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Initial insights into ceramic production and exchange at the early Bronze Age citadel at Shimao, Shaanxi, China

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ABSTRACT

Over the last decade, excavations at the late Neolithic to early Bronze Age site of Shimao in northern Shaanxi Province have transformed our understanding of the archaeology of early China. What was previously seen as an area that was peripheral to the development of early dynastic centers in northern China is now being heralded by some scholars as a precursor of Chinese civilization. However, despite incredible finds of large-scale stone architecture, bronze working, thousands of jade artifacts, and elaborate stone carvings, our overall understanding of the economic and political organization of the inhabitants of Shimao is still very limited. In this study we examine the most common artifact class at the site, pottery, using petrographic analysis, in order to explore production methods as well as potential production organization and exchange. As our results demonstrate, most of the pottery used at Shimao was likely produced locally, potentially by multiple production groups at or near the site, but the ceramics were not particularly standardized in regard to paste recipes. These results likely reflect that ceramic production was not tightly controlled or formalized, but instead took place in local households or workshops, much like ceramic production in many other parts of northern China at the time.

1. Introduction

In recent years, excavations at the massive stone-walled site of Shimao (2300-1800 BCE) in northern Shaanxi Province, China have revealed a complex urban settlement well outside of what has traditionally been considered the core zone of early Chinese civilization on the northern Central Plain (Sun et al., 2016, 2017, 2018, Sun et al., 2020a, 2020b) (Fig. 1). Several scholars have positioned this discovery as the latest in a long line of early "Chinese" centers that eventually led to the development of the earliest historically attested dynasties (Jaang et al., 2018; Li, 2016; Rawson, 2017; Shao, 2020). Arguments for this connection to later Chinese civilization focus largely on the perception of Shimao as a technologically advanced political and economic center that held control over the surrounding region and acted as an economic hub with ties that stretched far north into the steppe and south into what is now central China and beyond.

Currently, however, this hypothesis is based on a relatively limited amount of data, including short annual site reports from the last decade of excavations at the site, commentaries on some of the more unusual finds such as bone instruments and stone construction techniques, and broad comparisons of artifact types, primarily pottery styles, between regions. Thus, many of the conclusions being drawn, especially relating to economic, military, and political control, are based on very general results of excavation, but not yet on detailed analysis of specific artifact categories. For example, hypotheses of Shimao's widespread trading relationships and economic influence are based largely on the presence of exotic artifacts at the site, including jade items and cowrie shells. So far, however, published finds of cowries only record their presence in a single grave (Sun et al., 2016), while jades, although appearing at the site in large numbers, have not been definitively traced to specific origins, perhaps due to the general difficulties in jade sourcing (Wang, 2011). Thus, whether these objects are the result of direct procurement from, or control of, distant sources, or arrived via down the line exchange networks, which brought jade objects and shells to many parts of East Asia at this time (Flad, 2012), is not known. Additionally, the role that elite hierarchical control versus more heterarchical forms of

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organization had in managing production and exchange, remains unclear.

Owlett et al.'s (2018) extensive study of zooarcheological remains provide significant insight into animal production and consumption at Shimao. Their results revealed that like the nearby, but much smaller site of Zhaimaoliang, most domesticated animals (pigs, caprine, cattle) at Shimao were managed at the household level for use of primary products. Thus, it appears that food production and consumption, even at this large site, was undertaken locally at the household level, with no clear evidence of top-down control or dominance of this production. Additionally, there was no evidence for exchange of animals or animal products beyond the site. Now, detailed studies of other artifact and ecofact categories are needed to explore whether this system of social and economic organization extends to other industries at the site.

With that goal in mind, we present initial results from a study of a subset of the most abundant artifact category at the site, pottery. As has been demonstrated at other sites throughout the world, examination of pottery can provide insight into craft production techniques, organization of labor, human-landscape interactions, cuisine, ritual practices, political affiliation, and local and long-distance exchange patterns (Costin, 1991; Michelaki et al., 2014; Rice, 1987; Underhill, 2015). In recent decades, approaches to ceramic production have focused on multiple aspects of the production process including resource procurement (Michelaki et al., 2014; Rye, 1981), clay and temper preparation (Arnold et al., 1991), clay recipes (D'Ercole et al., 2017; Druc et al., 2018), forming processes (Liu, 2003; Rice, 1984; Roux, 2015), firing techniques (Bernardini, 2000; Gosselain, 1992), and distribution and use patterns (Ownby et al., 2014; Quinn et al., 2010; Stahl et al., 2008) in order to fully understand how production was organized. In many of these studies, the concept of communities of practice has been employed to build connections between patterns recognizable in the material record and specific groups of past potters (Bowser and Patton, 2008; Jaffe, 2016; Sassaman and Rudolphi, 2001; Stark, 2006). The reasoning behind this connection is built on observations of how modern potters pass down specific production techniques and paste recipes among typically insular groups of producers. While vessel forms and surface treatments can be relatively easily copied between groups, more hidden aspects of production, such as paste recipes and forming motions, are thought to be specific to an individual community of practice (Gosselain, 2000). When paste recipes can be matched with discrete geological features, then the location of these communities of producers, or at least the likely location where they gathered clays and tempers, can be inferred.

For this preliminary study, we focused on identifying paste recipes among a broad initial selection of sherds excavated from the central citadel and compared those to geological samples from across the site (see Fig. 1). The goal of this analysis is to provide initial insight into the materials used in ceramic production, including determining whether multiple groups of potters were involved in production and whether raw materials and/or finished vessels were obtained locally or potentially arrived at the site from other areas. Initial results point to probable local production, either at or near Shimao, potentially by multiple production

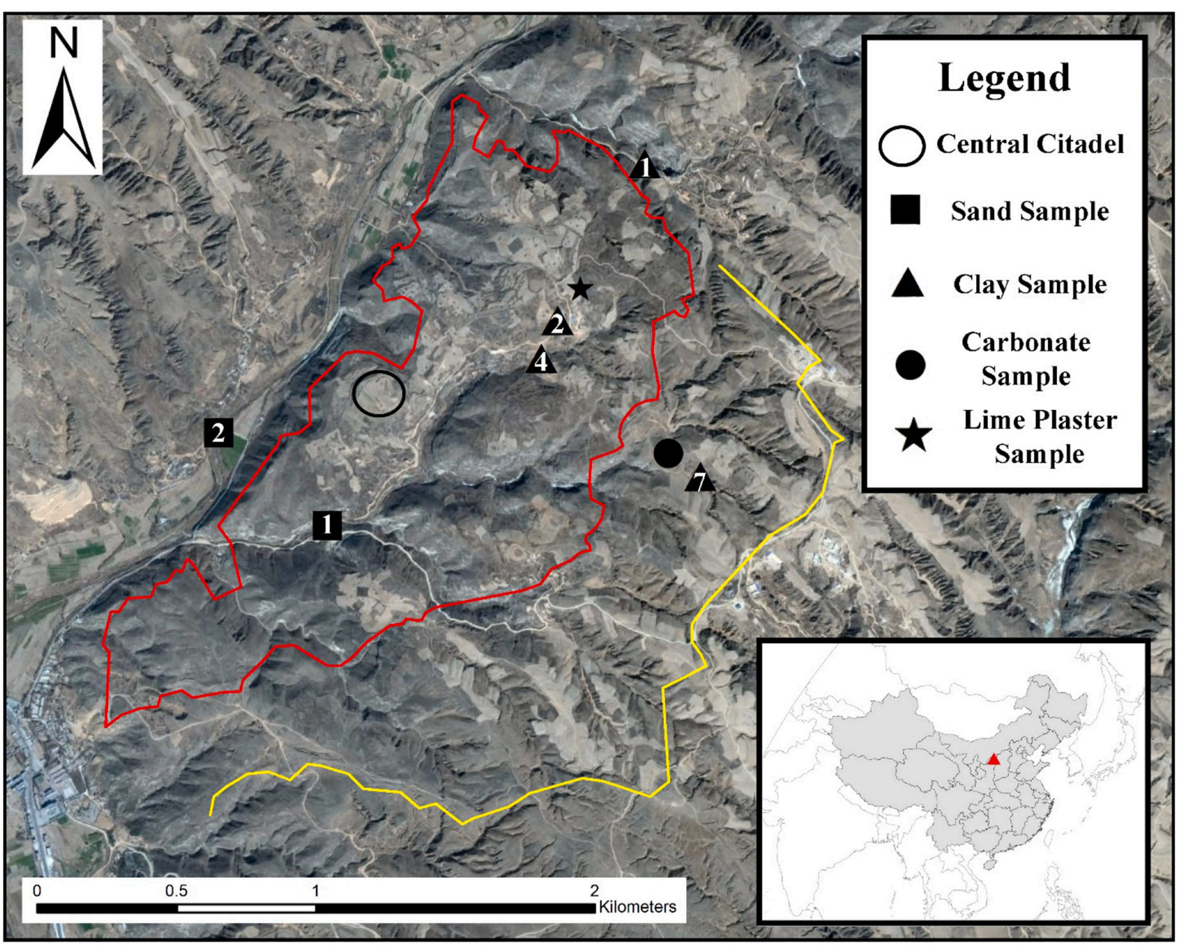

Fig. 1. Map of the Shimao site.
Areas marked on the map include the Inner Wall (red), Outer Wall (yellow), the central Citadel where ceramic samples were taken (black oval) and locations where sand, clay, carbonate, and lime plaster samples were taken by the lead author in 2019. Numbers inside clay and sand symbols correspond to sample numbers in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

groups, for the majority of sampled sherds, with a range of temper and clay combinations being used to produce a wide variety of vessel types. Additionally, there is evidence of importation of temper or finished vessels, however where exactly these items were imported from remains unknown.

