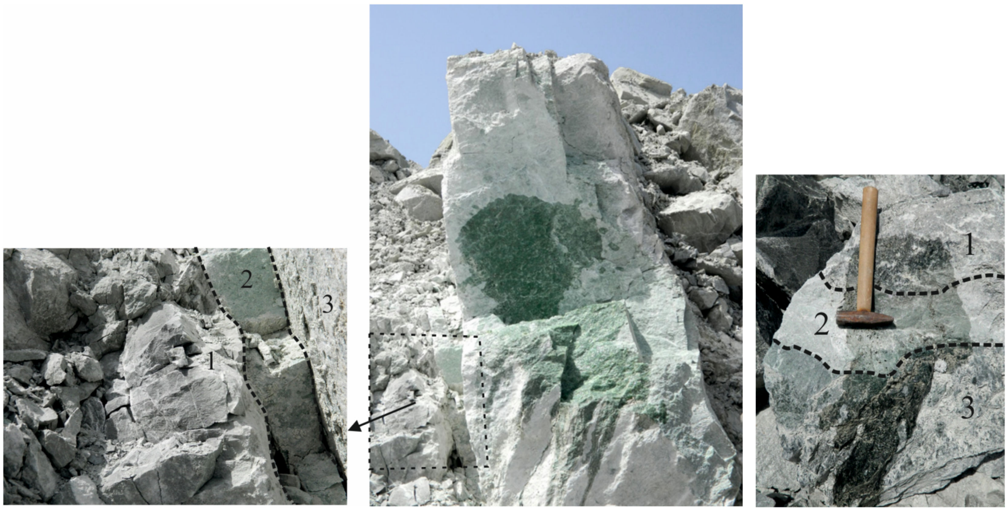

Figure 2. Blocks of nephrite.

In the South section, nephrite outcrops are also located on the western side between horizons −13 and −28 of the quarry. The nephrite is greenish grey. A zone of nephrite with a thickness of 20–30 cm was observed in the contact of gabbro and serpentinite (Figure 2).

4.2. Nephrite Composition and Properties

The color of nephrite is uniform to non-uniform saturated green (Figure 3) to light green, bluish green, greyish green, and whitish. Spots up to 5 mm, veinlets up to 2 mm thick, lenses 4–8 mm long of a bright bluish-green or, conversely, light green color were occasionally observed there. The texture is solid, mottled, and striped. The blockiness depends on the quarry drilling and blasting rocks and ranges from 5 cm to 2 m.

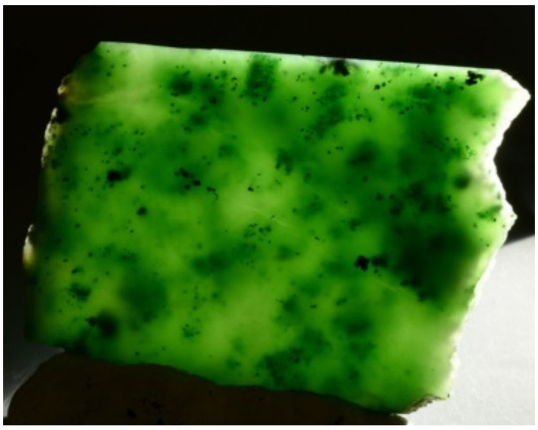

Figure 3. Translucent polished nephrite cut. Black dots are chromites. Plate 8 cm × 5 cm. South quarry. Sample by A.B. Loskutov and E.A. Novgorodova, photo by M.B. Leibov [13].

Both the nephrite (Figure 4), and the transitional tremolite rock (Figure 4) are composed mostly of tremolite (65–75%, less often—more than 80%). The mineral forms a fibroblast tangled-fibrous, sometimes porphyroblast, sheaf-like structure; the fibers are 0.06–0.138 mm in length. Tremolite from transitional tremolite rock contains much more FeO and almost all minor elements (Table 1).

Figure 4. On the left, a sample of nephrite OV-2 is shown, while on the right, a sample of tremolite transitional rock OV-3 is shown.

Table 1. Chemical composition of silicates (wt. %).

