Back on the horse: Recent developments in archaeological and palaeontological research in Alberta

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Pre-contact jade in Alberta: The geochemistry, mineralogy, and archaeological significance of nephrite ground stone tools

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ABSTRACT

This article is the second in the Alberta Lithic Reference Project series, the goal of which is to assist the identification of raw materials used for pre-contact stone tools in the province. Each article focuses on one raw material; the current article discusses a microcrystalline, actinolite-tremolite (amphibole)-rich rock called nephrite (jade) that originates in British Columbia, Washington, Yukon, and Alaska. Nephrite appears in archaeological sites in northern and central Alberta. We provide results from a variety of non-destructive techniques (portable X-ray fluorescence, X-ray diffraction, and near-infrared spectrometry) to determine the geochemistry and mineralogy of nephrite ground stone celts found in Alberta. Portable X-ray fluorescence offers a relatively simple, rapid, and reliable means to distinguish nephrite from other materials of similar appearance. Visible near-infrared spectrometry provides a rapid and reliable technique to source nephrite back to general production areas in British Columbia. The archaeological significance of nephrite celts in Alberta is briefly discussed. The accurate identification of nephrite can reveal significant cultural relationships that involved long distance exchange of raw materials between occupants of Alberta and British Columbia.

KEYWORDS

jade, nephrite, celts, Alberta Lithic Reference Project, serpentinite, pXRF, XRD, V-NIR, green, ground stone

1. The Alberta Lithic Reference Project

A lack of published references about pre-contact lithic materials (toolstones) in Alberta has led to inconsistent identifications. This article is one of a series of what will become chapters in a stand-alone Alberta toolstone guide. Each article focuses on a raw material used to make stone tools. A helpful, easy-to-use guide will amplify the utility of data generated by cultural resource management and academic projects; we hope this spurs new research agendas and helps answer questions about the province's past.

2. Introduction: Nephrite

This article explores pre-contact jade or nephrite artifacts in Alberta (Figure 1). Geological work across Alberta has failed to identify any outcrops of nephrite or host serpentinite (an ultramafic rock with which nephrite is usually associated). The nearest nephrite outcrops are west of the continental divide in British Columbia. It is unlikely that cobbles of nephrite would have been glacially transported into Alberta. This article was therefore written to provide a preliminary formal attempt at identifying these exotic jade artifacts. The

Figure 1. Nephrite celts recovered from Alberta. Accompanying sample numbers are included in the figure. Accession numbers, repositories, and associated Borden Numbers are: sample number one = Poohkay specimen from GlQl-4 (2004.7, Grande Prairie Pioneer Museum, Grande Prairie, Alberta); sample number two = Guilliford specimen from GcPk-4 (H09.37.1, Royal Alberta Museum, Edmonton, Alberta); sample number three = Veidt specimen from HbQj-3 (Bill Veidt private collection, Peace River, Alberta); sample number four = Bohn specimen from GiQs-26 (Rod Bohn private collection, La Glace, Alberta); sample number five = Weber specimen found near Horse Hills (no associated Borden Number) in northeast Edmonton (h72.7.2125, Royal Alberta Museum, Edmonton, Alberta); sample number six = tAnderson one specimen from GjQq-5 (2004.7, Grande Prairie Pioneer Museum, Grande Prairie, Alberta); sample number seven = Matlock specimen found near DeBolt (no associated Borden Number) in northwest Alberta (990.27.118.m3, Grande Prairie Pioneer Museum, Grande Prairie, Alberta); sample number eight = Craig specimen from near GfQs-1 (Gavin Craig private collection, Wembley, Alberta); sample number nine = Eberhardt specimen from FiPn-339 near Stony Plain in central Alberta (no accession number, Stony Plain Multicultural Heritage Centre, Stony Plain, Alberta); Anderson two specimen probably associated with GhQr-2 (2004.7, Grande Prairie Pioneer Museum, Grande Prairie, Alberta).

main objectives are to provide macroscopic, microscopic, mineralogical, and geochemical means to describe nephrite and to distinguish it from materials of similar appearance. A secondary objective is to provide a brief theory of the archaeological significance of these unique artifacts.

Jade is a commercial or lapidary term that refers to both jadeite and nephrite rocks. Almost all jade in Canada that is derived from bedrock and alluvial sources is of the nephrite variety (Leaming 1978). Nephrite is a microcrystalline to cryptocrystalline felted variety of tremolite-ferro-actinolite series amphibole (amphiboles are a large group of double-chain silicate minerals that typically occur as fibrous or columnar crystals). Nephrite rock is made largely of prismatic to acicular amphiboles consisting of randomly oriented and tightly interlocked bundles of tremolite-actinolite crystals (Simandl et al. 2000). The mineral orientation and microstructure make nephrite among the toughest naturally-occurring rock materials on earth (Bradt et al. 1973), which explains its preferential use in pre-contact times for ground stone celt production in British Columbia (Mackie 1995; Darwent 1998; Morin 2012, 2015a, 2015b). Celts are here defined as rectangular objects with a sharpened (bevelled) end along their short axes (Morin 2012) that were presumed to have been used primarily for woodworking. Celts include artifact types that were variously hafted such as adzes, axes, or chisels. Nephrite cannot be effectively knapped or flaked, so it was used exclusively for ground stone tools (Morin 2015c).

The use of nephrite by pre-contact people in British Columbia has been studied for decades (Dawson 1887; Emmons 1923; Carlson 1994; Mackie 1995; Darwent 1998; Morin 2015a, 2015b) but the archaeological occurrence of nephrite in Alberta has received almost no attention. This may be partially due to local unfamiliarity with nephrite as a raw material but is also likely a result of its rarity in the province: the authors documented only 13 known and two suspected occurrences of nephrite artifacts in Alberta, all of which are ground stone celts that appear in the parkland and boreal forest regions of central and northern Alberta. For context, ground stone tools in Alberta are comparatively rare. Of the more than 40,000 archaeological sites recorded by the Archaeological Survey of Alberta, there are seven recorded instances of celts and 39 adzes, only some of which are ground. Most of the recorded adzes were produced by flintknapping, as opposed to grinding, and are likely more properly called flaked celts, choppers, or axes. Based on familiarity with private collections, local museums, and a cursory review of site forms, we estimate that there are less than 60 known ground stone celts in Alberta.

The colour of nephrite is most commonly a lustrous green but it can vary from black to white with yellow and brown varieties. It is not uncommon to observe two to three distinct colours on the same nephrite artifact. In western Canada, archaeologists have called this raw material greenstone, jade, nephrite, and jadeite. We suspect that it has been misidentified and overlooked in some of Alberta's artifact assemblages. Based on materials of similar appearance, nephrite has probably been misidentified as black chert, green slate, jadeite, and possibly basalt.

Wormington and Forbis (1965:107) were among the first archaeologists to formally document what were thought to be jade artifacts in Alberta. They noted a "jadeite celt" from the Hugh Bower Collection found near Red Deer (the authors could not relocate this specimen in the Red Deer Museum, which now houses the Bower Collection). Ross Thomson recorded a jade adze in a private collection in the Peace Region in 1969 (Thomson 1973 and the site form of GjQr-1). Forbis later documented a "jadeite or nephrite adze blade" near Cochrane in southern Alberta (from the site form of EgPp-18). In the 1980s and 1990s, jade artifacts were recorded in northern Alberta during mostly non-permit projects that were intended to document private collections of artifacts (Peace River Archaeological Society 1991; Le Blanc 2004).

3. Methods overview

We use a variety of techniques to distinguish nephrite from other superficially similar lithic materials. We are specifically interested in the establishment of non-destructive techniques to preserve the integrity of artifacts under investigation. In particular, we believe that the speed and affordability of portable X-ray fluorescence (pXRF) analysis makes this an effective technique to quickly distinguish nephrite from, for example, serpentinite, fine-grained volcanics (such as basalt), chert, and metasedimentary rocks. More involved mineralogical techniques such as X-ray diffraction (XRD) can further help distinguish among amphibole-rich rock types. Near-infrared spectrometry (NIR or visible near-infrared, V-NIR) has already proven to be a valuable non-destructive technique for identifying thousands of nephrite artifacts in British Columbia (Morin 2012, 2015a), China (Zang et al. 2007), and jadeite artifacts in Mesoamerica (Curtiss 1993). Chemometric analysis of NIR spectra derived from nephrite artifacts, and from the sawn cores from which they were produced, can be used to correlate the finished artifacts to their centres of production (Morin 2012, 2015b). We employ V-NIR in an attempt to link the Alberta nephrite celts to their probable centres of production in British Columbia.

4. Geographic distribution of nephrite in western Canada

Nephrite bedrock outcrops are recorded at more than 52 sites in British Columbia, with an additional four known bedrock outcrops in Washington, three in Yukon, and one in Alaska (Figure 2). Nephrite also occurs in California and Wyoming (Leaming and Hudson 2005). The Wyoming occurrence is especially pertinent to archaeology in Alberta because of the large number of obsidian artifacts in the province that have been sourced to Wyoming. However, the lack of identifications of nephrite artifacts in lithic assemblages from Wyoming, suggests that pre-contact people did not use the local nephrite (Leaming and Hudson 2005).

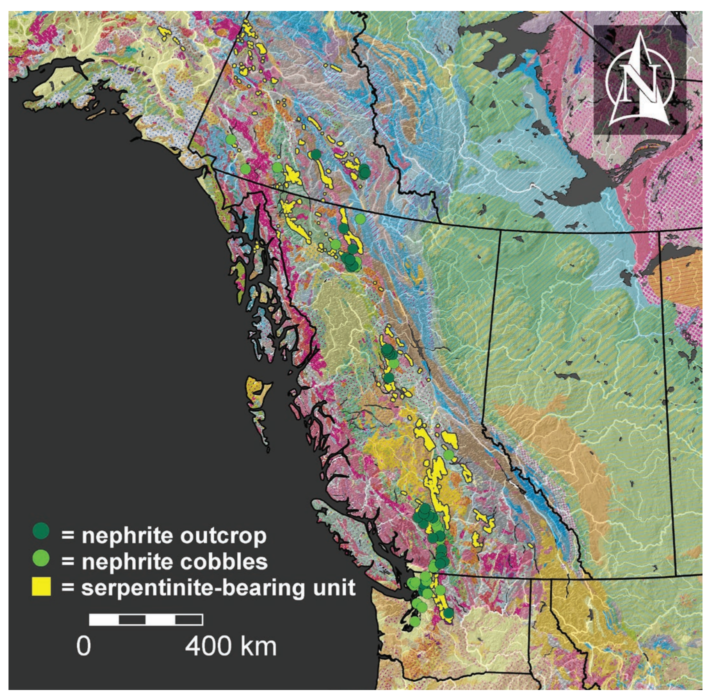

Figure 2. Nephrite sources, serpentinite units, and bedrock geology of North America (bedrock geology data from USGS 2015, serpentinite data generated from geological unit shapefiles from the Alaska Division of Geological & Geophysical Surveys, 2016, Yukon Geological Survey, 2016, British Columbia Geological Survey, 2016, and the Washington Geological Survey, 2016).

Nephrite forms at fault contacts of serpentinite belts and mafic (magnesium- and iron-rich) to felsic (rich in silicon, aluminum, sodium and/or potassium) igneous rocks (Harlow and Sorensen 2005). These types of contacts occur principally in ophiolites (pieces of oceanic plate thrust or obducted onto continental plates), which, in North America, extend as a belt from Washington to Yukon; Leaming (1978) dubbed this the 'Cordilleran nephrite belt'. Figure 2 outlines recorded serpentinite outcrops of Alaska, Yukon, British Columbia, and Washington. According to Dinu Pana of the Alberta Geological Survey (e-mail communication, March 14, 2016), Alberta lacks any record of serpentinite bodies.

The most common occurrence of nephrite is in the form of secondary sources produced by colluvial (gravity-driven), fluvial (river), or glacial erosion of, and transportation from, primary outcrops (Figure 3). These secondary sources are relatively numerous in Washington and British Columbia, which have a combined total of roughly 36 recorded locations (Figure 2). Undoubtedly, there are many more areas where nephrite cobbles have been found but not formally recorded. Most of the Fraser River between Bridge River, north of Lillooet, and just downstream of Hope can be considered a secondary source area. This region has been designated a public jade preserve (Hudson 2006:162). Based on pre-contact nephrite production debris (sawn cores and debitage), the most important sources for nephrite were alluvial cobbles and boulders in the vicinity of Lillooet and Lytton along the Fraser River (Figure 4) and further downstream near Hope in southwest British Columbia (Morin 2015b, 2016). Currently, there is no evidence that nephrite bedrock outcrops were exploited in pre-contact times. This is logical given that bedrock quarrying would add significant time to artifact processing compared

Figure 3. Nephrite cobbles from British Columbia. The upper image is of a sawn core (G63.13.836) from the Fraser River area donated to the Royal Alberta Museum (the sawn face is not visible). The lower images are Fraser River and Dease Lake cobbles courtesy of Kirk Makepeace, 2016 (prepared by Todd Kristensen).

