The Hardness of Fei Cui
A Gemmological Perspective
從寶石學角度看翡翠的硬度

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輝石玉（翡翠）由不同數量的硬玉、綠輝石和鈉鉻輝石組成。“翡翠”一詞被廣泛接受和採用。由於報導的綠輝石硬度低於硬玉，因此應明確區分富含綠輝石的翡翠和其他翡翠，而硬度亦直接影響耐用性。在本文中，作者研究了這兩個主題，並利用驗證和理論原則以簡化的形式呈現出來。

Abstract

Jade has a long and varied nomenclatural history, with its definition altered in the current age for practical and cultural reasons. Due to the discovery that many pyroxene jades are composed of various amounts of jadeite, omphacite and kosmochlor, the term “fei cui” has been proposed and widely accepted. It has been suggested that since the reported hardness of omphacite is lower than that of jadeite, a clear distinction should be made between omphacite-rich fei cui and other fei cui because of the potential long-term durability issues. Hardness also has a complicated history, as there are many factors to be considered when assessing the hardness of a material as well as its relation to scratch resistance. In this paper, the author examines these two topics and presents them in a simplified format based on empirical evidence and theoretical principles, while also considering the data available in literature.

Background

Several decades ago it was relatively simple to separate jadeite (a pyroxene jade) and nephrite (an amphibole jade), however the circumstances surrounding jade nomenclature have become more complicated due to the discovery that many gems labelled as “jadeite” also contain varying amounts of other clinopyroxenes such as omphacite and kosmochlor.

As with all rocks, jade is made up of many tiny crystals/grains; frequently these crystals/grains are made up of different minerals. This makes the accurate determination of the exact end-member percentages of a rock extremely difficult and impractical. To what end should we as gemmologists attempt to do this? It not only causes confusion but is also irrelevant to the end-consumer.

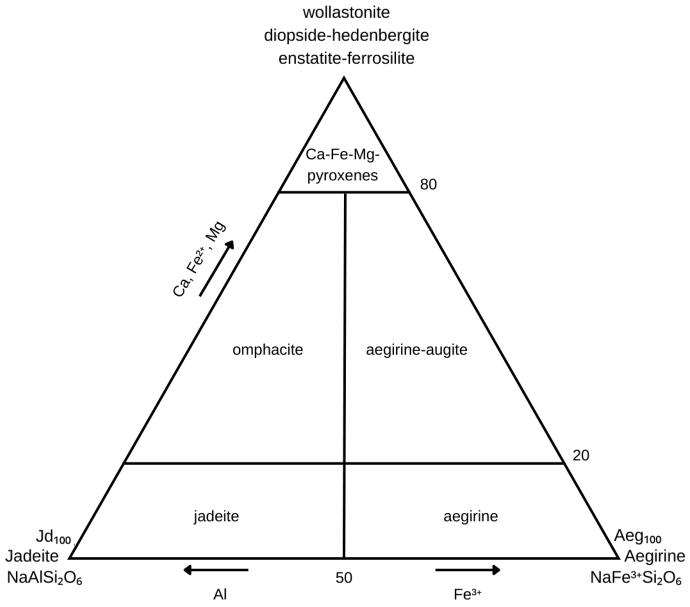


Fig. 1 Pyroxene classification diagram modelled after Morimoto et al. (1988)
輝石分類圖解

Definition of Omphacite

Omphacite has a complicated nomenclatural history (Clark & Papike, 1968) due to its complex chemistry and intermixing with jadeite and/or kosmochlor. Previous descriptions of a material called chloromelanite (no longer in use) match the current parameters for omphacite (Dana & Ford, 1932). Simply put, omphacite is a clinopyroxene with complicated chemistry. It has the general chemical formula $(M2)(M1)[Si_2O_6]$: the M2 cation site can consist of either Ca or Na and the M1 cation site can consist of either Al, Mg or Fe^{3+}. It has an intermediate composition within the jadeite $[NaAlSi_2O_6]$—diopside $[CaMgSi_2O_6]$—aegirine $[NaFe^{3+}Si_2O_6]$ series. There may also be minor substitution with other cations such as Fe^{2+}, Ti^{4+} and Mn^{2+}. The specific chemical parameters have been stated by Morimoto et al. (1988) and this is illustrated in Fig. 1.

Although not an end-member, omphacite is classified as a distinct mineral because it has a different crystal structure from its related clinopyroxene members (Matsumoto, Tokonami & Morimoto, 1975). The space group symmetry of omphacite is related to its specific composition. Intermediate compositions have the space group P2/n whereas the omphacites with compositions closer to diopside or jadeite end-members have the space group C2/c (Deer, Howie & Zussman, 1992). The different space groups are related to the cation ordering and may potentially exhibit measurable differences in some physical properties (Brenker, Prior & Müller., 2002).

Relation to Jadeite and Kosmochlor: Fei Cui

Jadeite and kosmochlor (formerly known as ureyite) are more closely related to each other than they are to omphacite because their substitutional cations occur in only the M1 site and are solely homovalent: $Al^{3+} \rightarrow Cr^{3+}$. Nevertheless, omphacite is still found in association with jadeite and kosmochlor (Franz et al., 2014; Shi et al., 2012).

Identifying a polymineralic material based on its end-member percentages is a tedious task that usually involves destroying the sample to analyse its constituents properly. Omphacite and kosmochlor are often tightly intermixed with jadeite and the point and bulk measurements on the surface are not necessarily representative of the entire sample.

Due to this, the term *fei cui* (pronounced like 'fay-choy') has been proposed as an umbrella term by The Gemmological Association of Hong Kong (The Gemmological Association of Hong Kong, 2016) for pyroxene jades that consist of jadeite, omphacite and/or kosmochlor in varying amounts. From this point on, our pyroxene jade samples will be referred to as "fei cui" where appropriate. "Jade" will be used in reference to both pyroxene jade (fei cui) and amphibole jade (nephrite).