		SiO_2	TiO_2	Al_2O_3	Cr_2O_3	NiO	FeO	MnO	MgO	CaO	Na_2O	K_2O	∑
Tremolite OV-2 (21)	Max	58.32	0.04	0.62	0.55	0.14	3.52	0.20	22.33	13.69	0.09	0.02	97.72
	Min	57.81	0.00	0.18	0.18	0.03	2.70	0.02	21.60	13.25	0.00	0.00	96.53
Tremolite OV-3 (13)	Max	57.75	0.06	0.79	0.71	0.16	5.82	0.15	21.01	13.60	0.11	0.02	97.73
	Min	56.09	0.00	0.30	0.26	0.04	4.65	0.05	20.14	13.09	0.04	0.00	96.03
Grossular OV-2 (13)	Max	49.13	0.84	15.97	11.53	0.07	3.64	1.50	11.54	36.03	0.08	0.01	100.57
	Min	37.37	0.20	5.56	5.92	0.00	1.72	0.11	0.03	23.85	0.01	0.00	99.58
Uvarovite OV-2		30.84	0.18	14.14	16.61	0.00	9.08	0.67	0.13	28.49	0.00	0.00	100.14

Note: OV-2—nephrite, OV-3—tremolite rock. Hereinafter, analyses of minerals were performed on a CAMECA SX 100 electron probe microanalyzer (IGG UrB RAS, Yekaterinburg, analyst A.V. Mikheeva).

Nephrite is apple green with light green 4–8 mm long lenses, chromite grains 0.2–0.6 mm in size, and nickeline inclusions less than 0.1 mm in size. The tremolite transitional rock is light green in color with bright green 2–7 mm long and 2–5 mm wide lenses of tremolite–actinolite composition, chromite grains 0.2–0.6 mm in size, and bright green inclusions of chrome grossular up to 1 mm in size.

The presence of serpentine, presumably antigorite, was discovered petrographically by typical comb-like or micro-scaly structure, absence of abnormal blue or purple colors, characteristic of chlorite. X-ray phase analysis (analyst T.Y. Gulyaeva) showed weak peaks in the area of serpentine group minerals with a sharp predominance of tremolite. The serpentine sometimes forms small-scale aggregates; in this case, its content can reach 25–35%.

Talc was observed. Relict grains of clinopyroxene with uneven corroded grain boundaries were found, and the average size is 0.085 mm × 0.035 mm. Complete or partial pseudomorphoses of amphibole and serpentine on clinopyroxene were observed.

A characteristic mineral of the nephrite and the transitional tremolite rock of the Bazhenovskoye deposit is chromite, which makes up 3–5% of the rock. The mineral forms evenly distributed crushed and resorbed small (0.2–2.0 mm) grains of brownish-black color with clear boundaries; grossular forms along their cracks. Smaller crushed grains form linear structures. Microscopic grains of lighter brown color, due to their size, are distributed evenly. Whitish sections do not contain inclusions of chromite. Chromite is characterized by an increased content of Mn (in the nephrite—1.89–2.15 wt. % MnO and in the transitional tremolite rock—1.23–1.91 wt. %) and Zn (1.57–2.25 wt. % ZnO in the nephrite and 2.67–3.54 wt. % in the transitional tremolite rock, Table 2). Chromite from transitional tremolite rock contains less MgO and more ZnO (Table 2).

Table 2. Chemical composition of chromite (wt. %).

		SiO_2	TiO_2	Al_2O_3	Cr_2O_3	V_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	NiO	CoO	ZnO	∑
OV-2 (16)	Max	0.34	0.20	1.14	57.04	0.31	18.33	27.17	2.15	0.72	0.21	0.07	0.11	2.25	101.20
	Min	0.00	0.05	0.10	49.26	0.21	11.88	25.98	1.89	0.23	0.01	0.00	0.00	1.57	98.35
OV-3 (21)	Max	0.00	0.22	0.89	55.56	0.29	19.41	26.03	1.91	0.18	0.22	0.05	0.12	3.54	101.53
	Min	0.00	0.09	0.08	50.63	0.23	11.49	24.33	1.23	0.08	0.01	0.00	0.00	2.67	99.23

Note: Ferric iron is calculated from the stoichiometry of the mineral. See note to Table 1.