Figure 4. Nephrite was most commonly recovered from alluvial fans along Fraser River, British Columbia (left). Alluvial plain cobble and boulder bed that typically yields high quality nephrite along Fraser River (right) (both images by Jesse Morin).

with the more manageable task of working with nephrite cobbles (Morin 2015c, 2016). All of the sawn nephrite cores from British Columbia exhibit cortex suggestive of river transport. Alluvial cobbles tend to be of higher quality (internal consistency and lack of flaws) than colluvial cobbles closer to bedrock outcrops because rivers act as filters: only the most durable and uniform pieces survive long-distance transport along the Fraser River.

Nephrite production centres are within traditional territories of Interior and Coast Salish people. The most intensive period of use of this material for manufacturing celts has been dubbed the 'Salish Nephrite Industry' (Morin 2015c). Morin argues that the indigenous utilization of dispersed alluvial nephrite for celt production had important social implications because of the limited potential for corporate ownership and control of nephrite sources among Salish people.

Sixty-five sawn nephrite cores (Figure 5) and 66 sawn cores used for manufacturing celts made of other raw materials have been recovered from the Fraser River drainage and Salish Sea area (Figure 6). In terms of core size, pebbles (4-64 mm), cobbles (64-256 mm), and boulders (>256 mm) were utilized for celt production. Nephrite cores could be more than 500 millimetres in length and up to 25 kilograms in mass (Morin 2015b, 2016). Following major drainages (e.g., the Fraser River and Wapiti River), more than 800 kilometres of travel would have been required to transport artifacts from their alluvial sources and places of production (Lytton, Lillooet, and Hope) to archaeological sites in northern and central Alberta.

5. Geological origins of nephrite

Though nephrite in different regions was formed through different means, British Columbia nephrite formed when serpentinite underwent metasomatism (the chemical alteration of rock by interaction with hydrothermal and other fluids). Magnesium-rich serpentinite reacted with a calcium-rich fluid associated with silicic rock such as shale, greywacke, argillite, or chert (Harlow and Sorenson 2005). This type of interaction occurs along contacts, structural boundaries, fractures, and/or faults. The interlocking microstructure that imparts such toughness to nephrite is thought to form by pseudomorphism (the crystallization of a mineral into a crystal shape foreign to that mineral) of serpentinite, perhaps in open cavities (Leaming 1978; O'Hanley 1996). This may encourage a type of growth called "nephritic" fibre-mat crystallization, which is the defining characteristic of nephrite (as opposed to crystals growing in particular orientations or veins).

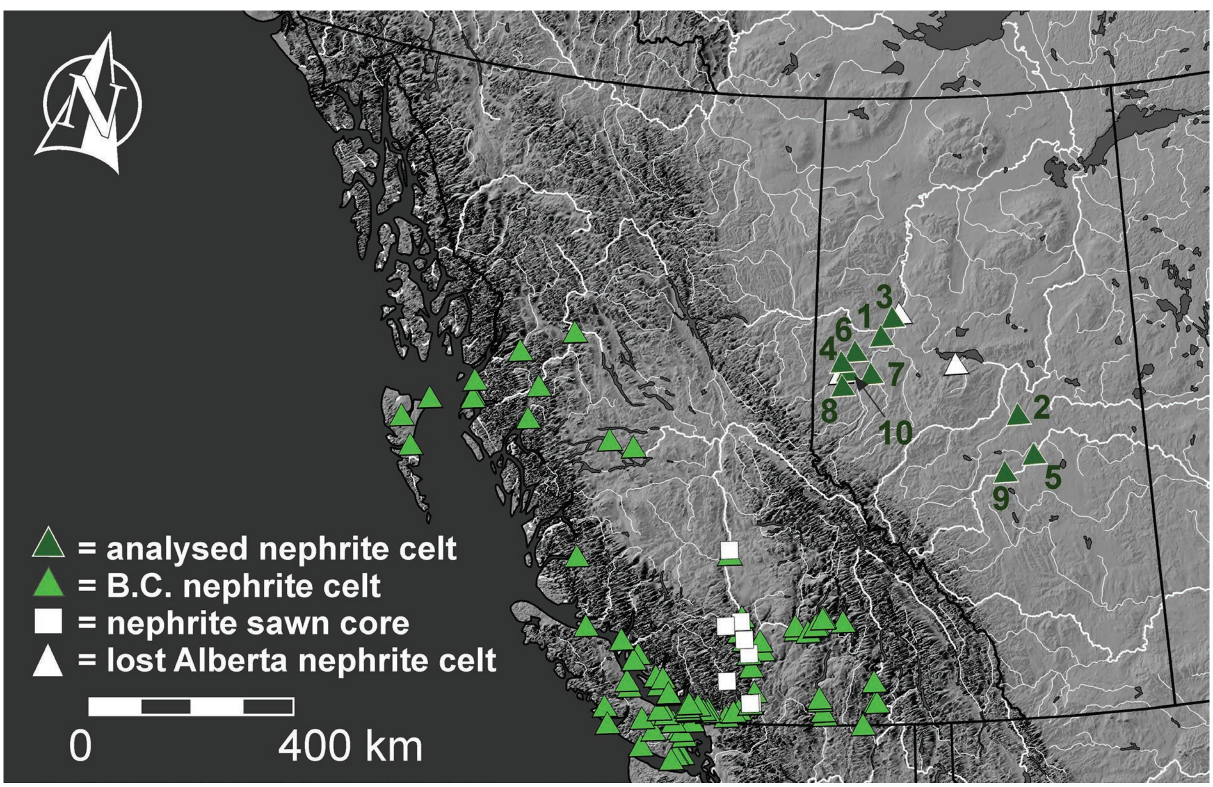

Figure 5. Map of Alberta archaeological sites with nephrite celts analyzed in the current study (and their associated sample numbers) in relation to recorded nephrite celts and sawn cores from British Columbia (data from Morin 2012). 1=GlQl-4, 2=GcPk-4, 3=HbQj-3, 4=GiQs-26, 5=Weber specimen found near Horse Hills, 6=GjQq-5, 7=Matlock specimen found near De Bolt, 8=GfQs-1, 9=FiPn-339, and 10=GhQr-2.

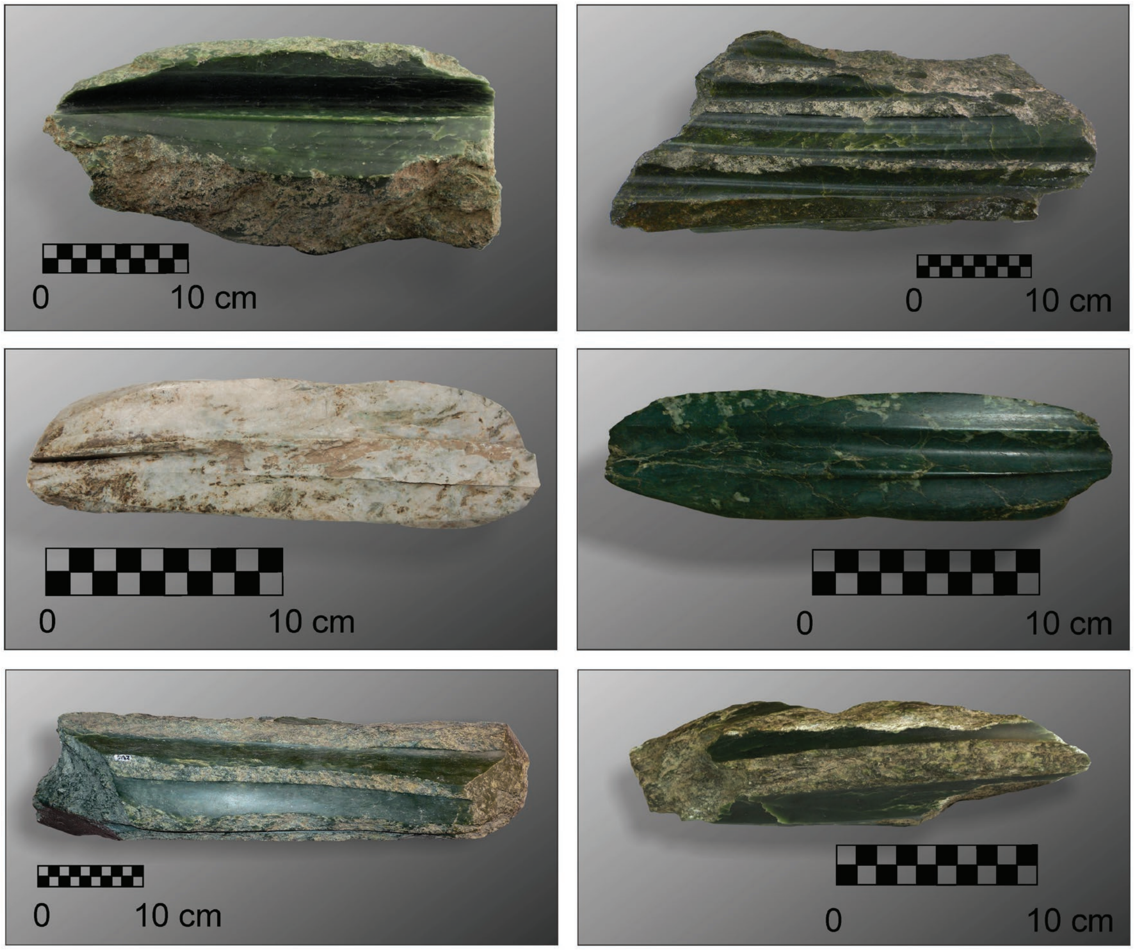

Figure 6. A representative sample of sawn nephrite cores from British Columbia. Artifact find locations are (clockwise from top left): Fraser River (scale approximate), Lytton (scale approximate), Lytton, Lytton, Lillooet, Lytton.

Boulders and cobbles of nephrite were transported from outcrops in colluvial and fluvial deposits. In the case of the Lytton and Lillooet areas, such boulders and cobbles were concentrated on gravel bars along the Fraser River (Figure 4) and some of its tributaries such as Bridge River and Coquihalla River (Morin 2015c, 2016).

The durability of nephrite is of archaeological importance. Ethnohistoric and experimental research suggest that it takes roughly 40-100 hours to produce a single average-sized nephrite celt through sawing, grinding, and polishing (Darwent 1998; Morin 2012). Larger "property" celts (artifacts greater than 15 centimetres long created for prestige as opposed to functional purposes) may have taken up to 1000 hours to make (Morin 2012). Because of the hardness of tremolite-actinolite crystals in nephrite (6.0-6.5 on the Mohs scale), pre-contact celt production tools are limited to items higher on the hardness scale. Initial sawing probably involved quartz or agate pieces set in a wooden brace and used to create a groove, followed by sawing with a sandstone slab. Later polishing involved sandstone and/or gritty water (Teit 1909:473; Emmons 1923:22-24).

6. How to identify nephrite

According to Leaming (1978), the identification of nephrite requires confirmation that the main amphibole component has a nephritic texture, which is only possible through microscopic study of thin sections. This is not feasible for archaeological studies because of its destructive nature. Leaming suggests that tentative identifications can be made through observations of colour, density (specific gravity, with a range of 2.95 to 3.01), hardness (Mohs 6.5), toughness, translucency, and lustre, several of which are discussed below. The next section outlines geochemical analyses that demonstrate that, short of identifying nephritic texture, a suite of techniques can narrow down the possible raw material types through identification of proxy indicators of nephrite and by ruling out other raw materials on the basis of geochemistry and mineralogy.

Nephrite is most commonly "spinach-like" green (Harlow et al. 2014) with black, gray-green, light brown, light yellow, and off-white varieties. Figures 7 to 21 depict the variability of nephrite and other materials analyzed in this study, while Figures 22 and 23 compare thin sections and

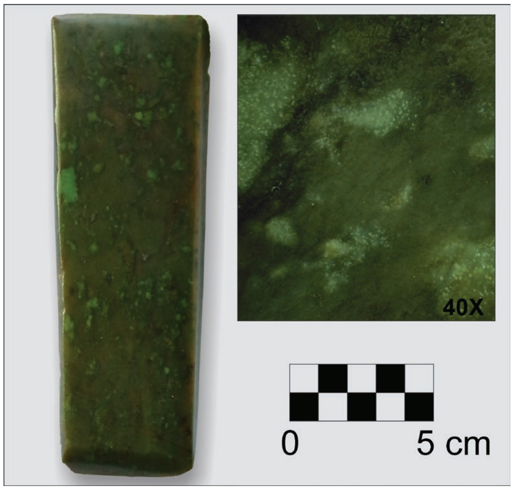

Figure 7. The Poohkay specimen (sample number one) from GlQl-4 (Grande Prairie Pioneer Museum, Grande Prairie, Alberta). NIR suggestst that light green mottling represents chromium garnet inclusions.

