Nephrite Jade from Washington State, USA, Including a New Variety Showing Optical Phenomena

Jean-Pierre Jutras, Cara Williams, Bear Williams and George R. Rossman

ABSTRACT: In 2018, a new type of nephrite jade was recognised from the DJ project in Washington State (USA) that exhibits subtle-to-strong directional colour variations when viewed at different orientations. Its colouration ranges from green to blue in light-to-dark tones, and its mineralogical and gemmological properties are consistent with nephrite jade from other localities. The optical phenomenon is related to pleochroism resulting from the internal structure of the tremolite fibres constituting the nephrite. These fibres show high-angle to orthogonal cross-felting, often with variations in chemical composition, and appear to result from more than one generation of formation. The presence of sheen (caused by the scattering of light from fibrous tremolite domains) is sometimes seen in addition to the pleochroic optical effect. This phenomenal material has the toughness required to be cut into cabochons or carved without any stabilising treatment, thus possessing workability that qualifies it as a new and unique variety of nephrite jade. Three other nephrite types—classified here as Ornamental, Carving and Gem—additionally occur at the DJ project, and are also described in this article.

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Nephrite jade is prized for its attractive appearance as well as its toughness, both of which contribute to its desirability in jewellery and *objets d'art*. A new type of nephrite jade with a unique optical phenomenon was recently identified from Jade Leader Corp.'s DJ project, located in Washington State, USA. Unlike most nephrite jades, which typically show fine-grained texture and a fairly even colouration, this new material has coarser texture and exhibits subtle-to-strong directional colour variations when properly cut or carved (Figure 1).

Although several nephrite varieties have been defined from the DJ occurrence, only one type exhibits the optical phenomenon. The unusual appearance of this nephrite was first noticed in 2018 by author J-PJ, but it took him until mid-2022 to develop the proper cutting protocols to best reveal the phenomenon. The range of colour and translucency shown by the material was initially explored in an early test suite comprising 10 stones totalling nearly 400 carats (2.7–164.95 ct each) that were cut by author J-PJ. Since then, this nephrite has been cut into a wide variety of cabochons and carvings.

Regarding the two internationally recognised jade varieties—*nephrite* (amphibole-dominant) and *jadeite* (pyroxene-dominant)—all the materials described in this article are nephrite, consistent with most previous analyses of jade materials from Washington (e.g. Ream 2022). The new phenomenal nephrite is distinct from the 'cat's-eye jade' or 'chatoyant jade' that was recently documented from Washington (Hogarth 2019, 2022). For such chatoyancy to be displayed, the tremolite or actinolite fibres must have optically continuous areas of parallel alignment, which means the material lacks the interlocking or felted texture that is necessary for the material to properly be called *nephrite jade* (LMHC 2011; Barnes 2022). Therefore, Hogarth (2022) indicated that GIA's laboratory would refer to the chatoyant material mentioned above as 'cat's-eye actinolite' (or, 'cat's-eye

Figure 1: Four views are shown of a marquise-shape nephrite cabochon (17.1 × 7.4 mm) during a 90° counterclockwise rotation under a fixed light source. It exhibits multiple domains showing strong colour variations depending on the viewing angle. Composite image taken from a video by J.-P. Jutras.

tremolite', depending on the dominant mineral composition), rather than 'cats's-eye nephrite'.

This article examines the four different types of nephrite jade from the DJ occurrence and focuses on the phenomenal type in particular. The history, geology and exploration of the jade deposit are described, and samples of each nephrite type are characterised mineralogically and gemmologically. Finally, the cause of the optical effect in the phenomenal nephrite is explained.

LOCATION AND ACCESS

The DJ project consists of a group of contiguous lode-mining claims covering roughly 350 acres of land with multiple nephrite showings in north-western Washington State, USA (Figure 2). Specific information on the location of the deposit is not provided here to prevent unauthorised visitation and collection of material from the claims.

The project is readily accessible by paved and gravel (U.S. Forest Service) roads, within 20–30 minutes from the nearest community with services such as food, fuel and field supplies. Access to the property to conduct exploration and extraction activities is typically possible from April to November, with slight annual variations depending on winter snow loads. The project is located on public lands, and regulated activities are administered jointly by the Bureau of Land Management and the U.S. Forest Service.

HISTORY AND NEPHRITE VARIETIES

Nephrite was used prehistorically in Washington State, with one of the earliest mentions of such artefacts made around 1900 by archaeologist Harlan Smith of the American Museum of Natural History (Leaming & Hudson 2005). In modern times, hobbyists have collected jade and other ornamental stones over the past several decades from various localities in the USA's Pacific Northwest (Ream 1974, 2022), but only limited organised mining has taken place. Commercial nephrite production in Washington has historically lagged behind that of neighbouring British Columbia, Canada, where annual jade production has sometimes exceeded 500 tons (Ward 2015). By comparison, the Washington Gem Jade and Mining Company, which was one of the larger operations for lapidary materials in the 1970s (Ream 1974), had a total production estimated at some 50 tons (Leaming 1995). Recently, a small group has been marketing cat's-eye actinolite from Washington (Hogarth 2019, 2022).

The initial discovery of the nephrite deposit that is the subject of the present article was reportedly made by Lucky Case and Fred Krapsicher in the early 1970s (L. Ream, pers. comm. 2018). They noted a pod of nephrite of unreported quality hosted by heavily serpentinised ultramafic rocks that was exposed in a road cut, which

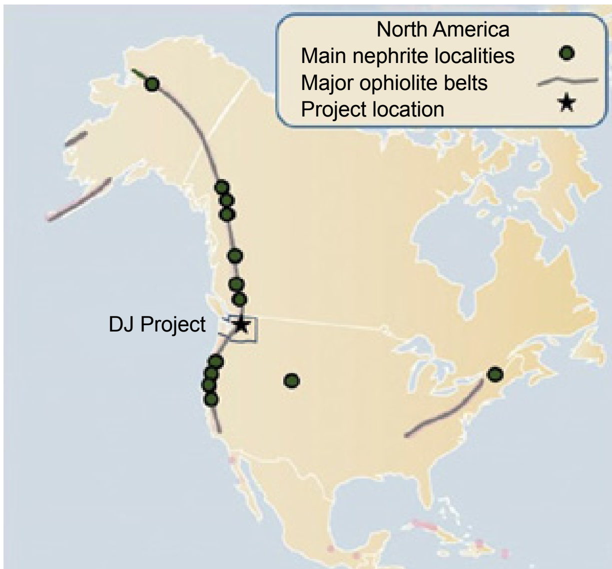


Figure 2: The general location of the DJ project in Washington State is shown in the context of other North American nephrite jade localities. Modified from an illustration by G. Harlow in Hughes (2022).

Figure 3: The first jade pendant (7.5 cm long) cut and polished by author J-PJ from the DJ project shows the good quality and high lustre of some of the nephrite from this deposit. Photo by J.-P. Jutras (the lower image is a reflection).

led them to stake mineral claims. These claims were repeatedly sold, expired and re-staked with little formal exploration or development work until some new owners re-staked the showing and, starting in 2014, began more systematic prospecting in the area.

Author J-PJ first visited the deposit in July 2015, with the consent of the then-owner of the claims, as part of a general nephrite research project. Samples collected at one of the main outcrops were cut to reveal a fine-grained, highly translucent bluish green nephrite. It showed an unusually high polish lustre (e.g. Figure 3) for North American nephrite jade other than the material from Wyoming, USA.

In 2017, author J-PJ co-founded Jade Leader Corp., a Canadian-listed public company with a mandate to explore for and develop nephrite occurrences in the continental USA. Jade Leader first optioned and then purchased the above-mentioned Washington claims, now referred to as the DJ project, in 2018. The company then began exploration work to better define the various nephrite types present, determine the appropriate cutting protocols and evaluate the commercial potential of the jade occurrences. The previous property owners estimated that roughly 2 tonnes of various types of nephrite were mined from 2014 to 2018, with the largest single block weighing approximately 550 kg (D. Smith, pers. comm. 2022). This material was largely collected for the previous owner's lapidary hobby use and did not enter the market in any significant commercial sense. Exploration work since 2018 has included mapping, trenching, core drilling, geophysical surveys and nephrite characterisation studies done in-house by Jade Leader and also in conjunction with the University of Arizona (Tucson, Arizona, USA).

DJ project nephrite has been classified by author J-PJ into four major types according to its visual characteristics and likely potential uses: (1) *Ornamental*, (2) *Carving*, (3) *Gem* and (4) *Phenomenal* (see Figures 4 and 5). These categories are further described below in the Results and Discussion section.

Unusual botryoidal nephrite material has also been found at a few of the DJ project's jade occurrences, but it is not listed here as a specific category due to its rarity. Long-fibre tremolite, likely capable of exhibiting chatoyancy if cut *en cabochon*, has also been noted in some areas.

The new Phenomenal-type nephrite (Figures 1 and 4d) that is the main subject of this article was first presented publicly at the Canadian Gemmological Association conference in October 2022.

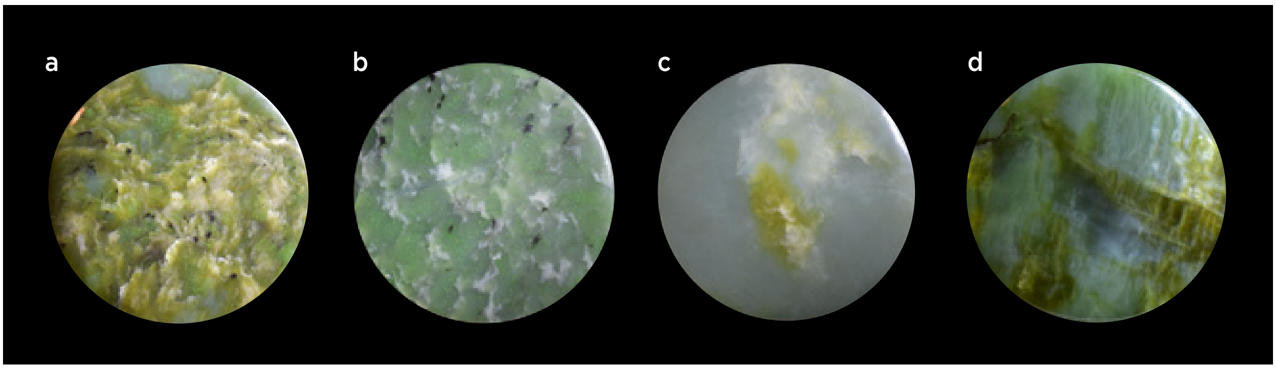


Figure 4: The four types of nephrite jade from the DJ project are represented by these cut and polished reference discs: (**a**) Ornamental (50 mm in diameter), (**b**) Carving (55.7 mm in diameter), (**c**) Gem (50 mm in diameter) and (**d**) Phenomenal (36.6 × 36.1 mm). Composite photo by J.-P. Jutras.

