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Materials and technology of Chinese jades dating to the Western Zhou period (1050－771 BCE)

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Excavated jades dating to the Western Zhou period (1050－771 BCE) from the Xi'an area in Shaanxi Province, China, and contemporaneous jades in the collections of the Arthur M. Sackler Gallery at the Smithsonian Institution have been studied to learn about the jade and stone materials and how they were worked during the Western Zhou period. Materials identification was carried out using a combination of techniques such as Fourier-transform infrared spectroscopy and X-ray diffraction. Tool marks were studied using stereomicroscopy and examination of mold impressions using scanning electron microscopy. All of these objects were produced through simple processes involving solid drilling, riffling, and sharp point abrasion; and no evidence was found for the use of rotary tools for incising or sawing.

jade, nephrite, stone, China, Western Zhou, scanning electron microscopy, materials, technology, tool marks

1 Introduction

The Western Zhou period (1050－771 BCE) in China is pivotal in China's early history due to the wide range of technical advances made during that time. The materials and technology of the magnificent bronzes of the Western Zhou period have received great scholarly attention, but little work has been carried out on the jades. During that time, the structure of society was changing greatly, and jade was no longer simply a sign of rank within a hierarchy, but also signified relative position within a particular level of hierarchy[1]. The present study of excavated jades from the Xi'an area in Shaanxi Province, China and jades in the collections of the Arthur M. Sackler

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Gallery, has its goal to learn about the stone materials used during the Western Zhou period and how they were produced. The findings of this research will help illuminate the approaches used by Western Zhou people to work and use jade materials, and facilitate the study of unprovenanced jades in museums and private collections in terms of their cultural and archaeological context.

Prior to the eighteenth century, most jade objects originating from early China are composed of nephrite, a massive, fine-grained variety of the tremolite-actinolite series of amphiboles [$Ca_2Mg_5Si_8O_{22}(OH)_2$ and $Ca_2MgFe_4Si_8O_{22}(OH)_2$, respectively] where tremolite refers to the iron-poor member of the series and actinolite refers to the iron-rich member. Other stone materials were used as well that are often also termed “jade”. Some of these may be similar in appearance to nephrite, and some were probably chosen because of their appearance, physical properties, and/or availability. The stone materials used in ancient China include the massive varieties of serpentine, talc, quartz, calcite, prehnite and pyrophyllite[2].

Approximately 3000 unearthed Western Zhou jades are known in Shaanxi Province[3], and more are being found as excavation continues. Most fit into one of four categories: ritual, ornamental, utilitarian, and burial jades. Ritual objects include *ge* (blades), tablets, and *cong* (tubes); ornamental objects include *huang* (arch-shape pendants), animal- and human-shaped decorations, pendants, bracelets; utilitarian objects include ear picks; and burial jades include decorations for the coffin such as fish and cowries. Most tend to be carved from flat pieces of jade with cut-out type profiles; more three-dimensional representations are rarely seen.

After the Zhou conquest of the Shang people, the Zhou seemed to have assimilated and continued the Shang jade-working techniques[4]. The early Zhou jades are generally similar to the Shang objects, and include mainly animal-shaped amulets, primarily birds and fish; and less commonly, *bing* (handles), *huang* (arch-shaped objects), and a relatively small number of dagger-axes and *ge* (blades) which may be antiquities from Shang Dynasty. In the early Western Zhou, stone beads, jade plaques and pendants were placed in burial in modest numbers.

New styles and configurations began to emerge in the 10th and 9th centuries BCE. Innovative designs in jade patterns coincided with a great increase in the numbers of jades worked during the middle and late Western Zhou period[5]. New shapes with complex surface patterns emerged alongside one of the most profound ritual changes in ancient China which affected the use of jades in burial. During this time, it was believed that valuable protection could be attained by positioning jades on the dead. In the middle Western Zhou period, larger numbers of beads and ornaments began to be placed in graves, sometimes as many as one or two hundred objects. In the late Western Zhou even larger numbers of beads, and stone/jade assemblages were used. Face coverings consisting of several small carvings were developed during this time. This eventually led to the fabrication of jades suits composed of small plaques that covered the entire body of the deceased.

2 Study of Western Zhou jades composed of nephrite and stone

The nephrite and stone materials examined in this study were excavated from the Western Zhou State of Yu. They are currently housed in three museums: the Baoji Municipal Museum of Bronzes, the Baoji Municipal Zhouyuan Museum, and the Qishan Zhouyuan Museum. Approximately 60 objects were studied at these institutions, and 38 fragments and samples were studied in the laboratory at the Freer and Sackler Galleries.