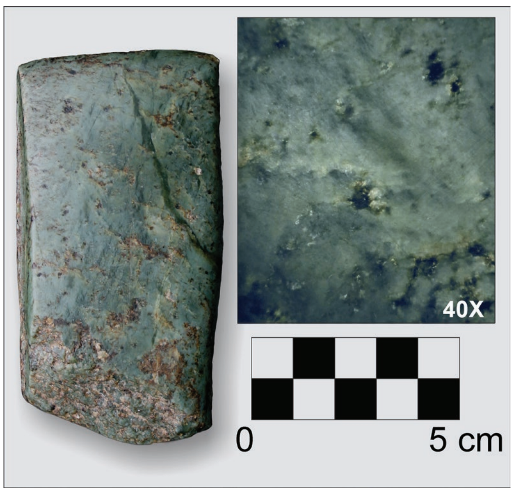

Figure 8. The Guilliford specimen (sample number 2) from GcPk-4 (H09.37.1) (Royal Alberta Museum, Edmonton, Alberta).

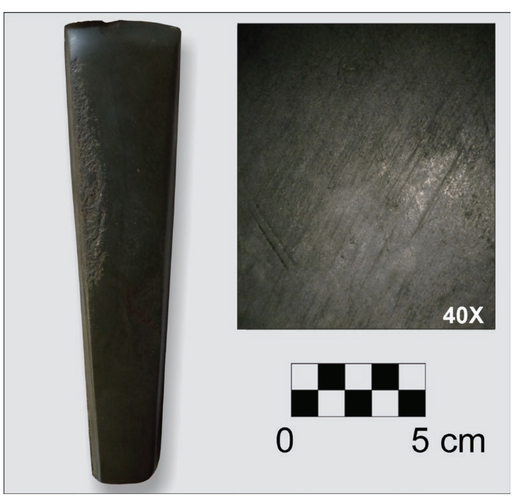

Figure 9. The Veidt specimen (sample number three) from HbQj-3 (Bill Veidt private collection, Peace River, Alberta).

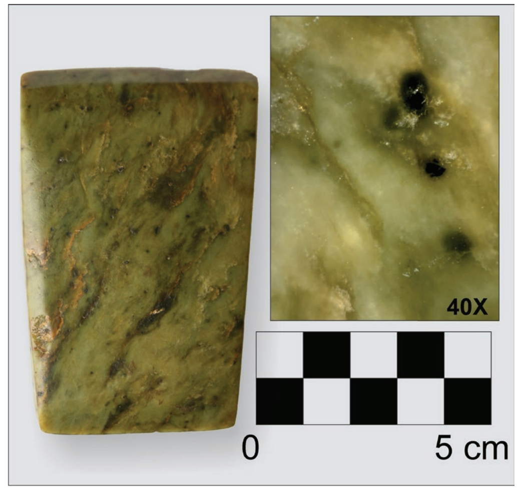

Figure 10. The Bohn specimen (sample number four) from GiQs-26 (Rod Bohn private collection, La Glace, Alberta). NIR suggests that black spots represent chromium-bearing spinel inclusions.

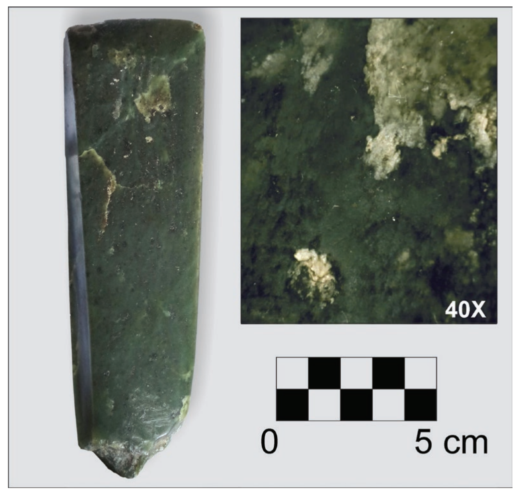

Figure 11. The Weber specimen (sample number five) found near Horse Hills in northeast Edmonton (h72.7.2125) (Royal Alberta Museum, Edmonton, Alberta). No associated Borden Number.

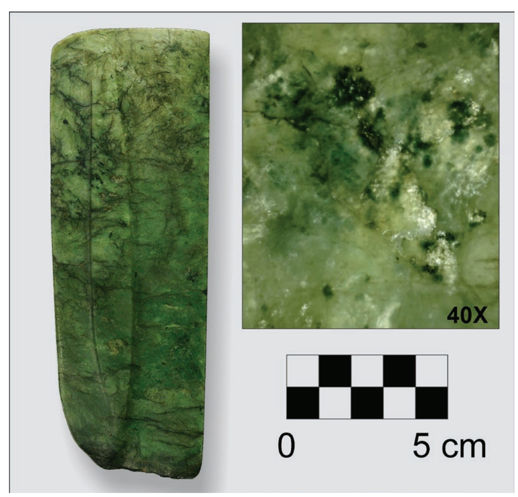

Figure 12. The Anderson one specimen (sample number six) from GjQq-5 (2004.7) (Grande Prairie Pioneer Museum, Grande Prairie, Alberta). Black spots represent chromium-bearing spinel inclusions. Note colour variability and presence of a ‘septum’ (the oval raised area left of centre that was the last piece sawn through to remove the celt from its core).

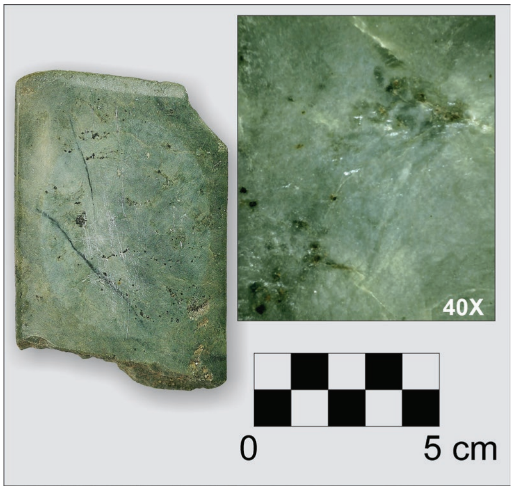

Figure 13. The Matlock specimen (sample number seven) found near DeBolt in northwest Alberta (990.27.118.m3) (Grande Prairie Pioneer Museum, Grande Prairie, Alberta). No associated Borden Number.

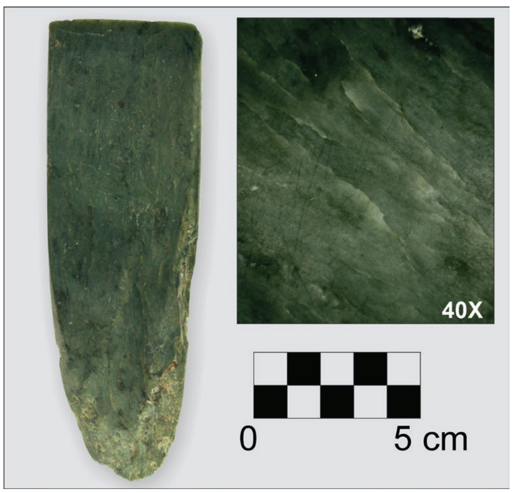

Figure 14. The Craig specimen (sample number eight) from near GfQs-1 (Gavin Craig private collection, Wembley, Alberta).

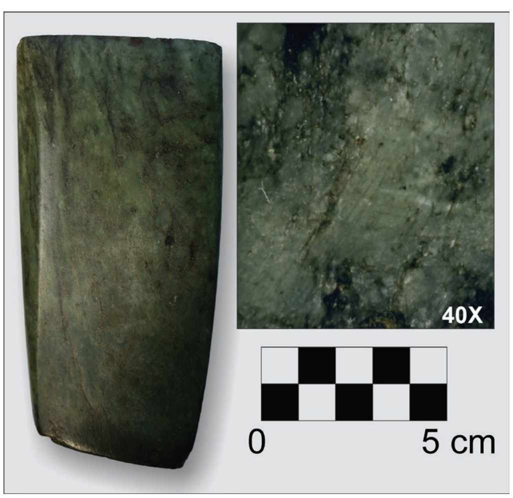

Figure 15. The Eberhardt specimen (sample number nine) from FiPn-339 near Stony Plain in central Alberta (Stony Plain Multicultural Heritage Centre, Stony Plain, Alberta).

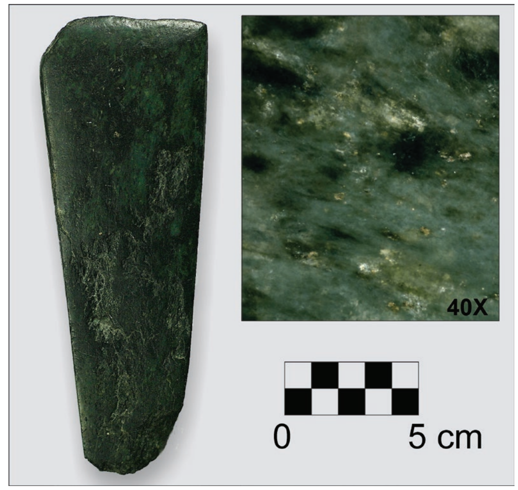

Figure 16. The Anderson two specimen (sample number ten) probably associated with GhQr-2 (2004.7) (Grande Prairie Pioneer Museum, Grande Prairie, Alberta).

Figure 17. The Howard one specimen (sample number 19) from the Howard Collection (G61-4:2634), location unknown but probably Alberta (Royal Alberta Museum, Edmonton, Alberta).

Figure 18. The Howard two specimen (sample number 11) from the Howard Collection (G61-4:2565), location unknown but probably Alberta (Royal Alberta Museum, Edmonton, Alberta).

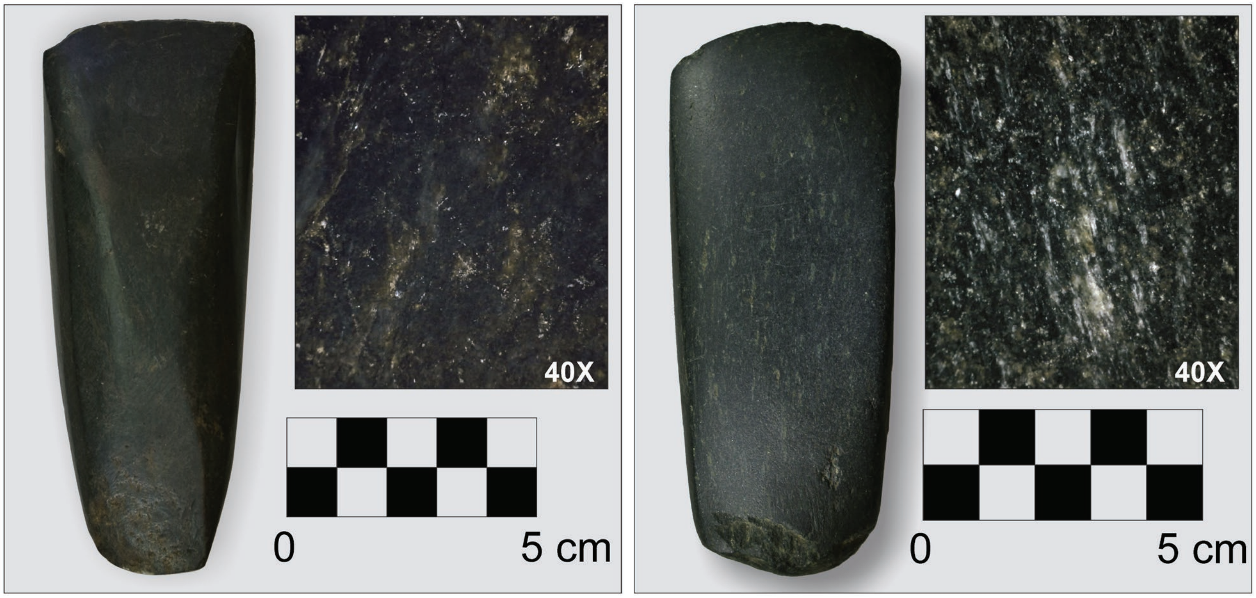

Figure 19. The Smith one (left) and Howard three specimens (right) (sample numbers 13 at left and 14 at right) from the C. P. Smith Collection (G63-13.92), and Howard Collection (G61-4:2569), locations unknown but probably Alberta (Royal Alberta Museum, Edmonton, Alberta).