Gemmologically Vs Mineralogically

Gemmology can be described as the bridge between science and commerce, whereas

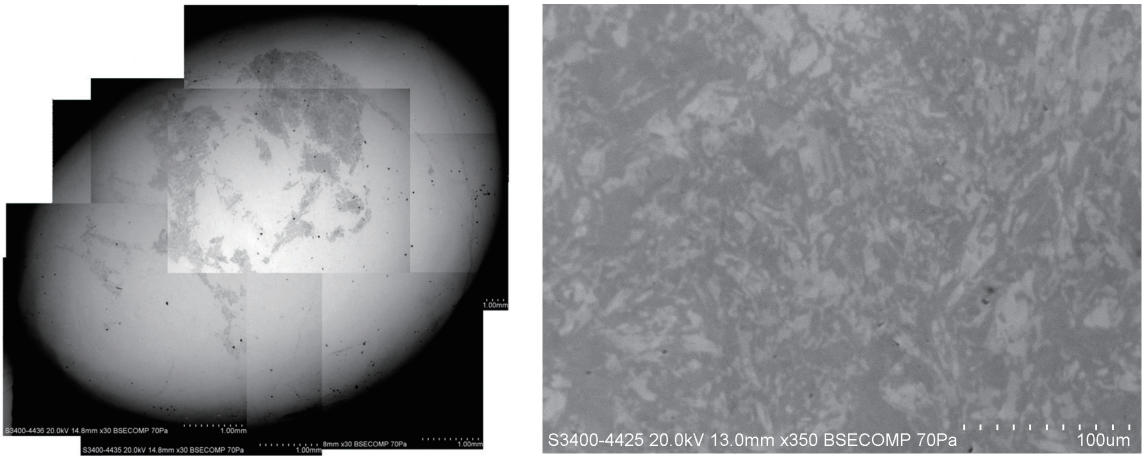


Fig.2 BSE images of a fei cui sample. Light areas are omphacite, dark areas are jadeite.
Left: Entire fei cui sample. Right: Magnified area showing the complex intermixture of omphacite and jadeite at a very small scale. *Photos courtesy of Edward Liu*
翡翠樣本的BSE圖像。淺色區域為綠輝石，深色區域為硬玉。左：整個翡翠樣品。右：放大區域顯示了綠輝石和硬玉在極小範圍內的複雜混合物。

Brief History of Fei Cui

Fei cui (sometimes *fei tsui* or *fei-ts'ui*) is the Chinese term that refers to the plumage of the kingfisher birds that have red (fei) and green (cui) feathers (Hansford, 1948). It is believed by Hansford (1948) that for centuries the term had been used to describe bright green nephrite due to the apparent similarity in colour with the bird. However, when jadeite from Myanmar began to make its way into China, the term began to be applied solely to jadeite (Hughes, 2022).

The modern nomenclature of fei cui is now applied to pyroxene jade (those consisting of varying amounts of the clinopyroxene minerals jadeite, omphacite and/or kosmochlor).

mineralogy is purely scientific. As Goddard Lenzen states in the preface to their 1970 book *The History of Diamond Production and the Diamond Trade* (Lenzen, 1970):

> It is therefore appropriate to consider gemmology not as a branch of a natural science, but simply as the knowledge of a certain type of merchandise

For example, gemmology promotes the use of varietal names that are relevant in assigning a value to the gem (i.e. ruby) but mineralogy does not allow varietal names (i.e. red corundum). Therefore, material definitions between the two fields do not always correlate. It may be mineralogically relevant to comprehensively identify a gem material based on its end-member percentages but there are always limitations to what is possible when dealing with polycrystalline (and polymineralic) rocks without destroying the sample; something that is not possible in gemmology.

Liu, Ou Yang and Ng (2015) have illustrated the misleading results that materialise in fei cui testing, even when using sophisticated variable pressure scanning electron microscope (VPSEM)-Raman coupled analysis. Edward (S. I.) Liu has allowed the author to re-use their backscattered electrons (BSE images Fig. 2).

This highlights the fact that even the most sophisticated analyses cannot comprehensively identify fei cui by its end-member percentages. Some other points to consider are:

1. In most cases, only surface analyses are performed and that may not represent the entire composition of the gem material.
2. Surface roughness can also affect measurement accuracy (Hernández-Murillo et al., 2022) and some determinations rely on small changes in peak position and shape. Many fei cui samples do not have a perfect polish and so this can be problematic.
3. Some mineral grains are so tiny that spectroscopy will only reveal the spectrum of the dominant mineral in the beam spot or an intermediate spectrum (Fig. 3).

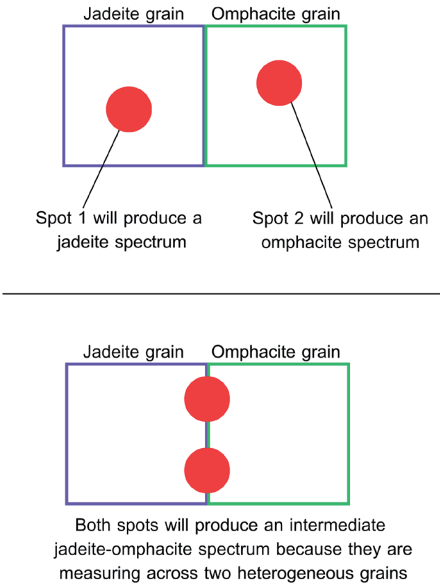


Fig. 3 Simple diagram to illustrate how adjacent inhomogeneous grains can influence spectral output
簡圖説明相鄰的不均匀顆粒如何影響光譜輸出

Definition of Hardness (Scratch Resistance vs Microindentation)

Young (1961) states in *The Microhardness of Opaque Minerals*, that:

> Hardness has been given many definitions but it is impossible to define it in precise terms because of the number of different physical properties which it embraces.

It was therefore advised by Young to use Ashby's (1951, pp. 33) definition:

> Hardness is a measure of the resistance to permanent deformation or damage.

Scratch resistance is typically derived using the well-known Mohs scale by traversed indentation of a material of a known Mohs hardness. This is a relative hardness measurement technique.

Microindentation hardness, using techniques like Vickers microindentation testers, provides an absolute hardness value; but the values depend on the load being applied (amongst other factors).

There are many factors that affect the measured Mohs and Vickers hardness values of a material. This is made more complicated by testing heterogeneous polycrystalline materials. These factors include load, load time, indentation depth, surface roughness, grain size, grain boundaries, fibrosity, defects, chemical composition, space groups, crystallographic orientation, and even a surface compaction phenomenon detailed by Young (1961) called 'work hardening' caused by the polishing process. All these can affect the measured hardness of materials. Craig and Vaughan (1994) detail many of these factors.