Chromite of the Bazhenovskoye deposit is cataclastic and disintegrated. Accumulation of Mg and Zn was observed in the marginal zones of minerals with a heterogeneity of their concentrations even within one grain. Concentrations of Ti and Ni are insignificant. Vanadium concentrations are uniform across all grains.

In some samples, chromite grains are corroded and overgrown with bright green fine-grained chrome grossular, which makes up to 5% of the rock (Figure 5). Isometric grains of chrome grossular destroy chromite. The mineral is bright green and forms halos of richer green color in the nephrite. The chemical composition of chrome grossular varies considerably. The content of Cr_2O_3 is 5.92–11.53 wt. % (Table 1). Boundaries between garnet and surrounding tremolite are gradual. Veinlets of uvarovite (Table 1) were noticed in the chromite.

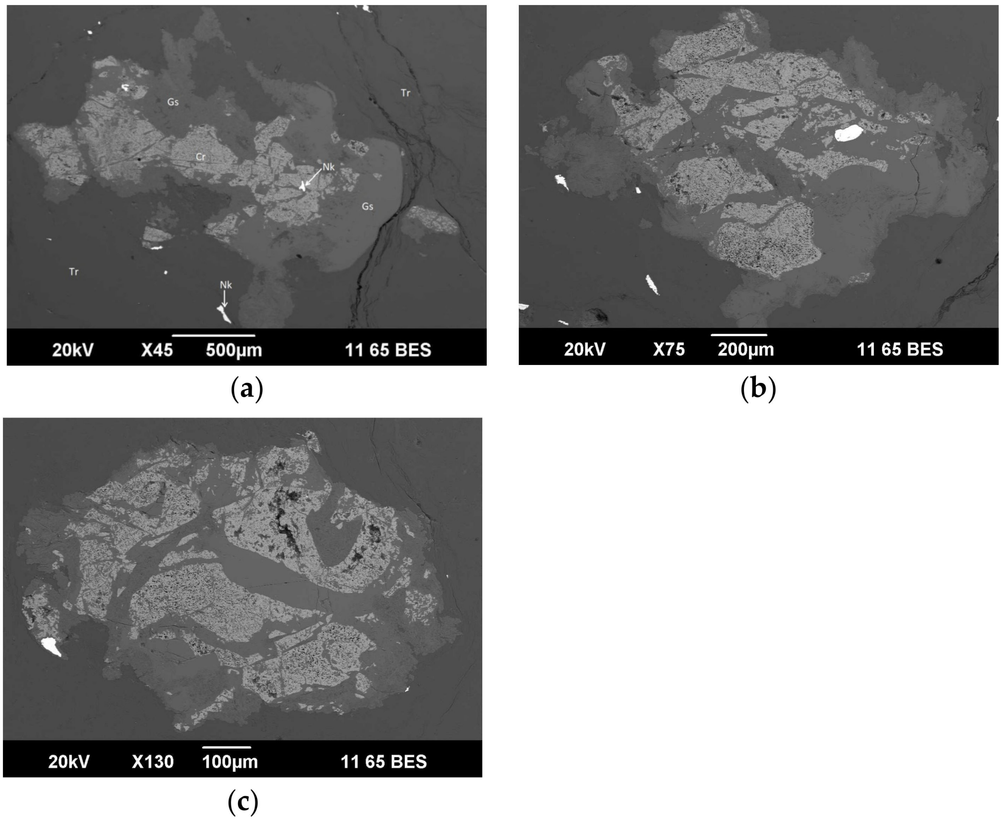

Figure 5. Resorbed chromite (Cr) grain is corroded and overgrown with a rim of chrome grossular (Gs). Nickeline (Nk) in both chromite and tremolite (Tr). (**a**) ×45; (**b**) ×75; (**c**) ×130.

The nephrite and the transitional tremolite rocks are characterized by thin, less than 1 mm, grains of nickeline and maucherite of light yellow color with a metallic luster. Single grains of nickeline with an admixture of antimony up to 7.24 wt. % (Table 3), 0.05–0.12 mm in size were found, both in tremolite and in cracks in chromite grains (Figure 5). Nickeline from transitional tremolite rock contains more Co (Table 3).

Table 3. Chemical composition of arsenides (wt. %).