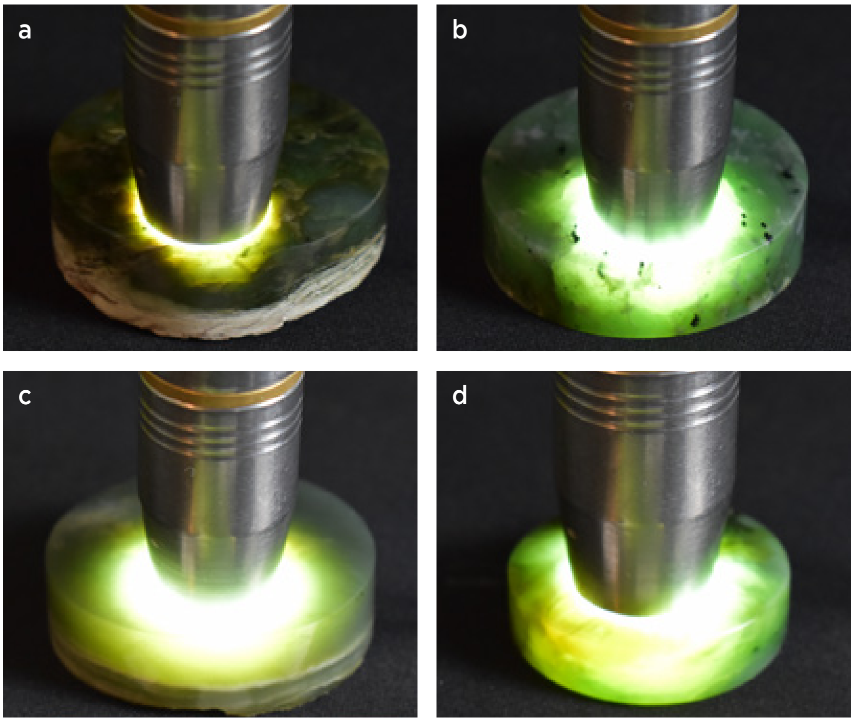


Figure 5: The same set of reference discs as in Figure 4 show variations in translucency and light transmission depending on the composition and texture of the nephrite. Sometimes referred to as the 'jade carver's torch test', the stone is illuminated by placing it in contact with a high-intensity torch to evaluate its texture and translucency, as well as the presence of fractures. Photos by J.-P. Jutras.

GEOLOGY

The DJ project is situated within a subduction zone-parallel coastal belt of thrusted and accreted ophiolitic rocks containing varying amounts of mafic/ultramafic units and associated serpentinites. These belts are known to host nephrite jade intermittently from Alaska to California (again, see Figure 2), and are well documented on the Canadian side of the border (Leaming 1978) and in California (Blankenship 2022).

The nephrite occurrence discussed here lies along the Devil's Mountain Fault where it cuts the Helena-Haystack melange (Tabor *et al.* 2002). Specific lithological units in this area include schistose metavolcanic rocks, phyllite, amphibolite and biotite-hornblende tonalite embedded in a serpentinite matrix. The nephrite is spatially related to serpentinite, similar in many respects to the Canadian counterparts described by Leaming (1978).

Tabor *et al.* (2002) reported formation ages of 141–150 million years for amphibolite units near the project site, and interpreted the Helena-Haystack melange as a thrust unit that was emplaced between 90 and 40 million years ago. No work has yet been performed to specifically define the age of nephrite genesis or the specific event related to its formation.

To date, three separate *in-situ* nephrite occurrences or 'lodes' have been recognised on the surface at the DJ project, all associated with a poorly exposed serpentinite unit. The nephrite forms veins, pods and elongated lenses extending over tens of metres at the sheared boundaries between more resistive units (e.g. rodingite, a metasomatic calc-silicate rock) and ductile serpentinite (Figure 6). The continuity between the individual discrete nephrite occurrences cannot yet be ascertained due to lack of exposure in the forested areas between the lodes.

The Phenomenal-type nephrite has been recognised within surface outcrops over some 40 m of strike length and was intercepted in core drilling at depths up to 30 m. This nephrite type is therefore present throughout the larger nephrite-bearing system and is not simply a localised anomaly. The largest block containing this type of nephrite recovered during test sampling weighed 37.4 kg and measured 47 × 34 × 19 cm.

EXPLORATION AND MINING

Since 2018, exploration sampling (including core drilling; Figure 7) and limited jade production has been conducted for material characterisation and test-marketing purposes. As the nephrite system crops out locally, extraction to date has been accomplished with the use of tools such as diamond saws, jackhammers and wedges (e.g. Figure 8). There is a very high contrast in competency between the variably fractured or foliated host rocks (rodingite and serpentinite; Ream 2022), which are relatively structurally weak, and the massive nephrite. This simplifies extraction and sorting of the target nephrite materials. A short video of an October 2022 pilot-scale nephrite extraction programme at the

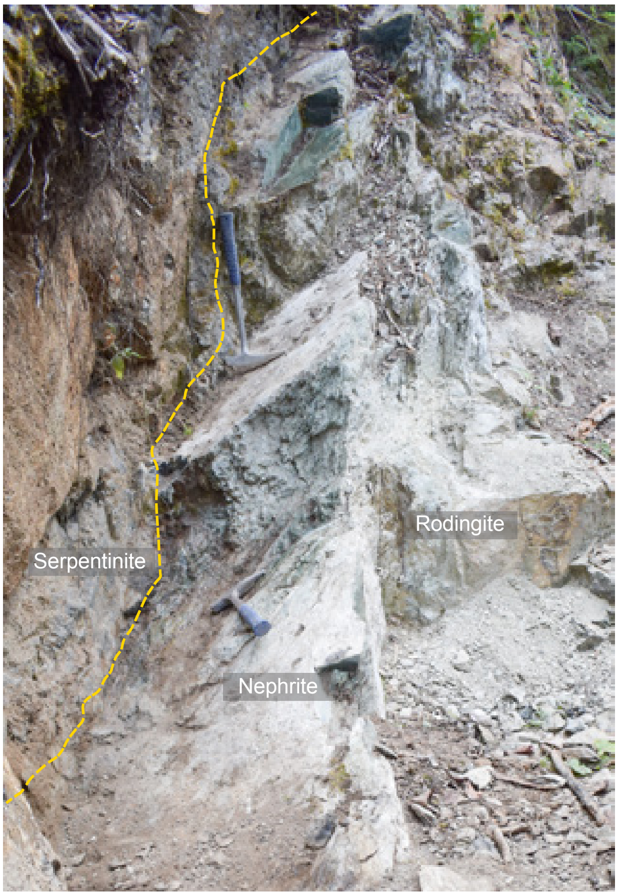


Figure 6: The mode of occurrence of nephrite at the DJ project is exemplified by this tabular, steeply dipping vein that occurs at a sheared contact between serpentinite and rodingite. The vein varies from 0.6 to 1 m thick at the surface (see the hammer for scale). The same nephrite vein was intersected by drill core 30 m down-dip below the surface of the trench, where it had expanded to 5.2 m wide. Photo by J.-P. Jutras.

DJ project can be viewed at https://www.youtube.com/watch?v=uI9V032p6Jo, and some of the resulting rough and polished production is visible at www.jadeleader.shop. In the future, extraction could involve typical quarrying techniques with mechanised equipment.

Most nephrite blocks have an alteration rind that must be sliced away to assess their quality and type. However, no other crushing or sorting equipment requiring a significant surface disturbance is necessary, nor is the use of water or the creation of tailings piles.

MATERIALS AND METHODS

An initial study of nephrite materials from the DJ project was conducted in conjunction with the University of Arizona in 2018 with the objective of confirming the mineralogical composition and textures, in order for the samples to be properly classified as nephrite jade. Specimens representing all four nephrite types were selected by author J-PJ and sent to Quality Thin Sections (also in Tucson), and seven of the resulting polished thin sections were supplied to Drs Hexiong Yang and Robert T. Downs at the University of Arizona for both microscopic characterisation (including mineral-phase identification) and chemical analyses. The latter were performed using a Cameca SX-100 electron probe micro-analyser (EPMA) in wavelength-dispersive mode with an accelerating voltage of 15 kV, a beam current of 20 nA and a beam diameter of < 1 µm. A total of 74 points were analysed of the main amphibole constituent of the thin sections, as well as 35 points for accessory mineral phases. Backscattered electron (BSE) images were obtained (using the same instrument) of some of the areas analysed.

More recently, in 2021–2022, several nephrite samples from the DJ project underwent gemmological characterisation, inclusion identification with Raman analysis, visible-near infrared (Vis-NIR) spectroscopy and chemical analysis by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy. Gemmological properties were obtained at Stone Group Labs by authors BW and CW on six samples (3.58–87.90 ct; Figure 9), which consisted of two partially polished rough pieces and four

Figure 7: A small, hydraulic, track-mounted core-drilling rig was used in November 2018 to test the continuity and variation at depth of the nephrite bodies at the DJ project. Photo by J.-P. Jutras.

cabochons representative of the two potentially most commercially important nephrite types (Phenomenal and Gem). RIs were measured on a standard gemmological refractometer and SG values were determined hydrostatically. The samples were observed with a Chelsea Colour Filter, and also under standard long- and short-wave UV lamps. A gemmological microscope was used to examine the nephrite texture. In addition, author J-PJ examined polished samples of the Gem-type nephrite with a polariscope to confirm that it acts as a polycrystalline (aggregate) material.

