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CRACK PATTERNS MORPHOLOGY OF ANCIENT CHINESE WARES

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Introduction

This paper presents the first results obtained within the project "Scientific Research on the famous crackled glazed ceramics of the Song Dynasty" launched in October 2012. This research study intends to provide information on the manufacturing technology, the function and the degradation of the so-called Guan and Ge Chinese crackled wares through the study of the formation and morphology of crack domains using image processing on archaeological Guan and imitation Guan wares. We show that this new methodology can be a very suitable non-destructive tool to study the morphology of ceramic crack domains. The contribution of this project to authentication and conservation aims to be of interdisciplinary interest.

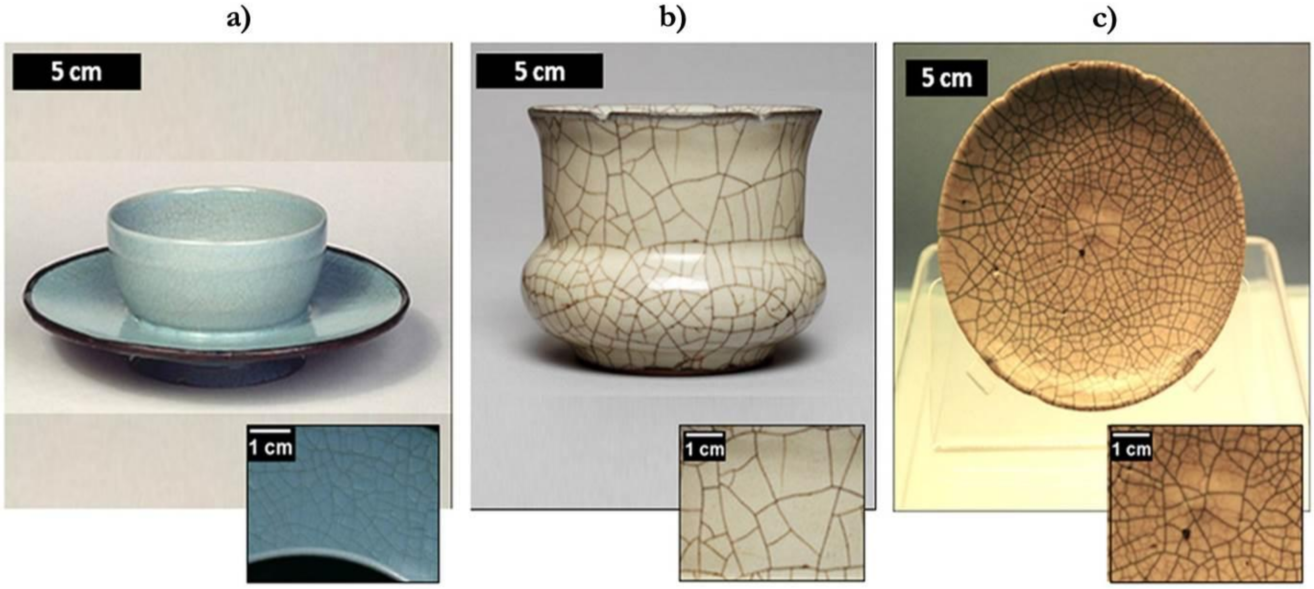

Figure 1. Photographs of the three crackle wares from the Song dynasty (960-1279 AD) and detail of their crackle glaze. a) Ru bowl stand, V&A Museum; b) Guan vase, V&A Museum; c) Ge plate, Shanghai Museum.

Archaeological background

Glaze crackling is a frequently occurring phenomenon in ancient Chinese wares. It is observed as early as the Shang (1600-1046 BC) and Zhou dynasties (1046-256 BC) on Deqing primitive celadons and later wares such as Yue or Yaozhou ceramics dating from the Eastern Han (25-220 AD) and Tang (618-907 AD) dynasties. However, it is only during the Song Dynasty (960-1279 AD) - which is the period that marks the summit of China's intellectual and technical achievements - that people especially the nobles and the royal family began to pay more attention to glaze crackling and valued it to an aesthetic level. Chinese potters of this period have empirically developed processes to manufacture crackle glazes evoking natural phenomena such as ice-crackles or fish scales. These ceramics were made in specific kilns and were exclusively dedicated to the court. They hold a very special position in Chinese ceramic history because of their aesthetical qualities and scarcity (Kerr and Thomas 2004).

