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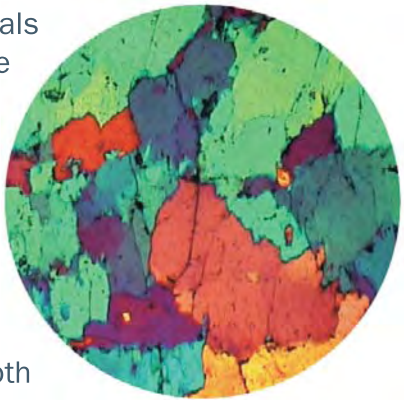
Jadeite jade from Myanmar: its texture and gemmological implications

Guanghai Shi, Xia Wang, Bingbing Chu and Wenyuan Cui

Abstract: Jadeitites, rocks consisting predominantly of jadeite, are the source of the precious stone known as feitsui by the Chinese. Jadeitites vary greatly in transparency, compactness and toughness due to their diverse textures and microstructures. The authors consider these textures in two major groups: (i) primary and (ii) deformed and recrystallized. In the first group, the rocks are coarse-grained with mosaic, granitoid or radial textures and some crystals are chemically zoned; such rocks can be porous. In the second group are jadeitites of finer grain size, generally formed by metamorphism of the coarse-grained jadeitites, with textures showing variable preferred orientation of crystals, mechanical twinning, shear zones, development of sub-grains, serrated high-angle sutured grain boundaries, or a 'foam' pattern. Texture, compactness and colour variation has generated a large number of trade names. The most precious jadeite jades are described as 'icy' or 'glassy', which relates to the quality of their transparency. Studies of jadeite textures have gemmological applications both in identifying and grading rough material and in the design, fashioning and grading of manufactured articles. Geologically, textures provide evidence of the formation and metamorphism of the whole range of Myanma jadeitites and it is probable that these processes are linked to the major Sagaing strike-slip faults.



Keywords: classification, gem trade terminology, jadeite, metamorphic textures, Myanmar, petrography

Introduction

The jade which dominantly consists of jadeite crystal aggregates has over the years attracted several names in different countries. The Chinese call jade feitsui (or feicui), which means jadeite jade, with no implications as to its source (e.g., Ouyang, 2003). Westerners simply call it jadeite (e.g., Damour, 1881), which sometimes causes confusion, since jadeite is also the mineral name for sodium-aluminium silicates of the pyroxene group. The Burmese use the term Myanma jade to designate jadeite jade from the Jade Tract in Myanmar (e.g., Nyan Thin, 2002). According to current gemmological opinion in China, jade is defined as a natural polycrystalline aggregate with fine compact texture, high toughness, good lustre and a medium to high degree of translucency. Both feitsui and medium- to low-quality jadeite rock are, petrologically, jadeitite, composed mainly of jadeite and other sodic- and sodic-calcic clinopyroxenes such as omphacite and kosmochlor. Jadeitite is a high pressure metamorphic rock deposited from jadeitic fluids (Ouyang, 1984; Harlow and Olds, 1987; Hughes et al., 2000; Harlow and Sorensen, 2005; Shi et al., 2003, 2005a, 2008; Yi *et al.,* 2006). However, not all jadeitites have the qualities required of feitsui, because they may have coarse-grained textures which are variably porous and therefore lack the coherence which is desirable for carving materials. Jadeitite which has the qualities of precious jade is rarely found even in the best deposits in Myanmar.

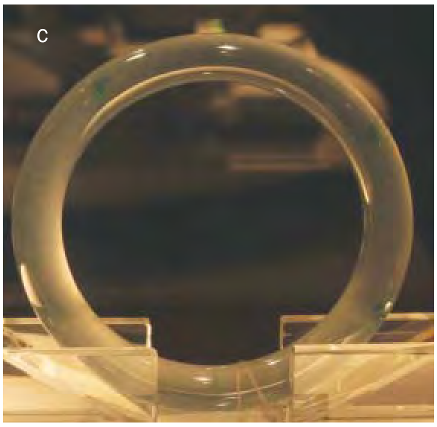


Figure 1: The glassy feitsui (green and colourless jadeite jades) from Myanmar. (a) A necklace of 15 exceptionally bright emerald green oval cabochons; (b) a ring with an imperial green oval cabochon; (c) a colourless bangle.

Having been mined for more than 300 years, the Myanma jadeite areas, called the Myanmar Jade Tract, still produce the emerald green imperial jadeite jade which is fashioned as cabochons for rings, bracelets, pendants and other jewellery pieces *(Figure 1)*, but on precious jadeite, research has so far been incomplete. Previous mineralogical and gemmological studies on jadeites have dealt with mineral and chemical compositions, fluid inclusions, and with which agents cause colour in jadeite (Gübelin, 1965a,b; Ouyang, 1984; Harder, 1995; Htein Win and Naing Aye Myo, 1994, 1995; Hughes *et al.,* 2000; Johnson and Harlow, 1999; Shi et al., 2003, 2005a, b, 2008). However, there has been little understanding about the primary textures of the Myanma jadeite materials, and much less about their deformed textures or microstructures, and the relationship of both kinds of texture to jade qualities. Also the process of transformation of coarse-grained to fine, compact jadeitite has not been explained. Although Ouyang (2000) and Shi et al.,(2004) have reported on some textures of Myanma jadeitites, the focus has been on their grain sizes, metasomatic textures and brittle deformation, without giving detailed descriptions of the deformed and recrystallized textures and gemmological applications. In this investigation, we present the primary and deformed textures of white jadeite materials (including icy to glassy jades) from Myanmar, attempt to establish correlations between textural features and jade qualities, and discuss the gemmological applications and implications.