Fifty-six Western Zhou jades from the Arthur M. Sackler Museum, Smithsonian Institution were selected for this study. Forty-seven of the objects are ornamental, such as small decorative items, pendants and beads. The remaining nine objects are burial/ritual objects, including the following shapes: *yuan* (disk), *bing* (handle), *ge* (blade), and trapezoidal plaque. The provenance of these objects is unknown, although most have unearthed analogues. As mentioned above, some of the early Western Zhou jades may belong to the Shang Dynasty as it is sometimes difficult to distinguish between many jades from these two periods. The materials were dated on the basis of curatorial evaluation and preliminary laboratory examination using stereomicroscopy.

3 Analytical methods

Initial study of all the objects was done using stereomicroscopy to record visual features such as color, texture, accretions and alterations. Excavated objects were examined in the storage facilities of the museums in Shaanxi Province, China. Access to the Sackler collections afforded more detailed study of these objects under laboratory conditions.

Mineral compositional information was obtained through a combination Fourier-transform infrared spectroscopy (FTIR) carried out on a Nicolet Nexus 6000 with a microscope attachment using a diamond anvil cell. A database of FTIR spectra was used for comparison purposes to obtain mineral identifications (for Infrared and Raman Users Group spectral database, see ref. [6]). Surface X-ray fluorescence spectroscopy (XRF) was carried out with an OMEGA FIVE (Modified Spectrace 6000) as described in Douglas[7,8]. In some cases X-ray diffraction (XRD) was performed using a Philips XRG-2600 with Gandolfi cameras.

For study of tool marks, scanning electron microscopy (SEM) in the backscattered electron mode using a FEI XL30tmp was used at 12 kV and 41 μA, on silicone molds of the tool marks from jades studied following the procedure outlined by Sax et al.[9]. Carved features were examined using optical microscopy at magnifications of up to 60X.

4 Excavated jade meaterials from Shaanxi Province

4.1 Materials identification

Nephrite and stone objects from the Baoji Municipal Museum of Bronzes and the Baoji Municipal Zhouyuan Museum were initially identified using standard mineralogical techniques such as visual and physical properties such as hardness, cleavage, texture, etc. Several assemblages were found to consist of a variety of nephrite pendants associated with beads of carnelian, rock crystal, serpentine and calcite. Below is a discussion of the objects from which we were able to obtain samples for analysis.

A relatively large flat plaque decorated with an incised face, BRM1:279, found within a grave at Rujiazhuang, Baoji, Shaanxi, dating to the10th – 9th century BC (page 48 of ref. [1] and Figure 191 of ref. [10]) is shown in Figure 1. The plaque was found close to the central area of the deceased along with bronzes signaling its importance as an object. FTIR results show that the plaque is composed of calcite. The layered texture with some crystalline areas indicated that the material was probably formed through precipitation in a cave environment. It is sometimes called “calcite alabaster” or “calcite onyx”. The fine texture of the material resembles that of jade.

Material identifications by FTIR for several objects dating to the Proto-Zhou through the late Western Zhou period are shown in Table 1. The Proto-Zhou period refers to the Zhou culture before they conquered the Shang people[11], and was contemporaneous with the late Shang Dynasty

(14th to 11th centuries BCE). Several samples from objects dating to the Proto-Zhou to early Western Zhou period are respectively from the sites of Fengchu, Licun, and Hejiacun in Qishan County. These fragments are from sites discovered respectively in 1976, 1977 and 1983, where some of the largest and earliest Western Zhou sites were found.

Decorative plaques dating to the middle to late Western Zhou period from the tomb numbered 96SFHM69 at Laobaozi, Huangdui, Fufeng County (see refs. [12,13]) were found to have been similarly worked in a variety of stones as shown in Figure 2[14]. Although these objects were found together, we do not understand exactly how they were used. They were likely to have been decorative elements and any organic material to which they may have been attached had long been deteriorated.

Figure 1 Calcite plaque, BRM1:279 excavated from Rujiazhuang, Baoji, Shaanxi Province, 10th—9th century BCE, image length = 12.4 cm.

Figure 2 Decorative plaques from Laobaozi, Huangdui in Fufeng County, 96SFHM69:14. image length = 25 cm.

Table 1 Excavated Western Zhou nephrite and stone materials from the Xi'an area analyzed by FTIR