		Hg	Pb	Ni	Co	Fe	Cu	Zn	Cd	S	As	Sb	∑
Nickeline OV-2 (9)	Max	0.14	0.16	43.09	0.80	1.12	0.04	0.03	0.03	0.06	55.65	1.19	100.12
	Min	0.00	0.00	41.59	0.60	0.27	0.00	0.00	0.00	0.00	54.35	0.83	99.19
Nickeline OV-2 (18)	Max	0.20	0.18	43.01	1.79	1.30	0.04	0.10	0.06	0.03	55.79	7.24	100.65
	Min	0.00	0.00	40.95	1.18	0.14	0.00	0.00	0.00	0.00	49.40	0.24	99.01
Maucherite OV-2 (9)	Max	0.19	0.01	50.41	1.24	0.74	0.08	0.10	0.03	0.03	48.53	0.91	100.64
	Min	0.00	0.00	48.92	0.72	0.23	0.00	0.00	0.00	0.00	46.81	0.13	99.28
Maucherite OV-2 (2)		0.00	0.00	47.70	1.54	1.70	0.16	0.00	0.06	0.00	47.85	0.33	99.33
		0.05	0.07	47.53	1.34	2.21	0.22	0.00	0.00	0.00	47.84	0.40	99.64

See note to Table 1.

Even finer grains of maucherite are sparse on a nephrite matrix. Maucherite from transitional tremolite rock contains less Ni, more Co, Fe, and Cu (Table 3).

In the transitional rock, talc in the form of scales up to 1 mm, associated with serpentine, and cavities filled with brownish-yellowish material, possibly after the destruction of carbonates, were rarely found in small amounts (3–4%).

The nephrite shines through to a depth of 0.5 to 2 cm. Macroscopic fracturing is slightly expressed. Individual samples are schistose, with many cracks on the surface. White to yellowish films of low-temperature calcite are separately developed along parallel cracks. The nature of the fracture is uneven, the luster is greasy to matte, and the hardness on the Mohs scale is 6–6.5.

Fracturing and decreased blockiness are caused by drilling and blasting work in the quarry. Nephrite accepts perfect polishing with a slight shagreen. Later veinlets stand out on the polished surface—some of them have an increased relief, while others, on the contrary, have an ideal mirror surface (Figure 6). The nephrite meets the requirements for an ornamental stone.

Figure 6. Ball of nephrite from the Bazhenovskoye deposit.

The chemical composition of the nephrite from the Bazhenovskoye deposit (Table 4) is similar to that of serpentinite type nephrite from known deposits [16].

Table 4. Chemical composition of nephrite and transitional tremolite rock (wt. %).

	SiO_2	Al_2O_3	Cr_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	NiO	As_2O_3	LOI	∑
OV-2	58.07	0.45	0.117	3.32	0.095	23.12	12.25	<0.1	0.14	0.071	2.4	100.00
OV-3	58.22	0.32	0.330	4.47	0.114	22.27	12.05	<0.1	0.13	0.119	2.1	100.05
OV-4	58.49	0.39	0.077	3.48	0.098	23.05	12.04	<0.1	0.13	0.039	2.2	100.00
OV-5	58.15	0.27	0.141	3.96	0.111	22.58	12.19	<0.1	0.07	0.100	2.5	100.01

Note: OV-2, OV-4, OV-5—nephrite, OV-3—transitional tremolite rock. The analysis was carried out by X-ray spectral fluorescence on an XRF 1800 instrument (Laboratory of Physical and Chemical Research Methods, IGG UrB RAS, Yekaterinburg). Analysts N.P. Gorbunova, L.A. Tatarinova, G.S. Neupokoeva.

4.3. Nature of Color and Crystal–Chemical Features

Double chains of silicon–oxygen tetrahedrons $[Si_4O_{11}]^{6-}$ with an independent anion $[OH]^-$ are involved in the crystal lattice of tremolite, they alternate with bands of cationic polyhedra. In the tremolite structure, cation sites M1, M2, M3 are octahedral, and site M4 is characterized by octantal coordination [17,18].

The common feature of the optical absorption spectra of the nephrite from the Bazhenovskoye deposit is the presence of a wide absorption band in the near-infrared area of about 990 nm (Figure 7).