Geological setting

Myanma jadeitites occur within the N–S striking Hpakan ophiolite complex which is about 50 km long and 5–10 km wide, situated in the east of the Indo-Myanmar Range and north of the Central Myanmar Basin. The ophiolites straddle a fault which is possibly a branch of the north Sagaing Fault *(Figure 2)*. Geographically, the Indo-Myanmar Range is flanked on the east by the Central Myanmar Basin, and the national border between Myanmar and India generally follows the high points of the Range. Geologically, along the eastern boundary of the Range is a line of discontinuous ophiolite and ophiolite-derived blocks. In this terrain accumulation and deformation of rocks have taken place within a zone where oceanic crust of the Indian plate has been subducted beneath the Burmese plate with intra-oceanic features (Shi *et al.,* 2009). Based on ages of zircon inclusions, this subduction and formation of some jadeite probably took place in Upper Jurassic times (Shi *et al.,* 2008). The Central Myanmar Basin (16°N–25°N, 94°E–97°E), consists of low land between the Indo-Myanmar Range and the China-Myanmar high land. The Sagaing fault is a major strike-slip dextral or right-lateral continental fault that extends over 1200 km and connects to the Andaman spreading centre at its southern end. It has been interpreted by some authors as a plate boundary between India and Indochina (LeDain *et al.,* 1984) and accommodated nearly 60 % of the relative motion between the two plates. Two low-angle branch faults connect directly to the main fault at its northern end, and a sub-parallel fault to the west is also a location for jadeitites (Bertrand and Rangin, 2003; Morley, 2004).

The Hpakant ophiolite complex consists mainly of serpentinized peridotite, chromite-bearing peridotite, metagabbro and metabasalt. Also within the complex are jadeitite veins or blocks, usually separated by sodic- and sodic-calcic-amphibolites, some of which can contain the rare pyroxenes kosmochlor and omphacite (Ouyang, 1984; Harlow and Olds, 1987; Hughes *et al.,* 2000; Shi *et al.,* 2003, 2005a; Yi *et al.,* 2006). The jadeitite veins, e.g. the one at the Maw Sit mine near the north end of the Jade Tract, are almost vertical, strike N–S, are 1.5 to 5 m wide, and 5 to 100 m long. These veins are crosscut in some places by thin veins of late-stage albitite, which are commonly less than 5 mm wide. Adjacent to the peridotites, there are high-pressure rocks such as phengite-bearing glaucophane schists, stilpnomelane-bearing quartzites, and amphibolite facies rocks such as garnet-bearing amphibolites and diopside-bearing marbles (Shi *et al.,* 2001).

Primary and deformed textures

A few jadeitites retain an undeformed massive structure, with euhedral to subhedral jadeite prismatic crystals which can exceed 20 mm in length. Most jadeitites, however, have been deformed and are fine-grained. Accordingly, the jadeitite samples are described in two textural groups: 1) with primary texture and 2) with deformed, recrystallized texture.

The primary textures

Primary texture is defined as that of jadeitite which has formed through deposition from a jadeitic fluid within its host peridotite/serpentine and has undergone little or no ductile deformation. These jadeitites are coarse-grained and to variable degrees, porous; their quality is not considered as precious (see *Figure*

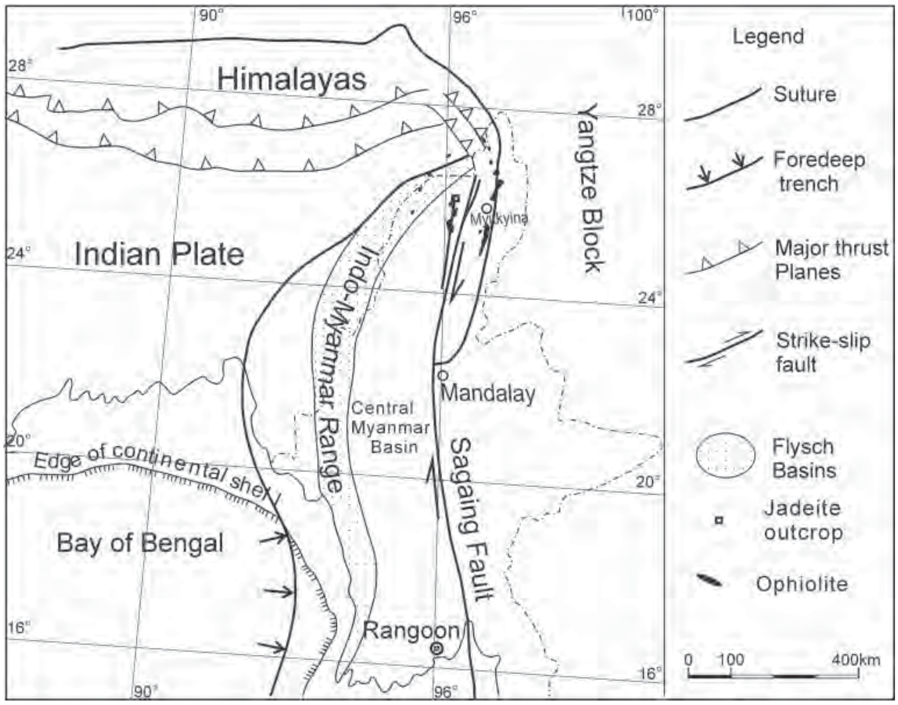


Figure 2: Simplified tectonic map of northern Myanmar. The jadeite deposits straddle a fault adjacent to the northern end of the Sagaing Fault and which is possibly a branch of it. The Fault is active and interpreted by some geologists as a plate boundary between India and Indochina accommodating nearly 60 % of the relative motion between the two plates (modified after Morley, 2004; Chhibber, 1934).

Materials and methods

From more than 150 samples collected in the Myanma jadeite area, we selected 20 white jadeitites of which four were coarse-grained with granite-like appearance, and 16 were fine-grained and chosen to represent a range of transparencies from translucent to icy and glassy semi-transparency. All samples were prepared as polished thin sections. Microscopes at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS) and at the Ruhr-University Bochum (RUB), Germany, were used for extensive textural and microstructural observations on each section and to obtain representative photomicrographs taken in polarized and cross-polarized light. Cathodoluminescene (CL) imaging was also performed on the thin sections and representative images of the undeformed and deformed jadeite materials were acquired.