Raman spectroscopy was performed at the California Institute of Technology (Pasadena, California, USA) by author GRR to identify inclusions commonly present in the Carving-type nephrite, as well as to analyse the main amphibole phase of the jade. The analyses were done on two discs that were cut from a single nephrite slab (Figure 10), using a Renishaw inVia system operating with a 514 nm laser and a 50 × objective lens with about 1.5 mW power on the samples. Typically 3–10 spectra were averaged from each analysis point to improve the signal-to-noise ratio. Mineral identification was accomplished by comparison to reference spectra in the RRUFF database (https://rruff.info).

Vis-NIR spectroscopy was also performed by author GRR on a polished slice of nephrite (1.53 mm thick) cut from one of the discs mentioned above, using a custom-built microscope spectrometer for the 380–1000 nm range that employs a silicon photodiode array detector, and a Thermo-Nicolet iS50 Fourier-transform infrared (FTIR) spectrometer for the 1000–2500 nm range equipped with an InGaAs detector and a silica beam splitter.

The bulk chemical compositions of the nephrite and its host rocks were investigated using portable EDXRF analysis by Dr Shane Ebert (Prince George, British Columbia, Canada). The samples consisted of four slabs representing the different nephrite types, and two host-rock slabs of rodingite and serpentinite. An enclosed workstation housed an Olympus Innov-X Delta-series unit equipped with an X-ray tube (operated at 40 kV and 4 W) and an Rh anode excitation source. Samples were analysed using the factory-set 'mining plus' analysis mode utilising two beams, each with a run time of 30 s. This configuration allows meassurement of Mg, Al, Si, K, Ca, Fe, Cr and several additional trace elements. The sample window was 9 mm wide, which is the minimum area that can be sampled during analysis (therefore, sample heterogeneity may influence the results in some cases). Precision and accuracy for each analytical session were monitored with a factory calibration disc, reference standards and an SiO_2 blank, and through multiple duplicate analyses. EDXRF analysis was also performed on the disc of Phenomenal-type nephrite supplied to Stone Group Labs using an Amptek X123-SDD spectrometer.

Figure 8: A portable diamond saw is used to extract masses of nephrite, shown here during initial sampling in October 2017. Photo by J.-P. Jutras.

Figure 9: A suite of polished rough and cut nephrite from the DJ project was used for gemmological characterisation. It includes both Gem-type nephrite (a polished block weighing 15.5 g and a 19.5 × 14 mm oval cabochon) and Phenomenal-type material (a disc measuring 36.5 × 35.5 mm, a polished rough piece weighing 5.8 g, a 17.1 × 7.4 mm marquise-shape cabochon and a 23.5 × 7.8 mm pear-shape cabochon). Photo by J.-P. Jutras.

Figure 10: Two discs (each 19.3 mm in diameter) were cut and polished for inclusion studies from an 8 × 5 cm slab of Carving-type nephrite. Photo by J.-P. Jutras.

RESULTS AND DISCUSSION

Table I provides representative EPMA analyses of minerals in the four types of DJ project nephrite. Figures 11–14 show images of each of the nephrite types, including photos of selected polished samples, thin-section photomicrographs and BSE images. The mineral species labelled in the BSE images include a main Fe-poor tremolite phase, a more Fe-rich tremolite phase, and the accessory minerals diopside and chlorite.

Mineral Composition and Texture

Tremolite formed the main mineral constituent of all four nephrite types. Some of the tremolite in the Phenomenal type was more Fe-rich. Diopside, chlorite and chromite were identified as accessory minerals in the Ornamental- and Carving-type nephrites. Minor barite and Fe-Cu oxides were also noted in the Ornamental type. In addition, the Carving-type samples contained a Ca-Si-Cr-bearing phase that could not be identified by EPMA analysis.

The EPMA data showed that the main (Fe-poor) tremolite phase had an average composition of $Ca_{1.96}Na_{0.01}K_{0.01}(Mg_{4.51}Fe^{2+}{}_{0.44}Al_{0.03}Mn_{0.01})Si_8O_{22}(OH)_2$, whereas the more Fe-rich tremolite phase in the Phenomenal-type nephrite showed an average composition of $(Ca_{1.99}K_{0.01})_{2.00}(Mg_{4.08}Fe_{0.82}Mn_{0.05})_{4.95}Si_{8.02}O_{22}(OH)_2$. Some of the latter analyses verged into the actinolite field, as per the International Mineralogical Association's 1997 definition of actinolite and as outlined in Hawthorne *et al.* (2012).

The Ornamental-type nephrite (Figure 11) generally tends to be coarser grained and has a darker, more yellowish green appearance than the other categories.

Table I: Representative EPMA analyses of various minerals in nephrite from the DJ project.*

Mineral	Tremolite (Fe-poor)				Tremolite (Fe-rich)	Diopside		Chlorite	
Nephrite type	Orn	Carving	Gem	Phen	Phen	Carving		Orn	Carving
Sample, point	DJ-O, 35/1	DJ-GJ, 72/1	DJ-G, 108/1	DJ-C, 21/1	DJ-C, 18/1	DJ-GJ, 77/1	DJ-GJ, 69/1	DJ-O, 40/1	DJ-GJ, 68/1
Figure/label	11d/MTr	12d/MTr	13d/MTr	14d/MTr	14d/FeTr	12d/Dio	12d/Dio	11d/Chl	12d/Chl
Oxide (wt.%)									
SiO_2	57.49	58.25	58.65	58.61	57.22	54.91	54.17	31.89	37.00
TiO_2	nd	0.01	nd	nd	nd	nd	0.01	nd	nd
Al_2O_3	0.42	0.24	0.06	0.18	0.07	1.15	0.74	15.26	12.26
Cr_2O_3	0.06	0.05	nd	0.03	0.01	0.07	0.01	1.12	1.11
FeO	4.95	3.26	3.32	4.04	7.23	2.51	4.13	9.86	5.83
MnO	0.08	0.04	0.16	0.10	0.43	0.08	0.31	0.05	0.03
MgO	21.57	22.20	22.47	21.80	19.54	16.36	15.33	26.74	30.06
CaO	12.90	13.38	13.23	13.15	13.12	24.88	25.14	0.17	1.23
Na_2O	0.04	0.08	0.05	0.07	0.04	0.65	0.30	nd	nd
K_2O	0.02	0.09	0.07	0.05	0.05	nd	nd	nd	0.02
Total	97.53	97.59	98.02	98.02	97.70	100.61	100.16	85.09	87.53

*Data from Yang & Downs (2018). Abbreviations: nd = not detected, Orn = Ornamental and Phen = Phenomenal.

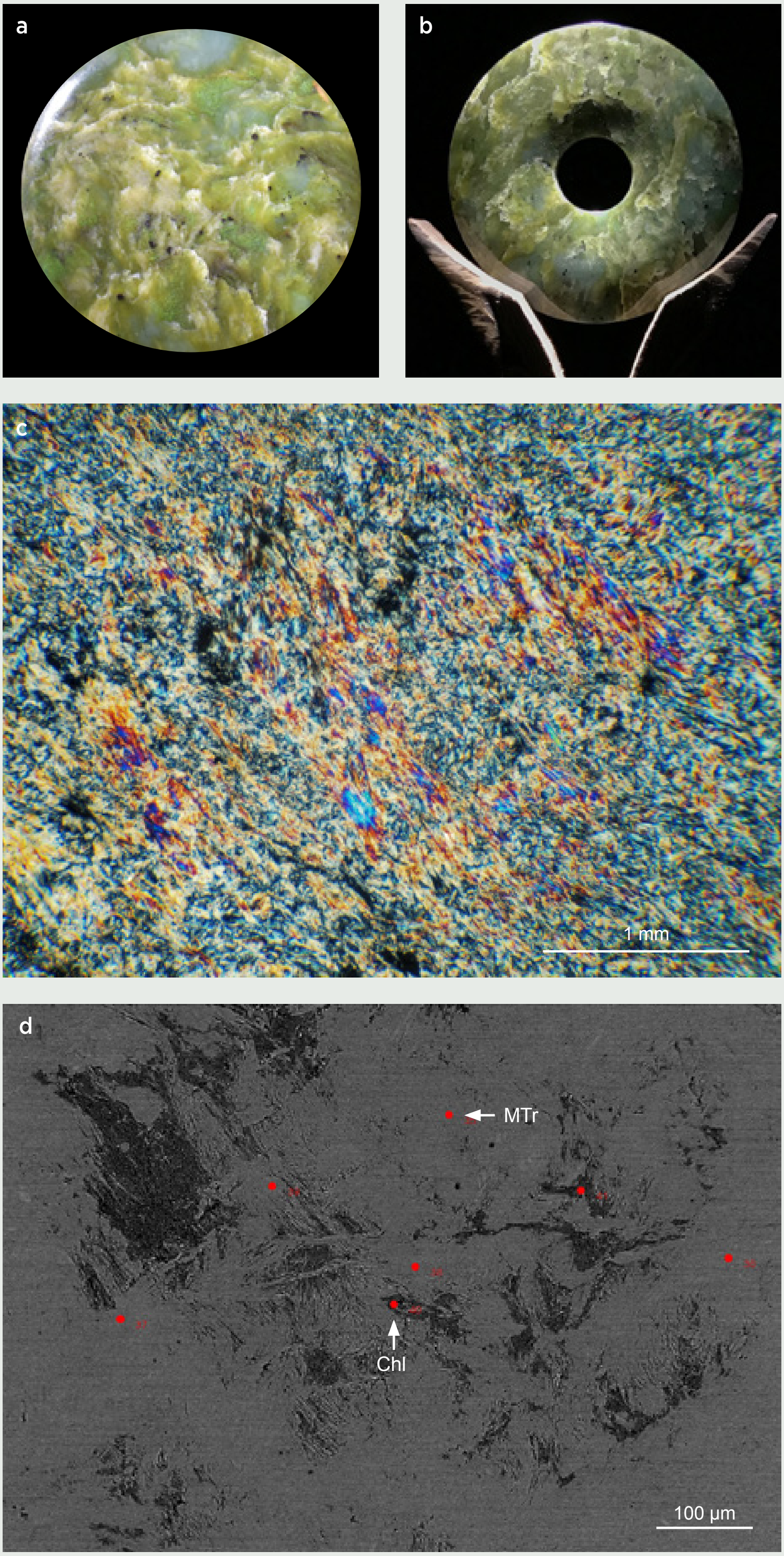


Figure 11: Ornamental-type nephrite is illustrated here by (**a**) a polished disc measuring 50 mm in diameter; (**b**) a carved *bi* disc of 75 mm diameter; (**c**) a petrographic thin section, viewed with crossed polarisers, showing the grain size and mostly random orientation of the constituent felted tremolite; and (**d**) a BSE image, with red dots showing the locations of EPMA analyses. Abbreviations: MTr = Main (Fe-poor) tremolite phase and Chl = chlorite. Photos a and b by J.-P. Jutras; images c and d courtesy of the University of Arizona.