During the Northern Song dynasty (960-1127 AD), Ru ware was celebrated for its sky-blue luminous crackled glaze attesting its technical superiority over preceding wares. Although modelled on Ru ware, the most sophisticated achievements of crackle glazes were obtained later on with Guan and Ge wares produced during the Southern Song dynasty (1127-1279 AD) (Figure 1). These ceramics had their own character, usually with a prominent crackle as their only decorative feature. Although they were extensively copied under the following Yuan (1279-1368 AD), Ming (1368-1644 AD) and Qing (1644-1911 AD) dynasties, the same level of quality was never achieved afterwards (Krahl and Harrison-Hall 2009).

Guan ware often has relatively large cracks. For decoration purposes, cracks were sometimes stained with iron-oxide or charcoal, most commonly for wares after the Song dynasty (Wood 1999). Ge ware is often characterized by scholars by its crackling effect called "gold threads and iron lines". This is a double crackle network with lines varying in width and colour: the major crackle is deliberately stained black and the minor crackle appears gold-brown (Vainker 1993; Scott 1993).

The shape, size, colour and decoration of Guan and Ge wares have been well studied and classified according to the period and site of production (Vainker 1993; Scott 1993; Li 1998). The global chemical composition of their glazes and bodies is also well known (Wood 1999; Li *et. al.* 2001; Li *et al.* 2009; Miao *et al.* 2012). However, many questions remain on the origin and evolution of manufacturing techniques of these wares.

Aims of the study

To manufacture glazed ceramics, a three step process is commonly used: 1) the glaze raw materials are applied on the ceramic body; 2) after drying, the whole is fired at a temperature high enough for the glaze to vitrify and cover the ceramic body; 3) the last step is the cooling, during which the glaze solidifies

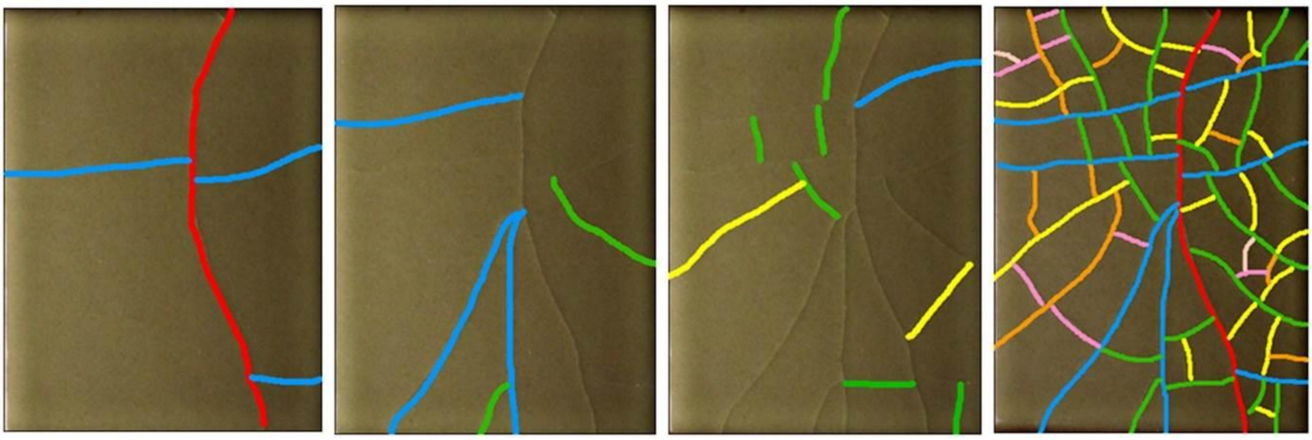

Figure 2. Succession on cracks in hierarchical patterns in a test glaze-body sample. From left to right, first (red), second (blue), third (green), fourth (yellow) and higher orders (orange, pink and light-pink).

and binds to the ceramic body. Cracks form during the cooling, when a mechanical stress occurs between the glaze and the body due to differences of thermal expansion (Eppler and Eppler 2000).

Whereas cracks in varnishes and paint have been the interest of many researchers in the field of Cultural Heritage these last decades, cracks in glazed ceramics have been almost totally neglected (Hodges 1988; Eggert 2006). However, in vitreous materials the morphology of crack patterns is a direct marker of the object history since it depends on the glaze-body properties, which comprises the chemical composition, the microstructure, the thickness etc. Furthermore, when the crack pattern is *hierarchical* - the cracks are formed successively (Figure 2) - the observed morphology can give access to the crack formation process (Bohn *et al.* 2005a; 2005b; 2005c). Therefore, we aim to provide information on the manufacturing of ancient Chinese crackled wares through the study of the formation and morphology of crack domains.