2. Recent research on late neolithic to early Bronze Age Ordos ceramics

Compared to the northern Central Plain, the Ordos region, encompassed by the northern bend in the Yellow River and surrounding areas in Inner Mongolia has not been considered as a core region for the development of Chinese civilization. In turn, this area has received less attention from archaeologists compared to the Central Plain region until recent years. Prior to the excavations at Shimao, the most well-known Neolithic to Bronze Age site in the region was Zhukaigou, in Inner Mongolia, which was excavated between 1977 and 1984 (Neimenggu and E 'erduosi, 2000). Dating from the late 3rd to mid-2nd millennium BCE, the site is generally contemporaneous with, or slightly later than, occupations at Shimao. The earliest phase at the site is closely related to developments of the Longshan cultural period, including having semi-subterranean houses with lime plaster coatings, black polished pottery, urn burials for children, and typical Longshan pottery forms including tripods, two handled jars, and stemmed vases. In the next phases pottery that is similar to Qijia style ceramics from Gansu appears, especially flat-bottomed jars, alongside small metal implements, oracle bones, and the inclusion of animal bones in burials (Neimenggu & E'erduosi 2000). Both Longshan and Qijia style pottery continued to be used at the site into the later periods, as contact appears to have increased in multiple directions. These contacts include the Central Plain, marked by adoption of Erligang-style bronze items, as well as the steppe, marked by ring-handled bronze knives (Cui, 1991; Linduff, 1995). Work at Zhukaigou established the relationship between sites in the Ordos region and Longshan sites, while also implicating that Ordos groups were potentially important for facilitating early interactions and technological exchanges between the steppe and the Central Plain.

Building on typological pottery analysis at Zhukaigou and other nearby sites, the first typologies of Shimao pottery were conducted in 2010, when large-scale excavations at the site were just starting (Yan, 2010). In that analysis, Yan breaks down the pottery from Shimao into four chronological groups based on form, find context, and relation to pottery from other sites. In that analysis, Group A is thought to be contemporaneous with the early Longshan (Miaodigou II) period (2900-2600 BCE), with both this group and later Longshan period Keshengzhuang pottery sharing some similar forms thought to be inherited from Miaodigou II pottery. Group B pottery is thought to be contemporaneous with the very end of the Longshan period, ca. 2000 BCE and comes primarily from habitation areas, while Group C is thought to be from the same period but appears to have more influence from Qijia-style pottery and seems to be more common in graves. Group D contains pottery from the last phase at Shimao and is thought to be contemporary with the early Shang Dynasty (ca. 1600 BCE) (Yan, 2010); however, at the time that article was written C14 dates were not yet available from Shimao itself.

Studies of pottery typology that draw on more recent excavations at Shimao as well as sites in the surrounding region have further refined our understanding of both external influences and local developments in pottery forms. Based on comparative typological analysis of pottery from the Hanjiagedan locale at Shimao as well as pottery from the surrounding region, it appears that pottery from the earliest phase at Shimao is similar to Longshan materials from other parts of Shaanxi as well as to Laohushan style pottery from southern Inner Mongolia (Shao, 2016, 2019; Sun et al., 2020b). While dated material from northern Shaanxi is rare, Laohushan materials appear around 2500-2300 BCE, potentially overlapping with the earliest occupations of Shimao. Typical pottery types include single and two-handled tripods, trumpet-mouthed vases, and constricted-neck and round-bottomed urns (see Fig. 2). These styles of pottery define Shao's refined Group A, simply referred to as "early" in Sun et al. (2020b), which represents the earliest occupations. Unlike Yan's classification, however, Shao only defines three groups of pottery for the entire occupation of the site, combining Yan's Groups B and C into a single Group B. Sun et al. (2020b) take a similar approach, replacing A, B, and C, with early, middle, and late (Fig. 2: A–C).

Group B/middle period pottery (ca. 2100 BCE) sees the disappearance of round bottomed and incised urns, while other styles of pottery show morphological changes. Other forms proliferate, including tripods, which have large, bulbous feet and single or double handles. Trumpet-mouthed vases develop sharper angles, while round-footed basins shrink in height. These styles shift in Group C/late period (ca. 1800 BCE), with tripod feet shrinking and bodies growing taller, and newly appearing large-mouth jars developing narrow bases and wide shoulders (Shao, 2016, 2019; Sun et al., 2020b) (Fig. 2). Interestingly, other sites in the regions show combinations of styles from groups A and B, B and C, and in at least one case A and C, perhaps indicating that developments at Shimao were not necessarily always adopted concurrently in the surrounding regions (Shao 2016, 2019).

While scholars have been able to establish common forms and surface treatments that dominate the Shimao assemblage (Shaanxi and Yulinshi, 2005; Shao, 2019, 2020; Sun et al., 2016), up to this point, research on how these pottery types were produced and used remains unexplored. This has left a significant gap in our understanding of the organization of production, sourcing of raw materials, and potential exchange of ceramics between the inhabitants of Shimao and other sites or regions. In order to begin investigating these topics, we have analyzed a group of 75 sherds from Shimao using ceramic petrography, a technique well suited to getting at just the kinds of data that are previously lacking from this site.

3. Methods, materials, and data

Given the many unanswered questions relating to ceramic production and use, this study focused on selecting samples of sherds with a variety of surface treatments in order to establish a basic understanding of production materials across a range of ceramic types. The goals were twofold, first, to attempt to establish general ceramic paste groups at the site in order to understand what methods and materials were being used for ceramic production. Second, we hoped to determine if any nonlocal paste types were present at the site and if so, where these might have originated.

3.1. Ceramic and geological sampling

Since many thousands of sherds have been excavated to date at Shimao, for this pilot study we decided to sample 75 sherds exhibiting a variety of surface treatments in order to understand what types of paste recipes were being used to produce different types of vessels (Fig. 3). To do this, we selected several groups of sherds exhibiting similar colors and surface treatments that matched particular vessel types at the site. These included grey basket-marked sherds (SM001–008; vases), orange fiber-point cord-marked sherds (SM009–016; tripods), light orange cord-marked sherds (SM017–024; tripods), grey cord-marked sherds (SM025–032; tripods), grey polished sherds (SM033–037; basins), grey sherds with a combination of incision, polishing, and cord-marking (SM038–049; round-mouth tripods), orange-black sherds (SM050–054; round-mouth tripods), grey sherds with waffle pattern (SM055–059; round-mouth tripods), grey sherds with basket marks (SM060–064; vases), and grey or grey-white sherds with a combination of applique, waffling, and/or incising (SM065–074; small single-handle tripods). Upon a second review the of sherds, coauthor Di noted that in a few cases (SM041, 46, 47, 50, 52, and 53) sherds with similar surface treatments likely came from different vessels than we initially thought. Our data were updated to reflect these new interpretations and we took

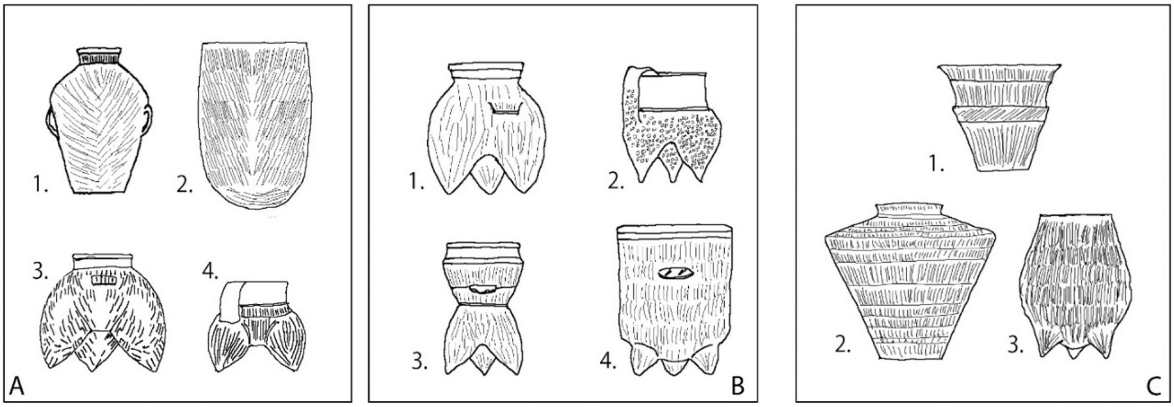

Fig. 2. Selected pottery types from Shimao.
A. Early period/Group A: A1. Trumpet-mouth vase; A2. Round-bottomed jar; A3. Two-handled tripod; A4. Single-handled tripod. **B.** Middle period/Group B: B1. Two-handled tripod; B2. Single-handled tripod; B3. Steamer; B4. Two-handled tripod. **C.** Late period/Group C: C1. Large-mouthed vase; C2. Vase; C3. Tripod (Categories and drawings after Shao 2016, 2019 and Sun et al., 2020b; for a full categorization see Sun et al., 2020a, 2020b).