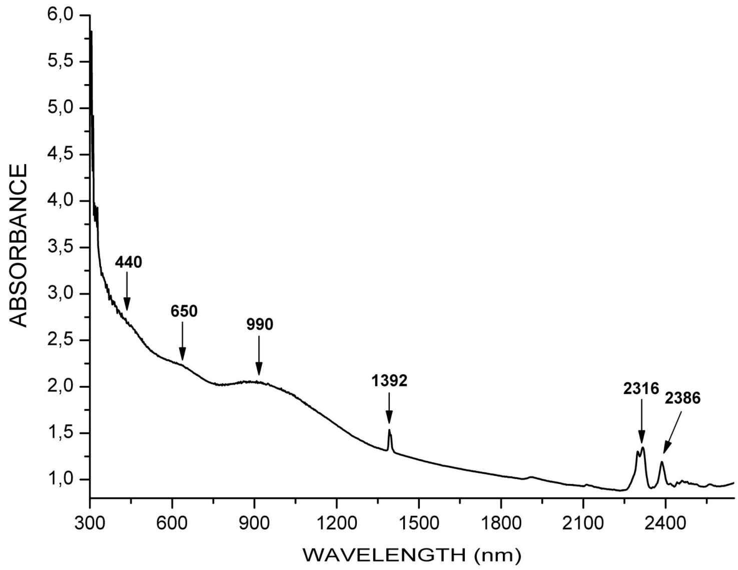

Figure 7. Optical absorption spectrum of the nephrite from the Bazhenovskoye deposit.

When studying the configuration of this line and the results of chemical analyses of the nephrite, it was revealed that this band is associated with spin-resolved transitions 5T2 (5D) → 5E (5D) in Fe^{2+} ions at positions M1, M2, M3, which replace Mg^{2+}. The absorption bands at wavelengths 440 and 650 nm are associated with Cr^{3+} ions, which also isomorphically replace Mg^{2+} ions in octahedral positions. The absorption bands about 440 nm and 650 nm in the spectrum of the studied nephrite are due to spin-resolved transitions from the ground state of 4A2d (4F) to higher energy levels of 4T1d (4F) and 4T2d (4F), respectively [19,20].

The narrow absorption bands at wavelengths 2316 and 2386 nm are associated with OH^--group vibrations in the tremolite structure, and the absorption line of 1392 nm is the first overtone of the main OH^--group vibrations [17].

Based on the interpretation results of the nephrite optical absorption spectra, chromaticity coordinates were calculated according to the international colorimetric system CIE-1931. The color coordinates of the dominant wavelength of the main color tone were λ = 576–578. 2 nm and the saturation value of the main color tone varied in the range of 34.4–54.29%.

The lines in the Raman scattering spectra of the Bazhenovskoye deposit's nephrite correspond mainly to actinolite [21].

Nephrite with the same shades can have different ranges of color saturation and intensity of color tone. Therefore, the determination of the color with the naked eye can be problematic. The main chromophore associated with the color of nephrite is Fe^{2+} ions. Fe^{2+}–Mg^{2+} isomorphism in the tremolite crystal structure leads to a change in the intensity and position of OH^--vibration lines in the infrared range of 3600–3700 cm^{-1}, which can be used to assess the composition of the nephrite and the features of its color [22,23]. There is a technique for determining the content of Mg^{2+} and Fe^{2+} ions in the crystal structure of tremolite by the intensity ratio of various lines associated with OH^--group vibrations [24]. According to this technique, the ratio of lines at wavelengths of 3646, 3662 and 3675 cm^{-1} OH^--vibrations about 1 is characteristic of white nephrite, 0.98–1—light-green, 0.90–0.98—bluish green, and below 0.91—bright green. The calculation of the relative intensity coefficients allows standardization of the nephrite color definition, identification, and evaluation of additional shades that are present in the nephrite color [24].

The intensity of the oscillation bands of the OH^--groups in the nephrite from the Bazhenovskoye deposit is in the range of 0.94–0.95 (Figure 8). This technique does not take into account the yellow shades of nephrite color, since the relationship of OH^--group lines and Fe^{3+} ions has not yet been studied in detail. According to the obtained results of Raman spectroscopy, we can confirm the green color of the nephrite from the Bazhenovskoye deposit, which is exclusively associated with Fe^{2+} ions.