The chemical compositions of the undeformed and deformed jadeites were obtained using electron probe microanalysis (EPMA) using a CAMECA-SX-51 at the IGGCAS with an operating voltage of 15 kV and a beam current of 12 nA. The microprobe standards comprise synthetic and natural jadeite, chromite, pyrope, amphiboles, feldspar and clinopyroxenes. Backscattered electron (BSE) images, which indicate the spatial distribution of the different elements, were also acquired. All samples were determined to consist of jadeite with more than 90 % of the jadeite molecule (Jd).

The orientations of the jadeite crystals were determined using electron backscatter diffraction (EBSD). The EBSD patterns and the orientation contrast images (OCI) were acquired using a scanning electron microscope (SEM) LEO 1530 at the RUB with field emission gun and forescatter detector, operated at an accelerating voltage of 25 kV, with the section tilted over 70° and a working distance of 25 mm. The EBSD patterns were indexed with the hkl software 'CHANNEL 4'.

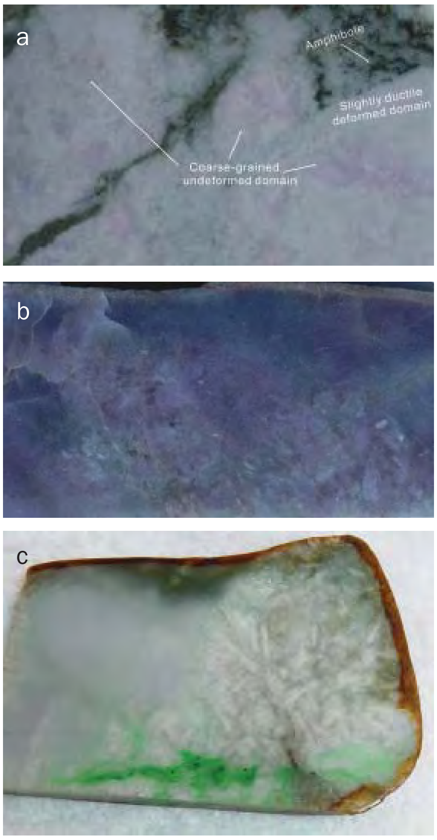


Figure 3: Cut jadeitite samples showing undeformed, coarse-grained jadeitite domains observed within and/or adjacent to slightly deformed jadeite aggregates. Sample widths (a) 30 cm, (b) 10 cm and (c) 12 cm.

3) but they can be utilized as B-jade materials and subject to acid-bleaching and resin-filling. The primary textures consist of zoned semihedral to euhedral jadeite crystals in mosaic and granitoid patterns.

Jadeite crystals in the mosaic and granitoid textures *(Figure 4a)* can be more than 3 cm long, and can be relatively even-grained (homogranular) or porphyritic. Most crystals are prism-shaped with flat contacts and random orientation. In some rocks, the crystals are in radial clusters. These jadeite crystals probably formed simultaneously with mosaic or granitoid textures. Mostly crystals have zones with slightly different extinction directions under cross-polarized light *(Figure 4b)* and this indicates some chemical variation. Cathodoluminescence imaging is even more effective in detecting such variation and can show distinct oscillatory zoning in crystals with no obvious optical variation: *Figure 4c* shows crystals with vivid blue, pink and yellow zones (see also Harlow, 1994; Sorensen et al., 2006). BSE images of the same area display almost the same oscillatory zoning patterns as the CL images, and are indicative of compositional zoning. With the aid of EPMA, we found that jadeites within the dark CL zones are very pure with more than 98 mol. % Jd, whereas 5-10 mol. % Di (diopside) is present in the bright CL zones (see details in Shi *et al.,* 2005b).

Due to these zonal differences in chemical composition, each jadeite crystal will have zones with variable refractive indices, thus producing optical interfaces or distortion between adjacent zones when light transmits. Therefore, the transparency of a zoned jadeite crystal will be less than that of an unzoned one. Crystals in primary textured jadeitites also have distinct cleavages and fluid inclusions (Shi *et al.,* 2000, 2005b) which will decrease their transparency further.

The deformed, recrystallized textures

These are the textures of jadeitites which have experienced shear stress, tectonic movement, apparent ductile deformation and recrystallization of their jadeite grains. The boundaries between the primary and recrystallized textures can be seen by careful examination of some hand specimens *(Figure 3)*, but they are better seen and more distinct