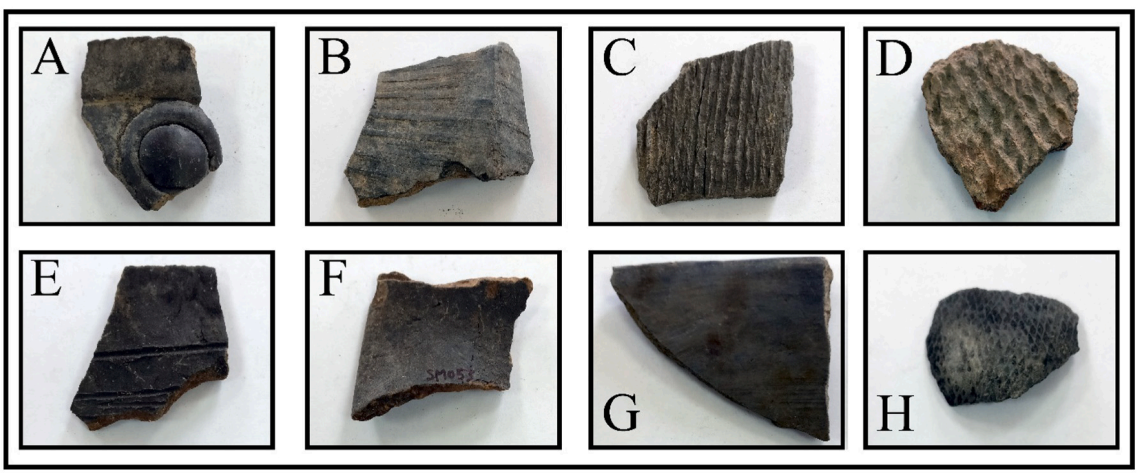

Fig. 3. Typical surface treatments on selected sherds.
A. Applique; B. Basket-marks; C. Cord-marks; D. Fiber Point Cord-marks; E. Incised Line; F. Plain; G. Polished; H. Waffle Pattern. Each individual box has a width equivalent to 8 cm.

them into account in our analysis. Given that we drew samples from among several hundred sherds, we did not attempt to definitively determine whether some sherds might have come from the same vessel, however in our results we note where the petrographic data between two sherds is similar enough to potentially warrant this concern. Complete information on each sample, including proposed vessel type, is available in Table 1.

For this study we wanted to explore whether particular types of vessels, such as grey basket-marked vases or orange cord-marked tripods, were all being made with the same paste recipes, likely indicating that a single community of potters produced all of a given vessel type, or whether multiple recipes were being used, which likely indicates that multiple groups of potters were all contributing vessels of a given type. In order to control for changes over time, we also wanted to sample from closely related depositional layers. Sherds from the 2017 excavation of material dumped over the side of a stone retaining wall related to a residential portion of the citadel, referred to as Badger Bank Area 4, Part 3, fit these requirements. The entire Badger Bank area is a large deposit made up of household refuse thrown over the edge of the citadel's retaining wall for disposal. Area 4, Part 3 is a 10 m section of the deposit, with level 4C including dense layers of household refuse with large amounts of pottery and animal bones. This layer sits just below a capping layer of burned material that has been C14 dated to 1800 BCE and is thought to be associated with a destruction event marking the end of occupation of the citadel. Therefore, the material from 4C should all come from deposits occurring just before the end of occupation at the site, providing a relatively secure depositional context.

In order to investigate potential variability in raw materials at Shimao, the lead author also conducted an initial geological survey of the site area in order to identify potential local sources of clay, sand, and other possible temper materials. Geological maps of the region identify sandstone, siltstone, mudstone, and gypsum as dominant rock forms, and loess as the dominant soil type. This was largely confirmed during survey, with the local hills at Shimao being made up predominantly of loess covered sandstone and mudstone that outcrops in many areas. The survey took place over the course of two days and consisted of walking each stream valley and hill top in and around the site area and sampling natural clay and sand outcrops where visible. The terrain around Shimao is quite rugged, with some valleys being inaccessible due to steep rock features, therefore this survey was only a preliminary endeavor which we plan to follow up with systematic, comprehensive survey in the future. Nevertheless, several sources of clay ($N = 4$), sand ($N = 2$), and natural deposits of carbonate rock ($N = 1$) were identified. The latter of

Table 1
Ceramic and Geological sample.

Sample #	Excavation Location and Level	Date Excavated	Color	Surface Treatment	Part	Paste Group	Optical Activity	Potential Vessel Type
SM001	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks	Shoulder	Fine Feldspar-Quartz Sand	Inactive	Vase
SM002	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks	Shoulder	Fine Feldspar-Quartz Sand	Inactive	Vase
SM003	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Light Grey	Basket-marks; Impression	Shoulder	Fine + Carbonate	Active	Vase
SM004	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Light Grey	Basket-marks	Shoulder	Fine Feldspar-Quartz Sand	Inactive	Vase
SM005	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks	Shoulder	Coarse Feldspar-Quartz Sand	Active	Vase
SM006	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks	Shoulder	Fine + Carbonate	Moderate	Vase
SM007	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks	Shoulder	Fine Feldspar-Quartz Sand	Active	Vase
SM008	Badger Bank Area 3 Part 4 Level 4C 12–9	2017.5.17	Grey	Basket-marks; Incision	Shoulder	Fine + Carbonate	Inactive	Vase
SM009	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Coarse Feldspar-Quartz Sand	Inactive	Tripod
SM010	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM011	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Moderate	Tripod
SM012	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM013	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM014	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM015	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM016	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Fiber-point cord-mark	Body	Metamorphic	Active	Tripod
SM017	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Metamorphic	Inactive	Tripod
SM018	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Metamorphic	Inactive	Tripod
SM019	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Metamorphic	Active	Tripod
SM020	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Shallow cord-mark	Body	Metamorphic	Active	Tripod
SM021	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Grog	Inactive	Tripod
SM022	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Metamorphic	Moderate	Tripod
SM023	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Cord-mark	Body	Metamorphic	Variable	Tripod
SM024	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Light Orange	Crossed cord-mark	Body	Coarse Feldspar-Quartz Sand	Active	Tripod
SM025	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Grog	Inactive	Tripod
SM026	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Coarse Feldspar-Quartz Sand	Inactive	Tripod
SM027	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Fine + Carbonate	Moderate	Tripod
SM028	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Metamorphic	Inactive	Tripod
SM029	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Coarse Feldspar-Quartz Sand	Inactive	Tripod
SM030	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Thin cord-mark	Body	Mudstone	Inactive	Tripod
SM031	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Thin cord-mark	Body	Coarse Feldspar-Quartz Sand	Active	Tripod
SM032	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Metamorphic + Clay Pellet	Inactive	Tripod
SM033	Badger Bank Area 3 Part 4 Level 4C 12–1	2017.5.17	Grey	Polished	Rim	Fine Feldspar-Quartz Sand	Moderate	Basin
SM034	Badger Bank Area 3 Part 4 Level 4C 12–1	2017.5.17	Grey	Polished	Rim	Coarse Feldspar-Quartz Sand	Moderate	Basin
SM035	Badger Bank Area 3 Part 4 Level 4C 12–1	2017.5.17	Grey	Polished	Rim	Fine Feldspar-Quartz Sand	Active	Basin
SM036	Badger Bank Area 3 Part 4 Level 4C 12–1	2017.5.17	Grey	Polished	Rim	Fine Feldspar-Quartz Sand	Active	Basin
SM037		2017.5.17	Grey	Polished	Rim		Active	Basin

(*continued on next page*)

Table 1 (*continued*)

Sample #	Excavation Location and Level	Date Excavated	Color	Surface Treatment	Part	Paste Group	Optical Activity	Potential Vessel Type
	Badger Bank Area 3 Part 4 Level 4C 12–1					Fine Feldspar-Quartz Sand		
SM038	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised Line	Body	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM039	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised Line; impression	Body	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM040	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised Line; Incission	Body	Mudstone	Inactive	Round-mouth tripod
SM041	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Polished; Incised Line; Cord-marks	Body	Coarse Feldspar-Quartz Sand	Active	Vase
SM042	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Polished; Applique	Shoulder	Fine Feldspar-Quartz Sand	Active	Round-mouth tripod
SM043	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Polished; Incised Line; Cord-marks	Rim	Coarse Feldspar-Quartz Sand	Inactive	Round-mouth tripod
SM044	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Polished; Incised Line; Cord-marks	Rim	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM045	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Decorated Rim; Incised Line; Applique	Rim	Mudstone	Inactive	Round-mouth tripod
SM046	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Decorated Rim; cord-marks	Rim	Fine + Carbonate	Moderate	Round-mouth tripod
SM047	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Grog	Inactive	Tripod
SM048	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Cord-mark	Body	Grog	Inactive	Tripod or round-mouth tripod
SM049	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised Line; cord-marks	Body	Fine Feldspar-Quartz Sand	Inactive	Tripod or round-mouth tripod
SM050	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Polished; Incised Line; Cord-marks	Rim	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM051	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Black (Orange)	Incised Line	Rim	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM052	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Black (Orange)	Basket-marks	Shoulder	Fine Feldspar-Quartz Sand	Active	Vase
SM053	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Plain	Rim	Fine Feldspar-Quartz Sand	Active	Vase
SM054	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Black (Orange)	Incised line; Applique	Rim	Mudstone	Active	Round-mouth tripod
SM055	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised line; waffle	Handle	Coarse Feldspar-Quartz Sand	Active	Round-mouth tripod
SM056	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised line; waffle	Body	Coarse Feldspar-Quartz Sand	Inactive	Round-mouth tripod
SM057	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Waffle	Body	Metamorphic	Variable	Round-mouth tripod
SM058	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Orange	Waffle	Body	Fine Feldspar-Quartz Sand	Moderate	Round-mouth tripod
SM059	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Waffle	Body	Coarse Feldspar-Quartz Sand	Moderate	Round-mouth tripod
SM060	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Basket-mark	Body	Fine Feldspar-Quartz Sand	Inactive	Vase
SM061	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Basket-mark	Body	Fine Feldspar-Quartz Sand	Moderate	Vase
SM062	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Basket-mark	Body	Metamorphic + Clay Pellet	Moderate	Vase
SM063	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Basket-mark	Body	Fine Feldspar-Quartz Sand	Inactive	Vase
SM064	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Basket-mark	Body	Fine Feldspar-Quartz Sand	Active	Vase
SM065	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey (white)	Incised line	Rim	Coarse Feldspar-Quartz Sand	Active	Small single-handle tripod
SM066	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey (white)	Plain	Rim	Mudstone	Inactive	Small single-handle tripod
SM067	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey (white)	Applique	Body	Mudstone	Inactive	Small single-handle tripod
SM068	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey (white)	Applique	Rim	Mudstone	Moderate	Small single-handle tripod
SM069	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey (white)	Plain	Body	Mudstone	Active	Small single-handle tripod
SM070	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Incised line; Polished; Waffle	Rim	Mudstone	Active	Small single-handle tripod
SM071	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Waffle	Body	Mudstone	Inactive	Small single-handle tripod
SM072	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Waffle	Body	Mudstone	Active	Small single-handle tripod
SM073	Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Thin cord-mark	Body	Mudstone	Inactive	Small single-handle tripod
SM074		2017.5.17	White	Waffle	Body	Amphibole Rich	Inactive	