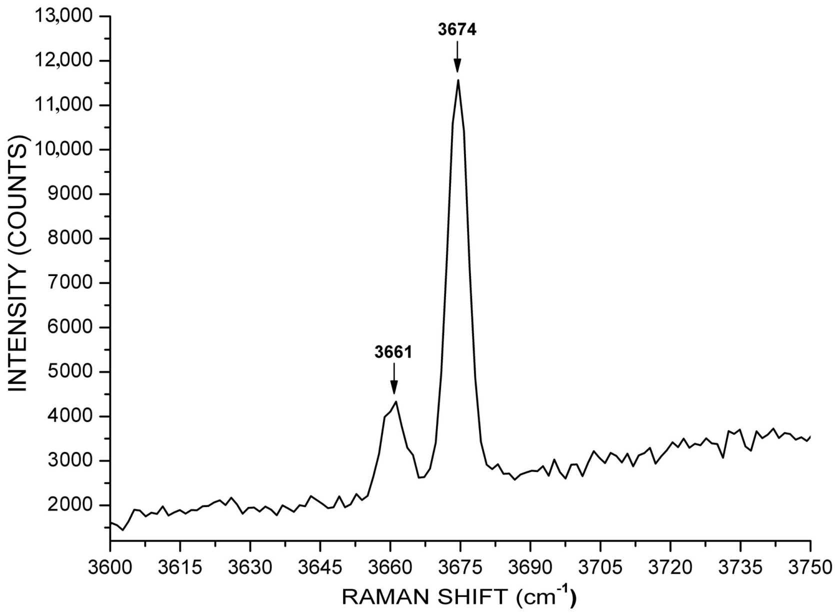

Figure 8. Oscillation bands of OH^--groups in nephrite.

5. Discussion

When performing this study, the tasks were set to show that the nephrite of the Bazhenovskoye chrysotile–asbestos deposit (Middle Urals) meets the requirements for this ornamental stone, to study its specific mineral composition and the nature of its color, and to determine the features of its origin.

In the Bazhenovskoye deposit, bodies of ultramafic type nephrite belonging to the most productive type—veins at the contact of after gabbro rodingites and serpentinites—were found. The nephrite color is uniform to non-uniform saturated green to apple green, grass green, spinach green, greyish green, light green, and whitish. Occasionally, spots, veinlets, little lenses of bright spinach-green or, conversely, light green color were observed there.

Nephrite is composed mostly of tremolite; chromite decreases the quality of the ornamental stone, but it is replaced by chrome grossular, giving the nephrite a brighter green color. The quality of the nephrite is decreased by admixtures of serpentine and talc, as well as by fractures due to drilling and blasting.

The chromite composition of the nephrite and the transitional tremolite rock significantly differs from the chromite composition of the chromitites (0.27–0.34 wt. % MnO and 0.19–0.24 wt. % ZnO) and the metachromites (0.80–0.93% MnO and 0.30–0.40% ZnO) of the Bazhenovskoye deposit [25]. On the other hand, the nephrite chromite of the Bazhenovskoye deposit is close in terms of the content of these elements to the nephrite chromite of other deposits, for example, to low-chrome ferrichromite of the Dzhida nephrite-bearing region, with 1.46–3.23 wt. % MnO and 0.09–7.93 wt. % of ZnO, and Ospinskoye deposit, with 0.34–2.02 wt. % MnO and up to 5.10 wt. % ZnO [16]. Vanadium concentrations are generally significantly higher than in the chromites of the Dzhida nephrite-bearing region and the Ospinskoye deposit [16].

Veinlets of uvarovite were observed in the chromite. Previously, uvarovite was observed in the nephrites of the Fengtien deposit in Taiwan [26], locality Nyrdvomenshor in the Polar Urals, and deposits of British Columbia, Canada [16]. The garnet of uvarovite–grossular solid-solution composition was mentioned for serpentinite type nephrite from the Nasławice deposit in Poland [27]. However, published analysis results of the garnet from the Fengtien deposit indicate chrome grossular (on average 11.6% Cr_2O_3, the maximum content is 12.86 wt. %, higher results of the analysis of the crystal core correspond to a mixture of chrome grossular and chromite), analyses of garnets from the nephrites of the Nyrdvomenshor and British Columbia have not been published. In the nephrite of the Kutcho district in British Columbia [28], garnet is defined as grossular.