One of the difficulties of this study is that in archaeological samples, the observation of crack patterns is not always obvious. Indeed, cracks are often translucent and more or less fine so the boundaries of crack domains are not always directly visible. Besides, the crack network can be very intricate and the surface of the samples altered which entails a detailed study of the crack patterns morphology. One of the techniques to improve the visibility of cracks is to use raking light photography. However, since cracks are oriented in very different directions, this method requires various raking illuminations, which can be demanding when it comes to non-professional photographers. To improve our knowledge of the crackling process of such complex artefacts as Chinese ceramics, we have used image processing in order to enhance the visibility of crack patterns and to obtain statistical data on the number of domains, their size, shapes, distributions, etc.

In this paper, we present results obtained using imaging processing on archaeological Guan and imitation Guan wares. We show that this new methodology can be a very suitable non-destructive tool to study the morphology of crack domains.

Method and results

Twenty-three samples of crackled glazed ceramics dating from the Song and Yuan dynasties have been studied. These shards belong to the collection of the Key Scientific Research Base of Ancient Ceramics. They all come from archaeological excavations in the sites of *Jiaotanxia*, *Laohudong* and *Fenghuang hill.* We have selected these samples according to their various crackle patterns. They have different shapes and sizes, as well as body and glaze colourations and thicknesses (Table 1). It implies that various raw materials, manufacturing and firing conditions would have been used. The inner and the outer glazes can also differ notably within one sample, so they are considered as independent glazes, ranging the total number of studied glazes to forty-six.

As mentioned above, it is not always easy to clearly observe the crack patterns. Therefore, we have used D-Stretch, which is a plugin to ImageJ software, developed by J. Harman[1]. Usually, this program is a tool for rock art researchers. In this paper, we show that D-Stretch can also be a powerful tool for researchers working on crackled ceramics since it enhances crackle networks and brings out fine cracks that are invisible to the naked eye.

#	Period	Site	Glaze colours	Group I glaze	Group O glaze	L (cm) I glaze	L (cm) O glaze
1	SS	Jx	opaque light blue-green	A	A	0.47	0.67
2	SS	Jx	translucent, light buff-grey	A	A	0.25	0.24
3	SS	Jx	translucent to opaque, light buff-grey	B	A	0.17	0.22
4	SS	Jx	opaque greenish-grey	A	A	0.32	1.41
20	SS	Jx	opaque blue-grey	A	A	0.48	0.45
21	SS	Jx	opaque greenish-blue	A	A	0.81	0.42
22	SS	Jx	opaque buff-grey	A	A	0.29	0.33
23	SS	Jx	opaque yellowish	*u*	A	*0.95*	0.18
7	SS	Lh	opaque greenish-blue	A	A	1.41	0.50
8	SS	Lh	opaque greenish-blue	A	*u*	0.53	*2.00*
13	SS	Lh	opaque greenish-grey	B	B	0.23	0.34
14	SS	Lh	opaque greenish-blue	A	A	0.37	0.38
5	SS or Y	Fh	inner: opaque blue-grey outer: opaque light blue-green	A	A	0.35	0.63
6	SS or Y	Fh	opaque greenish-blue	A	A	0.44	0.45
15	SS or Y	Fh	opaque brownish	A	A	0.21	0.18
16	SS or Y	Fh	opaque blue greenish-grey	A	A	0.26	0.42
9	Y	Lh	opaque greenish-grey	B	A	0.28	0.35
10	Y	Lh	translucent colorless	A	A	0.17	0.21
11	Y	Lh	inner: opaque dark greenish-blue grey outer: opaque greenish-grey	A	A	0.34	0.38
12	Y	Lh	inner: opaque greenish-grey outer: opaque greenish-blue	A	A	0.34	1.41
17	Y	Lh	opaque blue grey	A	A	0.30	0.27
18	Y	Lh	opaque blue-grey	B	B	0.45	0.51
19	Y	Lh	opaque greenish-blue	A	A	0.65	0.45

Table 1. List of the samples with their crack pattern morphologies (Groups A and B; u: unclassified) and their calculated characteristic length of crack domains L (cm). The following abbreviations are used SS: Southern Song dynasty; Y: Yuan dynasty; Fh: Fenghuang hill; Jx: Jiaotanxia; Lh: Laohudong.

D-Stretch works on digital camera images. Images are enhanced using colorspaces (csp) so the pictures should have a hue difference. Different colorspaces produce different results. They have names like RGB, LAB, YDS, YBK, LDS, and others. The assets of this methodology are that it is not invasive, relatively fast and no special filters or lighting are needed. However, the procedure for colorspaces enhancement has to be adapted to each sample.