(*continued on next page*)

Table 1 (*continued*)

Sample #	Excavation Location and Level	Date Excavated	Color	Surface Treatment	Part	Paste Group	Optical Activity	Potential Vessel Type
SM075	Badger Bank Area 3 Part 4 Level 4C 12–3 Badger Bank Area 3 Part 4 Level 4C 12–3	2017.5.17	Grey	Grid; waffle	Body	Coarse Feldspar-Quartz Sand	Active	Small single-handle tripod Small single-handle tripod

Sample #	Location		Sample Type
SG001	Baihuimian 1	2019.6.26	Lime plaster
SG002	Calcite 1	2019.6.26	Carbonate Rock
SG003	Sand 1	2019.6.26	Sand
SG004	Sand 2	2019.6.26	Sand
SG005	Clay 1	2019.6.26	Clay
SG006	Clay 2	2019.6.26	Clay
SG007	Clay 4	2019.6.26	Clay
SG008	Clay 7	2019.6.26	Clay

which could have been used to produce the lime plaster seen in house floors, mural painting, and on fragments of ceramic sculptures at the site.[1] Along with sandstone, there were significant alluvial deposits of pebbles and conglomerates, as well as a deposit of very fine sand (Sand sample #2).

All 75 of the ceramic samples, seven geological samples and single lime plaster sample were prepared at the Beijing Geological Museum's Petrographic Workshop, with the remaining sherds returned to the Shimao Archaeological Workstation. The thin sections were analyzed at the Stanford University Ceramic Analysis Laboratory using a Nikon Eclipse E200 Pol transmitted light microscope, Pixelink Pl-D775 camera, and Petrog Automatic Point Counting Stage and software.

3.2. Sample preparation and analysis methods

Analysis of thin sections proceeded following quantitative point counting methodology established by Stoltman (1989, 1991, 2001) with additional qualitative metrics being recorded following methodology laid out by Quinn (2013). Each of the 75 prepared thin sections was selected at random for analysis with no additional information on the sample provided beforehand. Two-hundred points were counted for each sample along a grid produced by the Petrog software and adjusted for the relative size of each sample so that no point was counted more than once. The choice of two-hundred points was based on the median of Stoltman's (2001) suggested 100–300 points and on the fact that the samples analyzed contain relatively homogeneous inclusions. Points were recorded as matrix, void, or inclusion. In the case of voids, the type of void, length, and width were recorded. For inclusions the length, width, sphericity (how close the shape is to a sphere), roundness (how rounded the edges are, regardless of shape), and type of inclusion were recorded. Inclusions encompass a variety of common minerals such as individual grains of quartz, various feldspars, biotite, muscovite, and carbonates among others, as well as clay pellets, grog, and occasional organic remains. Various lithic fragments, including mudstones and fragments of metamorphic rocks, also occur regularly in some samples, with the constituent minerals and likely parent rock types being recorded separately along with other metrics including the optical activity of the sample. Based on inclusion types, amounts, distribution, and sizes paste grouping were developed. These grouping typically describe the dominant lithics, minerals, or other defining inclusions and were refined using visual comparison of the 200 images automatically taken of every sample during analysis. Raw data and images from this analysis will be housed on the open source China Ceramic Petrography Database.

Raw quantitative data of inclusion types and sizes was exported from Petrog software into Microsoft Excel, where grain size measurements were used to categorize each inclusion into size groups defined by Stoltman (1989) for silt (<0.0625 mm), fine sand (0.0625–0.25 mm), medium sand (0.25–0.5 mm); coarse sand (0.5–1.0 mm), and very coarse sand (>1.0 mm). For this study we did not attempt to differentiate between natural inclusions (sand) and human added inclusions (temper) due to difficulties distinguishing between quartz-based sand and temper, which were present in many of the samples here (Stoltman, 2001, 301). Therefore, all inclusions above 0.0625 mm are classified as sand on the ternary charts. We do however individually discuss some cases where we suspect that the inclusions are the result of tempering. Grain types and size data were recombined with qualitative data as well as information on the sherd itself, including surface treatment. This information was then imported into the JMP statistical analysis software package for analysis and visualization.

4. Results

4.1. Petrographic data

In total eight distinct paste groups were identified among the 75 samples analyzed. Among these are four dominant groups as well as two minor groups and two outliers (see Table 1; Fig. 4; Fig. 5). The most numerous group ($N = 19$) is Coarse Feldspar-Quartz (Fig. 6). This group is defined by the predominance of 0.1-.5 mm feldspar and quartz mineral inclusions and lithics in a micaceous clay matrix. Silt and sand inclusion percentages range from 15 to 32% silt and 14–33% sand. Given that all four local clay samples have around 30% silt, it seems likely that if local clay was used for ceramic production, it was in most cases levigated or otherwise prepared in order to lower the silt content of the clay. Sand amounts in local clay, which are also predominantly quartz and feldspar, are around 6%, 17%, and 28%, making it initially appear that the sand in these sherds could be naturally occurring in the local clay. However, the average grain size for particles in the Coarse Feldspar Quartz sherds is 0.2 mm (including silt), while for the raw clay it is .07 mm for three samples and 0.04 mm for the fourth sample. Thus, the average particle size in the local clay is much smaller than the inclusions seen in these sherds, likely pointing to the intentional addition of sand-based temper with a larger grain size, or use of a clay source that naturally includes larger sand grains, but that was not found during our survey. The larger feldspar and quartz inclusions seen in these ceramic samples could come from a wide variety of rock types, and similar minerals of a comparable size to the inclusions in these sherds were seen

[1] Petrographic analysis of one lime plaster floor sample (see Fig. 1) and one carbonate rock outcrop sample revealed many similarities between the two, including in sizes and types of naturally occurring inclusions. However, the floor sample appears to contain carefully prepared layers of sand and plaster, with the plaster itself containing what appears to be naturally occurring sand as well as round textural features. Additional analysis is needed to fully understand the production methods of this material.

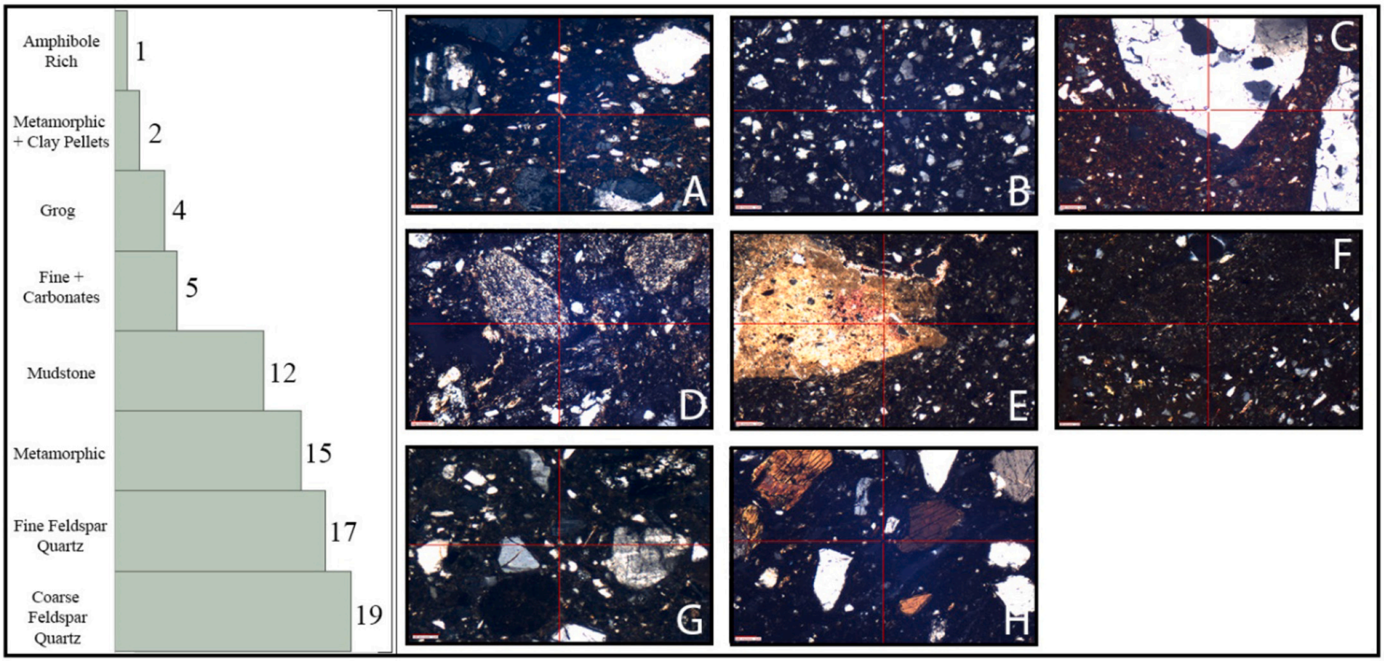

Fig. 4. Petrographic groups with total counts and representative pictomicrographs in XPL.
A. Coarse Feldspar Quartz; B. Fine Feldspar Quartz; C. Metamorphic; D. Mudstone; E. Fine + Carbonates; F. Grog; G. Metamorphic + Clay Pellets; H. Amphibole Rich. The scale bar in the bottom left of each image is 0.1 mm.