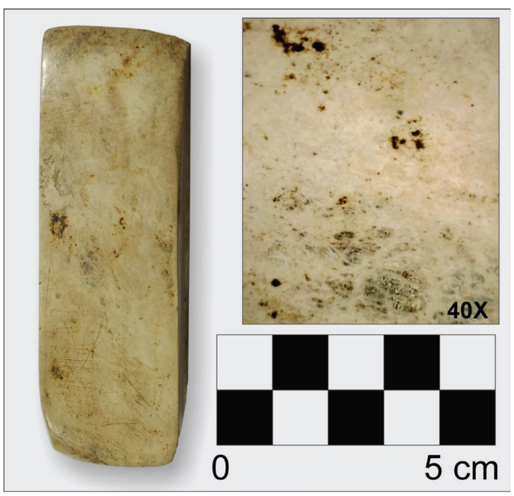

Figure 20. The Pickford one specimen (sample number 17) from the A. E. Pickford collection (G65-10:117) from Victoria, British Columbia (Royal Alberta Museum, Edmonton, Alberta).

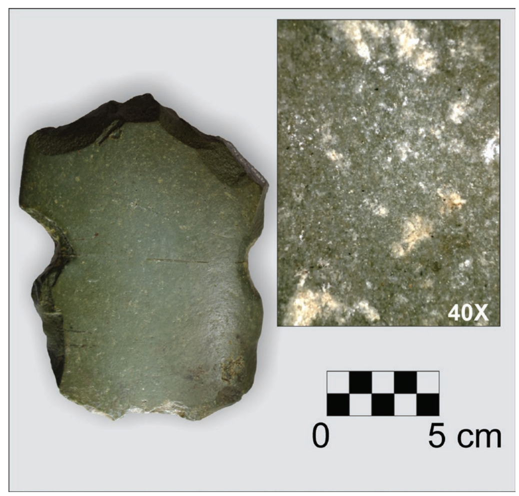

Figure 21. The Anderson three specimen (sample number 18) probably associated with GhQr-2 (2004.7) (Grande Prairie Pioneer Museum, Grande Prairie, Alberta).

microscope images of nephrite, serpentinite, and a green metasedimentary rock (sample 18). Mottling is common and the colour can be quite variable within cobbles/boulders and within artifacts. The relative abundance of iron and graphite appears to influence general colour (Liu et al. 2011) while darker spots on specimens are due to opaque oxides, chromium-bearing spinels, and graphite. Intense emerald green colours are common to British Columbia nephrite and have been linked to Cr^{3+} substitution in the amphibole (Harlow et al. 2014). Colour change in nephrite has been documented through a series of heat-treating experiments (Morin 2012); heat-treatment has been noted in many nephrite celts from British Columbia (Mackie 1995).

Nephrite generally lacks cleavage due to interlocking crystal growth so the overwhelming majority of pre-contact nephrite artifacts in North America are ground and polished as opposed to flaked. A half-joking geological field test for nephrite is to strike a suspected nephrite with a hammer: if the rock breaks, it is probably not nephrite, if the hammer breaks, it is probably nephrite. When nephrite does fracture, it does not display a conchoidal fracture but rather breaks in an irregular pattern sometimes described as "oyster shell". A quick but more reliable field test is to hold a high intensity flashlight to the edge of a polished piece of nephrite or nephrite artifact: high quality nephrite will be translucent.

Polished nephrite typically has a greasy to resinous luster although that can vary from dull to vitreous. For those interested in raw material comparisons, current repositories

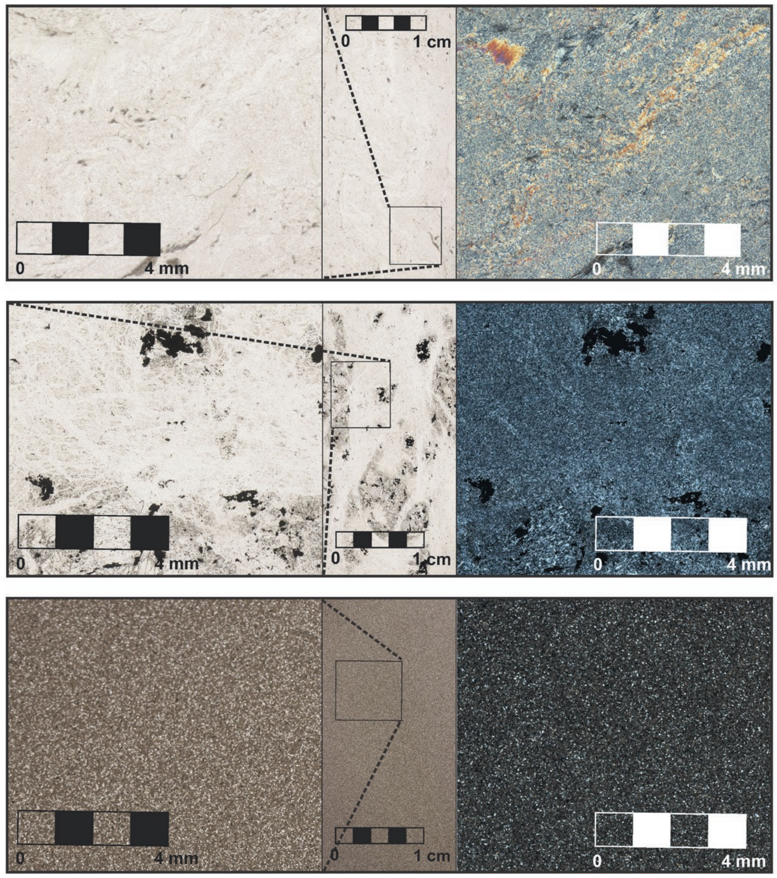

Figure 22. Thin section comparisons under normal (left) and cross polarized light (right). Raw nephrite (top), raw serpentinite (middle), and metasedimentary rock (bottom). The lower thin section is from sample 18.

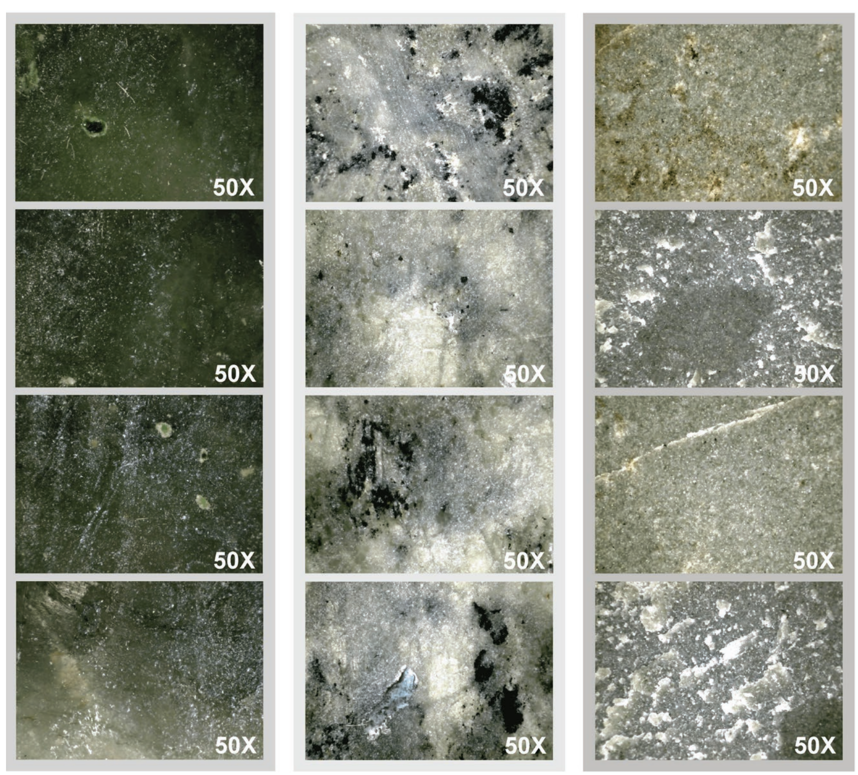

Figure 23. Microscope images of raw nephrite (left), raw serpentinite (middle), and an artifact of metasedimentary rock (sample 18 at right).

of nephrite in Alberta include the Royal Alberta Museum (Edmonton), the Department of Earth and Atmospheric Sciences at the University of Alberta (Edmonton), and the Department of Geoscience at the University of Calgary. Nephrite is relatively common in gem and mineral shops.

6.1 Similar materials to nephrite

The materials most similar in appearance to nephrite that are found in archaeological contexts include serpentinite, semi-nephrite, chlorite-rich rocks and amphibolite. In many cases, macroscopic and microscopic identification techniques are inadequate to distinguish these materials. This problem motivated the current geochemical and mineralogical study. In particular, a black nephrite variety (e.g., Figure 19, sample 13) is easy to mistake for a metavolcanic rock or volcanic rock such as basalt (e.g., Figure 19, sample 14) or even black chert. The latter two materials can usually be distinguished to some degree through microscopic identification of blocky crystals, which are typically not visible in nephrite using less than 50X magnification. Nephrite crystals are usually long, narrow, and fibrous ('nephritic').

Because all nephrite artifacts in Alberta appear to be ground, it is pertinent to discuss distinguishing characteristics of potentially similar-looking ground stone raw materials in the province. Metasedimentary rock like quartzite (the most common material for stone mauls in Alberta), greywacke, and slate typically contain visible quartz crystals using a hand lens or low-power microscope (e.g., Figures 18 and 21). Some ground stone artifacts in the province are of granite or diorite (plutonic) rocks (e.g., Figure 17, sample 19), which clearly have visible large and blocky crystal growth. Sandstone was also used for mauls in Alberta and can be easily distinguished on the basis of microscopic quartz grains.

7. PXRF, XRD, and V-NIR methods

We investigated all recorded instances of nephrite artifacts in Alberta and were able to re-locate ten celts, all of which were borrowed for detailed analyses (Figure 1). The geochemical make-up of samples (unaltered surfaces of artifacts) was assessed by portable X-ray fluorescence (pXRF) and their mineralogy was investigated using X-ray diffraction (XRD) and visible near-infrared spectrometry (V-NIR). Nephrite is both macroscopically and microscopically heterogeneous so efforts were made to assess intra-artifact geochemical variability by assessing multiple surface spots on a single specimen. Nine ground stone tools made of what were initially suspected to be non-nephrite materials were also analysed with pXRF and XRD for comparative purposes (Figure 24). Note that matrix-matched reference standards of well-established chemical composition for nephrite and the non-nephrite materials analyzed here are not available, which limited quantitative comparisons. However, a sawn block of identified nephrite, and a sawn block of identified serpentinite were examined for comparative purposes. The identities of these two specimens are not in doubt, even though their exact compositions have not been established.

Figure 24. Comparative specimens analysed by pXRF and XRD (with accompanying sample numbers).

7.1 Portable XRF analysis

Energy dispersive X-ray fluorescence (EDXRF) analysis, utilizing two Bruker AXS Tracer III-SD portable X-ray fluorescence spectrometers, was used to non-destructively assess the elemental composition of the various artifacts and materials analyzed in this study. The spectrometers, attached to laptop computers running the Bruker software S1PXRF configured for laboratory bench-top use, were powered using AC adaptors and operated remotely from their respective laptops. The Tracer III-SD units utilized are equipped with a Rh X-ray tube and a 10 millimetre^2 Silicon Drift Detector (SDD) with a measured FWHM resolution of 148 eV for Mn *K*α X-rays. The X-ray excitation beam that strikes samples is elliptical in shape, approximately 8 by 6 millimetre in size.

Given the lack of a suite of nephrite samples of known composition, and the exploratory nature of this study to evaluate the use of non-destructive methods of analysis to characterize archaeological artifacts and raw materials, it was realized from the outset that much of the XRF data would likely be qualitative (or at best semi-quantitative) in nature. Similarly, it was expected that many of the elements commonly used to source obsidian (e.g., Rb, Sr, Y, Zr, Nb) would probably be below, or close to, the portable XRF detection limit in nephrite jade. It was, however, considered worthwhile to evaluate the use of the major and minor elements (e.g., Si, Ca, Fe, Mg, K, Al, Ti, Ni and Cr) (Figure 25) for differentiating celts made from nephrite from those fashioned from other raw materials (e.g., fine-grained volcanics) based on the following rationale. Nephrite is a calcium magnesium iron silicate hydroxide with the general chemical formula $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$. In comparison, serpentine is a magnesium iron silicate hydroxide with the generalized formula $(Mg,Fe)_3Si_2O_5(OH)_4$. Comparing these two formulae, one would expect that the analysis of the Ca-content of a sample might be used to distinguish between nephrite and serpentine. Furthermore, it was hypothesized that non-nephrite raw materials used to fashion celts, e.g., fine-grained volcanics and metasediments, would be geochemically distinct from tremolite-ferro-actinolite-rich rocks. That is, we expected elements such as Ti, K, and possibly Al might be useful indicators to differentiate nephrite from raw materials of similar appearance.

Three different sets of operating conditions (i.e., accelerating voltage and operating current) were employed in the analysis of the study samples: a) 15 kV and 95 µA; under vacuum, with no excitation filter, 30 second live-time count period, b) 15 kV and 26 µA; under vacuum, with no excitation filter, 120 second live-time count period, and c) 40 kV and 30 µA; in air employing a Bruker AXS excitation filter (comprised of 0.1523 mm Cu, 0.0254 mm Ti and 0.3047 mm Al), 180 or 300 second live-time count period.