It also has a weak incipient foliation that slightly diminishes its competency. It was found to contain more abundant chlorite and other accessory minerals (i.e. pyrite, chalcopyrite and goethite). Although this nephrite type is attractive and similar to much of the jade production from neighbouring British Columbia, the DJ Ornamental-type nephrite appears better suited for architectural, ornamental or carving works than for jewellery use.

The Carving-type nephrite (Figure 12) is a marbled white and green stone, with local diopside veining and conspicuous dark grains of goethite. It tends to have a brighter appearance than the Ornamental type, and is suitable for carvings, beads, bangles, pendants and earrings.

The Gem-type nephrite (Figure 13) is very fine grained (constituent tremolite grain size is generally less than 0.1 mm) and strongly monomineralic with few accessory minerals, resulting in fairly uniform pale green to bluish green colouration as cut stones. It is translucent and shows a high (vitreous) polish lustre, and is therefore appropriate for use in fine jewellery.

The Phenomenal-type nephrite (Figure 14) displays subtle-to-strong directional colour variations when viewed in different orientations, ranging from green to blue in light-to-dark tones. Although it is difficult to capture the optical behaviour in static images, videos of several rotating samples can be viewed at https://www.youtube.com/watch?v=r9qtYM4_2Fg&t=99s. The dominant tremolite fibres are noticeably coarser (3–4+ mm long) than in the other nephrite types, and are commonly oriented directionally with kinked banding, as shown by the presence of bent fibres and cross-fibre growth (again, see Figure 14). It is well suited for beads, carvings and fine jewellery (e.g. in rings, brooches and pendants), as well as mineral specimens for collectors.

Gemmological Properties and Raman Analysis

RI values ranged from 1.613 to 1.617, and SG varied from 2.98 to 2.99. No reactions were noted with the Chelsea filter or with UV radiation. Examination of the Phenomenal-type nephrite with a gemmological microscope showed sharp-to-diffuse colour boundaries (Figure 15). The overall colour appearance in overhead fluorescent lighting was noticeably more bluish (with more obvious sheen) as compared to a yellower and more translucent appearance in incandescent transmitted light. Testing of a cabochon of Gem-type nephrite with a polariscope showed the typical bright appearance for an aggregate polycrystalline material.

Several bright green inclusions (Figure 16) exposed on the surface of the Carving-type nephrite were identified as andradite by Raman spectroscopy. Such inclusions are also sometimes present in the other nephrite types. In addition, Carving-type nephrite commonly contains minute, metallic-appearing inclusions, which were provisionally identified (poor Raman spectral quality) as pyrite. In the same sample, Raman analysis of the main constituent amphibole provided a good match with tremolite in the RRUFF database.

Vis-NIR Spectroscopy

Vis-NIR transmission spectroscopy (Figure 17) showed a sharp absorption feature near 1400 nm, which is the first overtone of the stretching vibration of the OH^- group (Mustard 1992). A weaker sharp feature near 950 nm is the second overtone of the OH^- group. An absorption band near 1920 nm results from a combination of stretching and bending motions of molecular water.

The Fe^{2+} in nephrite can occupy different sites in the crystal structure. Fe^{2+} in the octahedrally coordinated sites has two broad absorption bands near 930 and 1150 nm. Fe^{2+} in the distorted M4 site has a broad absorption near 1030 nm (Goldman & Rossman, 1977). The combination of these bands gives rise to the broad absorption in the 850–1250 nm region seen in Figure 17. There is a hint of a weak absorption feature at about 445 nm, and this is the region where andradite (which was identified in the sample by Raman spectroscopy) has its strongest Fe^{3+} absorption feature. Because of the green colour of the nephrite (again, see Figure 10), one might expect that the least absorption in the visible region would be in the 500–600 nm region. However, due to the scattering of light (which increases at shorter wavelengths) by numerous grain boundaries, there is an overall rise in absorption towards the lower-wavelength side of Figure 17 for light passing through the sample.

EDXRF Analysis

Major-element bulk compositions obtained by portable EDXRF spectroscopy of the various DJ nephrite types and their host rocks are presented in Table II. All four nephrite sub-types showed essentially the same major-element chemical composition.

EDXRF analyses obtained by Stone Group Labs on near-colourless and darker green portions of the disc of Phenomenal-type nephrite in Figure 9 showed that both areas had a similar composition, except the darker green nephrite contained greater amounts of Cr and Ni (Figure 18).

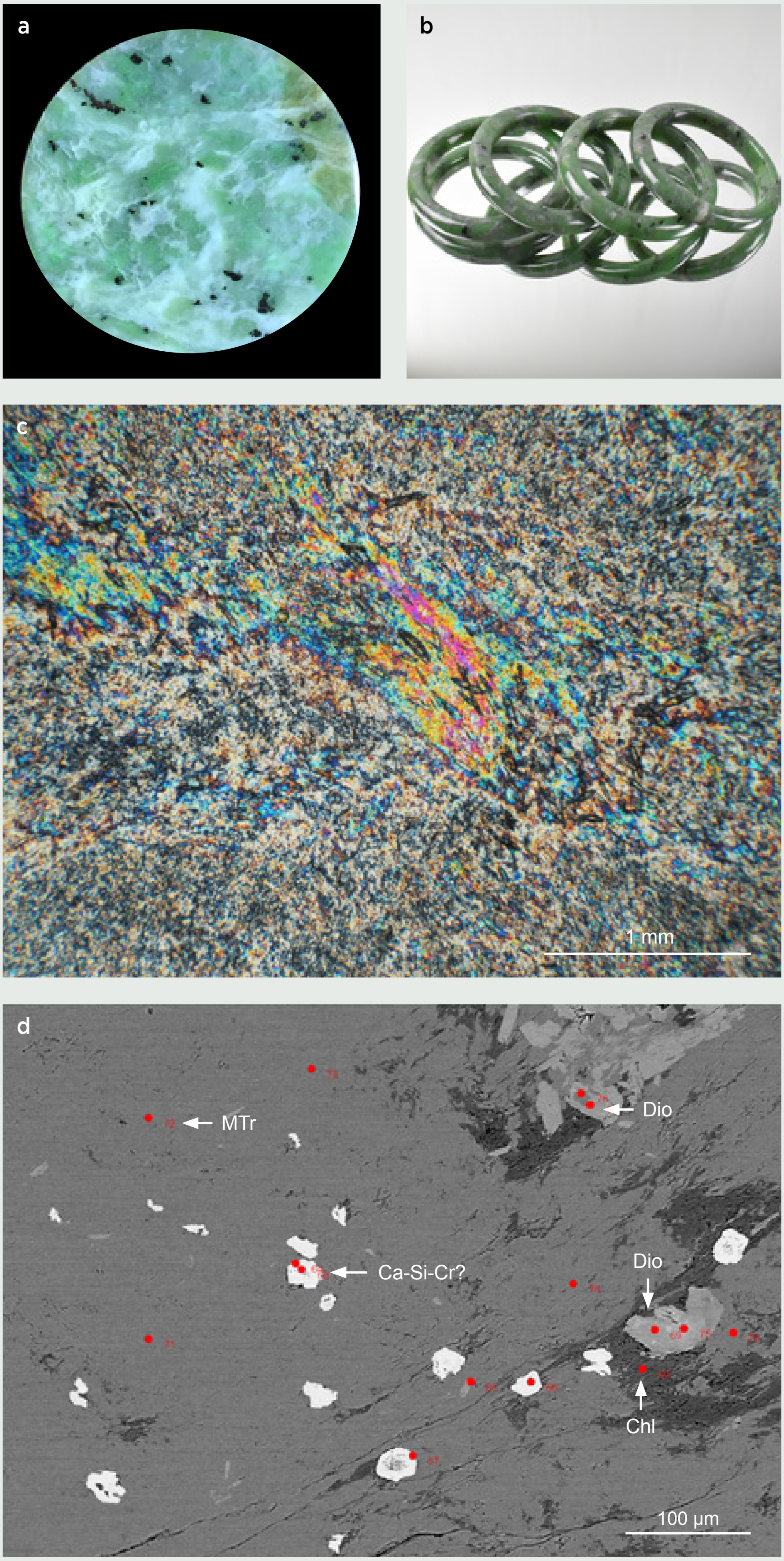


Figure 12: Carving-type nephrite is illustrated here by (**a**) a polished disc measuring 55.7 mm in diameter; (**b**) a set of four bangles with an average diameter of about 70 mm; (**c**) a petrographic thin section, viewed with crossed polarisers, showing the grain size and random orientation of the constituent felted tremolite; and (**d**) a BSE image with red dots showing the locations of EPMA analyses. Abbreviations: Ca-Si-Cr? = unidentified phase, Chl = chlorite, Dio = diopside and MTr = Main (Fe-poor) tremolite phase. Photos a and b by J.-P. Jutras; images c and d courtesy of the University of Arizona.