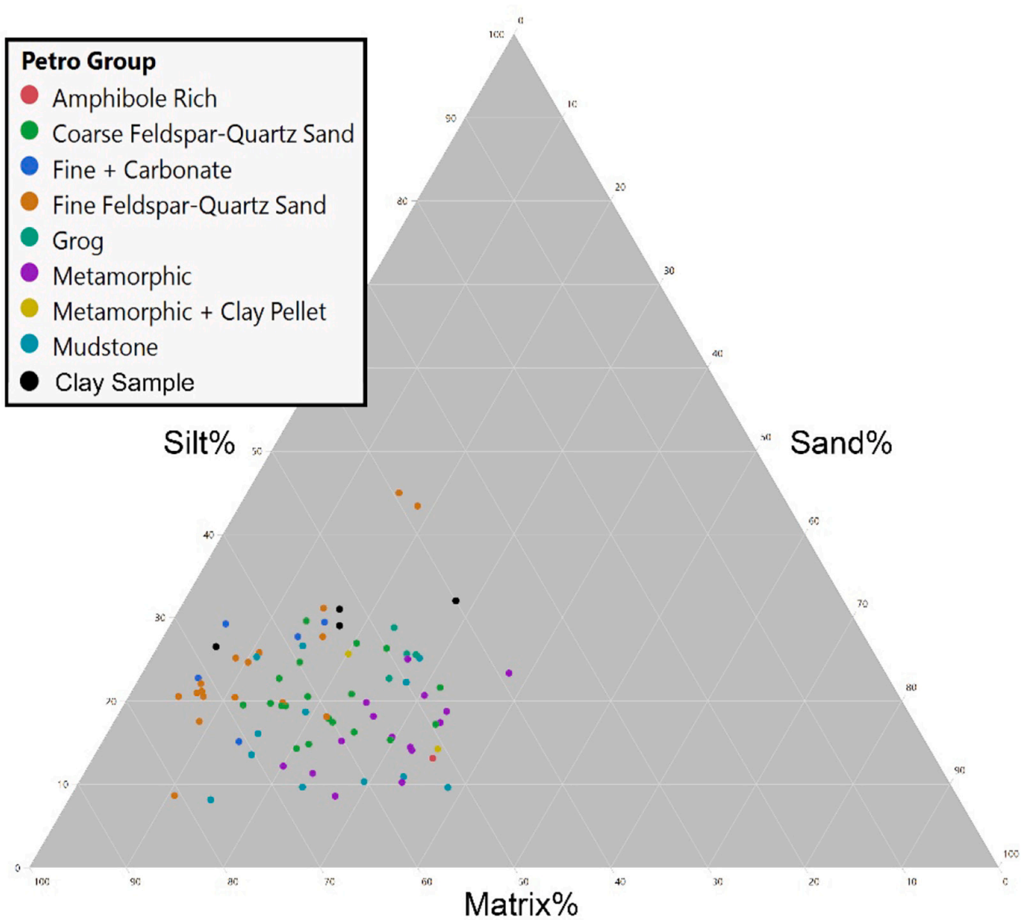

Fig. 5. Ternary Chart of all Petrographic Groups.
All samples categorized by Petrographic Grouping plotted by relative percentages of Matrix (clay), Silt (<0.065 mm), and Sand (>0.065 mm).

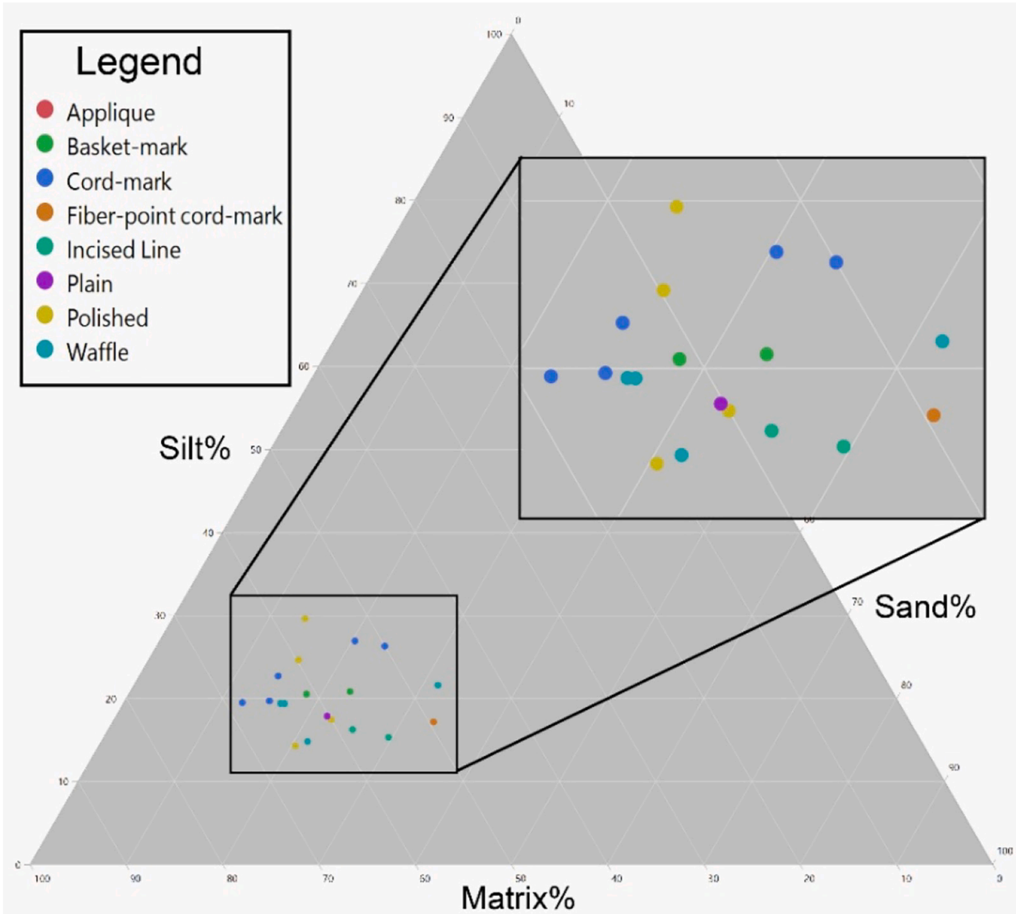

Fig. 6. Ternary Chart of the Coarse Feldspar Quartz Petrographic Group.
The ternary plot includes all Coarse Feldspar Quartz Group samples categorized by surface treatment.

in a local sand lens near the site (see Fig. 1, sand sample #2).

The second most common group, Fine Feldspar-Quartz ($N = 17$), is closely related to its coarser cousin. As the name implies, this group is defined by quartz and feldspar inclusions that are around .1 mm in size on a mica-rich clay matrix. In this group lithics are rare and generally sand-sized inclusions of any type are uncommon. The group is also not particularly homogenous in regards to percentages of matrix:silt:sand. While many samples cluster around 18–27% silt and 10–16% sand, there are also several outliers, with one sample only having 8.5% silt and two others having over 40% silt (Fig. 7). Thus, this group seems to be homogenous as far as inclusion types, but varies significantly in silt amounts, likely indicating origins in varying production groups utilizing either variable clay sources of unknown location or variable processing techniques, for example removing different amounts of silt during levigation. High and low silt clay is not currently available locally, however the inclusion types including fine feldspar and quartz sand were recovered during our geological sampling.

The third most common group is classified as Metamorphic Lithics ($N = 15$) (Fig. 8). This group is defined by numerous large lithic inclusions that contain predominantly feldspar (orthoclase and plagioclase), as well as some nepheline and micas that are typically greater than 1 mm in size. These lithics show signs of metamorphic deformation, hence the name of the group. These inclusions are typically angular, perhaps indicating they were produced by crushing rocks, and are housed within a mica-rich clay matrix. These samples cluster on the ternary chart with 10–20% silt and 25–33% sand. The origins of these large lithics are currently unknown as no metamorphic rock formations appear in the area on geological maps. Sand with such sizable inclusions was not found at or near the site during survey and rocks that could have been crushed to produce this material were also not identified, since virtually all rock samples taken during survey were sedimentary. It is possible that such materials were transported in the past via water to the area but are no longer visible or were simply not identified during survey.