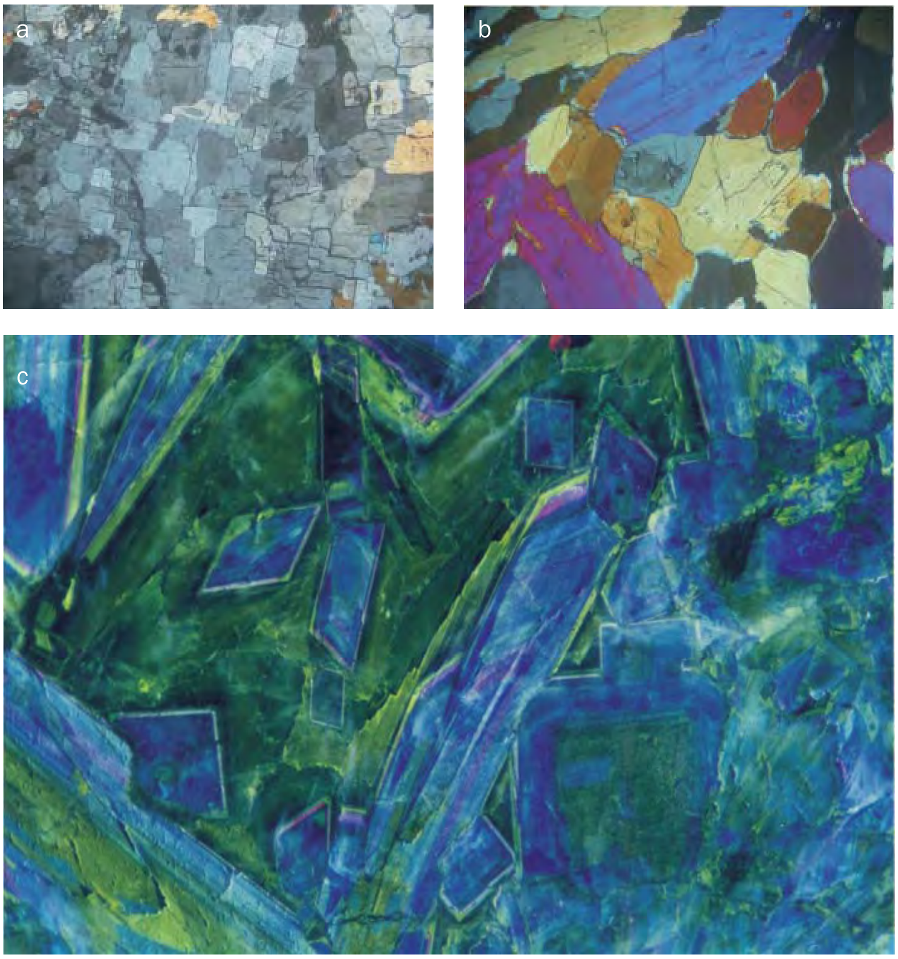


Figure 4: Representative primary textures of undeformed Myanma jadeitites: (a) Thin section photomicrograph of mosaic or granoblastic texture consisting of randomly orientated jadeite crystals with clearly visible cleavage planes (cross-polarized light, section width 2.5 mm); (b) Jadeite crystals intergrown in a hypidiomorphic texture. The pale yellow crystal near the centre has a patchy darker rim representing some compositional zoning (thin section cross-polarized light, section width 2.5 mm); (c) Complex rhythmical zoning patterns in jadeite crystals made apparent by cathodoluminescence imaging (section width 1.25 mm).

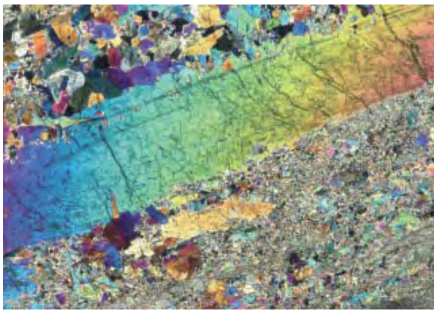


Figure 5: A 20 mm wide section showing the junction between coarse undeformed jadeitite (middle and upper left) and fine deformed jadeite domains (lower right). The original undeformed jadeitite evidently had a porphyritic texture.

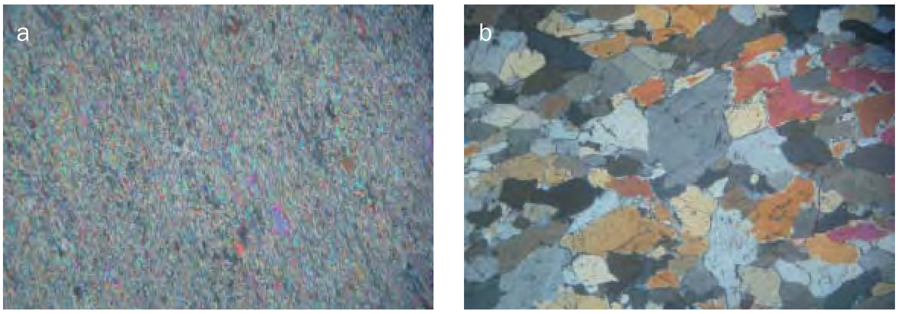


Figure 6: Thin sections showing semi-orientated to preferred orientated jadeite crystals in feitsui from Myanmar: (a) Fine-grained, orientated and compact texture of a near-glassy jade (section width 2.5 mm, cross-polarized light); (b) Semi-orientated grains of intermediate size form a translucent jade (section width 2.5 mm, cross-polarized light).

under the microscope. As shown in *Figure 5*, primary jadeitite with one large crystal in excess of 20 mm, is in contact with microcrystalline jadeite containing fragments of primary texture, suggesting that deformation and recrystallization occurred heterogeneously at the expense of the primary texture. With extensive deformation and recrystallization, the jadeites become nearly homogeneous in chemical composition, containing 95-98 mol. % Jd and display no compositional zoning (see detail in Shi *et al.,* 2005b). A number of sub-types of the deformed and recrystallized textures can be recognized, probably related to the deformation mechanism, and these are: textures with different degrees of preferred orientation of elongated crystals; sub-grain; micro-shear; sutured grain boundaries; mechanical twinning; and recovery texture. These are described below.

Textures with preferred orientation

Myanma jadeitites are composed dominantly of elongate jadeite crystals with length/width ratios (aspect ratios) ranging from 2.0 to 20; some are even fibrous. The grain sizes in this sub-group vary greatly, from thin fibres several micrometres wide to prisms more than 20 mm long and several mm wide. Microscope observations and EBSD results show that most of the jadeite aggregates have both shape-preferred orientations (SPO) and crystallographically preferred orientations (CPO). No obvious chemical zoning in jadeite crystals has been found in this texture. Sections of near-glassy jadeite jade *(Figure 6a)* reveal that their textures consist of very tiny jadeite grains with pronounced SPO and CPO, and indistinct grain boundaries; whereas translucent jadeitites with an exterior texture reminiscent of cooked sticky rice, have textures with larger grains of lower aspect ratio, more distinct grain boundaries and a lower degree of preferred orientation *(Figure 6b)*. Taking into account previous work on this topic (Ouyang, 2003; Shi *et al.,* 2004), it is concluded that the sizes, shapes, crystallographic orientations and features of the grain boundaries of the jadeite crystals are closely correlated to a jade's transparency; the finer and more preferred the orientation (with a homogeneous extinction direction), and the more indistinct the grain boundaries are, the better the transparency.