Hardness is defined by Dorner and Stöckhert (2004) as a solid's resistance to local (at the point of contact) deformation. Permanent (inelastic) damage to a material after an applied force (stress) is termed plastic deformation and can be simplified to the breaking of chemical bonds that result in the slipping of dislocations which causes the material to 'shift'. The stronger the chemical bonds, the more difficult they are to break. For example, diamond's high hardness results from its covalent tetrahedrally bonded carbon atoms in three dimensions, which are extremely strong.

Young (1961) suggests that hardness is the strength of the weakest bonding present in the material, however this would be extremely difficult to quantify in heterogeneous samples. The strength of a bond is related to the combination of the distance between the anion and cation, the valency and the bonding type.

Broz, Cook and Whitney (2006) note that there is a difference between hardness and scratch resistance. Scratch resistance (Mohs) is not only dependent on hardness; it is a complex function of hardness (resistance to inelastic deformation), fracture toughness (resistance to fracture), elastic modulus (resistance to elastic

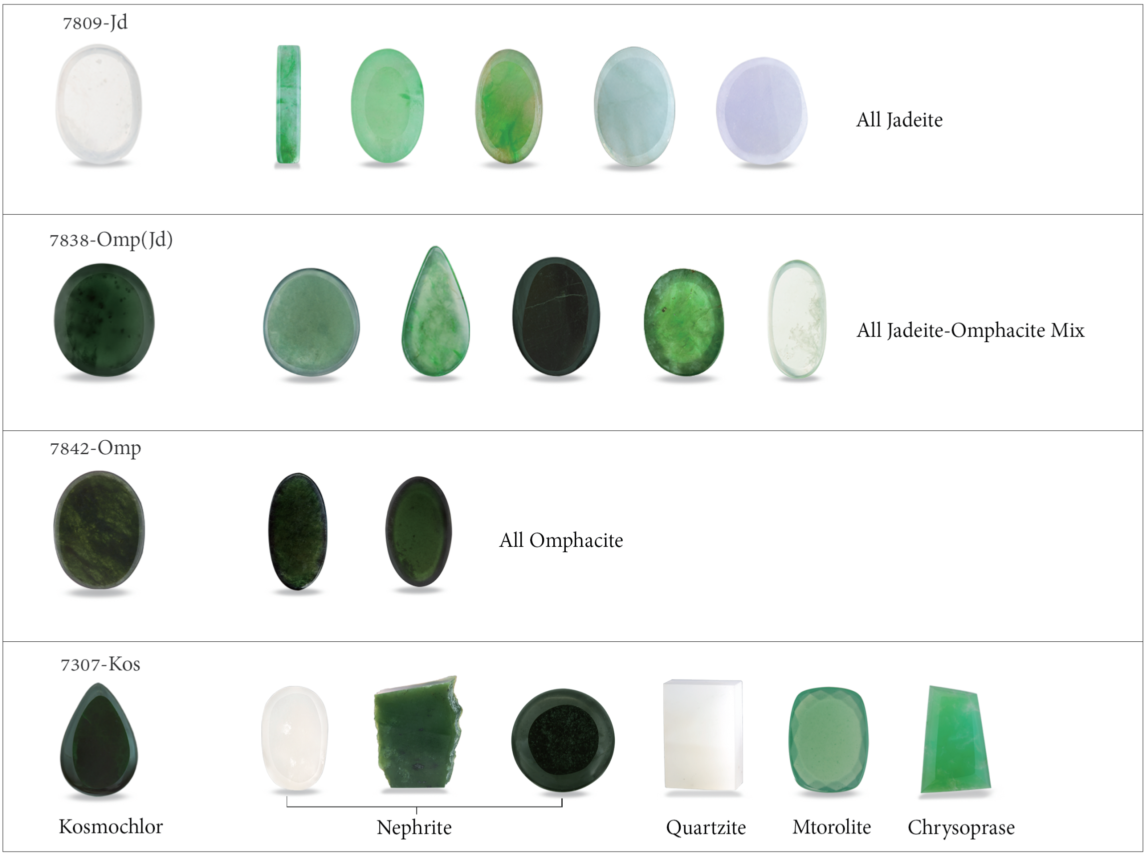


Fig. 4 All 22 samples in this study. *Photos: Ronnakorn Manorotkul*
本研究中的22個樣本

deformation) and the loading method. This has been experimentally supported by the studies of scratch resistance and hardness of glass (Sawamura & Wondraczek, 2018).

Sawamura and Wondraczek (2018) show that, in their study, the variance in the ratio of scratch resistance and hardness indicates the main difference between the two. They show that scratching generally requires higher effort to deform a material than indentation. This is due to the discrepancies in friction and material pileup. A scratch applies force both parallel to the normal and laterally, whereas indentation is only parallel to the normal.

Lawn and Marshall (1979) discuss the difference between indentation hardness and fracture toughness. When sufficient force is applied to a brittle material it will generally first deform (hardness) and then fracture (toughness) as the force increases.

Bradt, Newnham and Biggers (1973) studied the toughness of jadeite and nephrite. Toughness is a major contributing factor to the durability of a gem material, however investigating the toughness of the fei cui minerals is beyond the scope of this study.

Materials and Methods

The 22 samples chosen for this study are shown in Fig. 4. They were obtained through secondary sources (dealers, colleagues, markets). The samples were first polished to have two parallel flat surfaces. They were then analysed using the following instruments:

- Reflectance spectra: Bruker Tensor 27 FTIR with a Pike UpIR attachment.
- Raman spectra: MAGI GemmoRaman-532.
- Chemical analyses: Skyray EDX 6000B EDXRF set up with condition and curve parameters specific to jade.
- RIs and hydrostatic SGs were also measured.

The samples were then sent for Vickers microindentation measurements at the NSTDA Characterization and Testing Service Center (NCTC) in Bangkok. Subsequently, the samples were tested using a Mohs hardness pencil set.