Date, Location	Number of samples	Object	Material identification
Proto-Zhou to early Western Zhou period (1)			
Fengzhou, Qishan County	1	fragment	calcite
Lincun, Qishan County	2	fragment	muscovite
	1	gui (powder sample)	calcite
Hejiacun, Qishan County	1	button decoration	serpentine
	1	money (powder sample)	calcite
	1	bi (powder sample)	chlorite
Middle to late Western Zhou period (2)			
Liujia, 2004SFLM1	2	decorative plaque	muscovite
	3	decorative plaque	turquoise
	2	decorative plaque	quartz
	2	decorative plaque	nephrite
	2	decorative plaque	serpentine
Laobaozi, Huangdui in Fufeng County (see refs. [12,13,15])			
92SFHM25:24	2	fragment	muscovite
	1	fragment	calcite
95SFHM43	2	decorative plaque	muscovite
	1	decorative plaque	serpentine
95SFHM55:12	1	decorative plaque	muscovite
	2	decorative plaque	calcite
96SFHM65:008	1	decorative plaque	muscovite
	3	fragment	calcite
96SFHM68:008	2	decorative plaque	muscovite
	2	fragment	calcite
96SFHM69:14	5	decorative plaque	muscovite
	3	decorative plaque	calcite
	1	decorative plaque	shell

(1) Qishan County Zhouyuan Museum LRN:6416; (2) Baoji Municipal Zhouyuan Museum

The wide range of stones worked for small decorative plaques may have been for ornamental purposes. Of particular interest is the fragment composed of muscovite, more accurately described as its fine-grained, more massive equivalent, sericite. Figure 3 shows the FTIR spectrum of a muscovite (sericite) fragment along with a micrograph documenting its fine-grained, platy crystalline habit. Sericite is very similar to nephrite in color, texture and translucency, yet is much softer (2.5 on the Mohs scale) compared to nephrite (6—6.5 on the Mohs scale). Sericite's softness makes it easier to work than nephrite, and this may explain why it was chosen for the production of small, simple ornaments. Sericite is difficult to visually distinguish from nephrite, and few analyses have been reported. The authors know of no previous analyses of Western Zhou objects composed of sericite, although 13 of 204 stone objects were reported as composed of sericite from various Neolithic sites throughout China[2].

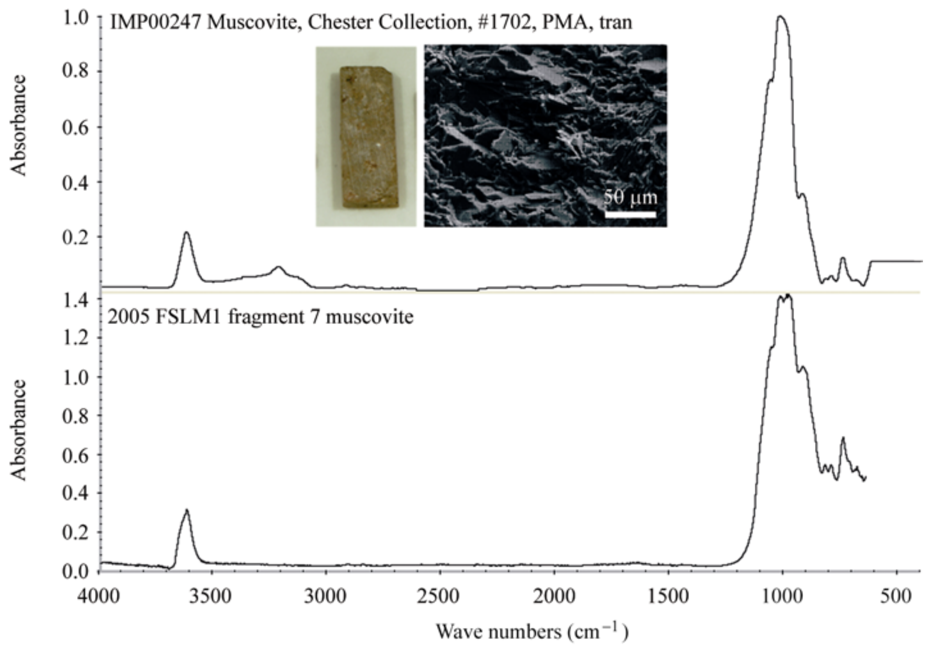

Figure 3 FTIR spectra of muscovite (sericite) fragment 1 from 96SFH M65:008, and muscovite reference material[6]. (left inset) decorative piece (right inset) SEM micrograph of muscovite (sericite) showing massive texture.

4.2 Evidence of manufacturing techniques

Optical microscopy showed that with the exception of the calcite fragments which are heavily degraded, tool marks are preserved on the generally unpolished surface of most fragments. Tool marks that are curved in plan view and/or have pronounced concave longitudinal depths indicate the use of a rotary wheel, for example for sawing during primary shaping[16]. Tool marks of this type were not found on any of the fragments. The absence of curved tool marks does not entirely preclude the use of rotary saws because these tool marks could have been erased during subsequent working. Instead of curved tool marks, straight lines with long parallel longitudinal striations were found on both flat surfaces and edges on some of the fragments. These may be the result of sawing using hand-held tools that were moved backwards and forwards across the surface of the stone. The tools are likely to have been saws with long straight working edges and/or files with similar but broader working edges charged with abrasive.