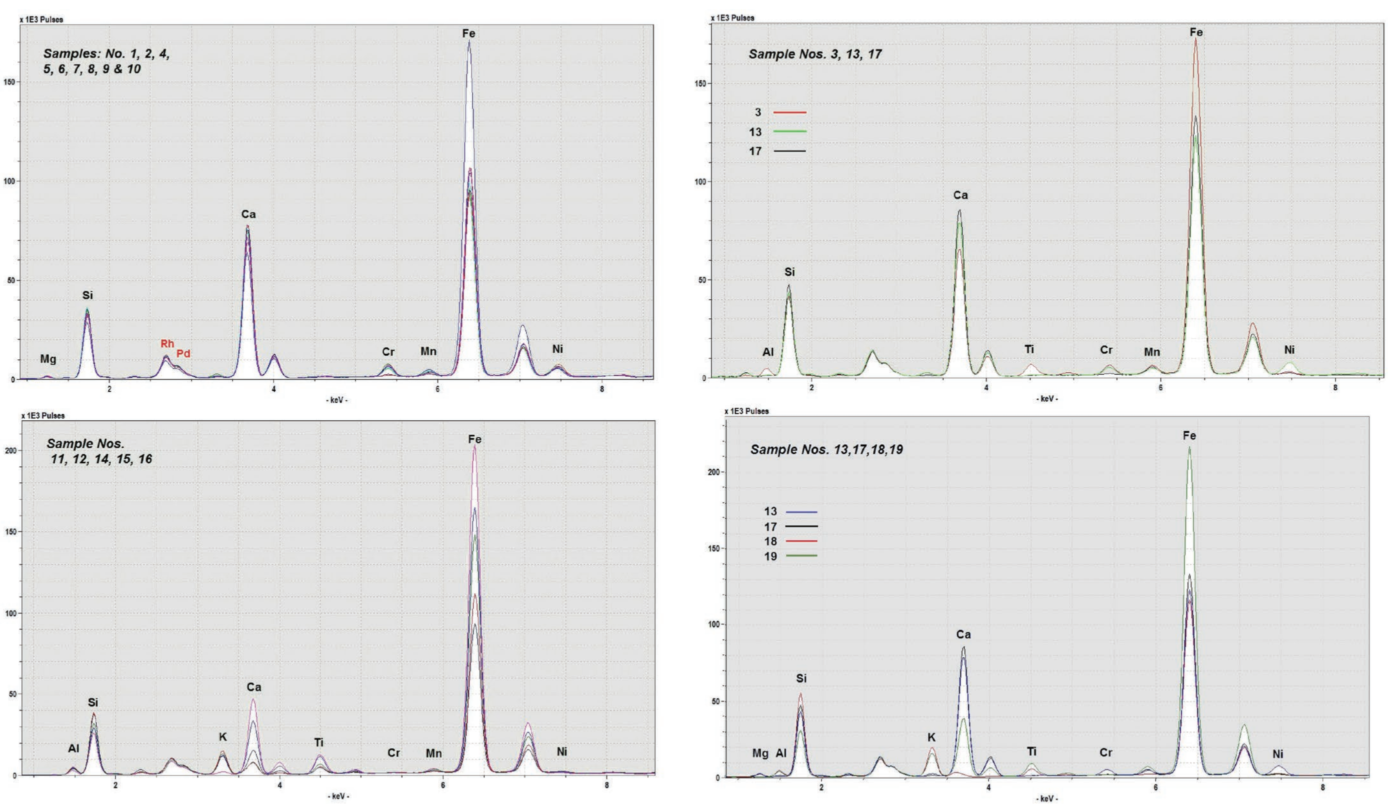

Figure 25. Comparative pXRF spectra of samples 1-19.

The Bruker AXS software SPECTRA v5.3 was used to evaluate the XRF spectra of the major and minor elements (primarily in the 1-8 keV energy range) analyzed in the study. The software corrects for spectral interferences (e.g., overlaps, escape and sum peaks) returning fitted net X-ray photopeak areas. It is these net peaks areas, in particular those for Si, Ca, Fe, Ti, Cr and Ni, which are used in this study to differentiate nephrite from non-nephrite materials.

As an initial step, sample X-ray spectra were compared visually (Figure 25) given the lack of matrix-matched standards with which to develop fully quantitative elemental analyses of nephrite and non-nephrite samples in this study.

In lieu of fully quantitative elemental compositional data for the samples, ratios of the net peaks areas of the major and minor elements (e.g., Si/Ca, Fe/Ca, Fe/Ti, Fe/Ni) have been used to differentiate nephrite-jade from non-nephrite jade-like materials. Using the elemental net peak area ratios normalizes for possible different counting times and, where the characteristic elemental X-ray energies are close in energy (e.g., for Fe and Ni), probably reduces potential matrix effects. For the majority of samples a number of surface spots were scanned and the results were averaged to compensate for potential geochemical variability within an individual sample. For example, B.C. nephrite is known to contain chromium-bearing spinel and chromium-bearing garnet inclusions of markedly different chemistry than the tremolite-actinolite matrix.

7.2 X-ray diffraction

X-ray diffraction patterns were acquired using Bragg-Brentano parafocussing reflection geometry with a Rigaku Ultima IV θ-θ diffractometer that has a goniometer radius of 285 millimetre and a Co X-ray source (Kα 1.78899 Å) operated at 38 kV and 38 mA. A fixed divergence slit of 0.67°, and a 10 millimetre height limiting slit were used in the path of the incident beam. Soller slits of 5°, an anti-scatter slit of 2°, and an iron foil filter were used in the path of the diffracted signal. The detector was a 1D silicon strip (D/tex Ultra). Each diffraction scan was run from 5 to 90° 2θ in continuous mode with a step size of 0.02° 2θ, and a count time of 0.6 seconds per step.

Each sample was oriented in the instrument with the use of a bubble-level. Generally, the longest axis of a celt was parallel to the floor of the instrument and perpendicular to the X-ray source to detector direction (Figure 26). The rectangular area of analysis changes in X-ray diffraction as a function of 2θ angle, and was measured at low angle to be a maximum of 12 by 30 millimetres.

The diffraction patterns were interpreted with the use of the software package JADE (version 9.5.1, produced by MDI) and both the ICSD 2015 database (FIZ Karlsruhe) and the PDF-2 Release 2013 database (ICDD).

Following identification of the minerals present in an XRD pattern, the whole-pattern fitting module in JADE was used to undertake Rietveld refinement (McCusker et al. 1999; Madsen and Scarlett 2008) of the mineral proportions (reported in percent by weight) using a standard suite of parameters. The background was modelled with a fourth-order polynomial, specimen displacement was refined as a function of cosθ, and a correction applied for anomalous scattering. The refinements were carried out to convergence. In contrast to the customary use of finely-powdered samples for XRD, the diffraction patterns were acquired from the (unpowdered) celts and sawn blocks; this approach has been successful in other studies of nephrite artifacts (Casadio et al. 2007; Adamo and Boccio 2013). Because the samples are not fine powders, and do show preferred orientation of crystallites, the final Rietveld fitting uncertainties were multiplied by a factor of five to estimate the probable errors in the mineral proportions.

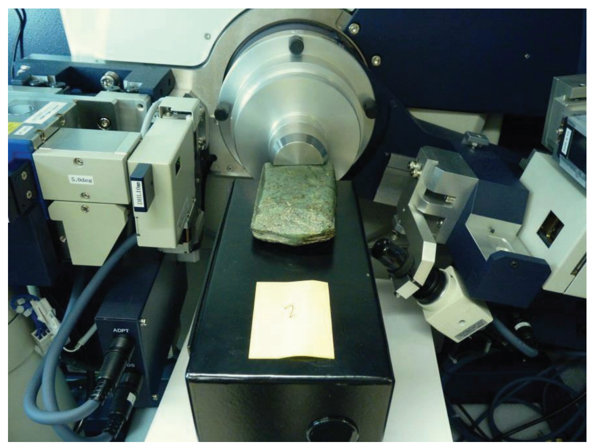

Figure 26. Typical sample orientation in the diffractometer. The X-ray source is at left, and the detector at right.

7.3 Visible near-infrared spectrometry

Lithic materials are typically analyzed in sourcing studies using XRF or similar analytical techniques that quantify minor and trace elements in a sample (Pollard et al. 2007). Instead of producing elemental concentrations, visible near-infrared spectrometry (V-NIR) collects reflectance spectra measured as percent reflectance (Y-axis) of wavelength (or wave number) along the visible and near-infrared spectrum measured in nanometers (Bonnano et al. 1992; Clark et al. 1990; Bokobza 1998; Ostrooumov 2009). The principle underlying V-NIR spectrometry is that many materials, including minerals, produce unique interpretable V-NIR spectra (Clark et al. 1990; Ostrooumov 2009). The minerals that compose nephrite produce unique interpretable V-NIR spectra that are readily distinguishable from those of other minerals, including non-nephritic actinolite-tremolite (Zang et al. 2007; Morin 2015a, 2015b). V-NIR spectrometry has been used in a variety of archaeological applications (Beck 1986; Curtiss 1993; Wiseman et al. 2002; Ostromoov 2009; Parish 2011).

Two major applications of V-NIR to archaeology include: 1) raw material identification and, 2) raw material qualification or classification (Kemper and Luchetta 2003). Raw material identification refers to assigning a material identity by way of comparison of spectra from a large database of known materials (Figure 27;Clark 1999; Kemper and Luchetta 2003). In earlier studies (Morin 2012, 2015a, 2015b), V-NIR was used to identify the mineralogy of 2027 celts and related artifacts in southwest British Columbia using TerraSpec®, a portable V-NIR spectrometer specifically designed for collecting spectra of geological samples (TerraSpec® measures both V-NIR and NIR spectra from 350-2500 nm). V-NIR spectra derived from artifacts were compared to a database of 1200 rocks and minerals and more than 300 varieties of nephrite (i.e., a spectral library) to identify raw materials. Thirty of these nephrite samples were also analyzed using electron microprobe analysis (EMPA) by Y. Iizukua and were confirmed to be nephrite (Morin 2012:127). We used the same spectral library to identify the mineralogy of ten celts from central and northern Alberta using V-NIR spectrometry.

Raw material qualification or classification refers to assigning a sample of a particular material type to a sub-group of that same material (Bokobza 1998; Kemper and Luchetta 2003). In previous studies (Morin 2012, 2015b, 2016), a large sample of sawn nephrite cores from British Colunbia was classified into two spatial clusters (Lytton-Lillooet and Hope) using chemometric methods. Chemometrics is a specialized branch of statistics defined as “the extraction of chemical information using computers and mathematics” (Bokobza 1998:4). Chemometrics differs from other multivariate statistical approaches applied in geoarchaeology and archaeometry in that very large data matrices are employed – regularly thousands of variables and hundreds to tens of thousands of samples. Earlier research has demonstrated that geological nephrite sources in British Columbia can be differentiated using chemometrics through their V-NIR spectra, and that nephrite celts can be linked to geochemical signatures of nephrite cores (Morin 2012). Chemometric methods of analysis and classification of both the geological and archaeological nephrite are detailed in Morin (2012:384-450; 2015b).

Because nephrite has a complex petrogenesis, variable inclusions, and considerable within-source heterogeneity, straight-forward classification of nephrite varieties by rare earth minerals is unlikely to be successful. This is probably why no one has ever published a paper sourcing nephrite this way, despite its global significance. Iizukua and Hung (2005) and Iizukua et al. (2005) have approached nephrite sourcing in a similar way, but rather focused on the geochemistry of the inclusions on nephrite using EMPA. Iizuka’s exploratory work on British Columbia nephrites with Morin (2012) was not able to find clear separation of sources using this method. Z. Jing has been studying the geochemistry of nephrite for more than two decades (Wen and Jing 1992) and introduced the use of V-NIR to the analysis of Chinese and British Columbia nephrites.

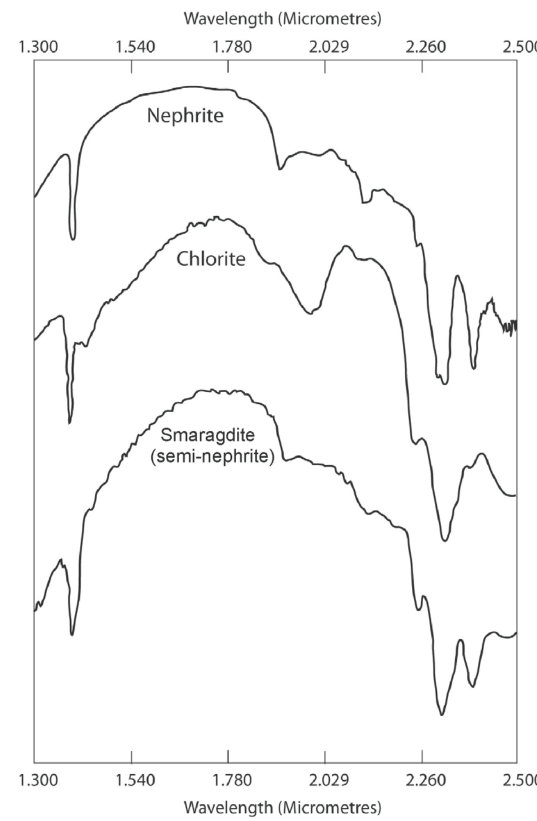

Figure 27. V-NIR stacked spectra.