Tan et al. (1978) used the microindentation method suggested by Hutchinson (1974) to obtain hardness data on their nephrite samples from Hualien, Taiwan. They found a range of hardness data for their samples and found that their nephrite samples correlated to Mohs 4.1 to 7.0 depending on crystallographic orientation. The nephrite samples included in this study, that were used as references, showed good correlation with the data from Tan et al. (1978). Therefore, the methods suggested by Hutchinson

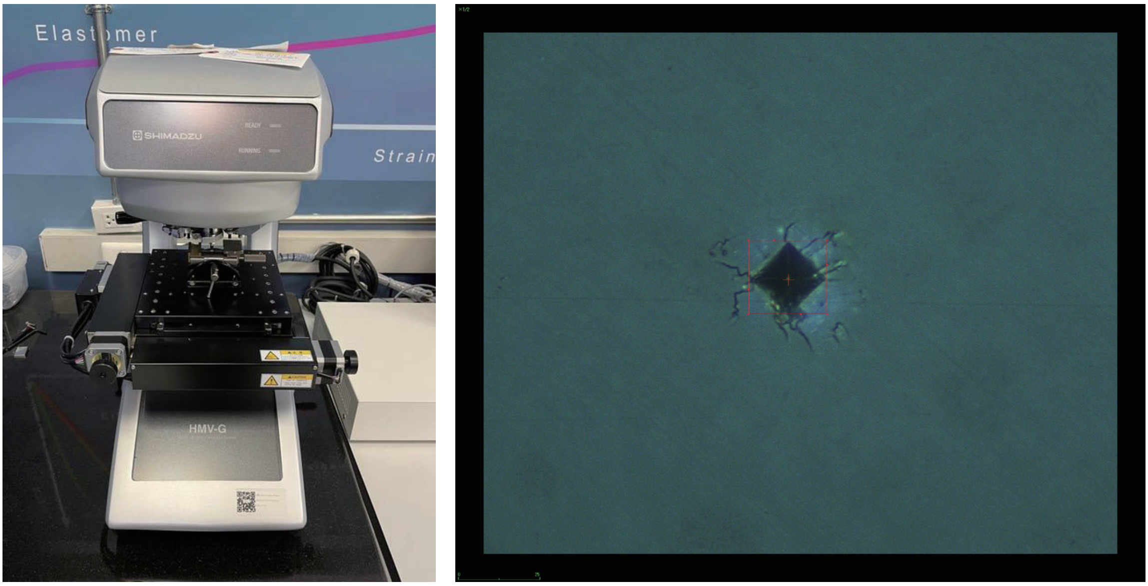


Fig. 5 Left: Shimadzu Microhardness Tester HMV-G31-FA-D-HC60
Right: Example of a Vickers microindentation. FOV: 0.2 mm. *Photos courtesy of NCTC*
左：島津顯微硬度計 HMV-G31-FA-D-HC60。右：維氏顯微壓痕示例。視場：0.2 mm。

(1974) were taken under advisement when choosing the specific indentation measurement parameters for this study.

Out of the 22 samples in this study, focus was assigned to these four representatives:

1. Jadeite: 7809-Jd
2. Omphacite: 7842-Omp
3. Omphacite-Jadeite mix: 7838-Omp(Jd)
4. Kosmochlor: 7307-Kos

These samples were selected for focus because they represent this study's 'purest' sample of each fei cui mineral. Sample 7838-Omp(Jd) is the closest representative to a 50/50% mix of jadeite and omphacite. The identifications are based on the EDXRF, multi-spot Raman and multi-spot reflectance FTIR measurements that were obtained. Even though, as mentioned above, there is currently no scientifically accurate way to determine the total composition of a rock such as fei cui, these combination analyses allowed a general idea of the measurable surface components present in the samples. The results of the other samples were also considered.

Note that another kosmochlor sample cut from the same rough as the one in this study was analysed using SEM-EDS by Edward Liu and contained trace amounts of chromite ($Fe^{2+}Cr^{3+}{}_2O_4$). This may affect some of the measured data of the sample, such as EDXRF.

Results

The results of our testing are summarised below with focus on the four representative samples.

Chemistry

Table 1 Chemical composition of fei cui samples based on EDXRF measurements. These analyses may not represent the true chemical composition of the samples because EDXRF is only semi-quantitative.
由EDXRF測量的翡翠樣品之化學成分。因為EDXRF只是半定量的，這些分析可能並不代表樣品的真實化學成分。

Sample (wt. %)	Na_2O	MgO	Al_2O_3	SiO_2	CaO	Cr_2O_3	Fe_2O_3	Trace
7809-Jd	12.76	0.00	25.21	60.93	0.67	0.00	0.35	0.07
7838-Omp(Jd)	9.68	3.48	15.17	59.81	8.20	0.00	2.61	1.05
7842-Omp	4.36	9.98	11.34	56.74	13.15	0.00	3.43	0.99
7307-Kos	5.12	1.33	4.97	39.55	4.12	41.53	2.47	0.92

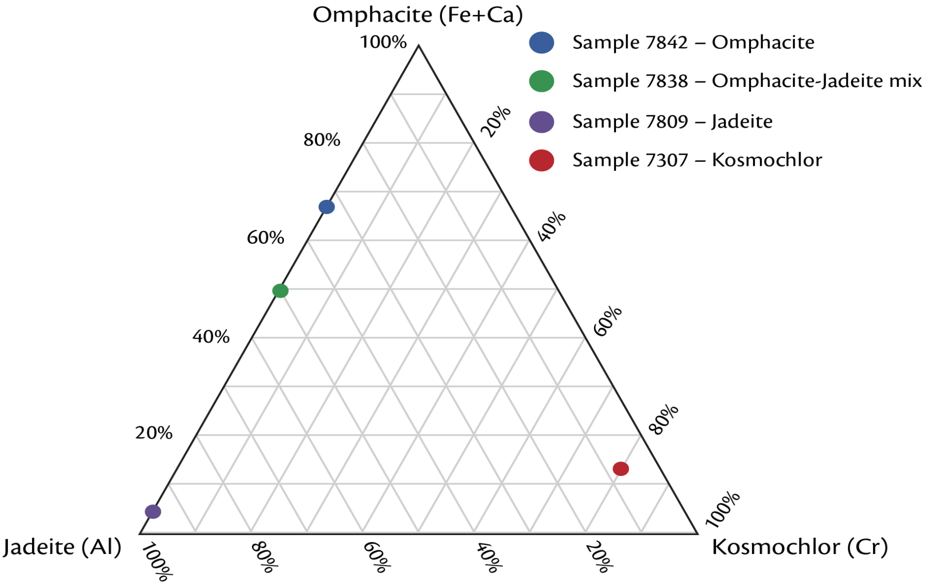


Fig. 6 Compositional ternary plot of the fei cui samples. Mineral compositions were normalised by the main associated cation (or combination of cations) based on EDXRF data. Note that the EDXRF chemical analyses are limited because they are only semi-quantitative.
翡翠樣品成分三元圖。以EDXRF數據，通過主要陽離子（或陽離子組合）對礦物成分進行標準化。請注意，EDXRF化學分析是有限的，因為它們只是半定量的。

