Chaîne Opératoire and the Construction of Buddhist Cave Temples in Northwestern China

Francesca C. Monteith,[A1] Ruiliang Liu,[B] Chris Gosden[B] and A. Mark Pollard[B]

[A]Peking University: School of Archaeology and Museology

[B]University of Oxford: School of Archaeology

[1] Corresponding author F.C. Monteith: fcmonteith@pku.edu.cn

ABSTRACT: In this paper we present the first application of the *chaîne opératoire* to the construction of rock-cut Buddhist cave temples in Northwestern China. We discuss a series of ten steps which might have been part of the construction of these cave temples. Although the steps identified are informative, we suggest that the most valuable outcome is the greater appreciation it provides of the practical complexity of the individual processes involved. The result is a new set of questions which should stimulate further research, particularly suggesting a greater role for archaeological investigation in the study of these important monuments.

INTRODUCTION

Buddhist cave temples are (usually) a cluster of (often) decorated caves carved into rock formations (fig. 1). In Northwestern China (the provinces of Xinjiang and Gansu; fig. 2) they begin to appear in the Northern Liang dynasty (AD 397-439) and continue to be constructed (and earlier caves modified) until the modern era.

This paper focuses specifically on the construction technique employed in this region. In contrast to Northern India and Central China, the rock in these regions consists of variably friable sandstone or cemented gravels, requiring the use of particular construction techniques to produce stable caves to house the statues, wall paintings and ritual space.

This technique involves applying thick layers of rendering tempered with chopped straw as a base layer to the walls, partly for consolidation, and partly to provide a flat surface for painting. In this region, a lack of suitable stone has led to the statues being created from a wooden, reed or straw framework which is then covered in plaster. Even with these adaptive techniques, the cliffs themselves are notoriously unstable, and many caves have been lost or damaged as a result of rock collapse. Periods of iconoclasm, or even unsympathetic attempts at restoration, have further contributed to the accumulated damage seen today.

THEORETICAL FRAMEWORK OF THE *CHAÎNE OPÉRATOIRE*

One of the most significant changes in the way that archaeologists have approached technological studies in the last thirty to forty years has been the adoption of the concept of 'technological choice' to study the acts required to produce complex objects, incorporating the *chaîne opératoire* of Leroi-Gourhan (1964, 1965, 1993), deriving inspiration from the work of Mauss (1979).

It has been most intensively applied as a means of integrating technological studies of archaeological ceramics with other more traditional forms of archaeological information, used to gain insights into the choices made by the potter

(Sillar and Tite 2000; Tite 1999). The starting point for this is the observation made by Kingery (1996), which he termed the "materials science paradigm". This paradigm holds that the structure and composition of the finished ceramic are a direct consequence of the choices made by the potter in terms of raw material selection, processing, firing, decoration and use. In effect, the choices made during manufacture and use are encoded in the observed composition and structure of the finished object. Sillar and Tite (2000) identify the following "five areas of choice" within any ancient technology:

- Raw material selection (to which we would add processing);
- Tools used to shape the raw materials;
- Source of energy to transform the raw materials and power any tools used;
- Techniques used to orchestrate the raw materials, tools and energy to achieve a particular goal, and;
- The sequence (*chaîne opératoire*) in which these acts are linked together to transform raw material into the finished product.

At each point, the materials science properties are considered alongside the practical, aesthetic and 'ritual' choices made by the potter. In many cases, the physical properties are a significant component of this choice, but the *chaîne opératoire* allows for other factors to be taken into account–for example, if the selection of a particular raw material is influenced by factors such as symbolic value. This paper applies these ideas to the production of cave temples in Northwestern China, although not all of the 'areas of choice' listed above are relevant. The construction of a cave temple is a complex process involving a range of craft activities; from the initial design and excavation of the cave to the final painting. Furthermore, it requires a range of materials, which themselves need collecting and processing. These materials may be local or, particularly in the case of pigments, may need to be imported over great distances.

There are several descriptions of the production techniques of cave temples at particular sites–for example, the display in the Dunhuang Exhibition Centre at Mogao. These explanations, however, tend to be specific to each cave site, and are essentially descriptive. Additionally, there have been several studies undertaken into textual and art historical records of the people involved in the construction of the Mogao Grottoes (Fraser 2004; Ma 1997). This paper takes a broader perspective, partly to generalise the production of these monuments within a framework which allows the question of why certain choices were made, and partly to compare specific aspects of cave temple construction across Northwestern China. In very general terms, the production of a cave temple in Northwestern China includes some or all of the following stages as specified in Table 1.