Here, we use multivariate statistical methods on V-NIR spectra to classify eight nephrite celts from Alberta to one of two groups of sawn cores in southwest B.C.: the Lytton-Lillooet (Mid-Fraser) cluster (represented by 41 sawn cores and 105 spectra), or the Hope (or Lower Fraser) cluster (represented by 17 sawn cores and 33 spectra). This sample of nephrite cores includes 91% of all reported examples of this artifact type in western North America.

After selecting segments of the NIR spectrum of interest, spectra were scaled using the single normal variate transformation(SNV), and principal components analysis (PCA) was conducted on segments of these spectra to reduce the number of variables from 1125 to seven principal components (Dunteman 1989; Jackson 1991; Beebe 1998:83; Baxter 2006). Analyses were undertaken using The Unscrambler 10 software designed for chemometric analyses of spectral data. Linear discriminant analysis (LDA or MDA) was then applied to the first seven principal component scores for all samples. These analyses were undertaken using JMP statistical software. This technique classified each nephrite spectra from the celts to one of two groups of nephrite cores (note that only two groups were provided because these are the most archaeologically concentrated core production areas). Analysis of the eight Alberta nephrite celts was run simultaneously with a sample of 12 nephrite celts from southwest British Columbia to explore variation between groups.

8. Portable XRF results

In keeping with its generalized formula, X-ray peaks from Fe, Ca and Si dominate the spectra of nephrite (Figure 28) with minor photopeaks from Cr, Ni, and Mn. In comparison, Ca is essentially absent in the X-ray spectra of analyzed serpentine (and the rock-type serpentinite) and Mg slightly more prominent compared to nephrite (Figure 28). As a consequence of the 'soft', or low energy, nature of Mg X-rays (1.253 keV), the intensity of the Mg X-ray photopeaks in Figures 25 and 28 are small in comparison to those of Fe, Ca, and Si. The Rh and Pd X-ray photopeaks labelled in Figures 25 and 28 are, respectively, a consequence of scattering of the primary X-rays from the Rh X-ray tube and excitation of the Pd examination window grill of the X-ray spectrometer. The X-ray spectra for the known nephrite jade celts (sample numbers 1, 2, 4, 5, 6, 7, 8, 9 and 10; Figure 25) all show a very strong resemblance to the nephrite X-ray spectra (e.g., Figure 28) indicating that these particular celts are nephrite jade. In contrast, the X-ray spectra for samples 11, 12, 14, 15, 16, 18 and 19 (Figure 25) display, to varying degrees, X-ray photopeaks of Ti, K and Al, and much reduced Cr and Ni photopeaks. The presence of K in particular is contrary to both nephrite jade and serpentinite.

Table 1 lists the measured net X-ray photopeak count ratios for the analyzed celts and raw materials, together with the number of sample "spots" analyzed, and the one sigma standard deviation of the photopeak count ratios. The Si/Ca ratios for the known nephrite celts (sample numbers 1, 2, 4, 5, 6, 7, 8, 9, and 10) are both consistent (0.39±0.01), display a small coefficient of variation (3.31%) and are in quite good agreement with the measurements of unmodified nephrite (0.31±0.04). In comparison, the Si/Ca ratio for serpentinite (61±3) is clearly distinguishable from that of nephrite. The Fe/Cr X-ray photopeak count ratios for many

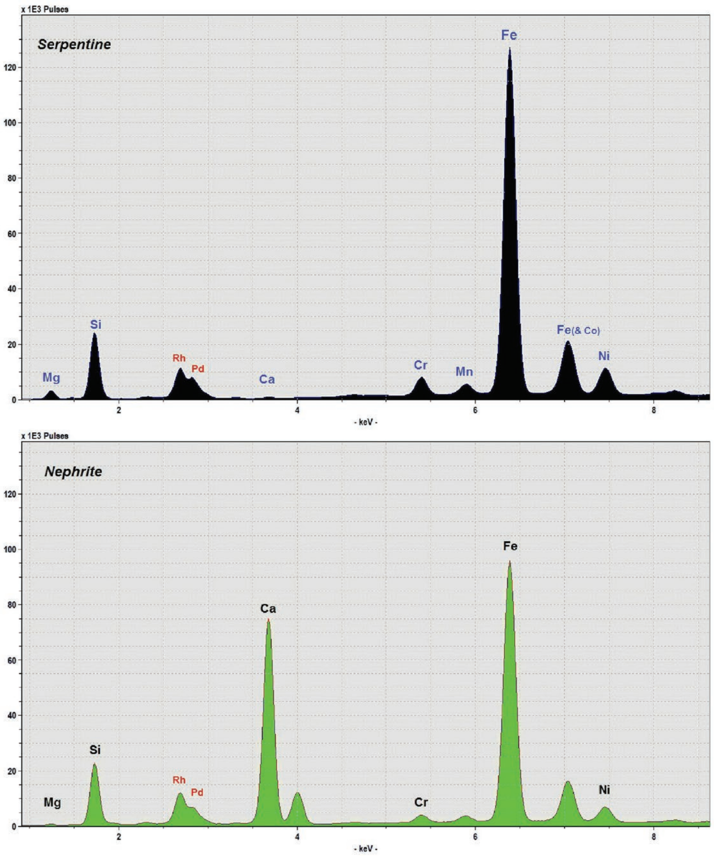

Figure 28. Comparative pXRF spectra illustrating the differences in calcium and magnesium between serpentine (top) and nephrite (bottom).

of the samples analyzed (both nephrite and non-nephrite) show large standard deviations, indicative of mineralogical heterogeneity of Cr-bearing minerals noted earlier.

Figure 29 illustrates that photopeak ratios of Fe/Ti vs. Si/Ca largely separate the nephrite jade celts from those fashioned from non-nephrite material (and from serpentine) with the exception of sample 3. However, an accompanying triangular diagram in Figure 29 using (Fe/Ti)/100-(Fe/Ni)/100-Ca/Si permits the differentiation of all the nephrite jade samples from the non-nephrite material (and serpentine) and clearly shows that samples 3 and 17, while nephrite, are dissimilar from the bulk of the remaining nephrite jade celts. This observation, based on geochemistry, is supported by the XRD results reported below.

The sample trace element data (Table 2), though preliminary in nature, support the nephrite/non-nephrite material identification based on the major and minor X-ray photopeak ratio data. Rubidium, Zr, and Y were not detected in the raw nephrite sample, known nephrite celts, and raw serpentinite analyzed, although they were readily measurable in the non-nephrite samples.

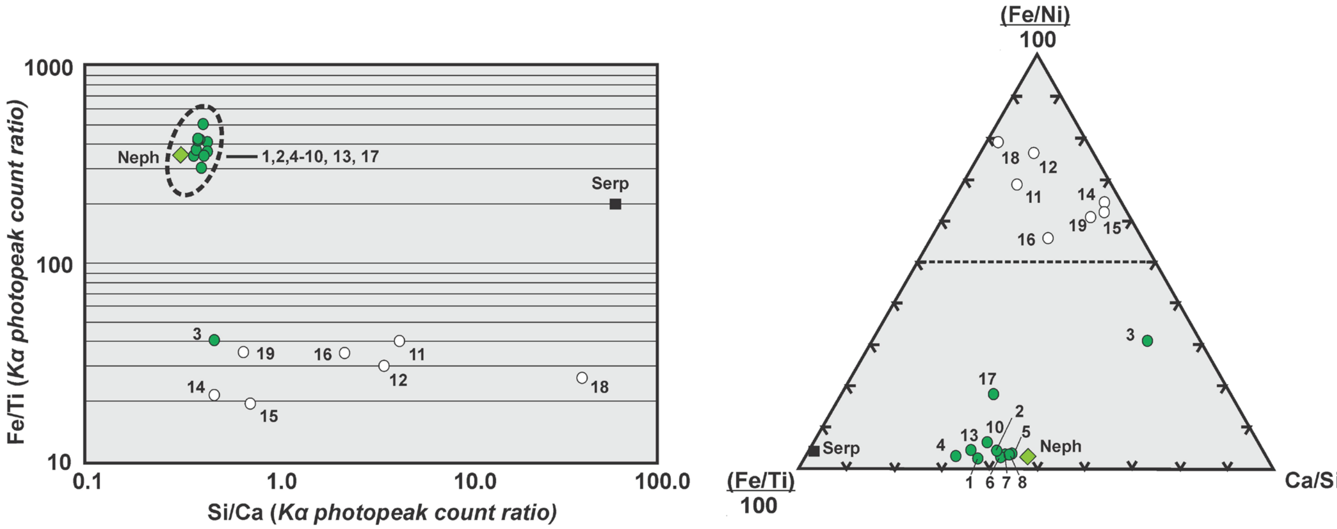

Figure 29. Photopeak count ratio of Fe/Ti and Si/Ca (left) and triangle plot of photopeak ratios based on pXRF (right). The dashed line in the triangular diagram represents a reliable cut-off to distinguish nephrite/serpentinite/semi-nephrite (below line) from non-nephrite (above line).

Table 1. X-ray photopeak ratios from pXRF.

ID/No.	n	Si/Ca (± 1σ)	Fe/Si (± 1σ)	Fe/Ca (± 1σ)	Fe/Ti (± 1σ)	Fe/Cr (± 1σ)	Fe/Ni (± 1σ)
Nephrite	5	0.31 ± 0.04	4.63 ± 0.81	1.39 ± 0.04	356 ± 47	38 ± 9	18 ± 1
1	4	0.40 ± 0.01	3.65 ± 0.10	1.45 ± 0.01	422 ± 32	64 ± 5	17 ± 1
2	7	0.39 ± 0.01	3.92 ± 0.29	1.54 ± 0.09	349 ± 28	38 ± 9	24 ± 2
3	7	0.46 ± 0.03	6.75 ± 0.41	3.10 ± 0.03	41 ± 9	46 ± 14	115 ± 5
4	5	0.41 ± 0.02	3.75 ± 0.27	1.53 ± 0.05	509 ± 55	49 ± 16	23 ± 1
5	7	0.40 ± 0.02	4.68 ± 0.57	1.86 ± 0.27	309 ± 83	24 ± 8	20 ± 1
6	3	0.38 ± 0.02	3.75 ± 0.13	1.41 ± 0.02	374 ± 51	37 ± 15	27 ± 3
7	5	0.37 ± 0.02	3.99 ± 0.24	1.47 ± 0.07	353 ± 19	32 ± 15	19 ± 1
8	5	0.39 ± 0.01	3.81 ± 0.24	1.50 ± 0.06	320 ± 54	19 ± 10	20 ± 1
9	4	0.39 ± 0.01	3.64 ± 0.16	1.42 ± 0.03	358 ± 54	26 ± 12	23 ± 1
10	6	0.37 ± 0.03	8.71 ± 1.11	3.24 ± 0.29	418 ± 47	33 ± 18	47 ± 6
11	2	4.41 ± 0.31	5.04 ± 1.13	22.1 ± 3.4	40 ± 11	460 ± 50	137 ± 14
12	3	3.66 ± 0.32	7.56 ± 0.57	27.6 ± 0.6	30 ± 2	400 ± 22	183 ± 6
13	4	0.42 ± 0.01	4.38 ± 0.49	1.83 ± 0.15	410 ± 159	33 ± 2	23 ± 4
14	4	0.46 ± 0.07	11.6 ± 1.9	5.25 ± 0.18	22 ± 1	984 ± 129	435 ± 14
15	3	0.71 ± 0.02	8.54 ± 0.47	6.06 ± 0.44	20 ± 1	890 ± 288	265 ± 12
16	2	2.23 ± 0.08	3.53 ± 0.09	7.89 ± 0.07	35 ± 4	268 ± 6	103 ± 7
17	4	0.42 ± 0.02	4.32 ± 0.20	1.81 ± 0.03	365 ± 27	203 ± 10	133 ± 4
18	3	40 ± 10	2.92 ± 0.16	115 ± 25	26 ± 3	500 ± 9	111 ± 2
19	2	0.66 ± 0.07	10.4 ± 1.1	6.90 ± 0.08	35 ± 5	1628 ± 1351	284 ± 2
Serpentinite	3	61 ± 3	5.66 ± 0.61	343 ± 33	202 ± 35	24 ± 11	9 ± 1

Table 2. PXRF Rb, Sr, Zr, and Y results for celts and raw material samples of nephrite and serpentinite (concentrations in μg/g).