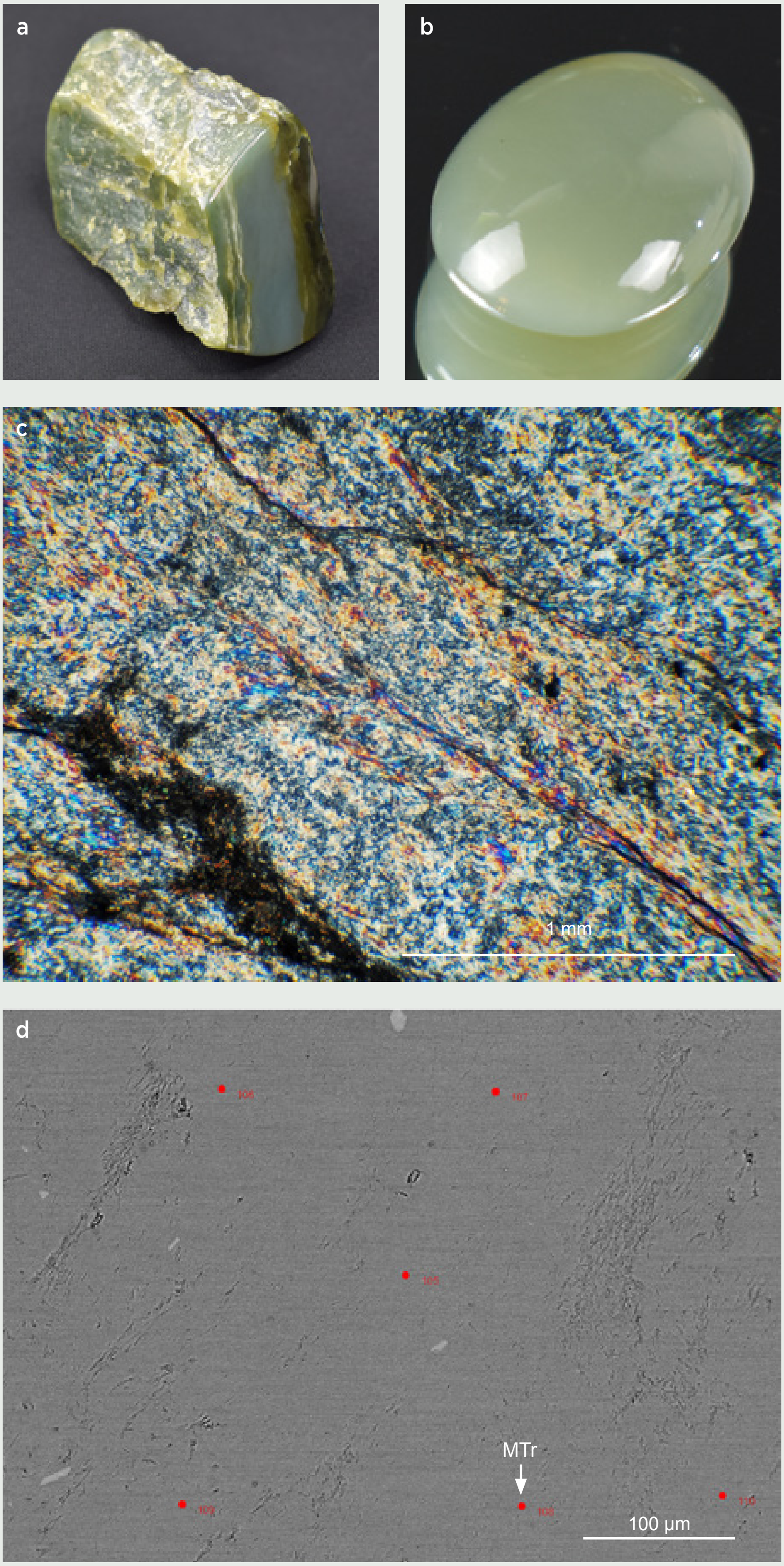


Figure 13: Gem-type nephrite is illustrated here by (**a**) a partially polished rough sample (312.7 g) that shows a central vein which is finer-grained, massive and lighter in colour that is cutting through coarser-grained, darker nephrite; (**b**) an oval cabochon measuring 19.5 × 14 mm; (**c**) a petrographic thin section, viewed with crossed polarisers, showing the grain size and random orientation of the constituent felted tremolite; and (**d**) a BSE image with red dots showing the locations of EPMA analyses. Abbreviation: MTr = main (Fe-poor) tremolite phase. Photos a and b by J.-P. Jutras; images c and d courtesy of the University of Arizona.

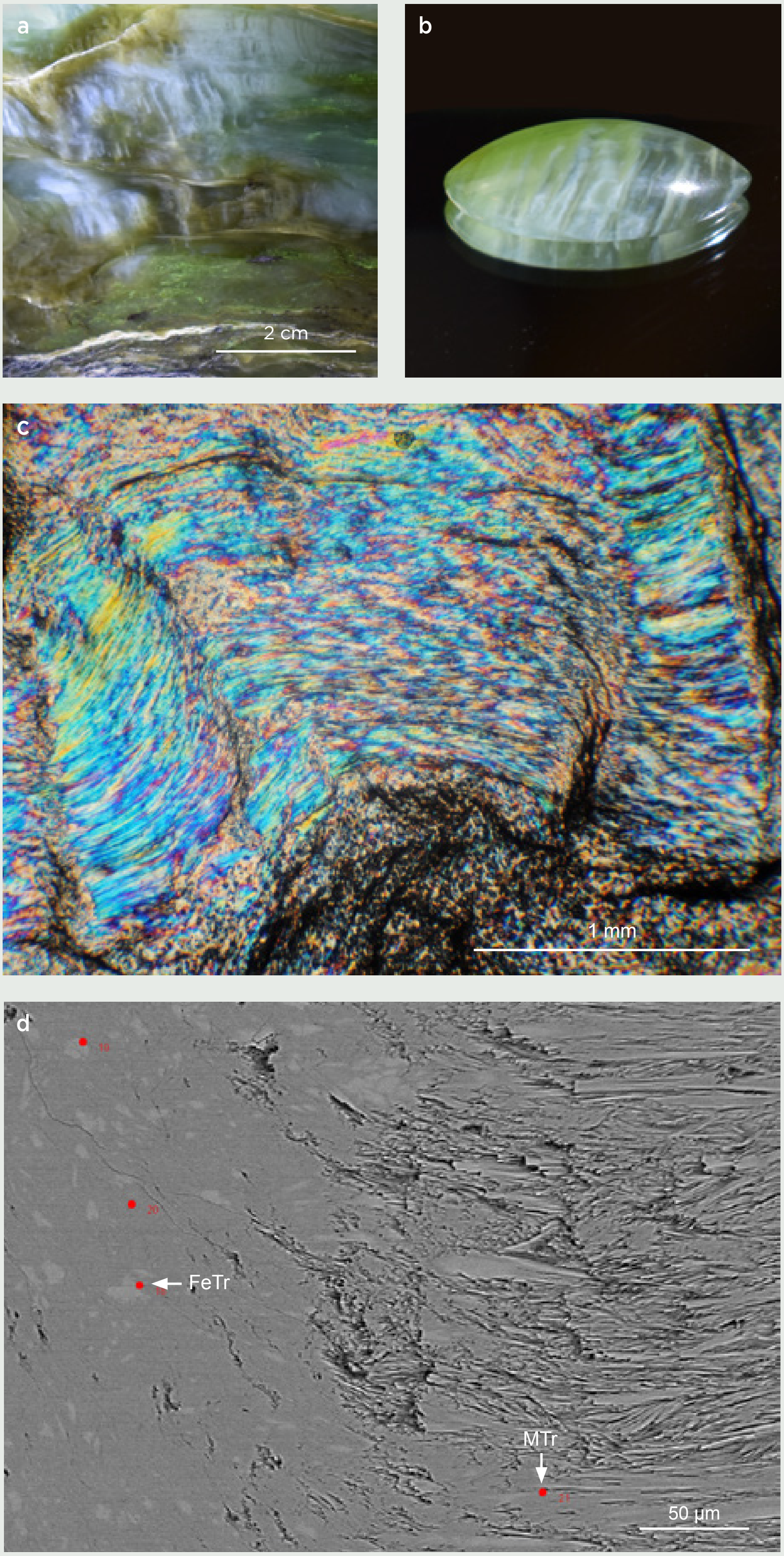


Figure 14: Phenomenal-type nephrite is illustrated here by (**a**) a polished slab that shows tremolite fibres elongated in two main directions; (**b**) a marquise-shape cabochon measuring 17.1 × 7.4 mm that displays colour banding; (**c**) a petrographic thin section, viewed with crossed polarisers, showing the relatively large grain size and elongated fibres of tremolite with kinked banding; and (**d**) a BSE image with red dots indicating locations of EPMA analyses. Both Fe-poor tremolite (MTr) and more Fe-rich tremolite (FeTr) phases are present. Photos a and b by J.-P. Jutras; images c and d courtesy of the University of Arizona.