Following some combination of these steps, stage one of the biography of the cave is complete. This is not, of course, the end of its life history, merely the end of the initial construction. Subsequent stages might include extension of the space within the cave (perhaps including some re-shaping to accommodate re-purposing), redecoration (repainting, with or without re-plastering, addition of new statues/sculptures, or modification of existing features). In later periods this also includes the repair of collapsed structures such as antechambers or access staircases which

often involved the creation or replacement of tunnels systems within the cliff (fig. 3), and historic (Ming/Qing) or modern conservation procedures, some of which may not always have made a positive contribution.

Figure 1: Placement of caves in the northern District of Mogao Caves (photograph by M. Pollard).

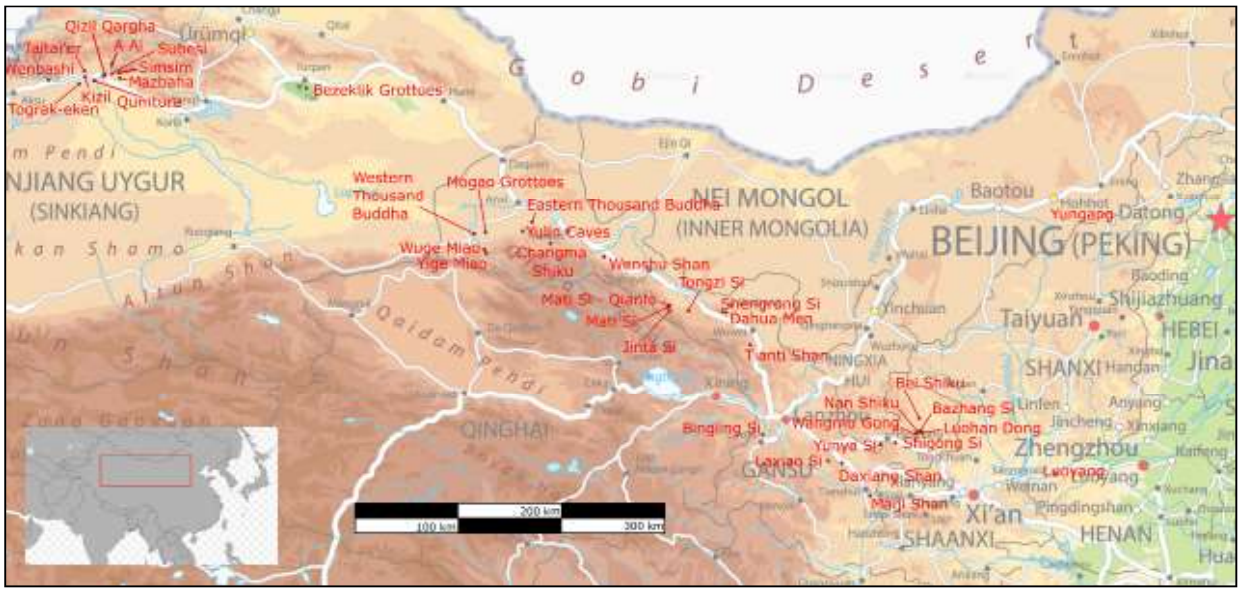

Figure 2: Map of the major cave temples Northwestern China and the two early Imperial sites of the Central plains (Yungang and Longmen Grottoes).

TOWARDS A *CHAÎNE OPÉRATOIRE*

STEPS I-III: NEED, LOCATION, CHOICE OF TYPE

In considering the need for a cave temple, it is first necessary to consider their function. The primary function of a cave temple must have been religious, potentially based on the requirement of a religious community to segregate itself from the rest of society. Other functions have been proposed, such as way-stations or caravanserai along the Silk Road (Vignato 2018).

Less tangible reasons for the selection of sites includes a desire to co-opt sites of previous spiritual significance into a new religion. The location of a cave temple would therefore be decided by a number of geographical, political, social and religious factors. The foundation 'myth' for the Mogao caves, inscribed into a stele found in Cave 332, states that a monk travelling to India in search of sutras had a vision of a Thousand Buddha on the cliff face at Mogao and decided to construct a mediation cave there instead. The tale is, however, most likely apocryphal, constructed at a later date to provide a suitably auspicious Buddhist origin story for the site. It is more likely they were constructed because the location already had a spiritual significance. Such co-option is recorded in early Buddhist Canon (DeCaroli 2004: 24) and is evidenced by Buddhist sites in Swat (Northwestern Pakistan), which adopted pre-existing animistic sites, and were then supplanted by Sufi practitioners (Filigenzi 2015: 47-48).