D-Stretch image processing has been used for all the archaeological samples of the corpus because the morphology of crack patterns was not clearly visible with the naked eye. Indeed, most of the glazes are constituted by very thin translucent cracks and the glaze surface is weathered or dirty. Figures 3 and 4 demonstrate that D-Stretch colorspace treatment can clearly enhance the crack patterns and bring out cracks that are not visible to the naked eye due to the alteration of the surface: the crackle network which was hardly seen on images with visible light, is clearly revealed after image processing. These types of images could help restorers or curators in establishing cleaning and conservation methodologies.

These images also allow us a better understanding of the crack formation process since it shows the presence or not of hierarchical patterns. For example, crack distribution of the outer glaze of sample #9 is very difficult to observe with the naked eye but after image processing a hierarchical pattern is clearly evidenced (Figure 3a). The distinction between primary and secondary cracks can also be facilitated thanks to the use of contrasting hues (Figures 4a-4d).

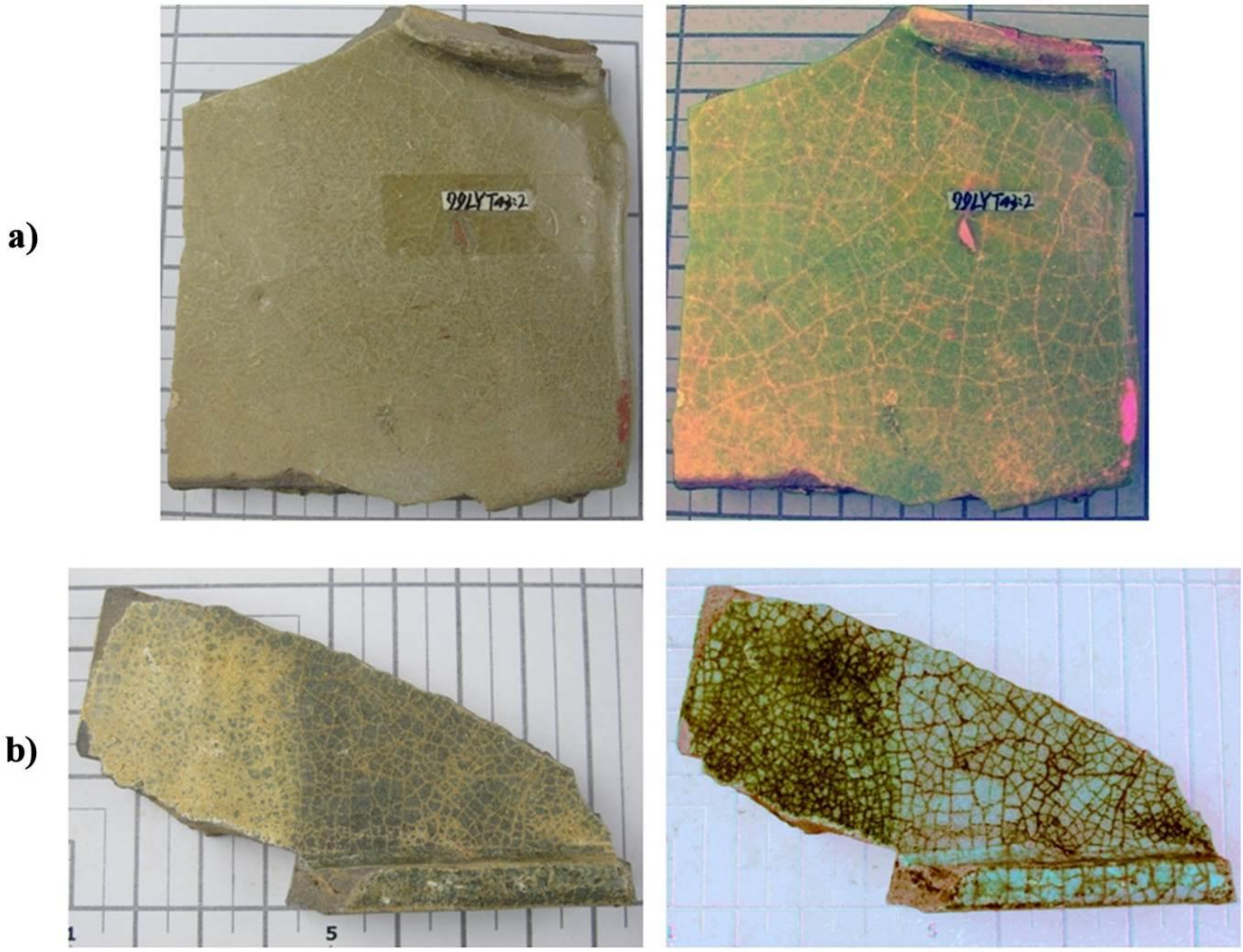

Figure 3. Image of the whole samples outer glaze crack patterns under visible light and after colorspaces treatment using D-Stretch, a) sample #9 csp YBK, b) sample #10 csp LXX.