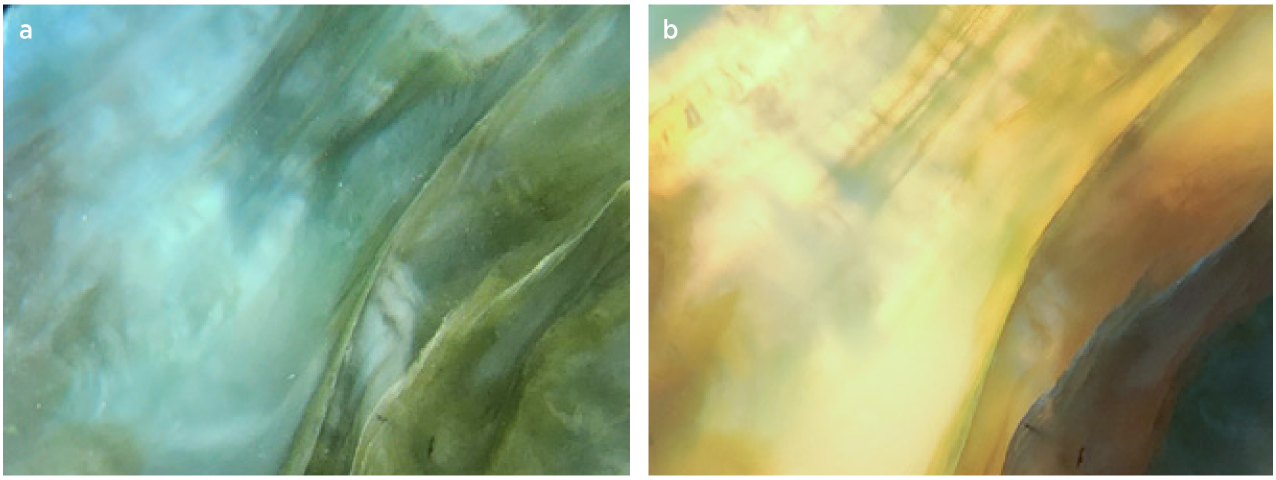


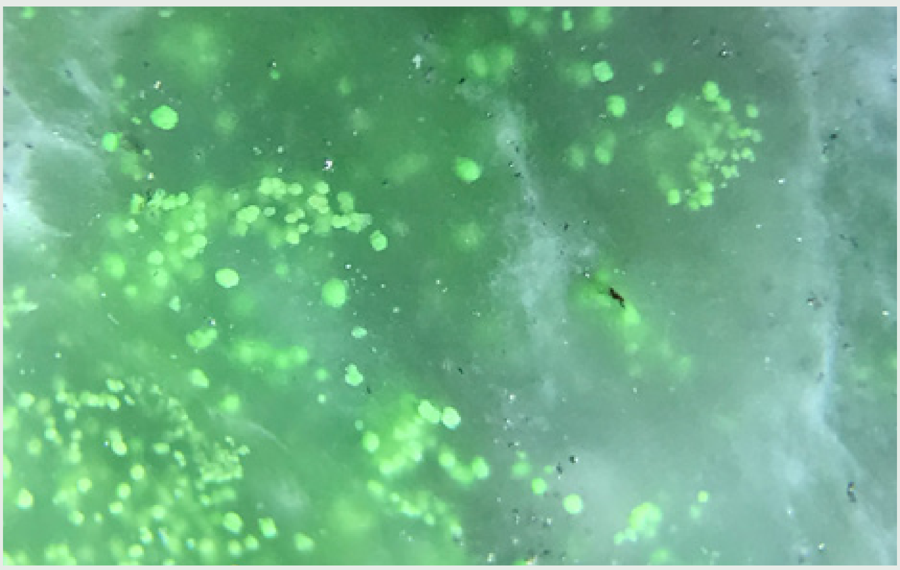
Figure 15: A microscopic view of Phenomenal-type nephrite (disc in Figure 9) is shown with (**a**) overhead fluorescent lighting at a 45° angle above the sample and (**b**) incandescent transmitted lighting. Note the sharp-to-diffuse colour boundaries. Photomicrographs by B. Williams; image width 0.75 mm.

Cause of the Optical Phenomenon

The cause of the optical phenomenon seen in some of the DJ nephrite is best illustrated via textural comparison with other nephrite types from this deposit, as all of them are otherwise essentially indistinguishable on the basis of their mineralogy and bulk chemical composition (Yang & Downs 2018; Tables I and II). Insights obtained through examination of rough and polished samples, as well as thin-section observation and BSE imagery, show the presence of more than one generation of tremolite fibres in the Phenomenal type, as exhibited by high-angle to orthogonal cross-felting and local variations in chemical composition (i.e. low-Fe and high-Fe tremolite). This is shown in Figure 14, as well as in Figure 19, where the longer-fibre, coarser-crystalline tremolite is labelled T1. The generally finer, orthogonally cross-cutting set of fibres is labelled T2, and these fibres are particularly evident on broken surfaces that display a splintery to hackly texture (Figure 19c).

Field evidence suggests that this type of fibre 'felting' is a consequence of nephrite formation in a changing deformation regime. The initial stages of tremolite fibre growth, replacing an unknown protolith within the serpentinite melange, occurred in a ductile environment, as illustrated by nephrite fold forms (e.g. Figure 20). Tension gashes that formed during this folding hosted the later generation of cross-cutting tremolite fibre growth. Areas of nephrite that experienced more extreme deformation tend to form elongated, typically sinuous pods and lenses with cross-fibre structure

Figure 16: The Carving-type nephrite commonly contains clusters of bright green inclusions that were identified as andradite by Raman spectroscopy. Also present are minute, bright, reflective inclusions that are possibly pyrite. Photomicrograph by J.-P. Jutras in reflected light; image width 6 mm.



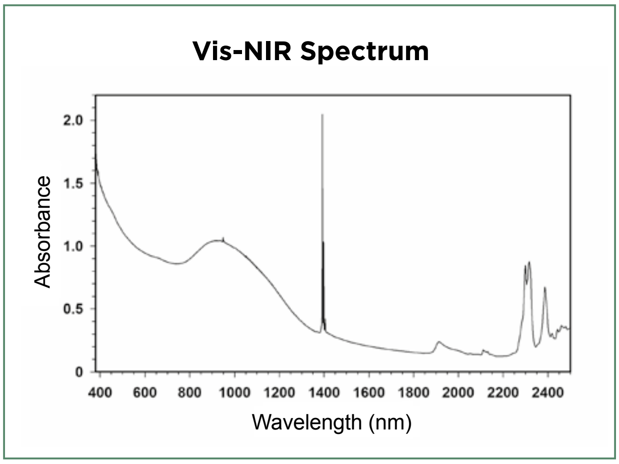


Figure 17: The Vis-NIR transmission spectrum of the nephrite shows main features due to the OH^- group (sharp lines at 1400 and 950 nm), molecular water (1920 nm) and Fe^{2+} (850–1250 nm). The features above 2250 nm arise from a combination of metal-oxygen bond stretching and OH^--group stretching vibrations.

(Figure 21) that often exhibits the optical phenomenon.

At the macroscopic scale, when enough of the T1 or T2 fibres bundle in any one direction, they can be seen to exhibit subtle to strikingly different pleochroic colours along the main tremolite crystallographic *c*-axis (long) direction and perpendicularly along the *a*- and *b*-axis directions (Figure 22). This has been observed by author J-PJ for both generations (T1 and T2) of fibre directions, and is seen in

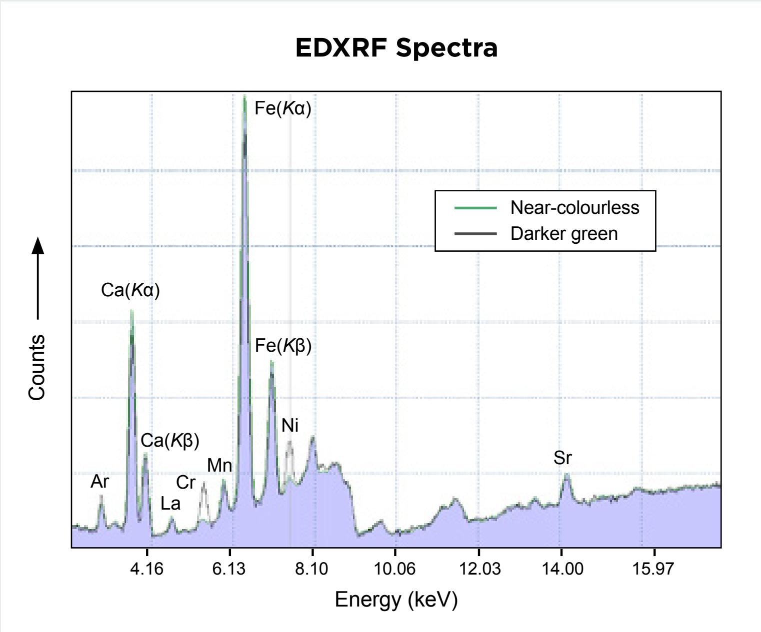


Figure 18: EDXRF analyses of near-colourless and darker green areas of Phenomenal-type nephrite show higher levels of Cr and Ni in the latter material.

Table II: Semi-quantitative major-element composition by portable EDXRF spectroscopy of nephrite and associated host rocks from the DJ project.[a]

Element (%)	Nephrite				Host Rocks	
	Ornamental	Carving	Gem	Phenomenal	Rodingite	Serpentinite
Ca	10.77	10.98	10.65	10.75	7.33	0.10
Mg	11.26	10.17	9.93	10.63	9.86	20.71
Si	24.5	23.84	23.57	24.28	22.03	21.86
Fe	3.38	2.60	3.08	3.34	4.37	5.57
Others[b]	49.26	51.98	52.38	50.68	53.72	49.03

[a] Data represent single analyses of the Ornamental and Gem types, and an average of three analyses of the Carving type and four analyses of the Phenomenal type.
[b] Components reported by the instrument as being outside the detection range (e.g. light elements).