The caves at Mogao are too close to the Dunhuang Oasis (two or three hour's travel) to have been way-stations or caravanserai. The location of other sites such as Wugemiao and the Western Thousand Buddha are more convincingly spaced. It is clear that they, set on the canyon walls of the river valley, were selected based on the crescent of low fertile ground in front of them (fig. 4). A further consideration

Table 1: Possible steps included in the construction of a cave temple.

Steps in constructing a cave temple	
i)	**Identification of the need for a cave temple**
ii)	**Identification of a location for the cave temple**
iii)	**Choice of the type of cave temple to be carved:** a. Design of cave temple – e.g., antechamber, main chamber, corridor, access mechanism, b. Carving of the internal space (including geometrical control necessary to carve a regularly spaced cave into a cliff), c. Removal and disposal of displaced rock, d. Creation or construction of major internal features within the cave (niches, platforms, etc.).
iv)	**Production of coarse rendering:** a. Collecting raw material, b. Processing raw material, c. Cutting/drying/chopping straw, d. Addition of straw temper, e. Sourcing/production of organic binder and addition to rendering.
v)	**Application of coarse rendering:** a. Erection of scaffolding, b. Plastering technology.
vi)	**Creation of moulded features and figures:** a. Sourcing/production of cane framework, b. Application and carving of rendering to produce features/figures.
vii)	**Application of fine surface for painting:** a. Collecting and processing of material, b. Addition of organic binder.
viii)	**Creation of pigment:** a. Sourcing of pigment, b. Preparation of pigment, c. Addition of organic binder.
ix)	**Painting:** a. Application of background white/red wash, b. Painting of coarse features, c. Painting of fine detail.
x)	**Dedication and use of the temple**

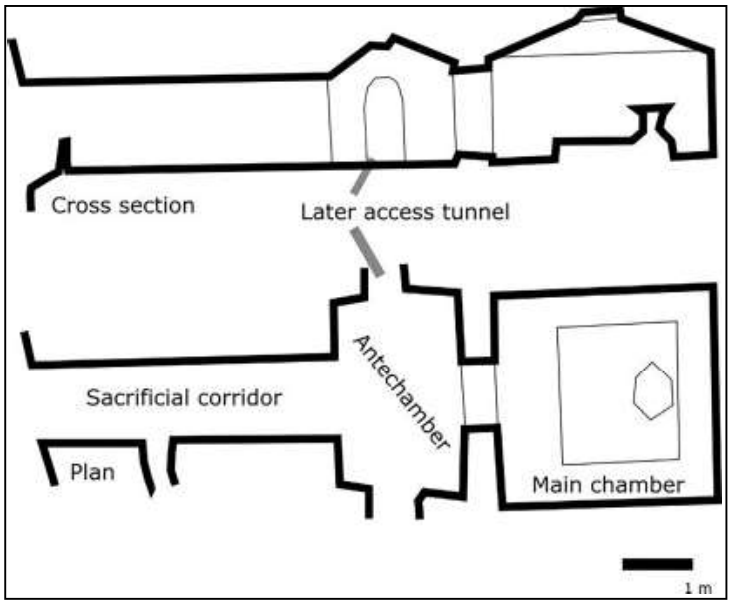

Figure 3: Cross-section of Cave 25 Yulin (after Sha 2016: fig. 3-9b).

is the liminality of these sites. They are often set in locations which mark the transition from one landscape to another.

Changma Shiku, for instance, is carved into a cliff face which marks the transition between flat, fertile farmland and hilly, barren scrubland. The Mogao Grottoes are carved in a valley which marks the transition between yellow sand dunes and mountains formed of blackish rock. In the Kucha region of Xinjiang, the majority of sites are carved into mountains which form the southern boundary of the ancient kingdom, and in close proximity to border forts occupying passages through the landscape.

Once the site of a temple has been selected, the caves therein appear to have been carved into functional districts. Vignato (2016: 16) argues that site selection would have included the placement of functional districts within the landscape. He outlines three functions within the rock monasteries of Xinjiang—ritual, residential and caves for meditation. Most cave temples in Gansu show no trace of either a residential or meditation district. It is possible that these activities were undertaken in lost external surface structures. Mogao is an exception, having a southern 'ritual' and a northern 'residential' district, but no meditation district. Within these districts the caves are carved in 'groups', originally accessed by the same path and used in a single ritual event.

The placement of new caves within a group or district appears to have been undertaken in a progressive contingent manner. In Kucha the earliest group form is believed to be a square cave and a monastic cell, subsequently replaced with a groups formed of a monastic cell and a central pillar cave.[1] Finally, the monastic cells were often converted into central pillar caves (Wei 2013: 46). The progression of cave forms has been examined over a larger geographical area by Nakamura and Okazaki (2016), but their discussion does not make allowance for the now collapsed front sections of the caves.