Sub-grain

An example of Myanma jadeitite showing development of sub-grain texture is shown in *Figure 7*. Lines of tiny sub-grains are visible across some of the larger jadeite crystals and mark lines of shear stress and recrystallization. In *Figure 7* areas of similar interference colour but consisting of a number of grains represent the original larger jadeite crystals. Most of the boundaries among sub-grains are distinct, but a few are still indistinct. These sub-grains are almost homogranular and tightly interlocking. If there is continued or resumed stress, there can be further generation of sub-grains and reduction in grain size to less than 0.05 mm. When shearing and recrystallization has been prolonged and thorough, textures resembling that in *Figure 6a* are developed. Generation of sub-grains is the main way of reducing grain size in a rock. This takes place by means of dislocation of boundaries and change in the angular mismatch between the two sub-grains. Normally 10–15 degrees misorientation

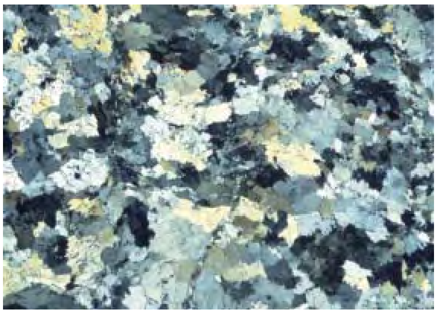


Figure 7: Photomicrograph in cross-polarized light of very compact sub-grain aggregate in Myanma jadeite (section width 10 mm), in which some precursor grains show sutured boundaries.

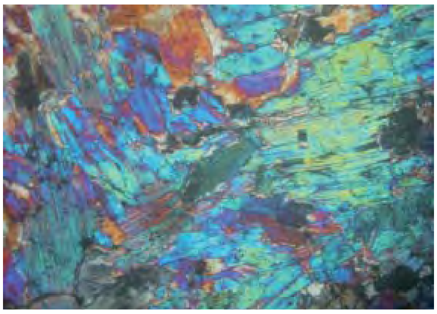


Figure 8: Photomicrograph showing medium to coarse jadeite crystals with cleavage and polysynthetic mechanical twinning in Myanma jadeitite. The presence of twinning is revealed by the parallel bands of alternating interference colours; some are slightly bent. (Section width 2.5 mm, cross-polarized light).

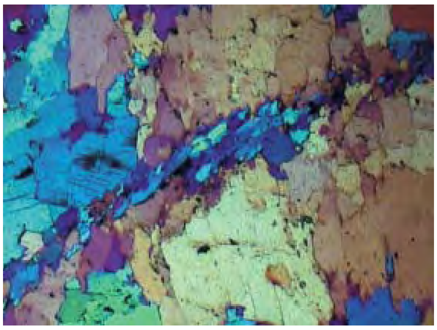


Figure 9: Section of medium to coarse-grained jadeite crossed by a zone of shearing which is marked by smaller more orientated crystals. Section 2 mm across, cross-polarized light with colours enhanced with inserted gypsum plate.

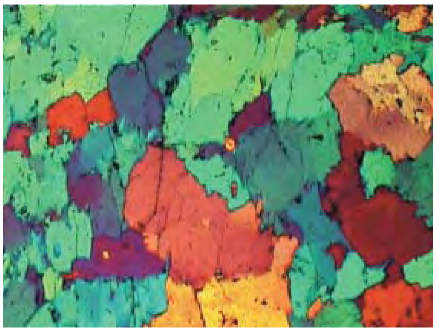


Figure 10: Thin section showing jadeite crystals with serrated high-angle sutured boundaries. Section 2 mm across, cross-polarized light with colours enhanced with inserted gypsum plate.

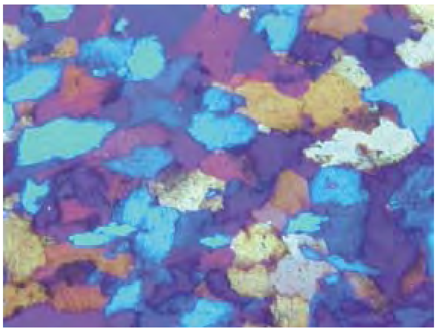


Figure 11: Thin section of jadeitite with a recovery texture resembling foam and showing a number of grains in the aggregate with triple junctions close to 120°. Section 1.25 mm across, cross-polarized light with colours enhanced by inserted gypsum plate.

among the newly-generated grains is commonly quoted (e.g., Hirth and Tullis, 1992).

Mechanical twinning

Generation of mechanical twinning is a stage in the process of grain size reduction; it commonly occurs in calcite, corundum, diamond and feldspar, but seldom in jadeite. So far, natural mechanical jadeite twinning has only been found in ultra-high pressure rocks and is regarded as the result of syn-seismic loading beneath the brittle-plastic transition conditions for such rocks (Treppman and Stöckhert, 2001; Orzol *et al.,* 2003). In Myanmar, mechanical twinning has occurred in both pure jadeitite and in surrounding amphibolite, and some twinned crystals have also been bent *(Figure 8).* These occurrences are useful for understanding how jadeite jade may form from the coarse-grained jadeitite.

Figure 12: Myanma jadeite jade showing abrupt changes in appearance. This is usually accompanied by changes in texture which are as important in understanding jades as inclusions are in other gemstones. Note that the appearance of jade in the centre resembles 'cooked sticky rice', but in the left of the picture looks like 'porcelain'. Length of carving 10 cm.

Micro-shear zones

In some jadeite jades, veinlets or lines, 10–100 mm long and about 1.0 mm wide, can be distinguished by their different colour and better transparency. They are a kind of deformed and recrystallized texture or microstructure described as micro-shear zones, which have not been distinguished before. They are not cracks, but do resemble 'healing fractures' and were formed by means of ductile deformation (e.g. Tullis and Yund, 1985). They are not real repairs, because they are part of an ongoing process of transformation of the rock, and are thus different from a simple healing texture. Micro-shear zones are characterized by tiny elongate jadeite crystals (like stacked tiles) with pronounced orientation (both SPO and CPO) at low angles to the shear zone walls *(Figure 9).* Some jadeite crystals crossed by a fracture or shear zone have conjugate profiles and crystallographic orientations suggesting that they are from one intact precursor crystal; the newly generated jadeite crystals in the shear zone have formed at the expense of this intact crystal. This is another cause of grain size reduction, of CPO, and ultimately of a tougher more transparent jadeitite.