The last major group is Mudstone ($N = 12$) (Fig. 9), which, per the name, has dominant large mudstone inclusions (see Fig. 10) similar to those observed in a sand sample from the river immediately below the citadel (see Fig. 1, sand sample #1). This group also contains carbonate inclusions, which potentially come from weathering of nearby carbonate rock deposits. Among this group, silt and sand levels vary significantly from 10 to 25% silt and 15–35% sand. Average grain size is 0.27 mm. Samples are spread fairly evenly in this range, perhaps indicating tolerance of significant variation in clay processing and addition of inclusions.

Along with these dominant groups, there are two minor groups, Fine + Carbonates ($N = 5$) and Grog ($N = 4$) (see Fig. 11 for all other groups). The Fine + Carbonates group is generally similar to the Fine Feldspar Quartz Sand group, but with the addition of large carbonate inclusions. Given the local availability of such inclusions in the form of carbonate deposits sampled during our survey, it seems likely that samples in this group could have been produced locally. The carbonate inclusions, however, are much larger than those seen in local clay and sand samples, likely indicating that they were purposefully added during the production process. Samples in this group are not closely clustered on the ternary chart. The samples range from 5 to 15% sand and 15–30% silt, with an average grain size of 0.17 mm.

The four Grog samples cluster closely together with 23–28% silt and 23–27% sand, although the average grain size varies from 0.2 mm to

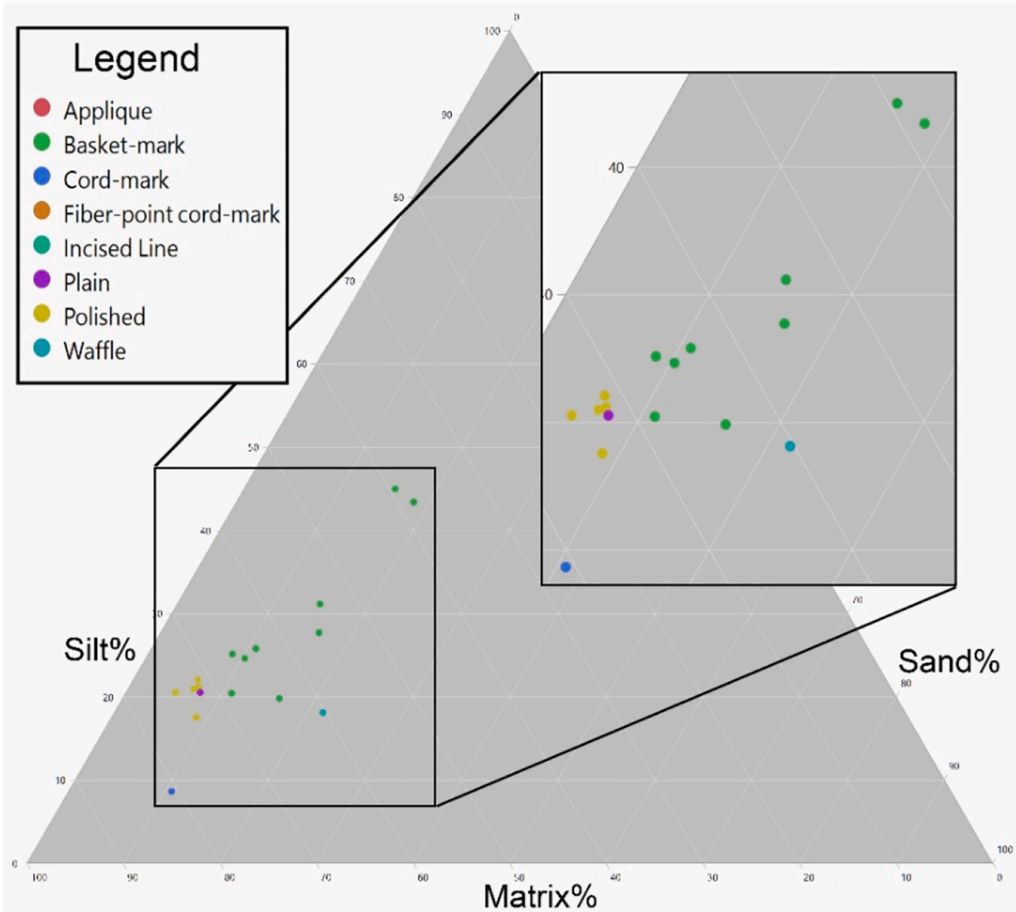

Fig. 7. Ternary Chart of the Fine Feldspar Quartz Petrographic Group.
The ternary plot includes all Fine Feldspar Quartz Group samples colored by surface treatment.

0.53 mm. These samples have fine feldspar and quartz inclusions as well as large grog inclusions (15–20% of inclusions were grog), alongside large carbonate rock and mudstone fragments. Characteristic shrinkage voids are notable surrounding the grog pieces, which are very dark, especially compared to the mudstone inclusions (see Fig. 10). The grog appears to be quite homogeneous and no grog-in-grog pieces were observed. Given the mixture of locally available materials with grog it seems likely that these were produced on site. The close clustering of two of these samples, well within the error range of quantitative petrographic analysis (Stoltman, 1991), may indicate that these two samples come from a single vessel type with a highly standardized paste recipe.

During analysis, two outlier groups with one and two samples, respectively, were recorded. The first, with two samples, is Metamorphic with Clay Pellets. This group is generally similar to the Metamorphic Lithic group, but with the unusual inclusion of large clay pellets. These pellets are not seen in local clay samples, so they were either intentionally produced and added, come from an unsampled local clay source, or come from a more distant clay source or production group. The two samples vary significantly in sand and silt levels, likely indicating variation in clay processing or sourcing.

The final outlier, labeled Amphibole Rich, contains inclusions that are not currently available locally. This sample contained nearly 35% sand including large individual amphibole grains, some biotite, and a variety of lithics that also incorporate these minerals. Given the types and amounts of inclusions, plus a low silt level (13%), the sample appears very similar samples observed among Qijia pottery in the Tao River Valley of Gansu Province (Womack et al., 2019). However, this type of inclusion could also potentially originate in a number of mountainous environments throughout northern China.

4.2. *Comparison of surface treatments and paste recipes*

While selecting sherds for this study, we attempted to sample sherds with of a variety of colors and different surface treatments in order to include a wide variety of vessel types (see Table 1). Based on our current understanding of vessels at Shimao (Shao, 2020), some surface treatments, such as basket-marks, are typical of a single vessel type, while others, such as cord-marks, are present on multiple vessel types. In our discussion we include vessel type references where we are sure of the association and refer only to surface treatment in cases where the associations are less certain.

The Coarse Feldspar Quartz fabric type appears to have been used to create vessels with a wide variety of surface treatments and colors (see Fig. 6). Out of 19 sherds, five have cord-marks, four are polished, and four have a waffle pattern, while four other surface treatments are also represented. Both orange, black, and grey vessels are all represented. This wide variety of surfaces may in some part be explained by the presence of vessels that have a variety of surface treatments and come in different colors, such as tripods, which have waffle patterns and plain sections, or stemmed basins, which can have incised designs and plain or polished sections (Shaanxi and Yulinshi, 2005). Alternatively, this may have simply been a standard, easily produced paste recipe that was versatile enough to make a variety of vessel forms suitable for various functions. Additional analysis of sherds from tripods and stemmed basins should help clarify this result.

The Fine Feldspar Quartz group ($N = 17$) is less diverse, with around half ($N = 9$) of the sherds in this group displaying basket-marks, eight of which are grey (see Fig. 7). In fact, there were only three basket-marked sherds that were not made with this paste type, perhaps indicating a

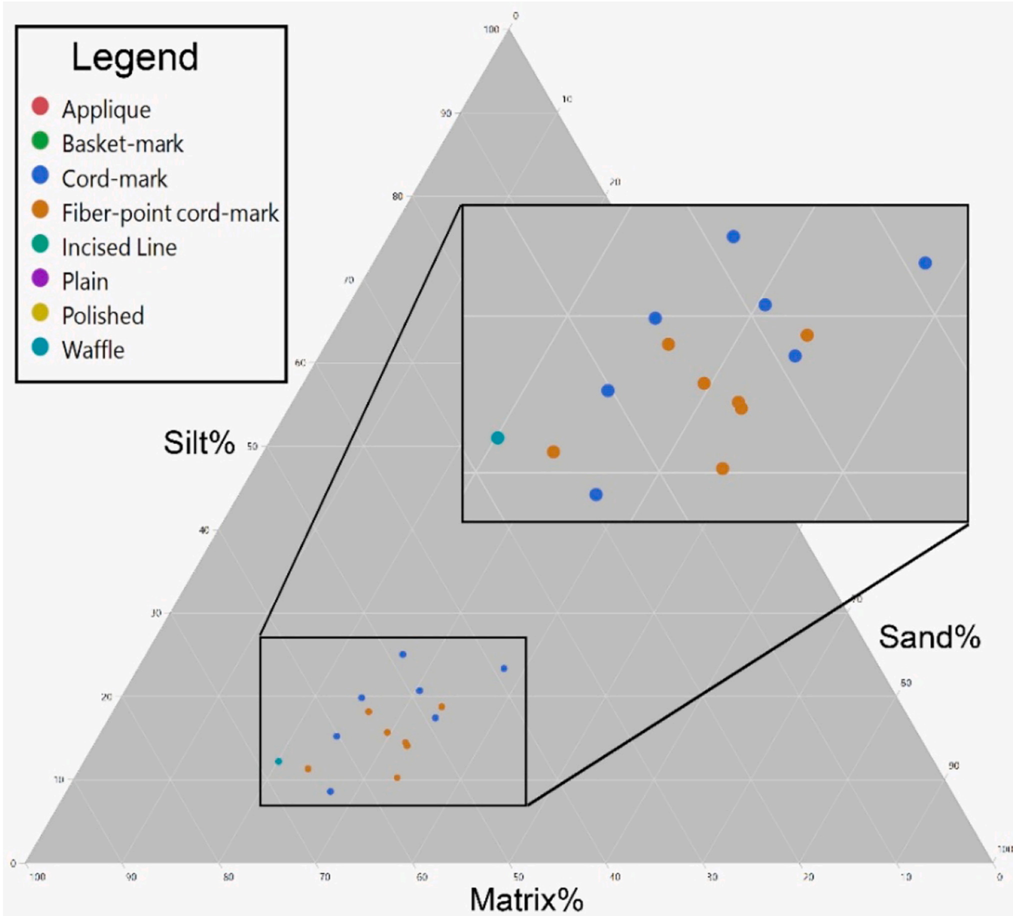

Fig. 8. Ternary Chart of the Metamorphic Lithic Petrographic Group.
The ternary plot includes all Metamorphic Lithic Group samples colored by surface treatment.