In the nephrites that have undergone recrystallization up to the formation of light grey veinlets, chromite becomes overgrown with a rim of chrome grossular or passes into zinc-containing ferrichromite [16]. Both of these phenomena manifested themselves in the Bazhenovskoye deposit, supplemented by the appearance of uvarovite.

Previously, nickeline and maucherite were observed in the nephrites of the Miass nephrite-bearing region [29], but their chemical composition has not been published.

The specific feature of the nephrite from the Bazhenovskoye deposit is the formation of nickeline, maucherite, and uvarovite. The green color is associated with Fe^{2+} ions. Chrome grossular, replacing chromite, causes the appearance of bright bluish-green spots. Nephrite of the Bazhenovskoye deposit meets the requirements for an ornamental stone. The origin of this nephrite includes a combination of tectonic and metasomatic processes.

Serpentinite type nephrite is traditionally considered to be a typical contact rock formed as a result of the metasomatic substitution of serpentinites, [16,30,31]. The composition of aluminosilicate rocks is different. The are dikes of acidic to basic composition most often. Veins of nephrite are confined to the contact of these rocks with serpentinites. The metasomatic origin with an important role of faults is shown for the Manasi nephrite deposits in the Xinjiang Uygur Autonomous Region of China [32], Jordanów in Poland [33], and Agardak in Tuva at Russia [34]. At the same time, R. Coleman [35] associated nephrite formation with high-calcium solutions formed during the serpentinization of lherzolites. A.P. Sekerin [36] supposed that the origin of such fluid is a mantle. The granitic rocks are proposed as the most likely source of Si-rich fluids due to spatial relations, high Si content in granites, as well as isotopic studies in a lot of papers [30,33]. The impact of granite-derived fluids for serpentinite-type nephrite formation is also supported by Sr isotope studies [27].

Along with the recognition of the role of fluids, other researchers pay great attention to the contribution of metamorphism; they believe that after ultramafic nephrite is confined to the zones of serpentinite mélange [37,38]. Metasomatism with the participation of fluids of metamorphic origin is accepted for the genesis of nephrite of Mount Ogden, British Columbia, Canada [39], the Southern Island of New Zealand [40], Fengtien in Taiwan [41], and the area of Kutcho, British Columbia, Canada [27].

Characteristic features of the relations between nephrite in the Bazhenovskoye deposit and other rocks support this statement. It is located at the contact of serpentinites and rodingitized gabbro at the area of big granite intrusions. Nephrite is accompanied by a transitional tremolite rock, development of prehnite, talc, and quartz, which indicates the metasomatic origin of the stone. In the nephrite itself, metasomatic replacement of chromite with chrome grossular occurs. On the other hand, low-thick dikes of gabbro or of plagiogranites are unlikely to work so powerfully on serpentinites. Additionally, their placement is controlled by faults. Apparently, calcium-containing fluids contributed to the formation of nephrite, and tectonic stress led to the appearance of cryptocrystalline tangled-fibrous structures.

Thus, tectonic and metasomatic processes were combined in the origin of the nephrite of the Bazhenovskoye deposit.

6. Conclusions

The bodies of serpentinite type nephrite at the Bazhenovskoye chrysotile–asbestos deposit (Middle Urals) were found. They belong to the most productive type—veins at the contact of after gabbro rodingites and serpentinites. The nephrite color is uniform to non-uniform saturated green to light green, bluish green, greyish green, and whitish. Occasionally, spots, veinlets, little lenses of bright bluish-green or, conversely, light green color were observed there.

Nephrite is composed mostly of tremolite; chromite decreases the quality of the ornamental stone, but it is replaced by chrome grossular, which gives the nephrite a brighter green color. The quality of the nephrite is decreased by admixtures of serpentine and talc, as well as by fractures due to drilling and blasting operations. The specific feature of the nephrite from the Bazhenovskoye deposit is the formation of nickeline, maucherite, and uvarovite. The green color is associated with Fe^{2+} ions. Chrome grossular, replacing chromite, causes the appearance of bright bluish-green spots.

Nephrite of the Bazhenovskoye deposit meets the requirements for an ornamental stone. The origin of this nephrite includes a combination of metasomatic and metamorphic processes.

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