Some fragments are incised with straight lines, which in some cases may be decoration, and in others, residue of primary shaping. In every case, the lines are straight with long parallel longitudinal striations as described above. Some of these straight lines have “U-shaped” cross-sections which suggest they may have been worked with a file or pointed tool guided by a straight edge. No concave longitudinal depths are present which would suggest the use of rotary tools, either for sawing, incising or polishing.

The fragments are remarkably thin, with the muscovite fragments ranging from 0.6 to 2.0 mm thick; and calcite fragments ranging from 1.7 to 2.4 mm thick. These decorative pieces may have been fashioned by first creating a larger rectangular block. First, the outer surfaces of the rectangular block would have been cut and possibly filed into shape. Then a series of plaques could have been sawed off the end with a guide to keep thickness relatively constant. Many similar pieces could have efficiently been produced from a given rectangular block in this way.

5 Jades in the collections of the Arthur M. Sackler Gallery

5.1 Materials identification

Fifty-six Western Zhou jade objects in the Sackler collections were studied using detailed visual examination by stereomicroscopy, mineral content determination by FTIR, and some additional study by XRD and XRF. Fifty were found to be composed of nephrite, and six were found to be composed of other stone materials, including two each of serpentine, muscovite and calcite. Almost all have surface accretions including soil, brown and black debris, and red material, identified as cinnabar by the presence of mercury by XRF. Powdered cinnabar is known to have been scattered within burials near or on the deceased, starting in the late Neolithic to early Shang Dynasty, and became widespread practice in the Shang and Western Zhou periods (for example, see Bagley[17] and Xu[18]).

The nephrite material of the Western Zhou jades in the Sackler collections is remarkably alike in color and texture. The color of translucent, unaltered nephrite typically occurs as various shades of light grayish olive, ranging from in hue 2.5 to 10Y; ranging in value/chroma from 5/2 to 6/4 (see refs. [19, 20]). The nephrite is generally fine grained, homogenous, and free of mineral inclusions, although occasionally small graphite inclusions were seen. No visual evidence of heating or burning was found, which would include an overall whitish color, and an opaque, hard surface[21]. Most jades display surface alteration that ranges from patchy to almost completely changed, and is typically light yellowish brown (10YR 7/4) to grayish yellow (2.5Y 7/4) in color. This surface alteration, referred to as “burial alteration”, is thought to occur in high pH burial environments, where selective dissolution of nephrite crystals occurs on a microscopic level[22,23].

Noninvasive surface XRF is an ideal method for compositional analysis of jades composed of nephrite beyond their basic mineral composition[7]. Two major types of nephrite deposits are known to occur in nature: 1) nephrite associated with metamorphosed dolomitic marbles, and 2) nephrite associated with ultrabasic serpentinites[2,8]. Dolomitic marbles are composed predominantly of dolomite, and the associated nephrite tends to have low iron content with no significant ionic substitution by nickel and chromium. Ultrabasic serpentinites consist predominantly of serpentine, and unlike nephrite related to dolomitic marbles, the associated nephrite tends to have higher iron content with some ionic substitution by chromium and nickel. The minor elemental composition of nephrite based on these ionic substitutions often indicates from which type of geological deposits the raw material has originated.

Surface XRF analysis of the 50 Sackler nephrite jades reported as oxides yielded a range of the FeO content of 0.27 to 5.48 wt.%, while the majority (46 of 50 jades) contain FeO <2.00 wt.%. MnO ranges from 0 to 0.41wt.%, while the majority (43 of the 50) contain MnO <0.20 wt.%. All the 50 jades had Cr_2O_3 contents of 0 to 0.02 wt.% and NiO contents of 0 to 0.01wt. %. These minor elemental compositions indicate that all of these jades are composed of low-iron (tremolitic) nephrite. The low-iron contents along with the low Cr_2O_3 and NiO suggest that the material originated from a geological deposit where nephrite is associated with metamorphosed dolomitic marbles, rather than ultrabasic serpentinites. This finding may help pinpoint exact jade sources in China, although no research in this area is currently underway.

The chemical and physical causes of nephrite color continue to be of interest to jade scholars. The original color, however, can change when an object undergoes burial alteration (which tends to lighten color), and/or acquires various surface discolorations (which tend to darken to brownish hues). Likewise, noninvasive analysis of Chinese jades using XRF can be problematic because certain trace compositions can be due to alterations, discolorations and accretions on the surface rather than due to the composition of material. In the current study, no strict correlation was found between Fe and Mn content, although some general trends can be seen as shown in the examples in Table 2. Although variations do occur, the general trend is for nephrite to get darker in color with increasing FeO and MnO content. Most of the jades are composed of nephrite with low FeO and MnO, and are a grayish olive color. An example of a jade object with a relatively high FeO and MnO content is the dagger-axe, S1987.871, which is dark brown in color.