Thanks to the enhancement of crack patterns morphology in the archaeological samples, we can obtain statistical data on the number of domains, their size, shapes, distributions, etc. An appropriate description of the crack pattern, based on the hierarchy and space-dividing properties, can be approached using the characteristic distance between cracks l as defined by Bohn *et al.* 2005b: $l = \sqrt{\frac{A}{N}}$, where A is the observed area and N the number of domains in the pattern. This parameter can vary linearly with the layer thickness (Bohn *et al.* 2005b). This will be discussed in further steps of the project (Lahlil *et al.* in prep.).

To count the number of domains *N* in each sample, we have used the open source software ImageJ that is an image processing and analysis program written in Java (Choi *et al.* 2007). The *Analyze particle* command allows counting and measuring objects in binary or thresholded images. In images of crackle wares, cracks appear in a slightly different colour or brilliance than the uncrackled part of the glaze. We have used this property to obtain thresholded images where crack domains can be considered as isolated objects that can be counted by the software. Analysis was performed on the selected area A (Figure 5).

L values range from 0.17 to 1.41 centimeters (Table 1) showing that a large variety of morphologies were obtained, from very close to very large crack patterns. This could indicate that obtaining a specific decorative effect with various sizes of crackling was not entirely controlled by potters. However, the limited number of samples does not allow us to confirm such hypothesis at this stage of the study. The images obtained with D-Stretch, as well as the characteristic length of crack domains, help us to establish two main groups of pattern morphology (Table 1; Figure 6). Among the 46 glazes observed, two of them could not be classified because of the absence or the insufficient number of cracks.

a)

b)