Spectrroscope

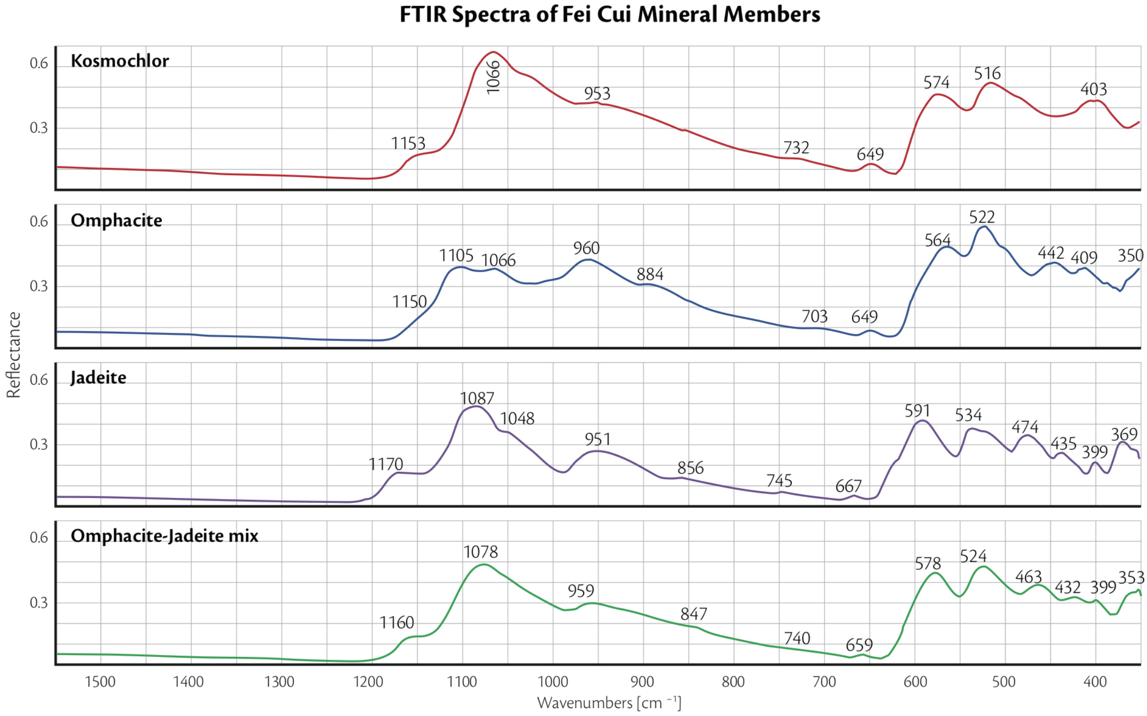


Fig. 7 Reflectance FTIR spectra of the four representative fei cui samples.
四個代表性翡翠樣品的反射FTIR光譜。