ID/No.	Rb	Sr	Zr	Y
Nephrite	< 2	20	< 10	< 4
1	< 2	25	< 10	< 4
2	< 2	37	< 10	< 4
3	11	434	49	12
4	< 2	23	< 10	< 4
5	< 2	30	< 10	< 4
6	< 2	37	< 10	< 4
7	< 2	13	< 10	< 4
8	< 2	16	< 10	< 4
9	< 2	27	< 10	< 4
10	< 2	28	< 10	<4
11	51	200	82	13
12	88	64	131	29
13	< 2	27	< 10	< 4
14	3	133	121	36
15	61	440	136	26
16	83	311	127	15
17	< 2	31	< 10	< 4
18	136	43	343	44
19	96	140	1060	24
Serpentinite	< 2	8	< 10	< 4

9. X-Ray Diffraction Results

The XRD results indicate that the reference nephrite block and samples 1, 2, 4-9, 13, and 17 are dominated by amphiboles of the tremolite-actinolite series (within two standard deviations of 90 percent tremolite-actinolite amphibole by weight; Table 3). In conjunction with their textures (Figures 1, 22) these results are consistent with their classification as nephrite as defined by Simandl et al. (2000). XRD patterns of samples 1-10 reflect their similar mineralogy (Figure 30; Table 3). Samples 3 and 10 have less amphibole (Table 3), but similar texture to the nephrite samples (Figures 1, 9, 16) and are referred to here as semi-nephrite (Simandl et al. 2000; Harlow and Sorensen, 2005). The XRD techniques are based on the crystal structure of a material, not the arrangement of crystals (microstructure), and cannot distinguish between tremolite-actinolite that has, or does not have, nephritic texture.

In addition to the examination of macroscopic and microscopic textures, and the XRD determination of abundant tremolite-actinolite amphibole, the overall mineral assemblage can be used to help identify nephritic rocks. Triangular plots of the relative weight abundance of mica, amphibole and chlorite, and of feldspar, amphibole, and quartz provide useful means to distinguish nephrite from semi-nephrite and to distinguish nephrite from other raw material types including regular amphibolites or metavolcanics (Figure 31).

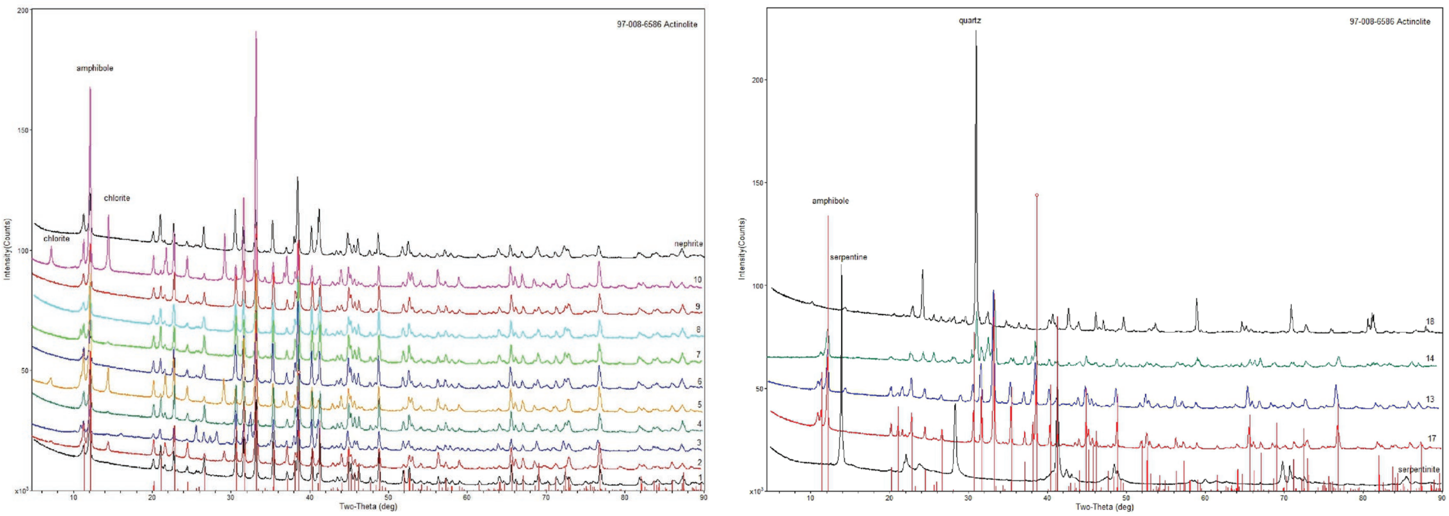

Figure 30. XRD patterns of Alberta celts, comparative specimens, raw nephrite, and raw serpentinite sample.

Table 3. XRD-determined mineral proportions (percent by weight). Estimated 1-sigma uncertainties are given in parentheses. The mineral species have been generalized in this table; the amphiboles of nephrite and semi-nephrite are of the tremolite-actinolite series. Note that sample five falls within two standard deviations of the 90 wt% amphibole boundary used to define nephrite.

Sample	Identification	Amphibole	Chlorite	White mica	Plagioclase	K- feldspar	Quartz	Other	Sum
Nephrite	nephrite	>99							>99
1	nephrite	>99	<1						100
2	nephrite	88 (7)	12 (3)						100
3	Semi-nephrite	62 (3)	6 (1)	7 (2)	23 (2)			talc 3 (1)	101
4	nephrite	96 (5)	4 (2)						100
5	nephrite	78 (7)	21 (4)						99
6	nephrite	>99							>99
7	nephrite	98 (5)	1 (0.5)					talc 1.5 (1)	100.5
8	nephrite	98 (6)						magnesite 2 (1)	100
9	nephrite	93 (6)	1 (0.5)		6 (2)				100
10	Semi-nephrite	70 (6)	25 (4)	3 (1)				talc 2 (1)	100
11	metasediment		13 (3)	16 (3)	26 (3)		44 (3)		99
12	metasediment		18 (3)	24 (3)	20 (3)		38 (3)		100
13	nephrite	85 (10)	9 (3)					talc 6 (2)	100
14	metavolcanic	48 (5)			36 (5)		15 (2)	kaolinite 1 (1)	100
15	metasediment		20 (2)	20 (3)	22 (2)	6 (2)	15 (1)	epidote 18 (2)	101
16	Not analysed								
17	nephrite	92 (7)						talc 8 (3)	100
18	metasediment		12 (2)	26 (2)	8 (1)		54 (2)		100
19	plutonic rock	33 (5)		16 (4)	27 (4)	14 (3)	3 (1)	kaolinite 7 (3)	100
Serpentine	serpentinite							serpentine >99	>99

Based on quartz content and texture (Figures 18, 21, 24), samples 11, 12, 15, and 18 are most likely metasedimentary rocks (Table 3). Sample 14 has a moderate amount of quartz and high amphibole content consistent with a metavolcanic rock. The mineralogy and texture (Table 3; Figures 17, 24) of sample 19 is consistent with a plutonic rock. The reference serpentinite sample contains >99 percent serpentine.

10. Near-infrared spectrometry results

Comparison of V-NIR spectra indicates that eight of the ten Alberta celts are nephrite (samples 1, 2, and 4-9), sample 3 is smaragdite (a variety of actinolite listed in the USGS spectral library, that we consider effectively synonymous with a feldspar-bearing variety of semi-nephrite) and the V-NIR results for sample 10 are dominated by chlorite (Table 4). We note that smaragdite has fallen out of use as a geological term and prefer the term semi-nephrite (Harlow and Sorenson 2005).

Sample 3, made of feldspar-bearing semi-nephrite, has a nearly identical NIR spectrum to a sample of smaragdite (in a spectral library derived from the U.S. Geological Survey). Its spectrum is also near-identical to spectra from several celts identified as smaragdite in Morin (2012, 2015a). The material is distinguishable, using V-NIR, from other celts identified as semi-nephrite that appeared to be composed of relatively pure actinolite but lacking a fully nephritic texture (Morin 2012, 2015a). This feldspar-bearing variety of semi-nephrite is a rock used for celt manufacture in interior northern British Columbia and on the north coast of British Columbia but is very rare elsewhere (Morin 2012, 2015a, 2015b:101). The largest known assemblage of this feldspar-bearing variety of semi-nephrite celts is McNichol Creek

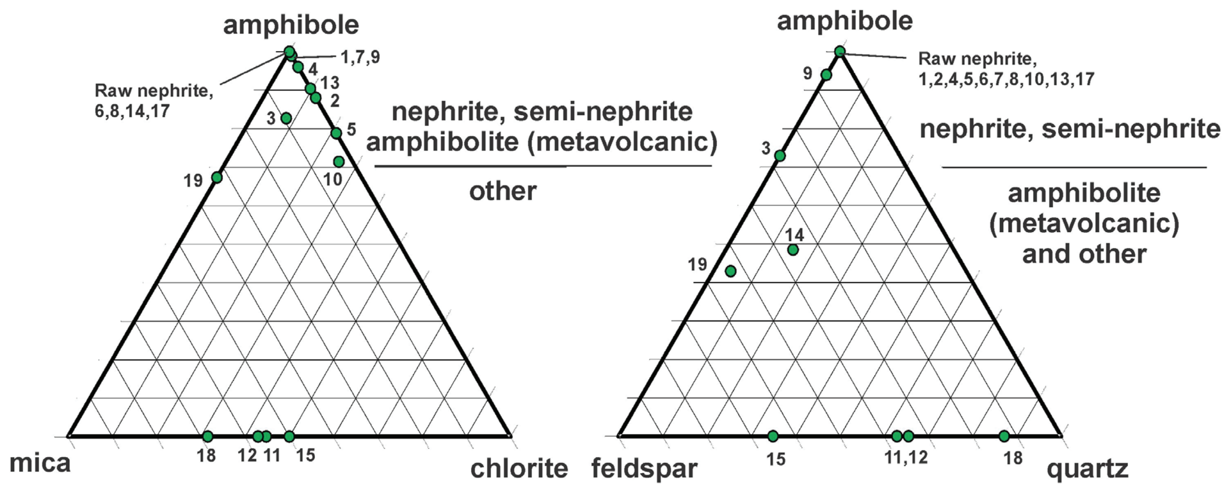

Figure 31. Triangular plot of relative weight abundance of mica, amphibole and chlorite (left). Amphibole-rich rocks including nephrite, semi-nephrite and amphibolite can be distinguished from other rocks. Triangular plot of relative weight abundance of feldspar, amphibole and quartz from XRD results (right); nephrite and semi-nephrite can be distinguished from regular amphibolite.

Table 4. Results of mineralogical classification using V-NIR and LDA classification results and probability scores for eight Alberta nephrite celts. *Smaragdite is better considered a variety of semi-nephrite as discussed above. **XRD demonstrates that this artifact contains chlorite but contains a higher percentage by weight of amphibole, therefore, we suggest that the term semi-nephrite is a better descriptor.

Sample	V-NIR Mineralogy	Type	Predicted	Probability (predicted)%	Others
1	nephrite	property celt	Lytton-Lillooet	88	L 0.12
2	nephrite	celt	Lytton-Lillooet	63	L 0.37
3	Smaragdite*	property celt			
4	Nephrite	celt	Lytton-Lillooet	73	L 0.27
5	Nephrite	celt	Lytton-Lillooet	92	
6	Nephrite	celt	Lytton-Lillooet	57	L 0.43
7	Nephrite	celt bit fragment	Lytton-Lillooet	94	
8	Nephrite	celt	Lytton-Lillooet	96	
9	Nephrite	celt	Lytton-Lillooet	62	L 0.38
10	Chlorite**	property celt			

(GbTo-6) in Prince Rupert Harbour (Morin 2012:298). The Alberta semi-nephrite celt (sample 3), however, is more similar in form to one from Beach Grove (DgRs-1) in the Vancouver area (Morin 2012:286, 298).

We note that, visually, sample 3 has several attributes that tentatively distinguish it from nephrite. First, it has relatively deep striations along its lateral margins where it was sawn from a core. These striations are much deeper than the faint scratches visible on nephrite celts. Second, there is a notable chip broken from the bit of sample 3. This chip has all the attributes of a conchoidal fracture, which is not characteristic of nephrite. Thus, it appears that this feldspar-bearing variety of semi-nephrite lacks a uniformly nephritic texture.

Sample 10 is a large, chlorite-rich celt that is not reminiscent of celts of similar composition found in British Columbia to date. The colour is similar to "jade green" and is quite different from the colour of previously recorded chlorite-rich celts that dominate central British Columbia coast assemblages (Morin 2015a, 2015b). It is not possible to be certain as to the origin of this particular celt.