Figure 13: A 'gamble stone' from Myanmar; the small polished window at one end is not sufficient to show the quality of the other part of the stone, but the patchy presence of some orientated crystals in the skin indicate good potential for a valuable piece. Stone length 13 cm.

Sutured grain boundaries

Some translucent to transparent jadeitites consist of crystals with sutured edges at high angles to adjacent grains and without interstitial spaces *(Figure 10)*. They are the result of an integrated deformation process including dislocation, granular flow and mass transfer (e.g. Tullis and Yund, 1985). The different boundary shapes are the result of different aspects of this process and could influence jade quality. The jades with such intergrown crystal boundaries have excellent toughness, even with grain-sizes up to 1–2 mm.

Recovery textures

The term 'recovery' in this context refers to textures formed through mutual annihilation and/or polygonization during or after the peak deformation, resulting from reduction in the strain produced by the deformation; such textures can show grain dislocation, development of sub-grains, polygonal patterns and recrystallization. Although some of these textures may be confused with the primary fine mosaic texture, they differ by the presence of the following features: the grains are crystallographically orientated, confirmed by EBSD results, they are nearly equal in size, mostly less than 0.08 mm, and have no obvious prismatic habit. The grain boundaries are straight or gently curved (resembling foam), a texture also similar to the quartz grains in mylonitized quartzite (e.g. Tullis and Yund, 1985), but not so far reported in jadeitite. In Myanma jadeitites with 'foam' texture, a few grains meet at perfect triple junctions with some boundary angles near 120° *(Figure 11)*. The jade with 'foam' texture usually has a high transparency, described as icy or glassy.

Discussion

Gemmological application

The importance of textures to the jadeite jades is comparable with that of inclusions to their host gemstones. Feitsui in Myanmar consists of jadeite aggregates of many different textures. In general, most carvings that appear similar probably have the same texture, whereas the parts and domains of different appearance reflect changes in texture (see *Figures 3, 5* and *12*). It is clear that the appearance and the transparency of jadeite jade are closely related to texture and if such correlations can be established, we could then predict the texture of a jade based on its appearance. The nature of the aggregate and its relative toughness could then be estimated quickly and non-destructively. Furthermore, if comparable data were collected from jadeite jades around the world, it may be possible to determine unique features for each locality. By studying textures of rough feitsui it is possible to identify, grade and evaluate them quickly. For instance, although bleached jadeite (B-jadeite) can be identified accurately using ultraviolet luminescence and the infrared spectrometer (see Fritsch *et al.*, 1992), a quick identification can be made using only the naked eye or a 10x lens. In this situation one should look for any damage

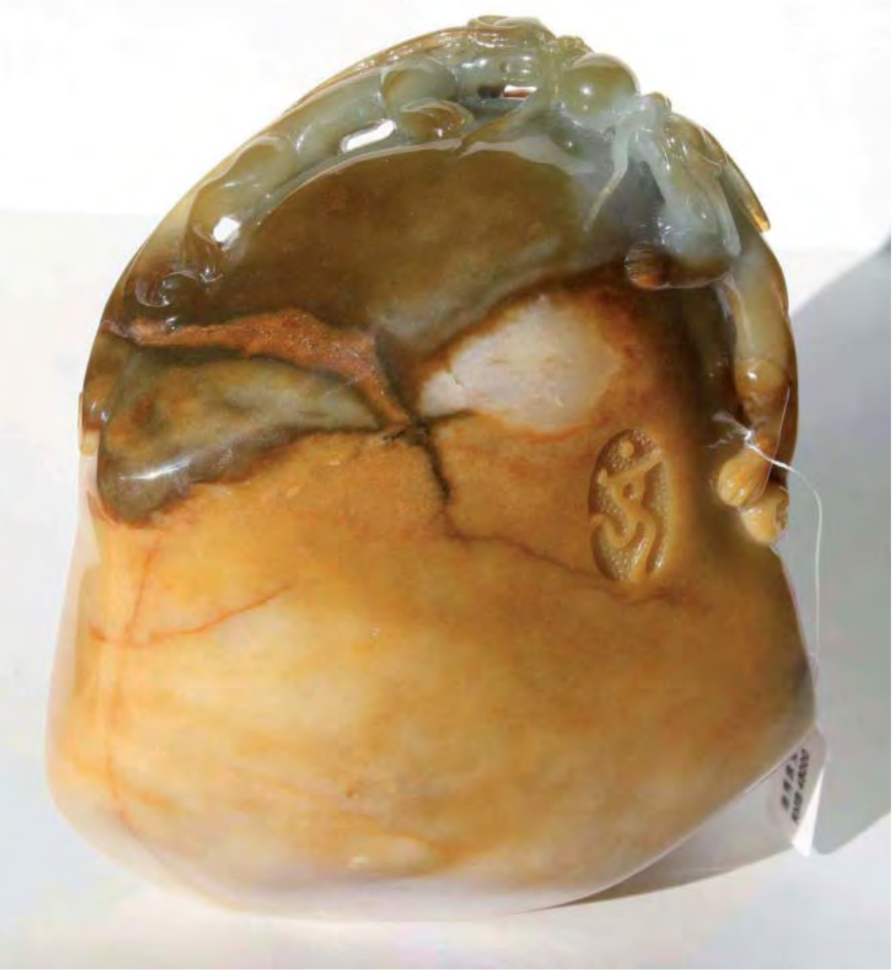


Figure 15: Another example of correlation between the texture and design in jadeite art; the coarsest part was designed as a rounded base and the 28th Olympics logo was carved in an area of relatively fine quality. Height 15 cm.

Figure 14: Dragon's head carved in the finest pure white jadeite jade but left unpolished to enhance the atmosphere of the piece: an example of the use of texture and colour in design of the jadeite carving. Height 6.5 cm.