Steps IV-VI: 'rough out' of cave and supporting architecture, internal carved features

The clearest evidence for the techniques employed in cave construction can be seen by examining unfinished caves. However, the friable nature of the rock in Northwestern China means that few unfinished caves survive. Although in another area, in the absence of anything more locally relevant, Peng's (2017) study of the

1: A cave in which a 'central pillar' has been left for the purpose of circumambulation.

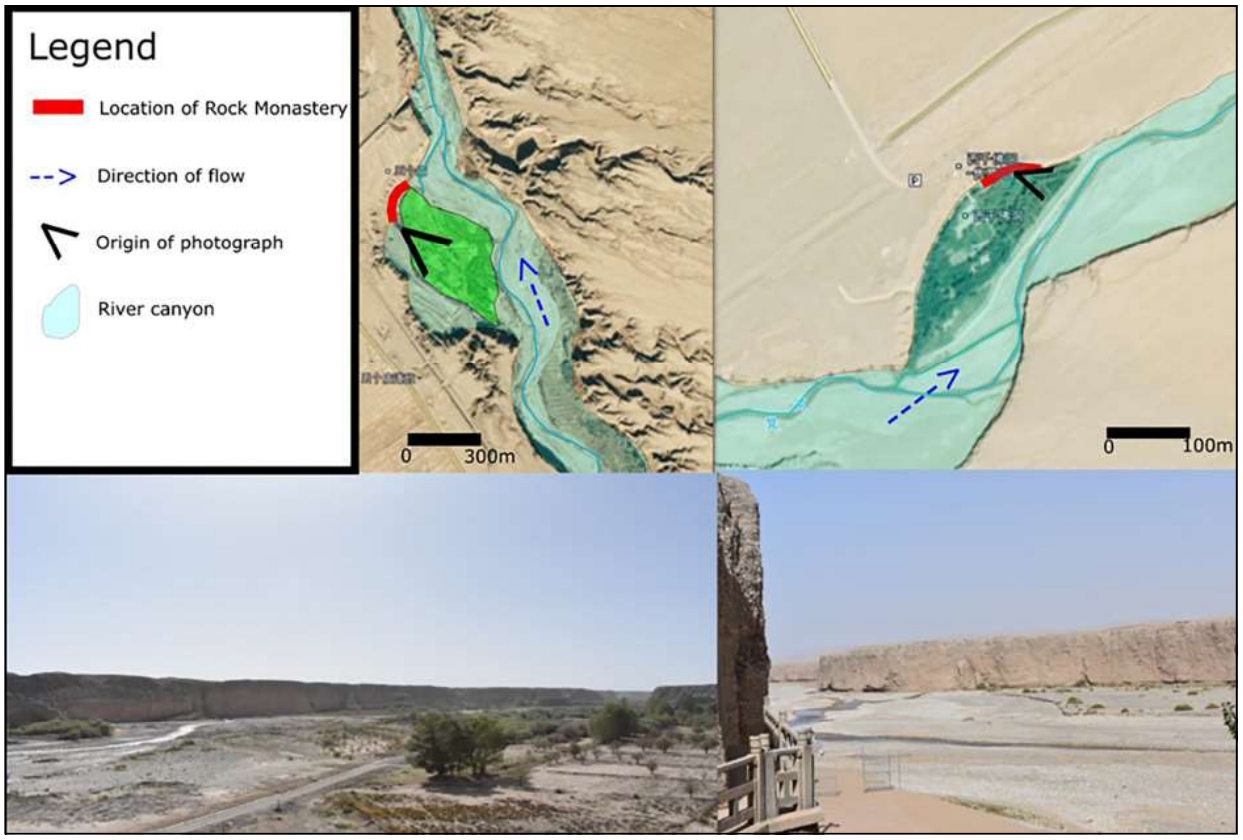

Figure 4: Satellite imagery and photographs showing the similarity between the location of the Wugemiao and Western Thousand Buddha sites (photographs and figures by F. Monteith).

construction methods employed at Yungang (near Datong) provides a useful starting point from which to consider how the caves in Northwestern China would have been constructed.

Peng (2017) raises one basic point regarding the construction of a cave, namely wherever possible it is always easier to work from the top down, since rocks are less likely to fall on the excavator. He suggests that the front section would have been carved first, with the whole front wall being created before carving backwards in stepped layers (fig. 5). This has several advantages. Firstly, in a tall cave, multiple people can work at the same time on different levels. Secondly, it makes the excavation of a regular cuboid space within the cliff much easier, since the sides can be kept parallel as the excavation works back into the cave. Finally, it largely negates the need for extensive scaffolding in a region with little wood.