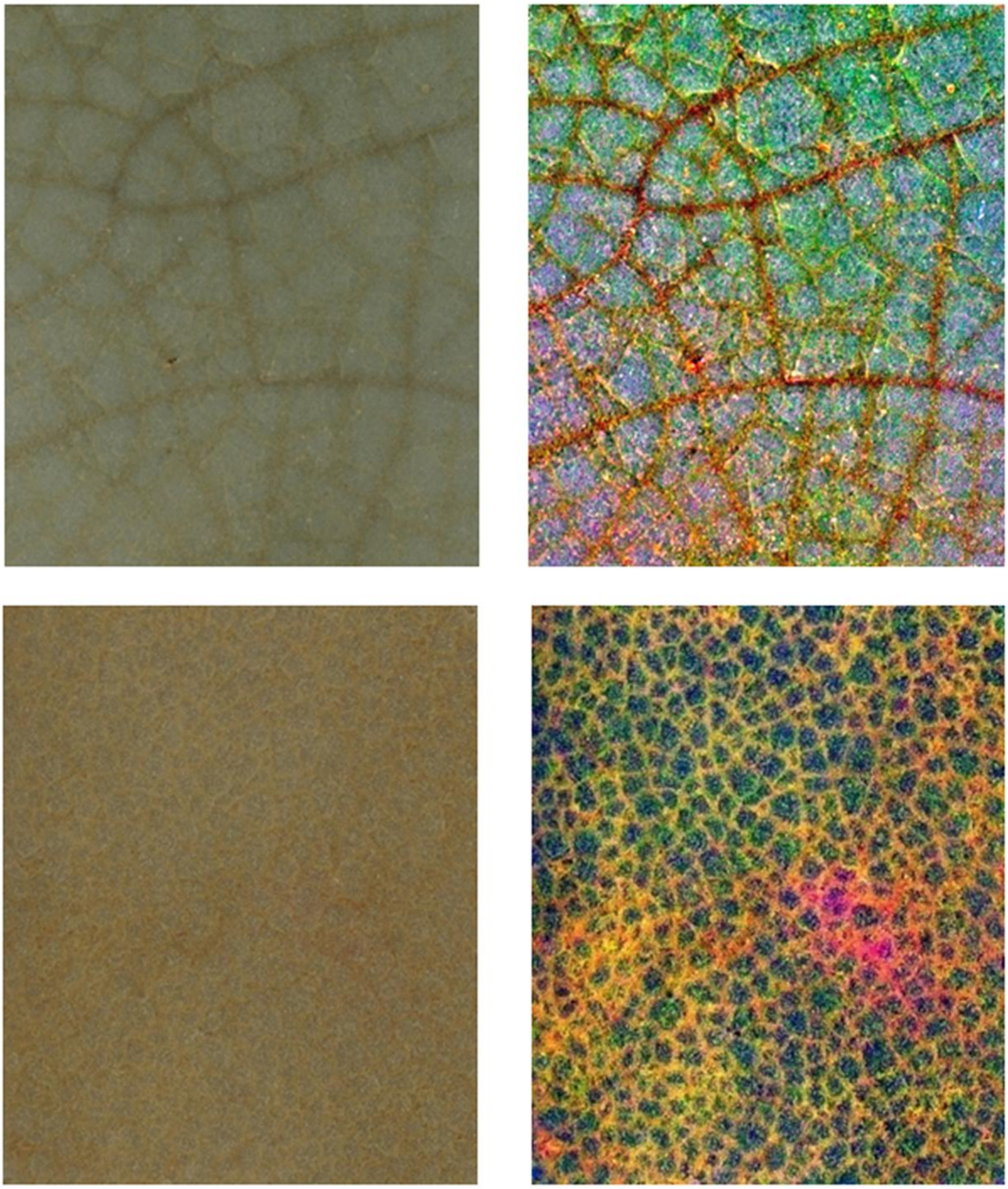

Figure 4a and b. Images of inner glaze crack patterns under visible light and after colorspaces treatment using D-Stretch, a) sample #6 csp YXX, b) sample #3 csp YBK.

Group A: 38 glazes display a hierarchical crack pattern. Cracks of different lengths are observed, forming a space-divided geometry. Crack formation process is similar to the one observed in test samples made under controlled conditions (Figure 2): one fracture has finished its propagation before the next nucleates. Cracks of lower order modify the mechanical stress field in the glaze and have thereby a direct influence on the morphology of newer ones. In the vicinity of an existing crack, the residual stress is parallel to it so, a new crack turns to join at a right angle when approaching an older crack (Bohn *et al.* 2005a). L= [0.17-1.41] cm.

Group B: 6 glazes have patterns similar to foams. They are formed of very fine and brittle translucent cracks with no apparent hierarchy. Similarly to the mechanism occurring in the formation of foams, these fractures can be considered as simultaneous (Stavans 1993). In these samples, the crack paths

c)

d)