Table 2 Some Western Zhou jades arranged by increasing iron content (by wt. %) along with the color[18,19] of the jade material. Nephrite tends to become darker with increasing FeO and MnO content

Object type, accession number	FeO	MnO	Color (Munsell notation)
Tubular ornament, S1987.931	0.4	0.03	light olive (10Y 6.4)
Bird pendant, S1987.667	0.28	0.03	grayish greenish yellow (7.5Y 7/4)
Yuan disk, S1987.674	0.49	0.04	light grayish olive (10Y 6/2)
Bird pendant, S1987.536	0.8	0.03	grayish olive (10Y 4/2)
Bird pendant, S1987.863	1.45	0.05	grayish olive (10Y 3/2)
Bird pendant, S1987.669	1.97	0.14	grayish olive green (5GY 4/2)
Ge blade, S1987.871	5.48	0.32	moderate olive brown (2.5Y 3/2)

The six objects analyzed by FTIR are found to be composed of stone materials other than nephrite, including serpentine (bird pendant, S1987.635, and fish pendant, S1987.642), muscovite (ox-head pendant, S1987.872, and ox-head ornament, RLS1985.48.3680) and calcite (trapezoidal plaques, LTS1985.1.285.1 and LTS 1985.1.286.2).

The trapezoidal plaques may have originally been part of a Type III assemblage as described by Braghin[5], where the assemblage consists of several strings of beads suspended from the plaque attached through linked perforations at its top and bottom. These assemblages may have been attached to the clothing or wrappings of the burial occupant. A similar object is the double phoenix-bird patterned trapezoidal plaque shown in page 200 of ref. [24], which is from Fengchu, Qishan County, Shaanxi, stored at the Qishan Zhouyuan Museum.

Two ox-head pendants (RLS1997.48.3680 and S1987.872) were found to be composed of massive muscovite, also called "sericite", similar to the Zhouyuan fragments discussed above. Again, the material of these objects is similar to nephrite in appearance and closely resembles the harder, more durable material. Although both objects are simple ox-heads they are not identical in size or composition, and therefore not thought to be related to one another in origin. As with the previously discussed objects, the ox-heads are small and of simple design. These objects are similar to other findings from Shaanxi, such as the ox-heads excavated from the Baoji area, held at the Baoji Municipal Museum of Bronzes, BZM9:13, BZM4:203, 204.

5.2 Evidence of manufacturing methods

Searching for evidence of the technological methods used to manufacture these jades involves the study of features on the jades and the tool marks left from shaping them using stereomicroscopy and SEM. No evidence was found for the primary shaping of jade, so the possible methods of rough cutting are still speculative. Curved cut marks such as those observed on the back of a decorative pendant, M2012:150-13 from Sanmenxia (see page 23 of ref. [25]) suggest that a cutting wheel may have been used at least in this case. The Western Zhou jades tend to have an even, matte polish. Study of the surface polish, however, also was not a major focus of this work because these surfaces may have changed due to alteration, later polishing, waxing and other treatments. Often parallel striations of polish marks are visible under the stereomicroscope, suggesting that the polish abrasive was not always finely divided. In other cases, the polish is minimal, and scratch marks left from the incising process are usually well-preserved on the outer polished surface of the jade (see Figure 4).

Three types of features were studied in detail using stereomicroscopy: circular holes, openwork, and incised decoration. Only the latter was studied by producing silicone molds that could be imaged in the SEM because extensive surface accretions on the jades in circular holes and openwork precluded the use of silicone molding material in these areas. Areas of the incised decoration could be found where it was feasible to produce silicone molds without damage to the objects. Silicone molds were produced and examined using similar methods outlined for studying Mesopotamian quartz cylinder seals and Chinese jades[16,26]. The silicone molds can be oriented and studied in detail using SEM, but one needs to remember that a mold is in reverse relief from the original jade object where a concave area on the jade appears convex on the silicone mold (and visa versa). Molds are also the mirror-image of the jade object surface; however the images shown here have been digitally rotated so that they are in the same orientation as the jade surface to aid comparison.

5.2.1 Circular holes. Nearly every object was likely strung as a pendant or ornament, and contained one or more circular holes. They are almost always tapered and biconical, indicating that each hole was created by drilling from both sides of the jade object. Typically these circular holes are 2.5—4.0 mm in diameter measured at the jade surface. In case the bottom of the drill hole is preserved, they have a “U-shaped” cross-section suggesting the use of a solid drill. A circular hole drilled with a hollow drill would have an annular, ring-shaped feature at the bottom of the hole, where the cylindrical core of jade material left in the hollow of the drill was removed. No holes of this type were seen, and therefore we conclude that drilling small holes was typically accomplished with a solid drill. Occasionally circular holes are straight-sided and appear to have been drilled from one side. Pecked holes are not seen, most likely because it would be difficult to produce small circular holes on thin objects composed of hard, tough nephrite using this method. A typical tapered, biconical drill hole can be seen in the nose area of the fish pendant shown in Figure 4.