As part of his work at Kumtura (Kucha, Xinjiang), Vignato asked modern workers how long it would take to dig out the caves: they said they could excavate 1m^3 of the local uncemented conglomerate a day (Vignato 2018, pers. com.). If this is taken as an approximate gauge, then a small cave such as Cave 268 in the Mogao Grottoes in Dunhuang, with a total internal space of approximately 23m^3, would have taken one person 23 days to excavate. Of course, this measures only the unskilled process of removing rock within the cliff, and not the time required to finish the walls, apply the plaster and paint the surfaces. The central corridor of

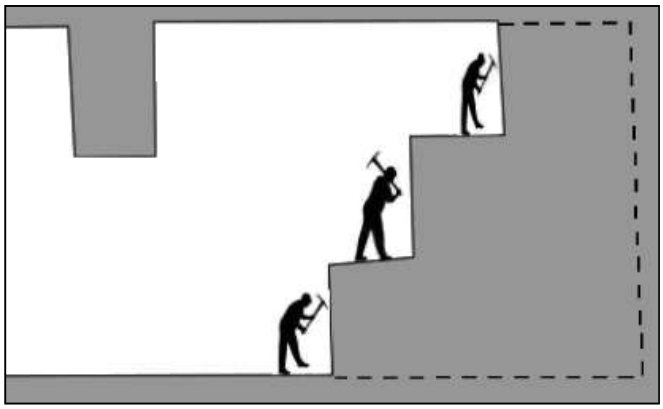

Figure 5: Stepped technique employed in the construction of a cave (following Peng 2017).

this cave is only 1.2m wide by 1.7m tall, which would not have permitted more than one person to be carving this space. In contrast, one of the largest caves at Mogao, Cave 16, has a total internal space of approximately 2500m^3, which would have taken 10 people 250 days, or eight months, to 'rough out'.

The rough-out form of a cave would have included the shape of the walls and niches within the caves. For monumental images, a stone core was left in place. There are several cases where the back corridors of a central pillar cave were left unfinished—either the corridors were a later addition, or the decoration of the outer sections of the cave started before the excavation of the interior was complete.

In terms of the tools used in the construction process, the best demonstration is seen in the *Hegong qiju tushuo*, an ancient Chinese text which outlines the various tools required to straighten a cliff and carve stone. Tool marks observed on site in the Eastern Thousand Buddha site appear to have been made using a chisel set at an oblique angle to the rock face and then hammered across (see also Ma 2018: 149). This method would have been necessary when working with the extremely friable rock found in Northwest China, where the greatest concern would have been preventing the collapse of the cave. This is most apparent in Cave 22 at Yulin, where a bulge in the ceiling clearly indicates that the removal of that section of rock was deemed too risky and it was left in place. Further evidence of the unreliability of the rock can be seen in the back of Mogao, Cave 16, where a wooden lattice has been constructed to support the plasterwork after too much of the rock had given way.

There are no references to the stone masons within the donor portraits or inscriptions within the caves. This would indicate that they held a lower social status than the other craftspeople involved in the construction of the caves (Ma 2018: 143).

STEPS IV, V, VII: COARSE AND FINE RENDERING

In a previous study of the rendering layers of the cave temple sites along the Silk Road, Zhao et al. (2005) showed that most sites have three layers within each layer of plaster, labelled coarse mud, fine mud and white layer. The coarse mud is generally 2~3cm thick, and is made of silty sand (粗泥) mixed with coarse wheat straw (麦草). The fine mud layer (细泥) is 2~5mm thick, and contains finer fibres such as hemp (麻) and wool (毛). Finally, a layer of gypsum or lime (白灰泥) with a thickness of about 0.11~0.2mm is applied.

This variation in the composition of the layers can be clearly seen at the entrance to Mogao Cave 17 (fig. 6), which is cut into the corridor of Cave 16. According to Zhao et al. (2005), the ratio of silt to sand in the thick mud layer is generally around

50:50, but ranges from approximately 80:20 to 20:80, implying that the sand and silt were not evenly mixed. They also suggest that the silty sand was dug from the soil near the cave, blended with rough cut wheat straw to make mud, and pressed onto the rough rock face. The mud for the fine layer would have been taken from the sedimentary silt of the riverbed in front of the Grottoes, and mixed with finer fibres.

Although it is possible that the coarse layer was simply collected from the sand surrounding the caves, the grain size analyses published by the above authors do not particularly support that. We suggest that both the coarse and fine rendering material was simply dug out of the river bed. Many of the cave temple sites in Northwest China are located very close to a river, which may be seasonal. Observation at several sites has shown 'pools' of natural sedimentary clayey deposits at low water levels, which would make an ideal base for rendering material, without further levigation.