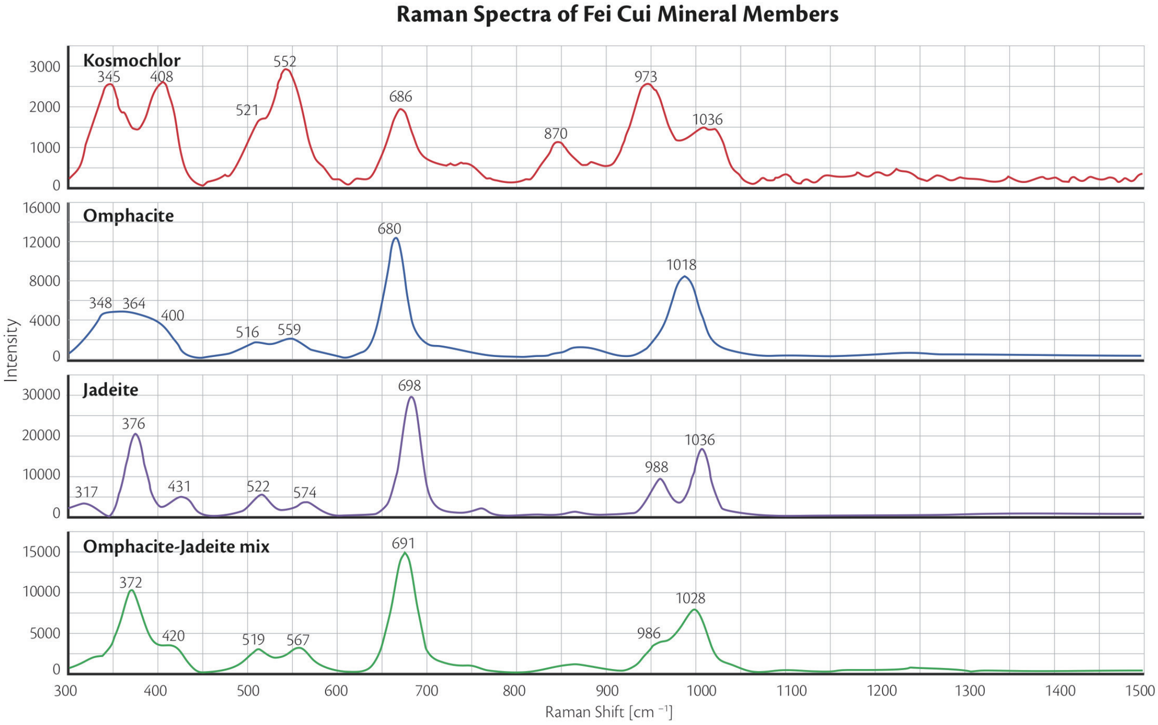


Fig. 8 Raman spectra of the four representative fei cui samples.
四個代表性翡翠樣品的拉曼光譜。

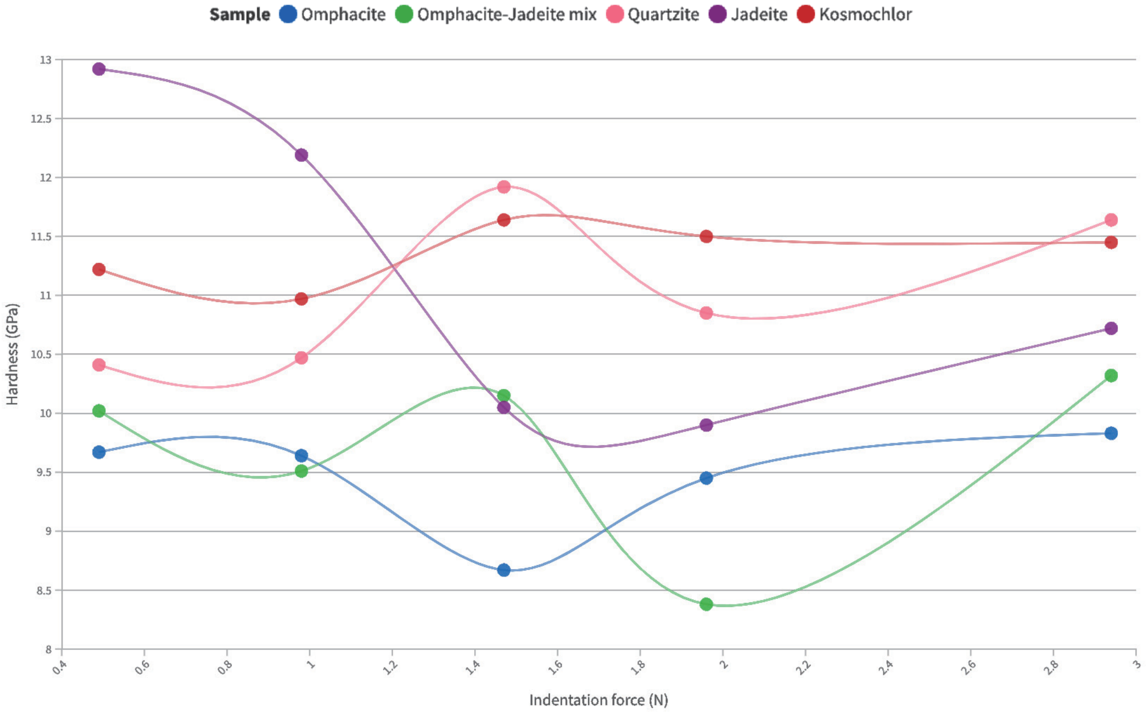
Vickers microhardness results

Table 2 Vickers microhardness values (in GPa) per indentation spot. Sorted according to the average values across the 5 spots.
每個壓痕點的維氏顯微硬度值（以GPa為單位）。根據5個點的平均值排序。

Sample (GPa)	ID	0.49N	0.98N	1.47N	1.96N	2.94N	Max	Min	Average
7842-Omp	**Omphacite**	9.67	9.64	8.67	9.45	9.83	9.83	8.67	9.45
7838-Omp(Jd)	**Omphacite-Jadeite mix**	10.02	9.51	10.15	8.38	10.32	10.32	8.38	9.68
7840-Qz	**Quartzite**	10.41	10.47	11.92	10.85	11.64	11.92	10.41	11.06
7809-Jd	**Jadeite**	12.92	12.19	10.05	9.90	10.72	12.92	9.90	11.15
7307-Kos	**Kosmochlor**	11.22	10.97	11.64	11.50	11.45	11.64	10.97	11.36

The Vickers microhardness (HV) was measured using five different indentation loads to account for the indentation size effect (ISE) that links the measured microhardness of a material to the load used. A lower load usually results in a higher hardness measurement and vice versa (Petrik, 2016). As there is not a standardised load suggested for clinopyroxenes, a range from 50g (0.49N) to 300g (2.94N) was used. The microhardness measurements are summarised in Table 2 and have been converted into GPa to correspond to the newtons (N) of force for each indentation spot (1 HV = 0.009807 GPa). The values of the quartzite sample have been included for comparative reasons discussed later in this article.

As can be seen in Fig. 9, a complete ISE was not observed in the samples measured, this is assumed to be due to the complex factors that affect the indentation hardness measurements of polycrystalline materials. The microstructural effect on the microhardness of ceramics investigated by Sargent and Page (1978) confirms this assumption and their studies further explain that the relationship between microhardness and grain size is likely due to the weakening of grain boundaries.



Lines are for visual aid only and do not imply trends

Fig. 9 Line graph illustrating the Vickers microhardness (GPa) vs indentation force (N) relationship of the quartzite and fei cui samples.
線圖顯示了石英岩和翡翠樣品的維氏顯微硬度(GPa)與壓痕力(N)的關係。

Additionally, Voyiadjis and Yaghoobi (2017) used indentation depth to compare the difference between the microhardness of single crystal and polycrystalline aluminium samples. Inhomogeneity likely also plays a role.

Comparison to Values Reported in Literature

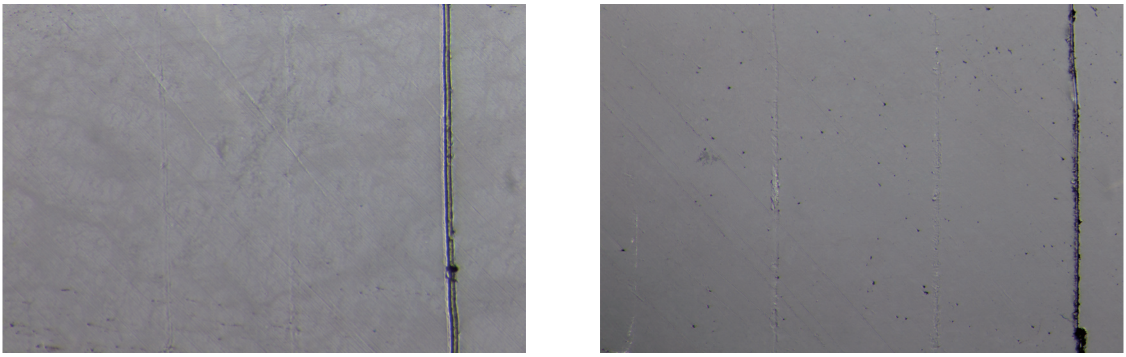
Tan, Ng and Lim (2013) measured the microindentation hardness of jadeite and found the Vickers hardness of their samples to be 1014± 69 HV, which equals 9.94± 0.68 GPa. However, because the load of the measurement was not stated, their findings cannot be directly compared to the ones in this study.