Figure 4 Detail of fish pendant, S1987.473, Arthur M. Sackler Gallery, showing tapered, biconical drill hole at the nose, and surface scratches due to working with a sharp point implement. Often circular holes are filled with cinnabar and other debris, which precluded the ability to mold these features for examination in the SEM.

5.2.2 Openwork. Openwork, a style for which a jade is decorated with patterned perforations, was not a common feature on the Western Zhou jades examined by us. Openwork had often been used to create holes and openings larger and/or different in shape than drilled circular holes. The Sackler *pei*, S1987.889, shown in Figure 5 is the one exceptional example of jade openwork dating to the Western Zhou period in the Sackler collections; it has 17 decorative openwork holes in addition to 14 circular holes. The openwork consists of elongated openings made through a combination of drilling an initial hole and subsequent enlarging to produce the decoration. The enlarging to create openwork may have been accomplished using a flexible string saw, which is a long string charged with abrasive and drawn back and forth through the drilled hole to remove material. The string used for this type of saw could have been fine cord, leather, sinew or other material. Similar openwork occurs on other Western Zhou jades (for example, figure M2001:452, disk with openwork, M2011:453 of ref. [27] and page 95 of ref. [28]).

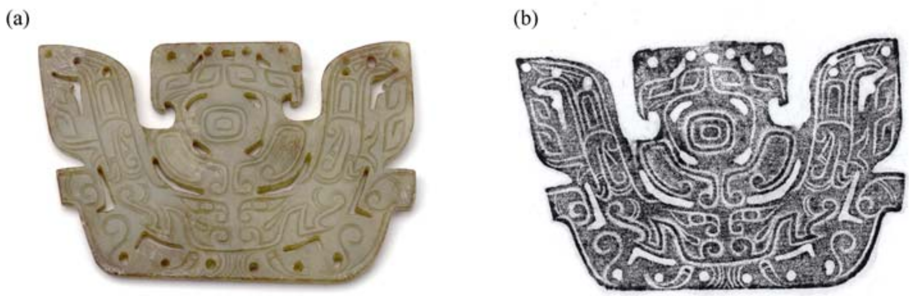

Figure 5 (a) *Pei* pendant, S1987.889 (6×9.1×0.4 cm), Arthur M. Sackler Gallery. The pendant has thirty-one perforations including circular holes and openwork. (b) Rubbing from pendant highlighting surface detail, circular holes and openwork.

5.2.3 Incised decoration. Incised decoration on these early jades is common, and begins with the late Shang to early Western Zhou animal pendants with incised eye rings and other detailing. Jades from the later in the Western Zhou period exhibit more complex incised designs, and in some cases, they incorporate the double beveled edge and/or negative relief.

Nine jades, listed in Table 3, were selected for the study of incised decoration by examining

Table 3 List of jades from the Arthur M. Sackler Gallery, Smithsonian Institution studied using silicone molds of incised decoration

Early Western Zhou period
Fish pendant, S1987.632
Bird pendant, S1987.704
Bing handle, S1987.847
Bing handle, S1987.521
Middle to late Western Zhou period
Bidisk, S1987.464
Xuanji pendant S1987.516
Yuandisk S1987.674
Late Western Zhou period
Tubular ornament, S1987.931
Xuanji notched disk pendant, S1987.516 (check date)

silicone mold impressions of tool marks. In a study of post-Neolithic Chinese jades[9], the established criteria were used to recognize the characteristics of tool marks made by several abrasive incising techniques: rotary sawing (involving disk-shaped tools or wheels), non-rotary riffling, sawing, and point abrasion. The criteria were concerned with several characteristics of the incised features: mainly, the surface texture, the shape in plan view (assessed directly above the feature) and the longitudinal depth (assessed from the side of a molded feature where the profile along the feature can be easily seen). Most tools would have been charged with loose mineral abrasives of varying particle size depending on the fineness of the area to be worked.