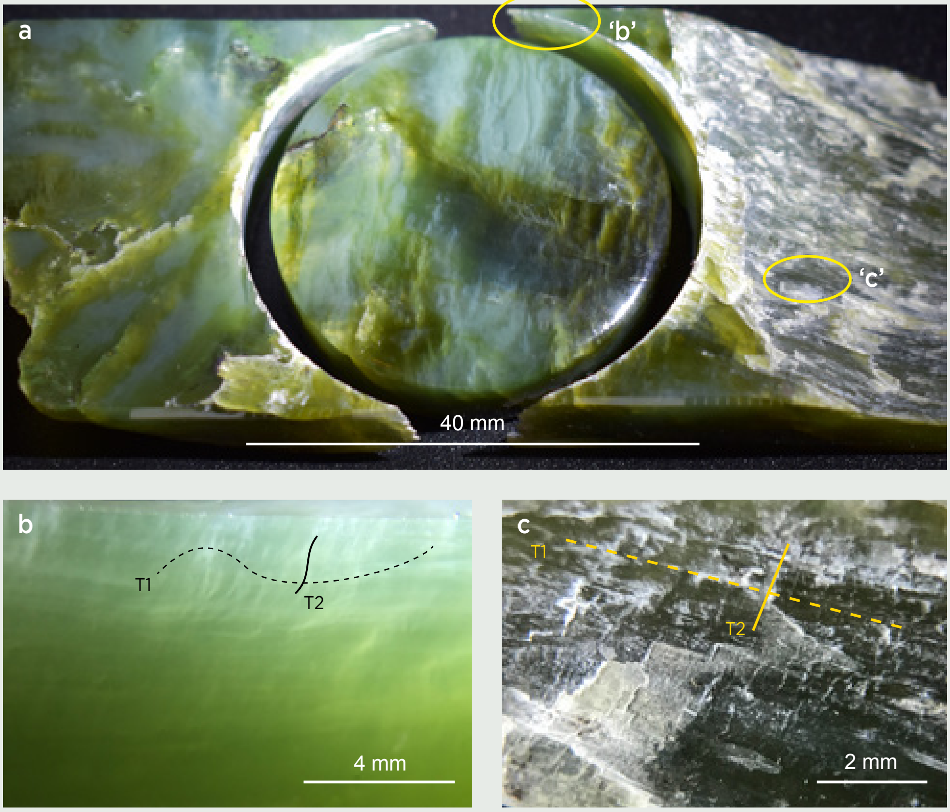


Figure 19: (**a**) A disc of Phenomenal-type nephrite (36.1 × 36.6 mm) was cut from a polished slab that is fractured on the right side. The disc is positioned in its original orientation to show fibre directions. (**b**) A side view of the slice through the polished slab with transmitted light shows the main long-fibre tremolite direction T1 and crosscutting T2 fibres. (**c**) A close-up of the splintery/hackly fractured surface also shows long, coarse T1 tremolite fibres and fine, cross-cutting T2 tremolite. Photos by J.-P. Jutras.

both lighter- and darker-coloured domains within single stones, excluding the possibility that the optical phenomenon is only controlled by the presence of the more Fe-rich tremolite phase. The range of colours along and across various generations of fibres varies from light to dark green, yellowish green, bluish green, pale blue and locally almost colourless. Although pleochroism is not an optical effect normally associated with nephrite, trichroism has been recognised in well-crystallised forms of tremolite (e.g. colourless, light yellow-green and light green), consistent with its monoclinic crystal structure (Zwaan & Hawthorne 2015; Zwaan *et al.* 2018). The generally high translucency of the jade exhibiting the pleochroic optical effect can also facilitate the appearance of sheen caused by internal light scattering from the different generations of fibrous tremolite domains. When present, the sheen effect can contribute to the brightness seen in certain areas of a sample, but it is separate from the pleochroic effect.

In cut and polished material, the maximum perception of the phenomenal effect is achieved by orienting the cut surface of the stone parallel to the main T1 *c*-axis direction (to maximise lighter T1 *a*- and *b*-axis colours), and as perpendicular as possible to the T2 *c*-axis direction for maximum contrast (Figure 23).

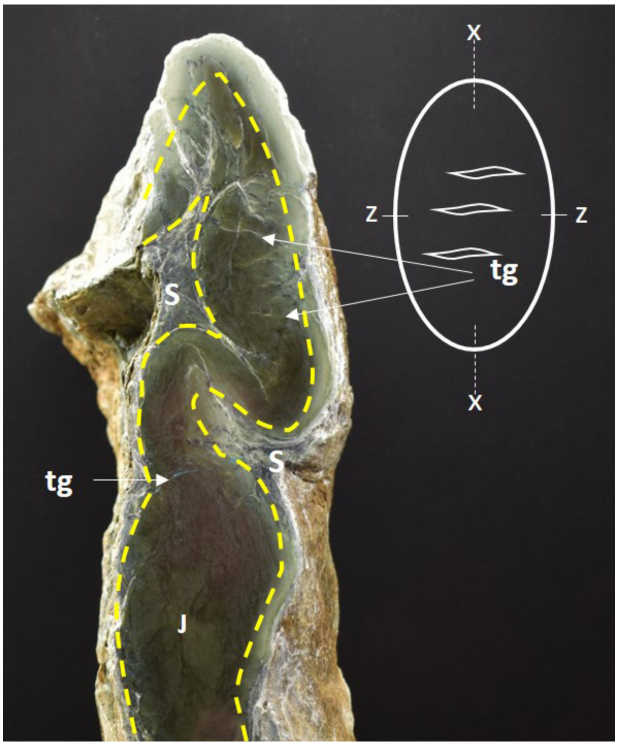


Figure 20: A sawn slab shows ptygmatic folds within nephrite jade (J) that is hosted by sheared serpentinite (S). The interpreted stress ellipsoid shows the axis of maximum compression (z) and the main extension direction (x) which is associated with tension gashes (tg). The sample is 33 cm tall and has a maximum width of 8 cm. Photo by J.-P. Jutras.

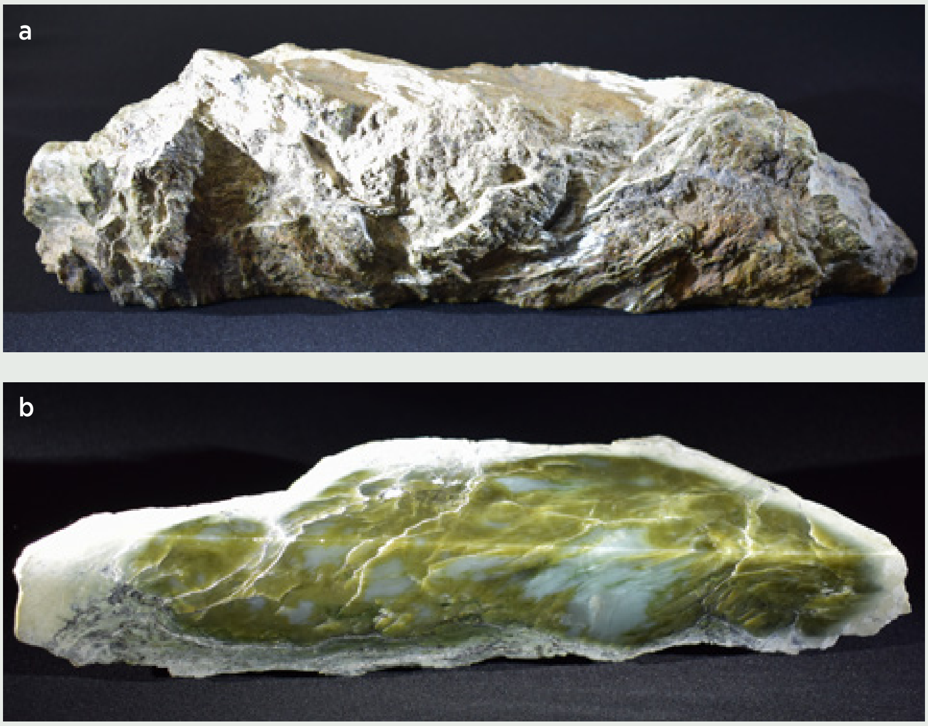


Figure 21: (**a**) This elongate nephrite pod (31 cm long) was extracted from sheared serpentinite host rock. Its weathered natural surface is likely due to interaction with near-surface groundwater, leading to the formation of a soft alteration rind hiding the stone's true texture and colour. (**b**) The same piece is shown after slicing and polishing, revealing that it consists of Phenomenal-type nephrite. The width of the upper polished surface is 8 cm. Photos by J.-P. Jutras.

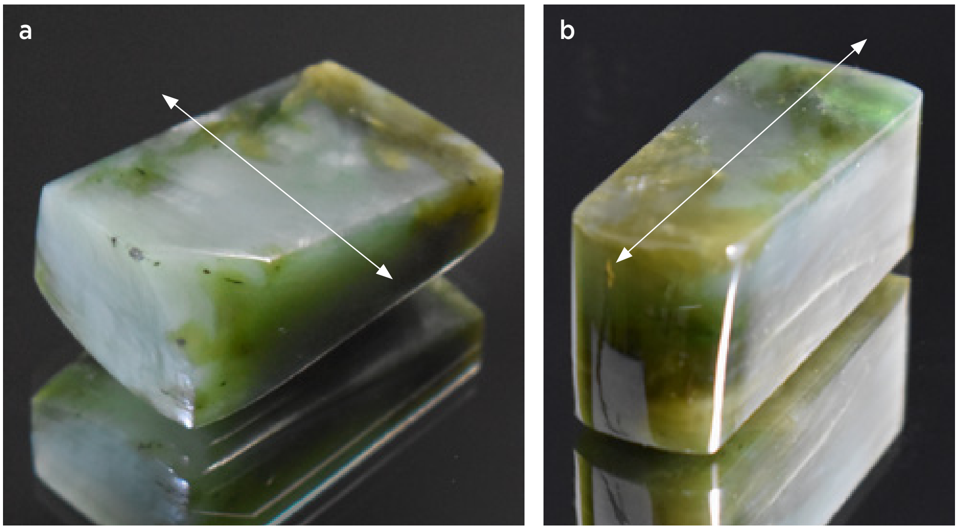


Figure 22: (**a**) A polished block (40 × 17 × 16 mm) of Phenomenal-type nephrite was cut to highlight the darker colour seen along the main fibre *c*-axis direction, which in this case is dark green. The *a*- and *b*-axis directions exhibit much paler colouration. (**b**) Similar colouration is shown by another polished block of Phenomenal-type nephrite (39.5 × 23 × 15.5 mm). Arrows indicate the main T1 fibre *c*-axis direction. Photos by J.-P. Jutras.

CONCLUSIONS

Nephrite jade from Washington State is an attractive gem material that takes a high polish (e.g. Figure 24) and exhibits a variety of appearances. In general, the gemmological and mineralogical properties of this jade are consistent with previous reports on nephrite from various world localities (Leaming 1978; Harlow *et al.* 2014; Barnes 2018; Hughes 2022).