V-NIR spectra from eight nephrite celts were also classified to one of the two groups of sawn nephrite cores, Lytton-Lillooet or Hope, using chemometrics. Principal component analysis (PCA) and combinations of PC scores did not clearly linearly separate the Alberta sample into two groups, but rather yielded an asymmetric or embedded data structure (Tominaga 1999). Linear discriminant analysis (using JMP) was employed to assign membership to one of the two spatial groups (Table 4 and Figures 32 and 33). The misclassification rate of the sawn cores was 25.4 percent, slightly higher than the 22.3 percent rate previously obtained with a much larger dataset (Morin 2012:434). It should be expected then that this model would similarly misclassify about 25 percent of the celts with regard to their source regions.

Spectra from the eight Alberta celts indicate that they all match the Lytton-Lillooet group (Table 4). Only one celt had a relatively low predicted (57%) probability of group assignment, and we can reasonably suggest that these eight nephrite celts were made in the mid-Fraser region of British Columbia. Twelve other nephrite celts from British Columbia assemblages were included in this V-NIR analysis for comparative purposes (from the Salish Sea and Lower Fraser River area) and they were classified to both the Lytton-Lillooet (75%) and Hope groups (25%). This agrees with previous results of classified nephrite celts in this area (Morin 2012:441-450). We are aware that the discriminant method forces an assignment of the Alberta nephrite celts to one of two well-documented nephrite celt production centres (Morin 2015b, 2016), and does not consider other production centres. However, the British Columbia sample includes 91 percent of reported nephrite cores in the province and almost certainly adequately represents past nephrite production areas. There may be an additional poorly documented nephrite celt production area in southeast Alaska, where two sawn cores are reported (Morin 2012), but based on morphology, visual attributes, and the statistical analysis presented here, we are confident that the Alberta nephrite celts were manufactured around Lytton/Lillooet along the Fraser River in British Columbia.

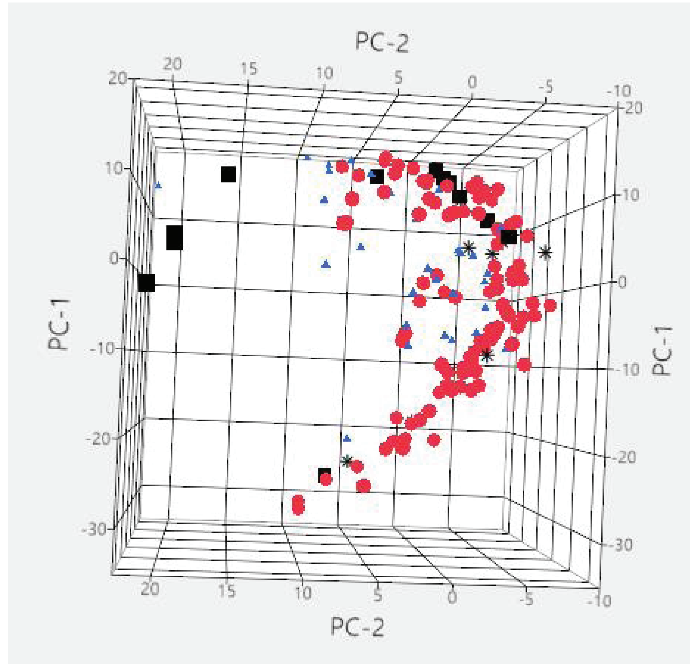

Figure 32. Plot of PC scores for the sample of V-NIR spectra from nephrite celts and cores. Red circles are sawn cores from Lytton-Lillooet, blue triangles are sawn cores from Hope, black asterisks are the Alberta celts, and black squares are the B.C. celts.

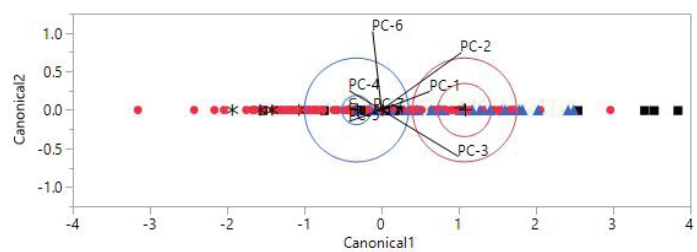

Figure 33. Canonical plot of linear discriminant analysis of the seven PC scores from the sawn nephrite cores and celts. Red circles are Lytton-Lillooet cores, blue triangles are Hope cores, black asterisks are Alberta celts, and black squares are B.C. celts.

11. Summary of results

All three techniques suggest that samples 1, 2, 4-9, are a cohesive nephrite group. V-NIR produced a statistically robust match between this group and sawn cores from the Lytton-Lillooet area of British Columbia. PXRF and XRD suggest that sample 13 is a black variety of nephrite, while sample 17 is an off-white variety of nephrite (similar to "chicken-bone" jade varieties). The XRD and V-NIR techniques are in agreement that sample 3 is dominated by amphibole minerals (over 60% actinolite-tremolite); the XRD and pXRF results suggest it should be classified as a semi-nephrite. V-NIR analysis classified this artifact as smaragdite, a varietal term listed in the USGS spectral library for an actinolite; we consider that this sample is better referred to as semi-nephrite. V-NIR and XRD are also in agreement that sample 10 is relatively rich in a magnesium-rich species of chlorite. It also appears dominated by actinolite, which, together with the pXRF analyses, suggests that sample 10 is a chlorite-rich semi-nephrite. V-NIR analysis appears particularly useful for identifying attributes that preclude a sample from being nephrite (i.e., notable amounts of chlorite) but less well-suited to identifying the mixed composition of those rocks (i.e., percentage by weight of actinolite versus chlorite).

The combined techniques provide a useful approach to non-destructive raw material identification and classification. PXRF using a portable Bruker XRF analyzer is an inexpensive and rapid means (i.e., within minutes) of quickly distinguishing major raw material types (nephrite from non-nephrite and serpentine), which can be further refined through XRD. V-NIR analysis using a portable spectrometer and a large spectral library is similarly a rapid method (also within minutes) of distinguishing raw materials. A large V-NIR spectral library and appropriate chemometric software offers a means to source or correlate nephrite artifacts to major production locales.

12. Archaeological Significance

Well-crafted ground stone celts are rare in Alberta, and the few that do exist are probably not of local manufacture. This may relate to a markedly smaller reliance on large-scale woodworking among Alberta First Nations like the Blackfoot, Dene, and Cree. Celts in British Columbia were primarily employed in canoe and house construction that involved labour-intensive carving of large softwood logs such as cedar. It is understandable that a similar wood-working tradition (and associated toolkit) did not percolate east across the Rockies where trees are smaller, canoes were made of birch bark, and houses were typically skin-covered. Nephrite celts appear to be absent in southern Alberta. Why then do nephrite celts appear in small numbers in northern and central Alberta?

While all of the nephrite celts fall within the range of celt forms from the Canadian Plateau (Morin 2015a), the Alberta celts are at the upper end of the spectrum of celt length and width when compared to those from British Columbia's Canadian Plateau and Salish Sea (Figure 34). In particular, all of the Alberta nephrite and semi-nephrite celts considered here fall within a group of wide celts from British Columbia. Most celts from British Columbia likely started their use lives at this width but, when they became worn down and stubby, they were bisected into two narrow celts, which explains the bimodal distribution of celt width (Mackie 1995; Morin 2015c). The relatively large width of Alberta celts, along with their length, indicates that they were nowhere near exhausted and do not compare to heavily used and re-sharpened specimens from British Columbia.

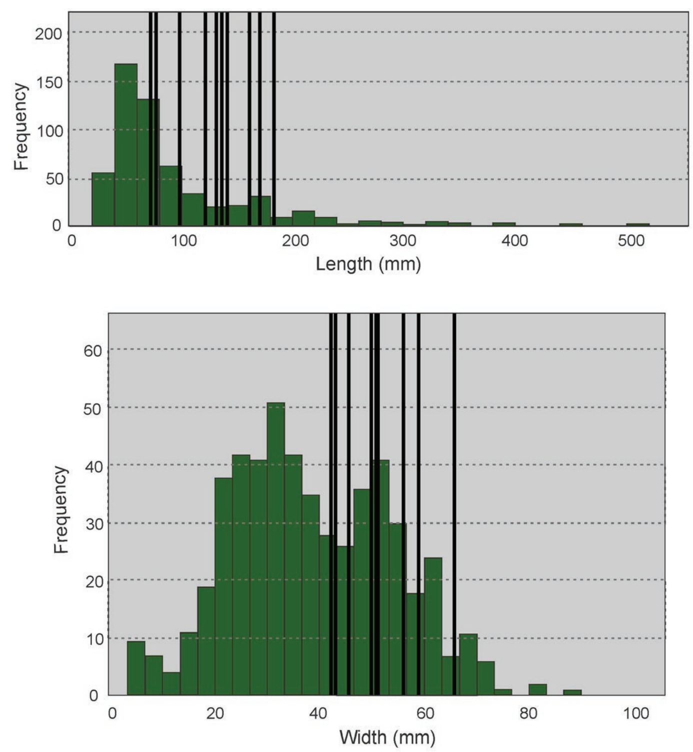

Figure 34. Histogram of Alberta nephrite celt dimensions in relation to those from British Columbia celts (adapted from Morin 2015a). Each thin black band represents one Alberta nephrite celt. The lower histogram captures a bimodal distribution of celt widths that relates to the practice of bisecting short and worn celts to produce two smaller celts. The majority of examples from British Columbia are of the smaller width, suggesting that they were commonly used to exhaustion before discard.

This large size indicates that several Alberta specimens may be akin to British Columbia's "property" celts, that is, celts that were traded, acquired, or gifted to advertise prestige/power or solidify relationships. These differ from functional celts that were regularly used for wood-working and tended to be much smaller, i.e., less than 15 centimetres long. The acquisition of celts for prestige in Alberta may explain why celt size is not consistent with that predicted based on down-the-line trade of raw materials, that is, that the archaeological expressions of exotic materials will decrease in size with increased distance from the source.

We hypothesize that nephrite celts in Alberta were largely non-utilitarian. The working edges of Alberta's nephrite celts terminate in relatively sharp corners unlike, for example, the convex working edge common to scrapers. Therefore, it is unlikely that they would have been used for processing hides. It follows that nephrite in Alberta should appear at archaeological sites in socially significant contexts, such as graves, and at sites where people gathered to perform ceremonies and exchange goods. Given the rarity of nephrite celts in Alberta, it is certain that very few people actually owned one. Their exotic nature and rarity, combined with the impressive visual qualities of nephrite, probably contributed to the prestige of Alberta celt-owners.

In terms of chronology, nephrite celt production began around 3500 yr BP in British Columbia and increased to peak productivity from 2000 to 1500 yr BP, with a smaller, secondary peak from 750-500 yr BP (Morin 2015a). Because the nephrite celts in Alberta were all recovered from farmers' fields or surface disturbances, their chronology is unknown. It is reasonable to suggest that Alberta's celts were produced and traded from British Columbia between 3000 and 250 yr BP.

The presence of celts in Alberta's boreal forest and parklands perhaps arose from shared cultural affiliations with pre-contact societies in British Columbia, principally Athapaskan or Dene-speaking groups. Athapaskan speakers occupied a more-or-less continuous band across northern Alberta and British Columbia (Krauss and Golla 1981). A key event in Athapaskan language family history is thought to have taken place in the interval between 2000 and 1500 years ago – the departure of Pacific Coast Athapaskan speakers from British Columbia (Krauss and Golla 1981; Ives 1990, 2003, 2010; Ives and Rice 2006). It is possible that ancestral Pacific Coast Athapaskan speakers were connected with exchange systems centring on the mid-Fraser River in this time range. If so, and if ancestral Canadian Dene and Apachean populations also existed east of the Rockies in the Peace Country and southern boreal forest, then nephrite artifacts may have spread from Mid-Fraser villages through trade and alliance networks that followed the dialectical chains typical of the Athapaskan language family.

The absence of nephrite artifacts among ancestors of Plains First Nations is perhaps indicative of weaker connections to cultural groups across the Rocky Mountains during the last 3000 years. Alternatively, Plains First Nations may not have valued nephrite celts because they valued other trade items from the west, had other preferred means of acquiring prestige, and/or were less interested in expensive woodworking tools than their neighbours to the north and west who lived in heavily forested environments.

13. Conclusion

PXRF, XRD, and V-NIR, when used in combination, allow identification of nephrite using non-destructive techniques. Element concentrations and mineral abundances can be used to develop thresholds to distinguish archaeological examples of nephrite from non-nephrite. PXRF and V-NIR are inexpensive and rapid means of differentiating major raw material types, which can be further refined through XRD. A large V-NIR library of pre-contact nephrite sawn cores can be used to source nephrite to major production locales. Because of their rarity and definitive connection to British Columbia, nephrite celts are significant artifacts in Alberta that warrant close examination to confirm raw material types. We argue that nephrite celts are exotic to Alberta and were used in pre-contact times as a measure of prestige or status.

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