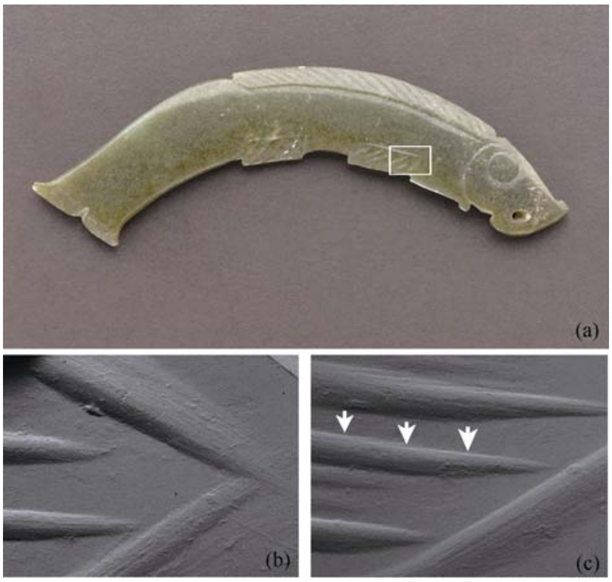

Figure 6 (a) Fish pendant, early Western Zhou, S1987.632 (9.0×3.0×0.5 cm), Arthur M. Sackler Gallery. (b) SEM micrograph of incised lines forming the fin (plan view) showing the incised grooves protruding upwards on the mold; parallel straight striations are present along their surfaces. (c) Mold of lines (oblique view) showing the profiles (arrowed) along grooves are straight or slightly concave. The fish fin was worked by non-rotary tools, such as small saws or riffler files.

Fine tool marks within the straight linear features depicting fins on the fish pendant, S1987.632, can be clearly seen in mold impressions (Figure 6). The impressions were imaged in both plan view and oblique angle, and show that the linear features are composed of long parallel straight striations. These striations were made by filing, probably with a riffler with a short working distance. As indicated on Figure 6(c), the impression has a convex longitudinal depth suggesting that the tool mark itself is composed of a concave longitudinal depth. Lines of this type are producing through filing rather than through the use of a rotary tool.

The *bing*, S1987.847 (Figure 7), is more complexly decorated. This jade is an exquisite example of the Western Zhou craftsman's ability to decorate with a combination of thick and thin intaglio lines and extensive beveling, which were decorative approaches not seen earlier in the Shang Dynasty[4]. This kind of decoration is sometimes called "false relief" because a raised line is made using two close, parallel lines carved into the surface of the jade (E. Pearlstein, personal Similar tool marks were found on the late Western Zhou *yuan*, S1987.674 (Figure 8), which is a flat incised disk with a double beveled edge design. Many near parallel, straight lines make up the sharp curves of the design indicating that these designs were created through a series of scratches by point abrasion. In other words, the curves are formed by a series of slightly offset straight lines. Feathered edge also indicates the use of sharp point abrasion. No discernable interface was observed in straight lines adjoining curved features. Likewise, no discernible difference in style or execution of "U-shaped" groves and radiating curves could be seen, so it is likely that they would have been made by using the same tools.

5.2.4 Additional discussion and conclusions. No evidence for the use of the rotary wheel for incised design on the Western Zhou jades in the Sackler collections was found. It is possible for incised lines consisting of a shallow groove (1—2 mm deep) to be scratched into the surface of nephrite in a relatively short time given that the tool itself or the abrasives used are sufficiently hard. Incised lines can be produced through a variety of methods, involving both abrasive methods and non-abrasive methods[29]. In this study, a sharp steel graver was found to effectively scratch nephrite, but the tool point quickly blunted. Both sharpened points of chert (7 on the Mohs scale) and diamond (10 on the Mohs scale) produced incised lines on nephrite — the diamond point being so hard that the abrasive cutting was difficult to control. Quartz-based materials such as chert, flint, and agate might be a readily-available and practical choice for point abrasion to produce incised designs on nephrite.

Conversely, several authors have suggested that the jades in the Western Zhou period were incised by using rotary incising wheels[24,28,30]. More recently, a study of a limited number of jades at the British Museum suggests that rotary incising wheels were first used occasionally during the Shang Dynasty, however it was not until the Tang Dynasty that they began to use them on a regular basis[9]. Experimental tests on nephrite using flint tools and diamond points displayed uneven characteristics and tended to form more or less parallel lines of uneven widths and depths. Hand-held saws and riffler files left groups of parallel, relatively continuous striations.

Study of the three jades implies an evolution in the approach and technology of jade working over time from the early fish to the later ring, although many more jades will need to be studied before drawing firm conclusions. Other factors include the overall quality of the jade, and regional or personal variations in technical skill. The design in the late Western Zhou *yuan*, S1987.674 shows a precision that becomes more typical during the subsequent Eastern Zhou period, and this approach was possibly due to a development of tools and techniques, and/or use of harder abrasives. Although quartz sand is usually thought to have been used as an abrasive, we cannot preclude the idea that the Chinese may have been using much harder materials such as corundum or diamond as abrasive.