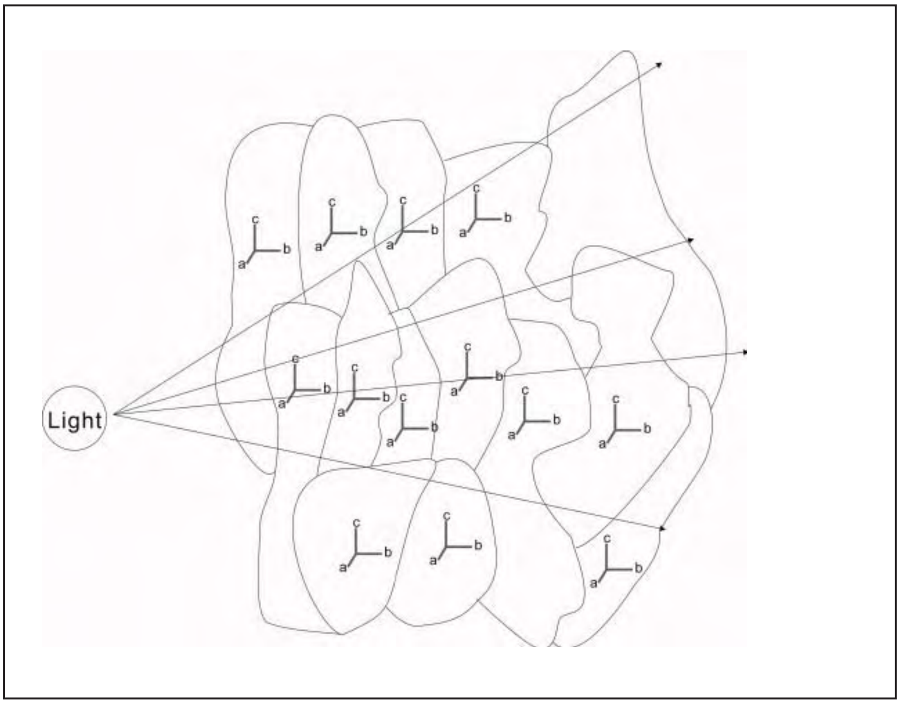


Figure 18: A model of the ideal texture for the best glassy jadeite aggregate. The jadeite crystals are fine-grained, with pronounced crystallographical orientation; they are compactly intergrown with minimal optical interfaces, and there is an absence of any obvious cleavage and chemical zoning; the net optical effect is of one jadeite crystal, allowing transmitted light to pass through without apparent internal reflection or refraction.

Figure 16: The green parts in two Myanma jadeitite carvings are finer and more transparent than their neighbouring white regions, indicating differences in deformation textures. Lengths of carvings 6 cm.

Figure 17: The green parts in this Myanma jadeite bangle are finer and more transparent than their adjacent white regions; another example of differences in deformation textures between green and white regions, probably formed under the same P-T and stress conditions. Bangle diameter 5.8 cm.

to texture caused by bleaching (see Tay *et al.,* 1993, 1996). As for grading jadeite jade, toughness is an important factor, and the tougher a jade is, the better its quality. In this respect jadeitites with serrated high-angle sutured and interlocking grain boundaries are probably tougher than other jadeitites of similar grain size.

Rough jadeite jade normally has an opaque weathered crust (also known as the skin) with a thickness between 1 and 50 mm, thus it is difficult to evaluate without cutting into fresh rock. For the rough stone market, traders sometimes cut and polish a small 'window' through the weathered surface of a stone for a better sale; this is called a 'gamble stone' by the Chinese. In *Figure 13* is a good example of such a stone with a 'window' revealing an interior of glassy transparency when illuminated by a torch. A potential buyer would have to evaluate the overall quality of the stone, including the part still covered by the weathered skin, on the basis of this small illuminated area. The indistinct preferred orientation shown by the surface crystals (SPO texture) is a positive indication that the whole stone is of good quality; it turned out to be glassy after the skin was removed, so the initial indications proved positive.

Studies of the textures of feitsui also help a jade manufacturer in deciding on the best way to design and carve a particular piece of jadeite jade. Because of its textural heterogeneity, jadeite jade enables designers to use their imagination to the best effect, and the best designers know how to make full use of this variability. Two artworks shown in *Figures 14* and *15* are good examples; in *Figure 14,* the dragon's head was carved in the finest pure white area and its unpolished surface gives the art a sense of mystery, whereas in *Figure 15*, the coarsest part was designed as the base, supporting the 28th Olympics logo which was carved in a relatively fine area of jadeite.

Preliminary investigations indicate that green jadeite jades have slight differences in texture and microstructure from white jadeites under the same pressure and temperature *(P-T)* and stress conditions. One can even distinguish some textural differences at the colour boundaries: the green areas tend to consist of smaller grains with more pronounced orientation, thus appearing more transparent than neighbouring white areas (*Figures 16* and *17*). Our studies to date of homogeneous green jadeite jades indicate that they have similar deformation textures to those described in the white jades. So, if textural studies of white feitsui can help understand green feitsui, the conclusions could provisionally be extended to the precious imperial green jadeite jade, which currently is too expensive to section for gemmological research!

Textural model of the glassy jadeite jades and how they formed

Its rarity indicates that jadeite cannot easily grow as large transparent crystals in Nature (see Zhang *et al.,* 2002). So far there have been no reports of a single jadeite crystal being cut or otherwise used as a gemstone. But some jadeite aggregates can come surprisingly close to appearing like a single crystal with an icy or glassy transparency nearly as clear as rock crystal. Our observations on the textures and microstructures of Myanma jadeitites suggest a theoretical textural model for such aggregates. In this model, the individual jadeite crystals are small equant grains or fine fibres too small to develop significant cleavage, which is therefore one factor that will not interfere with transparency. All the grains have preferred orientation, with their crystal and optic axes consistently aligned; therefore they show little, if any, differential refraction between neighbouring grains. This texture is also so compact that there are no spaces at any grain boundaries, so there are no obstructions to the transmitted light; this eliminates any significant internal reflection and refraction *(Figure 18).*

Transformation of coarse jadeitite into the transparent gem-quality jade, i.e. icy to glassy feitsui, should have undergone at least two coupled processes of grain size reduction and crystallographic orientation under conditions of jadeite stability.