preference of this paste recipe for basket-marked vessels. Basket-mark surface treatment is commonly seen on two-handled vases (Shaanxi and Yulinshi, 2005), which in other contexts, such as the Qijia culture of Gansu, seem to have been used for liquid or grain storage (Womack and Wang, 2020). Separately, five sherds in this group are highly polished greywares and cluster very closely together on the ternary chart, indicating a highly standardized paste recipe. Two of these samples are so closely aligned they could potentially come from the same vessel. It is likely that all of these highly polished grey sherds come from basins, which are thought to have been used as serving dishes. Thus, it appears that the majority of Fine Feldspar Quartz group sherds come from vessels potentially used for storing or serving food and drink. There are also one each of plain, cord-marked and waffle patterned sherds; however, aside from the plain sample, these sherds are not closely clustered with any of the other samples.

The Metamorphic Lithics group ($N = 15$) is dominated by light orange sherds with cord-marks ($N = 6$; also grey with cord marks: N = 1) and orange sherds with fiber point cord-marks ($N = 7$) (see Fig. 8). Such surface treatments are often associated with cooking vessels in Neolithic and early Bronze Age China and are seen on a wide variety of vessel forms (Womack and Wang, 2020). Silt and inclusion levels in these sherds are generally overlapping, further reinforcing potential similarities in paste recipes and clay preparation techniques. The presence of coarse inclusions as well as rough surface treatments such as cord-marks have both been seen as aiding in thermal shock resistance in cooking vessels in other areas of the world (Rice, 1996), further reinforcing the idea that such vessels were likely used for cooking. Whether the distinction between cord-marks and fiber point cord-marks, as well as orange versus light orange vessels, is due to different intended uses, production by different groups of potters, or some other factor currently remains unknown.

The Mudstone group (see Fig. 9) appears to have been the preferred paste recipe for building ceramics with applique decoration, as all four samples with circular applique designs are made with this recipe. It was also used widely for sherds with other surface treatments including waffle patterns ($N = 3$), plain ($N = 2$), polished ($N = 1$), and even cord-marks (N = 1) and fiber point cord-marks (N = 1). Virtually all of these sherds were reduction fired. Why this paste recipe should be used occasionally for sherds with non-applique surface treatments but is not the dominant group for any aside from applique, is unclear. However, the mudstone inclusions in this group are readily available in the form of sand at Shimao (sand sample #1), perhaps making this tempering material a convenient choice for a variety of locally made vessels. Additionally, mudstone and other tempers were used to produce whitewares during the Neolithic period on the east coast of China (Druc et al., 2020). Among the 12 mudstone samples, four do have a whitish tint, while the rest are reduction-fired grey. It is possible that the inclusion of mudstone in these four samples was due to a desire for a lighter finish, however more samples are needed to better understand this possibility.

Grog ($N = 4$) was used to produce cord-marked (N = 3) and fiber point cord-marked (N = 1) sherds, indicating that it was likely also a recipe preferred for cooking vessels, similar to the Metamorphic Lithic group. Given the close clustering of data points on the ternary chart and the local availability of raw materials, it is likely that these vessels were all produced by a single production group working locally.

The Fine with Carbonates group ($N = 5$) was also used to exclusively produce vessels with two particular surface treatments, in this case cord-marks (N = 2) and basket-marks (N = 3). All of these sherds are thick

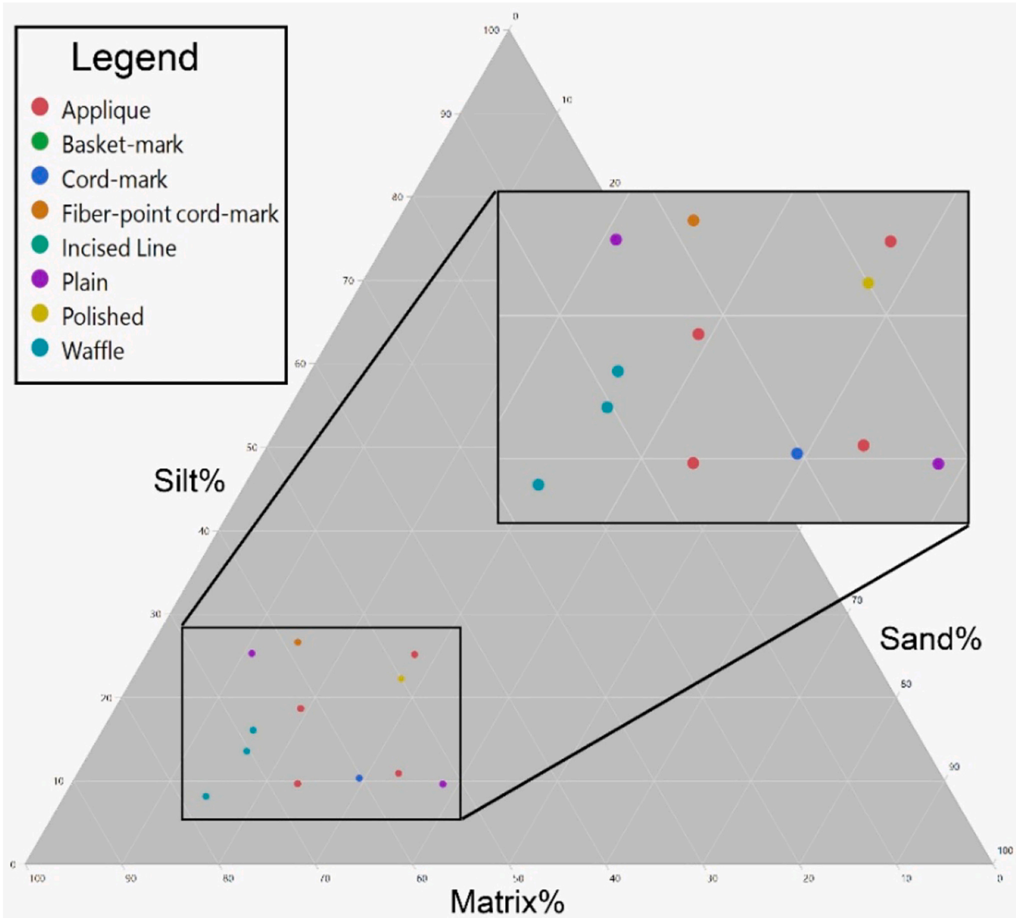

Fig. 9. Ternary Chart of the Mudstone Petrographic Group.
The ternary plot includes all Mudstone group samples colored by surface treatment.

and grey. As mentioned above, cord-marked vessels are often associated with cooking. While the function of basket-marked vessels has not been studied at Shimao, in other contexts basket-marked vessels appear to have been used for liquid or dry-good storage (Womack and Wang, 2020). Given these quite different vessel functions, it is possible that the Fine with Carbonates recipe could have been seen as acceptable for the creation of vessels with variable intended uses.

For Metamorphic with Clay Pellets, the two available samples have cord-marks and basket-marks, respectively. Additional samples are needed to understand how these samples relate to specific vessel types or production groups. The final outlier, SM074, is clearly not local, however it does have a surface treatment, a waffle pattern, that is relatively common at Shimao, as well as being present at other sites across the north and northwestern China. Additional research into this pattern and vessels that it comes from is needed to fully understand the significance of this sample.

5. Discussion

What is clear from the data we have so far is that much of the ceramic production for sherds recovered from the citadel at Shimao could have taken place locally using local raw materials. Given the presence of abundant amounts of clay and tempering materials at Shimao, as well as the massive amount of pottery that must have been used there over the lifetime of the occupation, it seems highly likely that significant production took place at the site. For example, of the four dominant paste groups identified through petrographic analysis, materials for production of three of them, Fine Feldspar Quartz, Coarse Feldspar Quartz, and Mudstone (total $N = 48$), were all discovered at or near (<1 km) the site during our geological survey (see Fig. 1). Additionally, some of the materials seen in the outlier groups were also available locally including for the Grog and Fine + Carbonate groups ($N = 9$). While the identified clay types would have needed some processing, such as levigation, to lower silt levels, and then would have had sand temper added to produce pastes seen in most of the recovered sherds, such processing is well known from this and earlier periods in China. Indeed, at other sites in northern China clay levigation pits have been uncovered alongside tools and other remains that have been characterized as workshops (Dai, 2006). Thus, it is certainly possible that similar techniques were used at Shimao to turn the local sand and clay into a wide variety of vessels. Alternatively, given the likely availability of clay and common quartz and feldspar sands in the wider region, it is also possible that pottery was produced at, and then exported from, other smaller sites to Shimao. While such regional exchange between smaller and larger sites is seen in later periods, such as at the Shang capital of Anyang (Campbell et al., 2011), there is not compelling evidence for this type of relationship between Shimao and smaller outlying sites from our initial study.