Although Dorner and Stöckhert (2004) measured the microhardness of jadeite and diopside (the end-members of omphacite), they did so at elevated temperatures and consequently their results cannot be directly compared to the ones in this study either.

Thus, the measurements of this study represent the novel value range for Vickers microhardness measurements at different loads for fei cui minerals at room temperature.

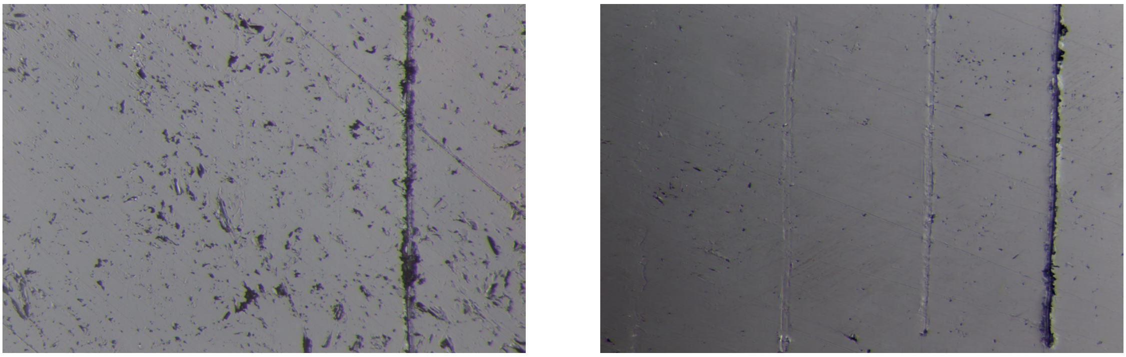
Fig. 10 A Mohs hardness scratch testing kit.
Photo: Chanon Yimkeativong
摩氏硬度測試套件

Photomicrographs of Mohs Testing



7307-Kos (FOV: 1.64 mm)

7838-Omp(Jd) (FOV: 2.40 mm)



7809-Jd (FOV: 2.12 mm)

7842-Omp (FOV: 2.12 mm)

Fig. 11 Photomicrographs of Mohs scratch testing: The samples were tested using Mohs pencils 5, 6, 7 and 8 (left to right). Note that some of the marks are very faint in the images because the samples were not scratched by some of the Mohs hardness pencils. *Photos by author*
摩氏划痕測試的顯微照片：使用摩氏筆5、6、7和8（從左到右）測試樣品。請注意，圖像中的一些標記非常微弱，因為樣品沒有被某些摩氏硬度筆劃傷。

Discussion

Tabor (1954, pp. 252) states that “scratching is associated with a ‘biting-in’; non-scratching with a ‘skidding-over’”. As can be seen in Fig. 11, sample 7842-Omp displays a ‘skidding over’ appearance when using a Mohs 5 pencil and a ‘biting-in’ appearance with a Mohs 6 pencil. Therefore, this omphacite sample could be labelled as Mohs hardness 5.5.

Interestingly, sample 7838-Omp(Jd) exhibits more deformation with a Mohs 6 pencil than it does with a Mohs 7 pencil, the author could find no reports of this anomalous observation in other publications at the time of investigation. This phenomenon was observed with many of the other fei cui samples.

Sample 7809-Jd exhibits a ‘skidding-over’ appearance up to the Mohs 7 pencil, but is severely scratched by the Mohs 8 pencil. This can then be described as a Mohs hardness 7.

Although sample 7307-Kos was severely scratched by the Mohs 8 pencil, it was not as severe as the other fei cui samples. This may indicate a slightly higher scratch resistance. However, similarly to sample 7838-Omp(Jd), the Mohs 6 pencil deformed the sample slightly more than the Mohs 7.

More than 200 years have passed since Friedrich Mohs published his scale on scratch hardnesses of minerals and there is still not a complete agreed understanding of the Mohs system (Gerberich et al., 2015). As some of the samples in this study did not show a linear degree of scratch deformation with increasing Mohs hardness points, it supports the idea that Mohs scratch testing on polycrystalline heterogeneous samples are not always straightforward.

Indeed, there have been discrepancies in the reporting of the Mohs hardness of fei cui (see Table 3).

Table 3 Mohs hardness of fei cui minerals as reported in literature
文獻報導翡翠礦物的摩氏硬度

Mineral	Dana & Ford 1932	Deer, Howie & Zussman 1992	Ou Yang et al. 2003	Adamo et al. 2006
Jadeite	6.5–7	6		
Kosmochlor		6		
Omphacite		5–6	7	6.5

Dorner and Stöckhert (2004) discovered that although their omphacite samples fell within the intermediate compositional range of jadeite and diopside, the mechanical data did not correlate to the intermediate of their end-member samples’ mechanical data. This led them to the suspicion that inhomogeneity of the omphacite samples could be a possible reason for the unexpected variability in their hardness.

In the studies of Tan, Ng and Lim (2013), a calibration curve was determined for relating Vickers microindentation values to Mohs hardness values. Following this curve, the HV and GPa values of some of the Mohs scratch pencils can be estimated (see Table 4).

Broz, Cook and Whitney (2006) measured the indentation hardness of the Mohs minerals; however, there is a better correlation between the measurements of Tan, Ng and Lim (2013) and the quartzite sample in this study.