The main process causing grain-size reduction is rotation recrystallization, also known as the progressive misorientation of sub-grains. This refers to the formation of sub-grains by the relative rotation of different parts of a crystal and was first identified in such minerals as quartz, feldspar and olivine under conditions of low pressure and high temperature. In jadeites, this phenomenon takes place at high pressure and low temperature in the jadeitites from Myanmar. Other processes causing grain-size reduction include mechanical twinning and shearing along micro-shear zones. In one crystal, such shearing can cause sub-grains that do mismatch but retain overall orientation within 15 degree limits of CPO. CPOs can also be generated from processes including grain-boundary migration (GBM) and diffusion processes (Tullis and Yund, 1985).

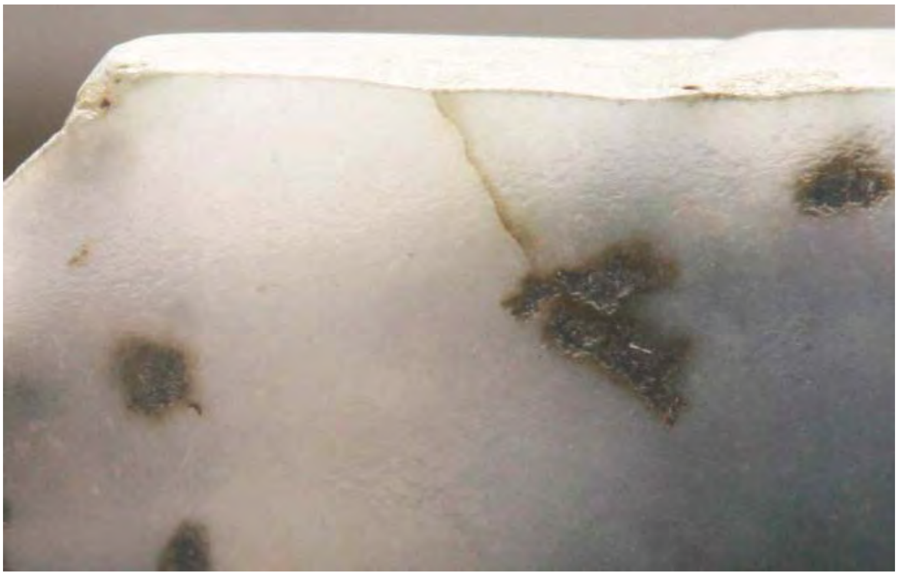


Figure 19: Jadeite from Myanmar described as water-like; the jadeite grains cannot be distinguished with the naked eye. Specimen 5cm across.

From the presence of some elongate jadeite crystals in the Myanma icy to glassy jadeitites, it is suggested that GBM had occurred during the transformation from coarse-grained jadeitite to fine jadeite jade. Since GBM tends to increase the size of the sub-grains, it is reasonable to include this process as part of the ideal or theoretical texture model. The linked processes of rotation recrystallization and GBM are the main causes of formation of the icy to glassy jades, and since both should have taken place under high pressure low temperature conditions, the conditions of formation for aggregates of jadeite with an icy to glassy appearance are thus very exacting. They are extraordinarily rare, only found so far in Myanmar, and the results are therefore precious.

The undeformed coarse jadeitite and the icy to glassy feitsui are the two end members of the transparency range of jadeite materials. Most jadeite jades from Myanmar are intermediate, being of moderate grain size, with partially orientated grains, and a translucent appearance.

Jadeite materials representing nearly all degrees of transparency are available on the market, and are sold under the varietal descriptions: 'glassy', 'icy', 'water', 'cooked sticky-rice', 'porcelain' and others *(Figure 19)*. These varieties do not take into account colour or impurities – these are other variables that can lead to more commercial varieties.

Formation of the most transparent feitsui has required long-lasting and intensive, localized geological forces, and it is very likely that the source of these was movement along the Sagaing strike-slip faults which have a displacement 150–300 km. Displacement along the faults over a long period of time led to local developments of intense metamorphism inducing ductile deformation and recrystallization, and where coarse-grained jadeitites were caught up in these movements, they were variably recrystallized and transformed.

Gemmological applications will benefit from further related investigations into jadeitite textures and make it possible perhaps to establish an ideal model of how the textures of the glassy jades were formed.

Conclusions

Jadeitites from Myanmar can be considered in terms of two groups of textures: primary, and deformed and recrystallized. Those with primary textures are coarse-grained, and have mosaic, granitoid or radial textures consisting of chemically zoned jadeite crystals; they are porous to some degree, are not transparent, and are not therefore considered as being of gem quality. The jadeitites which are deformed and recrystallized developed at the expense of primary textures, and are intermediate to fine-grained, with semi-orientated to preferred orientated crystals, some mechanically twinned. They may also contain micro-shear zones, sub-grains, serrated high-angle sutured grain boundaries, and 'foam' textures. These rocks are compact, tough and translucent to transparent, and have the most potential as gems.

One model for the icy and glassy jadeite jades might include the following parameters: the crystals are very small and compact with preferred orientation, they lack obvious chemical zones and cleavages, and the whole rock resembles a single crystal optically. Most jade in the gem market is classed as glassy or coarse. These categories are further subdivided on the basis of three variables: compactness, orientation and grain size, so producing a large number of jadeite varieties.

Studies of the textures have gemmological applications not only in identifying and grading the rough and fashioned jadeite jades, but also in their design and manufacture. Moreover, such studies help understanding of the textural model of the icy and glassy jadeite jades, the textures and microstructures of green and other coloured materials, and how they are formed.

The movements of the Sagaing strike-slip faults, which the Myanma jadeite deposits straddle, are inferred as the main cause of the formation of the feitsui.

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The Authors

Professor Dr Guanghai Shi
Laboratory Director at the School of Gemology, China University of Geosciences, Beijing 100083. China. email shiguanghai@263.net.cn

Miss Xia Wang and Miss Bingbing Chu
Postgraduates at the China University of Geosciences, Beijing 100083. China.

Professor Wenyuan Cui
School of Space and Earth Sciences, Peking University, Beijing 100871, China.