Many of the jades in the Sackler collections show stray scratches on their surfaces which originate from the incised design, and which strongly supports the idea that sharp points were used to work incised designs. Images of unearthed jades from various sites show similar features, some even more pronounced as shown in jades from Baoji, Shaanxi, housed at the Baoji Municipal Museum of Bronzes, such as a dragon pendant from tomb no. 2 at Rujiazhuang, and a circular pendant from tomb no. 9 at Zhuyuan'gou (pp. 48, 54 of ref. [31]). Similar stray scratches may have been originally present on many jades due to the incising process, but subsequently removed by the final steps of surface finishing and polishing.

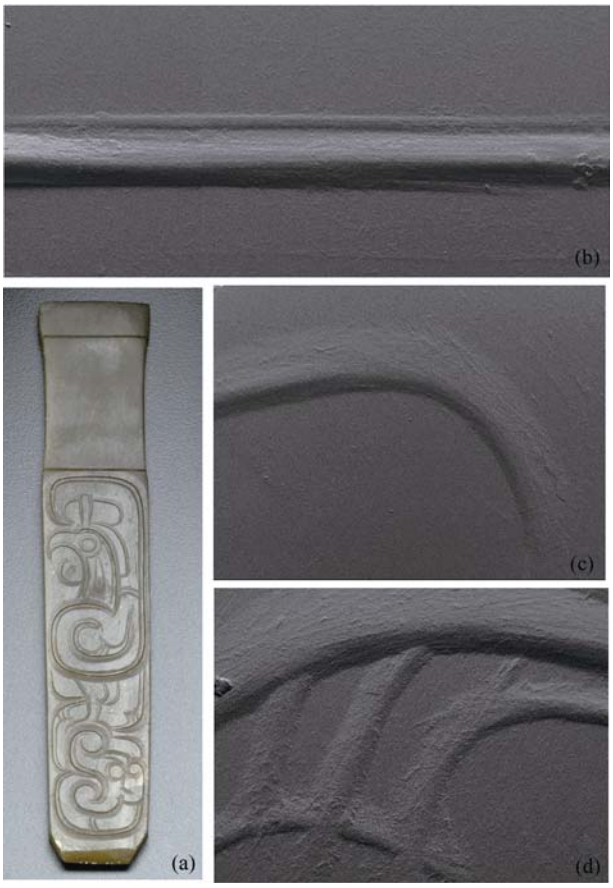

Figure 7 (a) Handle, *bing*, middle Western Zhou, S1987.847 (13.2×2.5×0.4 cm), Arthur M. Sackler Gallery. SEM micrograph of silicone molds from the surface of the *bing*; (b) upper incised straight lines with fine parallel striations along their surfaces, probably created with a straight saw or file; (c) curved line which is created through a series of fine straight striations; (d) detail of incised area showing the lines are made through a series of short striations.

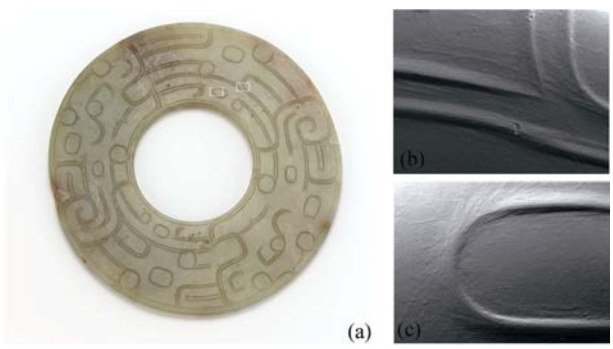

Figure 8 (a) *Yuan* disk, middle Western Zhou, S1987.674 (0.5 cm×16.7 cm diameter). SEM micrographs molds (a) and (b) show details of the incised features: their surfaces are characterized by single straight striations and series of parallel straight striations. These incised lines were probably made with files and/or sharp points.

6 Conclusions

Dr. Arthur M. Sackler's preferences for Western Zhou jades is reflected in his collection now at the Arthur M. Sackler Gallery which consists almost entirely of nephrite ornaments and pendants, whereas the archeological materials in Shaanxi indicate a much broader repertoire of nephrite and stone materials used in Western Zhou burials. Together, these collections provide insight into the relatively wide range of materials used during this period. Different materials seem to have been reserved for certain uses based on their visual appearance and workability. Also, small and simple decorative items tend to be worked from stone, whereas more complexly worked and decorative objects tend to be composed of nephrite. This is not always the case, for example the exceptionally high-quality calcite plaque, BRM1:279, excavated from Rujiazhuang, Baoji (see Figure 1). Other stone objects of exceptional quality may emerge as more mineral identifications are completed on excavated materials dating to the Western Zhou period.

All of the relatively small objects in the current study were produced through simple processes involving solid drilling, sawing, riffling, and sharp point abrasion; no evidence was found for the use of rotary tools for incising or primary shaping. Our understanding of the full repertoire of jade working methods used during the Western Zhou may be improved by the further detailed study of larger jade and stone objects dating to this period.

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