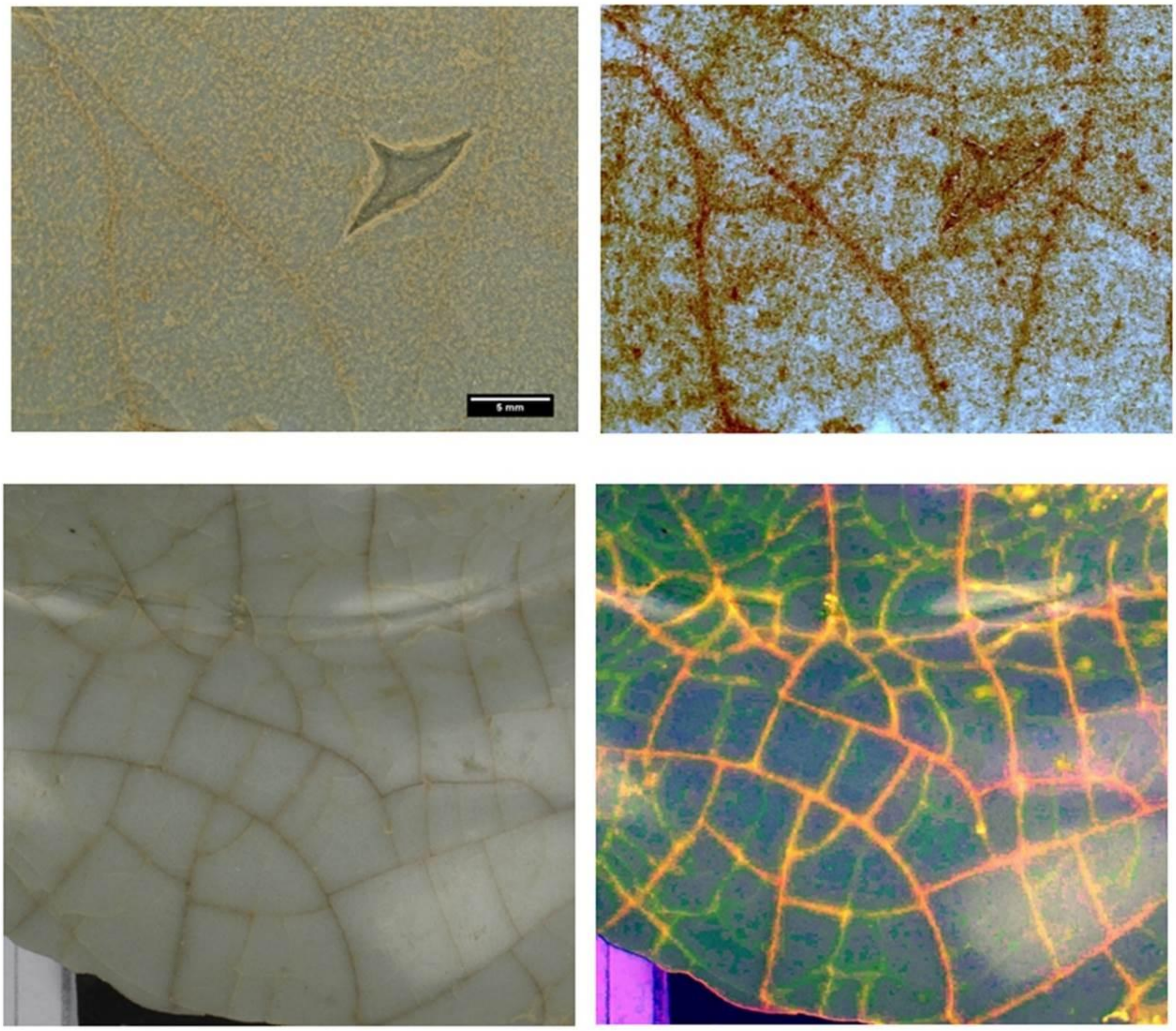

Figure 4c and d. Images of inner glaze crack patterns under visible light and after colorspaces treatment using D-Stretch, c) sample #7, csp YXX; and outer glaze of d) sample #5 csp YBK.

seem discontinuous and misshapen indicating that the propagation of the fractures is dominated by the material heterogeneity. L= [0.17-0.51] cm.

Group A has the large majority of glazes (38/46) confirming the intentional will of potters to obtain glazes with hierarchical crack patterns, which implies they produced glazes decorated with well-defined and organized cracks. However, various patterns can be observed within this group: among the 38 glazes of Group A, 30 exhibit a clear hierarchy of cracks with more or less large domains (five have very large crack domains). In five glazes, although the hierarchical pattern exists, cracks seem to have propagated more in volume and lead to slightly different morphology which resembles ice crackling (samples # 15, outer glaze #11, inner glazes #12 and #23). We also noticed three glazes where the hierarchy of cracks is less striking than in the other samples and that are close to those of Group B (samples #10 and inner glaze #17), which let us think that slight changes in the manufacturing process could easily lead to one or the other type of crack patterns.

These preliminary observations show that, within the corpus of samples selected, no specific crack patterns for Song or Yuan period can be noticed. Neither is it the case for a specific archaeological site.

Conclusions

We demonstrate that image processing can be a very useful non-invasive tool for curators, restorers and researchers to better understand ancient Chinese crackle wares. It allows the enhancement of the crackled network where cracks are often pale, and brings out cracks invisible to the naked eye because of surface damage. Images obtained give access to the number of crack domains and their characteristic length, which in turn will help us to approach the