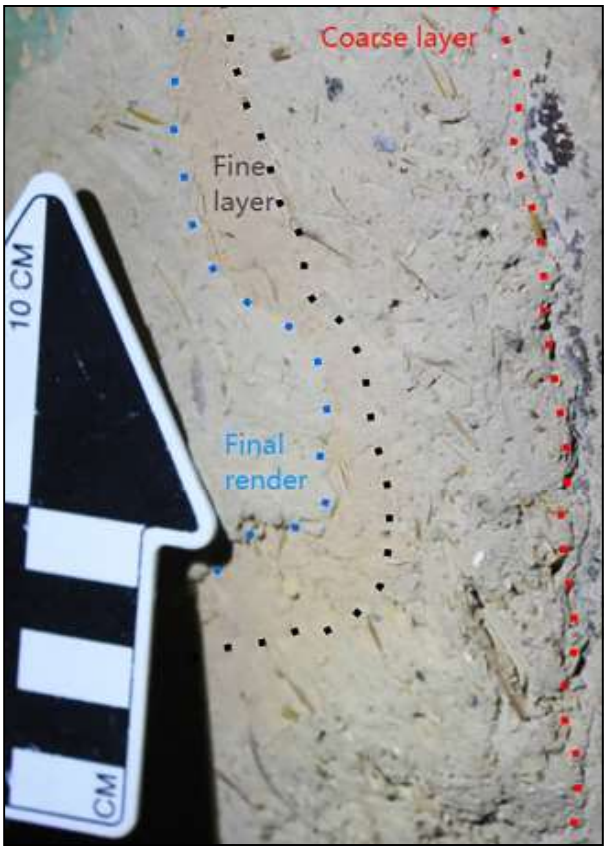

Figure 6: Layering of the plaster foundation (photograph and annotations by F. Monteith).

The variations observed by Zhao et al. in the type of fibres added to the coarse and the fine mud layers is also interesting. The use of hemp and wool in the outer layers would presumably have given a smoother surface to the fine layer. There also appears to be spatial and chronological variation. Particularly for wool, which is more common in Xinjiang province, where herding is more prevalent. It is also noteworthy that the identified fibres are all likely to be from domesticated rather than wild species. This suggests a link with agriculture, despite the desert location of the more westerly cave temples. As noted above however, several of these are associated with small areas of agriculture close to the river.

It seems plausible that an organic binding medium was added to the basic clay mixture for either the coarse or the fine layers. It is more certain that a binder was used for the paint pigments. In China, the traditional ways of making binders involved boiling animal skins (e.g. pigs, fish, rabbits) or collecting plant glues (e.g. peach), as verified by both historical documents and also by modern scientific analyses.

Much of the earlier analytical work on pigments was done using various spot tests for proteins, which are highly unreliable and non-specific. Analysis of the pigments at Kizil using HPLC (high performance liquid chromatography), a more reliable method, by Su et al. (2005) has determined the presence of amino acids, identified as animal protein, and referred to as 'animal glue'–presumably

Figure 7: Showing the use of iron wire in the construction of the main statue in Niche 147 at Maiji Shan (reproduced with permission from Dunhuang Academy, Zhongguo Shiku: 2014).

from boiled animal skin. There is, however, no archaeological evidence for animal processing at cave temple sites. Since these are Buddhist caves, it is unlikely that animal products would have been knowingly used in their construction.

If the identification is correct, this suggests that the pigments were prepared and used without specifying what they contained (or a blind eye was turned). There is a precedent for the use of animal products by the Samgha. *Vinaya Pitaka* does makes allowance for the use of leather to make shoes (Heirman 2016), but only to be worn by monks and nuns who were infirm or undertaking a long journey. The *Vinaya Pitaka* also says that a monk could eat meat if he did not suspect that the animal had been slaughtered specifically to feed him (Voyce 1983: 322). The use of animal glue in the creation of the caves could perhaps therefore be justified.

STEP VI: CREATION OF MOULDED FEATURES AND STATUES

The figures and moulded decorative features are made from a core of canes or bundles of straw, covered with a rendering layer which looks very similar to the fine layer described above (Su 1996). Exceptionally, at Maijishan the figures' fine features (particularly fingers) were moulded on iron wire, which probably allowed for finer modelling (fig. 7). We do not know where this iron originated, nor how the wire was made. There is no evidence to suggest that iron smelting or wire production took place in the vicinity. According to Hommel (1937: 27), the Chinese 'never succeeded in drawing iron wire'. Perhaps the artistic affordance of finer wire made it worthwhile to seek out iron wire instead of straw or cane, but clearly this requires more research.