Of the four different types of nephrite identified at the DJ project, one of them displays an optical phenomenon consisting of subtle-to-strong directional colour variations when viewed at different orientations. This effect is shown by highly translucent samples containing more than one generation of interwoven-fibre growth in macroscopically continuous domains. The optical effect is interpreted to result from tremolite's pleochroism, which can be seen as the stone is rotated and the orientation of the dominant *c*-axis direction of the fibre bundles changes relative to the viewer. Internal light reflections within the fibrous tremolite domains can also occur, but this is expressed as sheen and not an apparent change of the perceived colour.

The full extent of the lode occurrence hosting the Phenomenal-type nephrite has not been

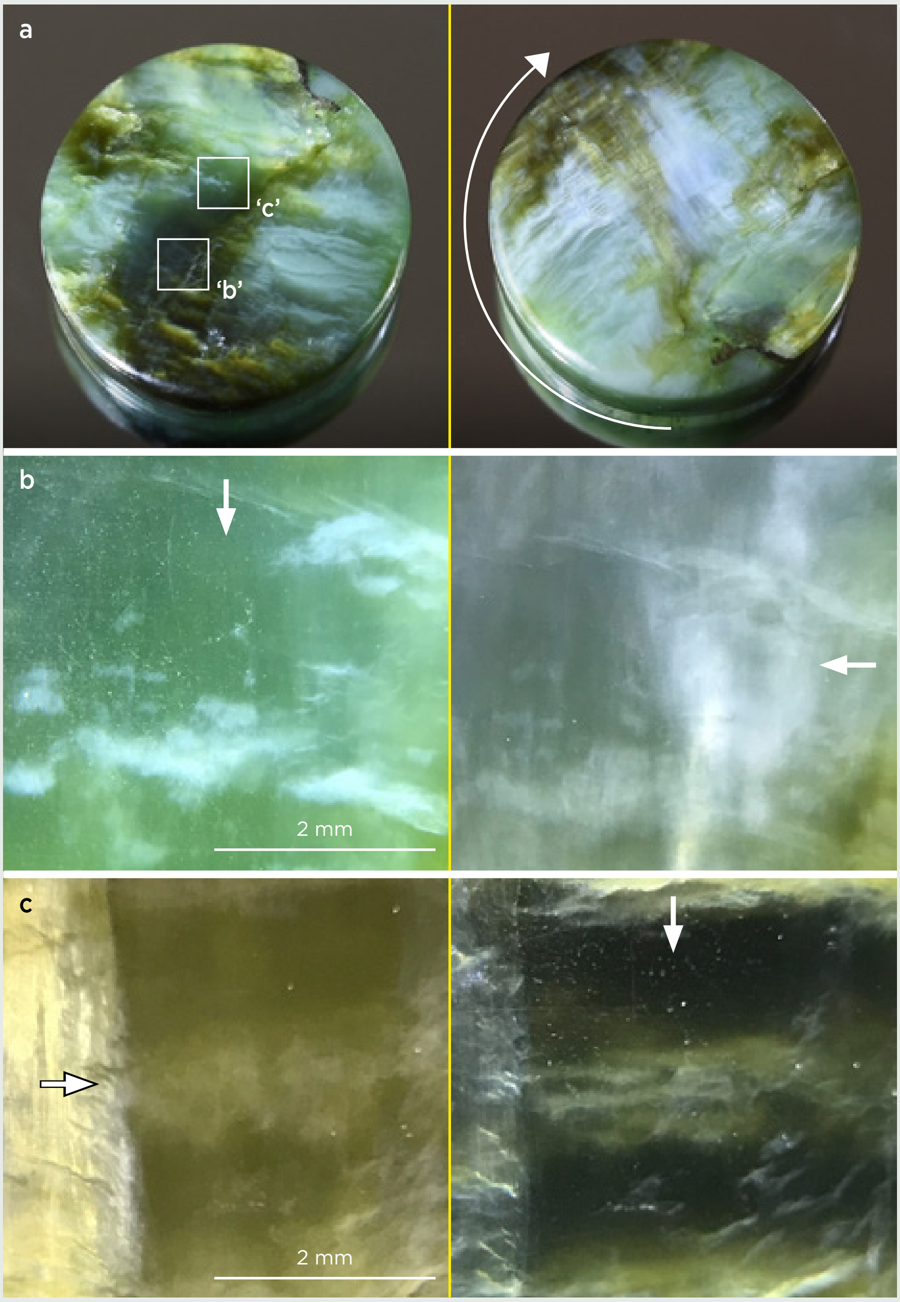


Figure 23: (**a**) A polished disc of Phenomenal-type nephrite (36.1 × 36.6 mm) is shown here rotated relative to a static light source. Photomicrographs of two areas of the disc (**b** and **c**) show differences in the perceived colouration according to the direction of the incident focused light source (as indicated by arrows). In both areas, the polished surface is parallel to the T1 long-fibre *c*-axis direction and nearly perpendicular to the T2 fibre *c*-axis direction. Photos and photomicrographs by J.-P. Jutras.

determined. Exploration work, including trenching and exploratory core drilling performed to date, allows for a target estimate of 5,900–6,800 tonnes of nephrite (inclusive of all types) in the DJ claim area tested. The future development of this occurrence will depend on market demand. While surface production work can continue to take place at a minimally intrusive small scale under the current permitting regime, a full operation plan compliant with all applicable environmental and social regulations would be required to obtain additional permits to scale up and potentially expand future operations.

Figure 24: This carved seashell (shown with an accompanying bead) of Phenomenal-type nephrite was done as a test of the new material's structural integrity. The carving is 5 cm long and is by jade sculptor Shane Hauser. Photo by J.-P. Jutras.

REFERENCES

Barnes, G.L. 2018. Understanding Chinese jade in a world context. *Journal of the British Academy*, **6**, 1–63, https://doi.org/10.5871/jba/006.001.

Barnes, G.L. 2022. True jades, false friends. *In*: *Tectonic Archaeology: Subduction Zone Geology in Japan and its Archaeological Implications*. Archaeopress, Oxford, 338–372, https://doi.org/10.2307/j.ctv35n89zf.

Blankenship, D. 2022. Chapter 11: North to Alaska, USA jade. *In:* Hughes, R.W. (ed) *Jade: A Gemologist's Guide*. Lotus Publishing, Bangkok, Thailand and RWH Publishing, Boulder, Colorado, USA, 195–219.

Goldman, D.S. & Rossman, G.R. 1977. The identification of Fe^{2+} in the *M*(4) site of calcic amphiboles. *American Mineralogist*, **62**(3–4), 205–216.

Harlow, G.E., Sorensen, S.S., Sisson, V.B. & Shi, G. 2014. The geology of jade deposits. *In:* Groat, L.A. (ed) *The Geology of Gem Deposits*. Mineralogical Association of Canada Short Course Series Vol. 44, Québec City, Québec, Canada, 205–374.

Hawthorne, F.C., Oberti, R., Harlow, G.E., Maresch, W.V., Martin, R.F., Schumacher, J.C. & Welch, M.D. 2012. Nomenclature of the amphibole supergroup. *American Mineralogist*, **97**(11–12), 2031–2048, https://doi.org/10.2138/am.2012.4276.

Hogarth, E. 2019. Gem News International: Cat's-eye nephrite jade from Washington State. *Gems & Gemology*, **55**(1), 124–125.

Hogarth, E. 2022. Gem News International: Washington jade update. *Gems & Gemology*, **58**(1), 92–93.

Hughes, R.W. (ed) 2022. *Jade: A Gemologist's Guide*. Lotus Publishing, Bangkok, Thailand and RWH Publishing, Boulder, Colorado, USA, 534 pp.

Leaming, S.F. 1978. *Jade in Canada*. Geological Survey of Canada Paper 78-19, Geological Survey of Canada, Ottawa, Canada, 59 pp.

Leaming, S.F. 1995. Chapter 13: Jade in North America. *In:* Keverne, R. (ed) *Jade*. Lorenz Books, London, 296–315.

Leaming, S.F. & Hudson, R.D. 2005. *Jade Fever: Hunting the Stone of Heaven*. Heritage House Publishing Co., Surrey, British Columbia, Canada, 191 pp.

LMHC 2011. *Information Sheet #11: Jade and Related Minerals*. Laboratory Manual Harmonisation Committee, 2 pp.

Mustard, J.F. 1992. Chemical analysis of actinolite from reflectance spectra. *American Mineralogist*, **77**(3–4), 345–358.

Ream, L.R. 1974. Washington gem jade. *Lapidary Journal*, **28**(4), 708–711.

Ream, L.R. 2022. *Nephrite Jade of Washington and Associated Gem Rocks: Their Origin, Occurrence and Identification*. LR Ream Publishing, Coeur d'Alene, Idaho, USA, 130 pp.

Tabor, R.W., Booth, D.B., Vance, J.A. & Ford, A.B. 2002. *Geologic Map of the Sauk River 30- by 60-Minute Quadrangle, Washington*. U.S. Geological Survey Geologic Investigation Series I-2592, U.S. Geological Survey, Denver, Colorado, USA, 67 pp. pamphlet and two map sheets, https://doi.org/10.3133/i2592.

Ward, F.C. 2015. *Jade*, 3rd edn. Gem Book Publishers, Malibu, California, USA, 64 pp.

Yang, H. & Downs, R.T. 2018. A Short Report of the Analysis on Four Jade Samples from JP Jutras. University of Arizona, Tucson, Arizona, USA, unpublished report, 2 pp.

Zwaan, J.C. & Hawthorne, F.C. 2015. Gem Notes: Tremolite from Mwajanga, Tanzania. *Journal of Gemmology*, **34**(7), 569–571.

Zwaan, J.C., Hawthorne, F.C. & Day, M. 2018. Gem Notes: Cat's-eye tremolite from Badakhshan, Afghanistan. *Journal of Gemmology*, **36**(1), 14–15.

The Authors

Jean-Pierre Jutras
Jade Leader Corp.
Calgary, Alberta, Canada
Email: jp@gold.ca

Bear Williams FGA and **Cara Williams** FGA
Stone Group Labs, PO Box 104504,
Jefferson City, Missouri 65110-4504, USA

Dr George R. Rossman
Division of Geological and Planetary Sciences,
California Institute of Technology, Pasadena,
CA 91125-2500, USA

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