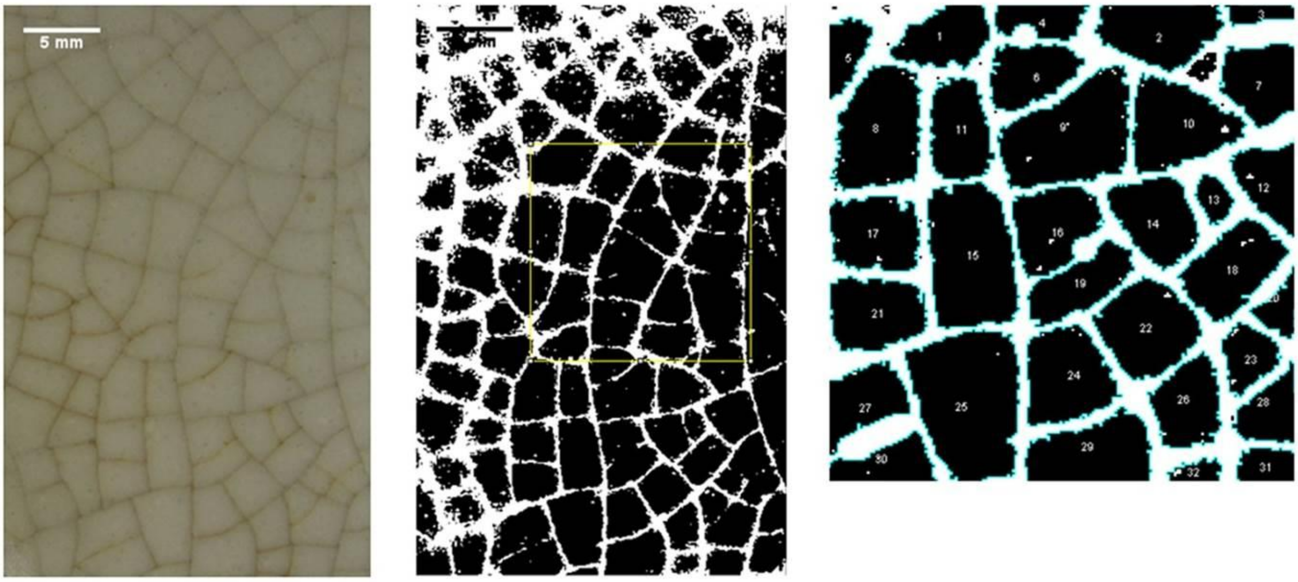

Figure 5. Imaging processing performed with ImageJ software following different steps: left) image in visible light; centre) B&W thresholded image and selection of a suitable area A; right) measurement of the number of crack domains N. For each domain, we have access to the area, perimeter, width, height, circularity etc.

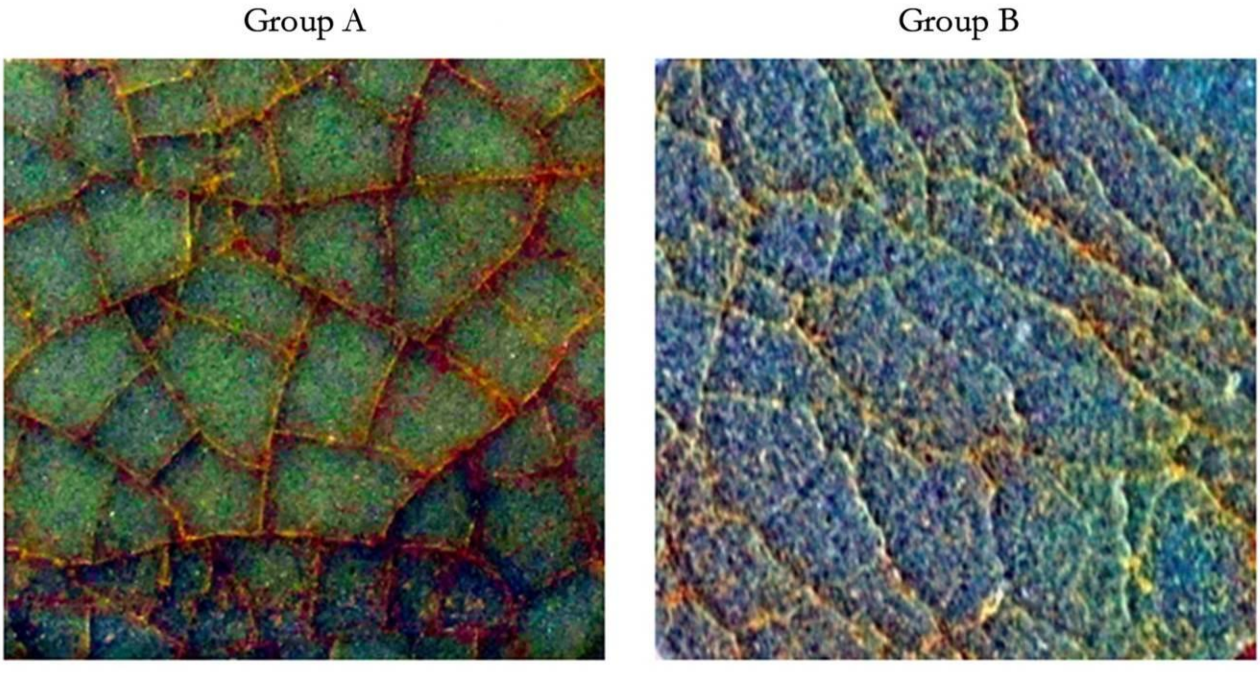

Figure 6. Different types of crack pattern morphology classified as Group A - hierarchical pattern, and Group B - foam-like pattern.

manufacturing technology of crackle glazed ceramics.

In the next step of the project, we will see if correspondence can be established between the morphology of crack patterns and the physical properties, the chemical composition and the microstructure of glazed ceramics. Samples with glaze compositions close to those employed during the Song and Yuan dynasties will be reproduced and compared to archaeological samples in order to understand the effects of the body, the raw material grain size, the composition, the thickness, the firing and cooling process of glazes on the morphology and on the kinetics of crackling.

Acknowledgments

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[1] http://www.dstretch.com/
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