A further form of decoration employs moulded tablets, which were observed in the Kucha region, Mogao and Maiji Shan (fig. 8). These tablets were applied to the walls of the caves in Kucha using fine mud plaster and wooden pegs (Vignato 2014).

STEPS VIII-IX: PIGMENTS AND PAINTING

The paintings within the caves show a variety of techniques. The ground layer was first applied to the walls. In earlier caves this is predominantly red, but in later caves it switches to white. The paint in these caves is applied in clear blocks of colour, without colour being mixed or multiple layers of transparent paint being used to give a particular colour (e.g. using red and white to give pink). These blocks of colour often appear to have been applied to the wall above fine paint work, which

might indicate that these paints were part of a later restoration. There is a stark technical contrast between the fine detail of the line work of the under drawing and the block colour. These two different forms of painting imply that there were at least two different techniques by which the paint was applied. The lines of the underlying drawing are long and consistent, perhaps indicating the use of typical Chinese brushes with a hollow between the bristles which allows for a greater amount of pigment to be carried between re-inking (Tseng 1993: 382).

Figure 8: Tablets used to decorate the back wall of Niche 31, Maijishan Grottoes (reproduced with permission from Dunhuang Academy, Zhongguo Shiku: 2014).

In some cases, particularly in the painting of the Thousand Buddha images, the ground layer of paint was not applied evenly, with the spaces in which figures were to be painted left bare (fig. 9b). The purpose of this is unclear, but could have been as simple as wishing to reduce the amount of paint used. In the more complex paintings, the design is first sketched in red paint. Fraser (2004: 75) connects rough sketches undertaken on the back of damaged sutras recovered from Cave 17 at Mogao to paintings of "the magical competition" in 15 different caves. She notes that these images are scaled up and down between these caves to fit the available space, indicating that the sketching technique was flexible.

Her reasoning, that those responsible for painting the caves would have had no control over the size of the cave, would suggest that there was no communication between the stone masons and the painters, which seems unlikely. The use of perforated templates (pounces), which were also recovered from Mogao Cave 17, indicate that in some cases standardised designs were employed. In Kucha there is also evidence of a chalk line being used to outline the frames of the paintings and the lines of Thousand Buddha images (fig. 9a).

Studies of the pigments used for wall paintings at Kizil, Mogao, Yulin, Tiantishan, Binglingsi, Maijishan and other sites (Su 2000; Zhao et al. 2005) have identified a wide range of minerals (table 2). Some of these may have been locally available (e.g. quartz, gypsum), but the majority must have been imported over some distance–the most obvious example being lapis lazuli, which is traditionally assumed to come from Afghanistan (Herrmann 1964). It is not known whether these would have travelled as raw materials, or been acquired as processed pigment. Nor is it known how the pigment would have been prepared for application–presumably a powder would be mixed with water or oil, or mixed with an organic binder as described above.

It is only in Mogao Grottoes that clear data exists regarding the social status of the artists who painted these caves because of the sheer number of inscriptions and craftspeople among the donor figures, alongside a wealth of documents uncovered from Cave 17, and Turfan with the documents recovered from tomb goods.

Ma (2018) identifies three phases of artistic interaction with the site. In the Sui (AD 581-619) artists start to sign their work, from the end of the Sui through to the ninth to tenth century AD artists start to appear in the donor figures. The number of artist donor figures only increased significantly after the foundation of a painting bureau in Dunhuang in AD 930 (Ma 2018: 30-31; Fraser 2004: 24).

STEP XII: ORDINATION, SANCTIFICATION AND USE

The three main forms of cave generally referred to are square, central pillar and monumental image (see Su 1996; Wei 2013). In terms of decorated caves they may be divided into two main types. Those which are intended to house an image and those which are intended for circumambulation. Circumambulation of the altar still plays a key role in Buddhist rituals.