Table 4 Mohs vs HV vs GPa based on the calibration curve of Tan, Ng and Lim (2013).
基於Tan校準曲線的HV及GPa對照

Mohs	HV	GPA
5	550	5.4
5.5	650	6.4
6	750	7.3
6.5	950	9.3
7	1100	10.8

Mukhopadhyay and Paufler (2006) show how the relationship between grain size and hardness is non-linear in certain materials. This could be a contributing factor to the microindentation measurements that were obtained. Another issue with measuring the hardness of fei cui is the inhomogeneity. For example, spot one could be measured on a large jadeite grain and spot two on a small kosmochlor grain, this could unfortunately skew the results.

Interestingly, Htein and Naing (1995, pp. 317) observed that in practice the Mohs hardness of jade varies from “slightly greater than 6” for coarse-grained aggregates to 7 for fine-grained aggregates.

Influence of Chemical Bonding on Hardness

Cameron et al. (1973) investigated the thermal expansion coefficients of the different bonding present in clinopyroxenes. Based on their studies, they stated that the following series is a function of decreasing bond strength:

Si^{4+}-O > Cr^{3+}-O > Fe^{3+}-O > Al^{3+}-O > Fe^{2+}-O > Na^{+}-O > Mg^{2+}-O > Ca^{2+}-O > Li^{+}-O

This is probably, at least in part, due to the effective ionic radii (which would affect the bond length of each cation-anion bond).

Young (1961) summarised the work of other researchers that found that the A–X distance, i.e. the length of a cation-anion bond, and Mohs hardness are related for oxides with similar structures. They also state that the increase in valency of ions causes an increased hardness. This shows good agreement with the findings of Cameron et al. (1973) above.

Dana and Ford (1932) postulate that many oxides and silicates have a higher hardness because they contain significant Al. Indeed, corundum (Mohs 9) and topaz (Mohs 8) both contain aluminium as a major component of their chemistry. This supports the notion that bond length and valency play a major role in determining the hardness of a material.

There is a good correlation between the above studies and our findings that the hardness of fei cui minerals seems to increase with the increase of kosmochlor ($Na\underline{Cr^{3+}}Si_2O_6$) and jadeite ($Na\underline{Al^{3+}}Si_2O_6$) contents and decrease in hardness with increased omphacite (containing more Ca^{2+} + Mg^{2+} + Fe) content.

However, hardness (and scratch resistance) is only one of the factors influencing the durability of gem materials. Toughness, i.e. resistance to breakage, is another major factor. Jade is notoriously tough and this is mainly due to the grains stopping excessive fracture continuation (Bradt, Newnham & Biggers, 1973). This makes jade an excellent carving material. Even though nephrite has a lower hardness than jadeite, its toughness is superior (Hughes et al., 2000).

Hardness in Relation to Quartz

It has been stated by Schluessel (in *Jade: A Gemologist’s Guide* edited by Hughes, 2022) that the hardest component of dust that jewellery would be exposed to is quartz and because quartz has a higher hardness than jadeite, wiping the dust off jadeite will slowly damage its surface. The composition of global dust has been studied by Claquin, Schulz and Balkanski (1999), Krueger (2004) and Laskina (2013) who found that the major components of global dust are clays, calcium-rich minerals (such as dolomite and calcite) and quartz. The exact composition varies depending on the dust source. The hardest of these is indeed quartz.

It also, therefore, makes sense to compare the hardness of quartz to that of the fei cui samples.

Many of the fei cui samples from this study were deformed (some to lesser degrees than others) by a Mohs 7 quartz-tipped pencil. Therefore, Schluessel’s advice on caring for fei cui is valid. However, because the scratches are only on a microscopic scale, it is unlikely that any fei cui gems are at severe risk of damage if stored properly.

There are some examples of expensive gems (i.e. tanzanite and opal) that do not have a hardness greater than quartz, but that does not mean their value is depreciated, they just require extra care.

Hänni, Brunk and Franz (2021) investigated the grinding hardness of their jadeite sample (that contained 35% chromian omphacite) and found it to have a grinding hardness less than many of the quartz varieties they tested, but not all of them. This highlights the difficulty in trying to comprehensively assess the hardness of a gem material, especially those of a polycrystalline/polymineralic nature.

Conclusion

There is no easy answer to the question “is one fei cui mineral harder than the other?”; the results detailed in this paper highlight the difficulty in assessing the hardness of fei cui and the difference between hardness and scratch resistance. Some fei cui samples that, based on the available testing data, contain higher amounts of omphacite seem to exhibit a lower hardness and scratch resistance than those with lower omphacite contents. However, due to the difficulty in accurately, and non-destructively, determining the omphacite content of fei cui gems, it would be superfluous to expect the gem trade to have to separate omphacite-rich fei cui gems based on the fear that they might be slightly less scratch resistant than jadeite- or kosmochlor-rich fei cui. There are other factors to consider when assessing the durability of a gem; fei cui and nephrite are both extremely tough materials. Nevertheless, it would be wise to treat all jade with the same care.

It would not be prudent to label a piece of pyroxene jade as "jadeite" as it is not scientifically defensible to do so. "Jadeite" is an end-member of the clinopyroxene group defined by its specific chemical composition and structure. Currently, no laboratory (gemmological or otherwise) can ascertain the exact composition of a piece of jade in relation to its end-members (and other constituents).

Mineralogy and gemmology are related fields but serve different purposes; the former is purely scientific where the latter serves the gem and jewellery trade by connecting science and commerce. Indeed, one of the most difficult parts of gemmology is to find the correct balance between science and practicality. Ultimately, the end-consumer needs to know the (gemmological) identification of the gem which they are buying, whether it is natural or synthetic and whether it has been treated in any way. Trying to describe a piece of jade as, for example: 65% jadeite, 20% omphacite and 15% kosmochlor is cumbersome (let alone not practically possible without destroying the gem) and would create unnecessary distress in the trade. The term "fei cui" is historically accepted by the largest consumers of the material and is both scientifically defensible and practical. As our knowledge of gems evolves, so too must our classification.

To accommodate this, all the gemmological reports issued by Lotus Gemology since 1 July 2023 use the term "fei cui". Future editions of *Jade: A Gemologist's Guide* will do the same.

About the Author

Born in South Africa, Kaylan Khourie's passion for gemmology started at a young age. He worked his way up to becoming the senior gemmologist at a top gemmological laboratory in the country, before making the move to Lotus Gemology in Bangkok, Thailand in 2023.

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