In examining central pillar caves, specifically designed for circumambulation, it is clear that the main chamber became progressively smaller over time. In some cases, holes in the flooring material were observed which could have supported a railing or table. It is therefore possible that the space might have been designed to

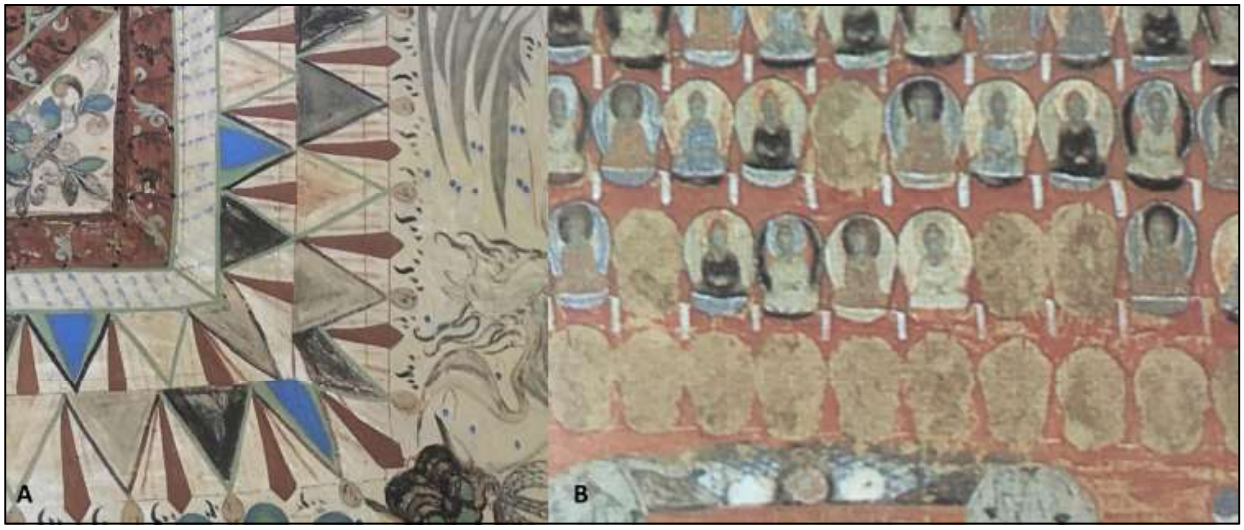

Figure 9: Showing: (a) chalk lines applied to the ceiling of Cave 285, Mogao Grottoes; (b) spaces left in the red background behind a Thousand Buddha image.

Table 2: Range of pigments used to create the various paint colours used in cave temples.

Green pigments:	***White pigments:***	***Red pigments:***	***Blue pigments:***	***Black and Brown-black pigments:***
Basic copper chloride *(Cu2(OH)3Cl)*	Gypsum *(CaSO4.2H2O)*	Red lead *(Pb_3O_4)*	Lapis lazuli *((Na,Ca)8(AlSiO4)6(S,SO4,Cl)1-2)*	Lead dioxide *(PbO_2)*
Red lead *(Pb_3O_4)*	Anhydrite *($CaSO_4$)*	Cinnabar *(HgS)*		
Cinnabar *(HgS)*	Calcite *($CaCO_3$)*	Iron red *(Fe_2O_3)*		
Iron red *(Fe_2O_3)*	Quartz *(SiO_2)*			

allow an offering table in the chamber rather than providing space for congregation (Vignato 2018). It is clear, therefore, that there is a strong feedback between cave design and ritual practice.

Little is known about the sanctification of the finished caves. One of the earliest Buddhist texts translated into Chinese is the *Scripture on the Production of Buddha Images*. This text, of which multiple versions have come down to us, outlines the means by which a 'living' embodiment of the Buddha may be created. One part of this process is the eye-opening ceremony which is still used to sanctify and 'enliven' a Buddhist image by dotting the pupils of the Buddha image (Sharf 1996). Examination of the paintings within the caves show that the eyes of the main figures have been painted, or repainted, at a later date, but it is uncertain if this is evidence of a ceremony or later restoration.

CONCLUSION: HOW THE *CHAÎNE OPÉRATOIRE* ADVANCES STUDIES OF BUDDHIST CAVE TEMPLES

The principal contribution of any *chaîne opératoire* approach to technological processes is to tease out and make explicit the various steps involved in the process. More specifically, it highlights the points at which decisions were made by the various artisans involved. The contribution of this study is to make explicit the range of processes involved in the construction of cave temples, almost certainly carried out by specialist artisans. The study of cave temples as archaeological sites rather than art galleries is still at a very early stage. With the exception of Mogao, only a few of the important sites have been excavated. Even at Mogao, excavations were largely focussed on stabilising and consolidating the cliff face.

Several features highligted in this paper deserve further study, such as the reason for the use of iron wire at Maijishan for statues rather than the cane and straw armatures used further west. Where this iron was made is completely unknown, and the reasons for its use are at present purely speculation. Furthermore, the process of putting together this *chaîne opératoire* for the construction of cave temples has revealed the previously unnoticed contradiction between the apparent use of animal glue to bind the pigment and the Buddhist prohibition of killing animals, which perhaps in itself justifies the approach.

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