Focusing on potential production at Shimao, the variety of types and amounts of local materials used in the clay recipes seen at the site speaks to significant diversity in local production. For example, vessels with basket-marks, which appear to only come from large vases, were made predominantly using a Fine Feldspar Quartz paste recipe. However, three other clay recipes were also used to make this vessel type, including two, Fine + Carbonate and Course Feldspar Quartz, that are also available locally. Given that these sherds were all found in overlapping contexts, it is likely that this variation is not due to change over time in paste recipes or production locations. Therefore, it seems possible that while there was a dominant production group utilizing the

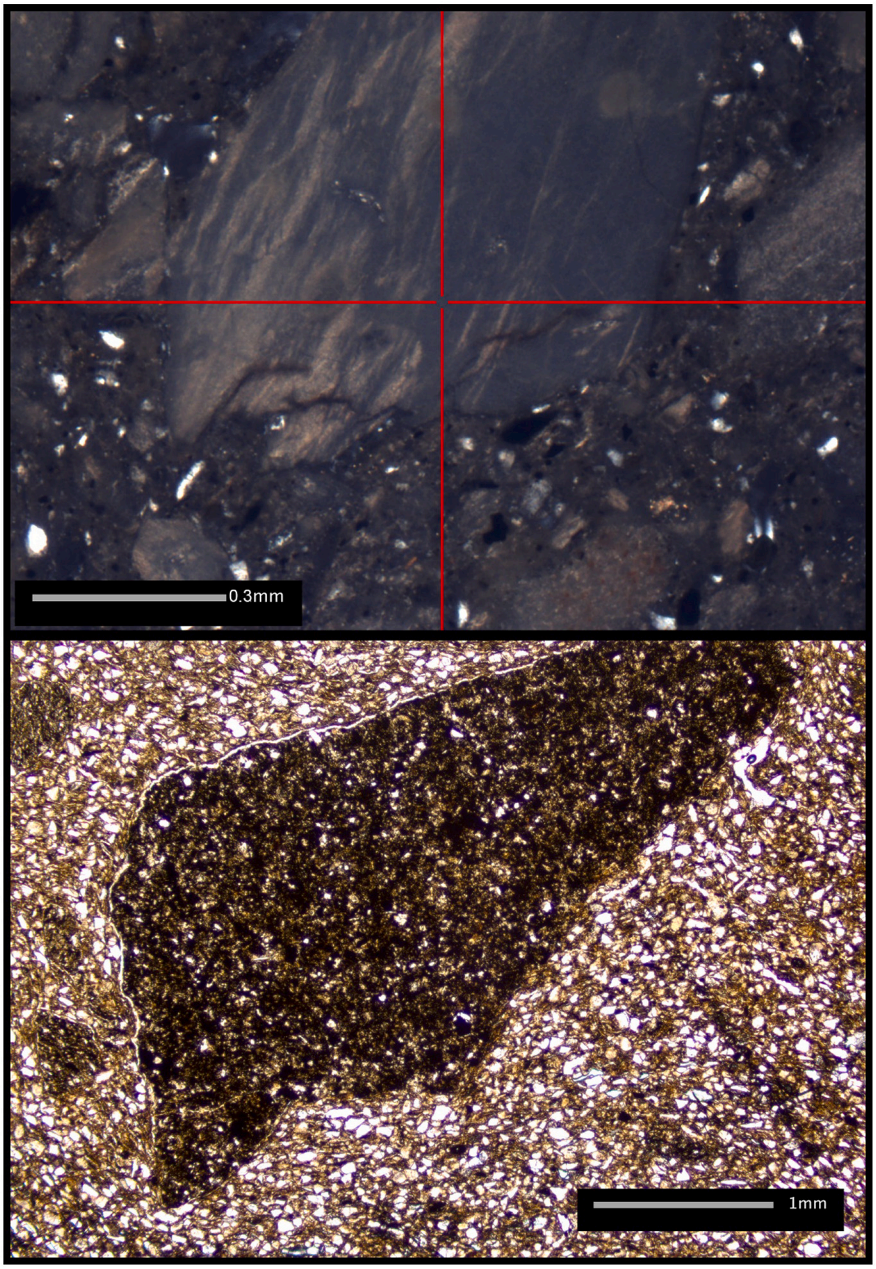

Fig. 10. Photomicrographs of mudstone and grog inclusions.
A Cross Polarized Light (XPL) image of a mudstone inclusion (top) and a plain polarized light (PPL) image of a grog inclusion (bottom).

Fine Feldspar Quartz recipe for production of basket-marked vessels, other groups of potters using slightly different recipes were also producing these items. It is currently unclear whether all of these groups operated at Shimao or whether some groups were based at other sites with similar raw materials. However, as noted previously, given the abundant raw materials available at Shimao, it is likely that at least one group was operating at this site. Even if all production groups were based at Shimao, it is possible that access to clay, temper, or knowledge of specific clay recipes could have been restricted to certain groups, leaving other producers to utilize alternative materials or recipes.

In other cases, it appears that a single production group may have been responsible for all of the production of a specific type of vessel. For example, vessels with a specific round applique decoration were all produced using the Mudstone paste type. However, even sherds with this specific decoration do not have similar levels of silt and inclusions, pointing to a lack of highly standardized production, while this paste type was also used to produce pottery with a variety of other surface treatments. Although the overall form and use of vessels with applique remains unknown, the knowledge or skill needed to produce such delicate decoration may have been restricted to a single group of potters. Given the small sample size however, additional sampling will be needed to further explore whether production of certain vessel types was restricted to certain groups.

Based on our current knowledge of local resources, it is possible that one of the largest groups of pottery was not produced at the site itself. The Metamorphic Lithic group (15% of total samples) contains large rock fragments with some unusual components, such as nepheline, that were not discovered at Shimao during our survey. While it is possible that this tempering material could have been imported to the site or existed at the site but was depleted or buried over the past 4000 years, the location where this material was gathered is currently unknown. This points to the likelihood that some specific vessel types, in this case

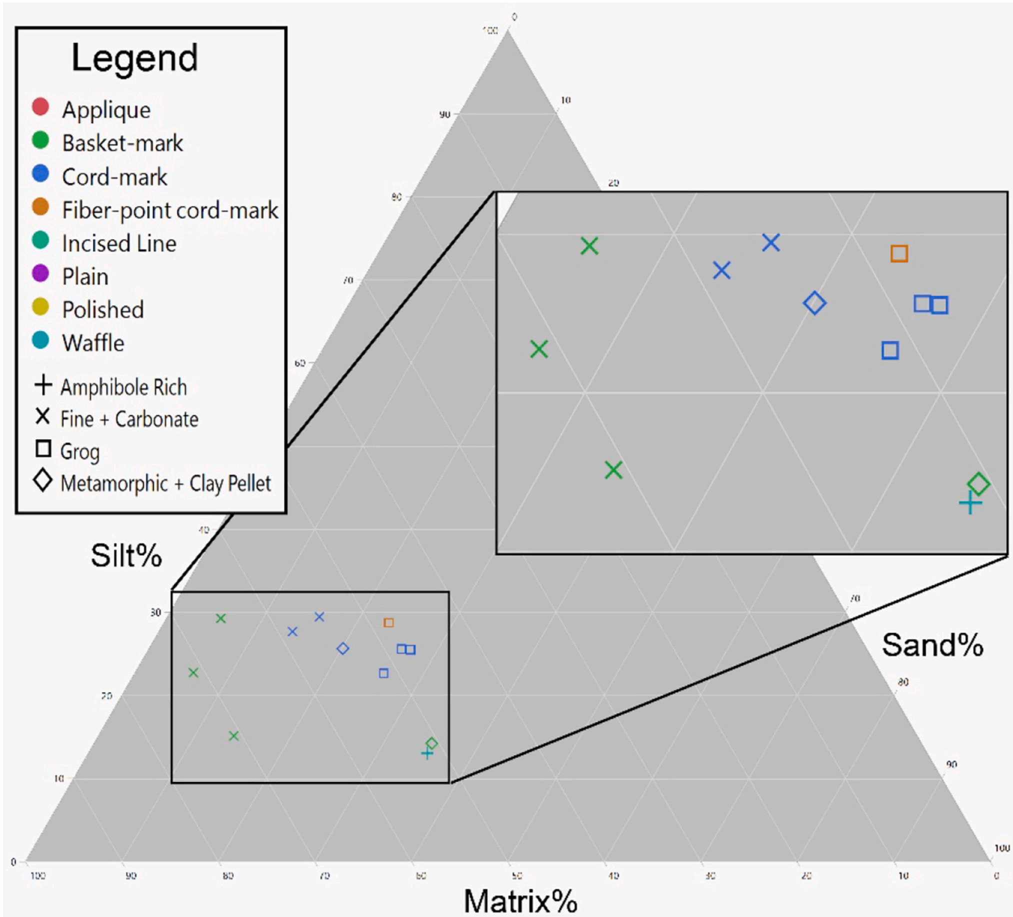

Fig. 11. Ternary Chart of all Outlier Petrographic Groups.
The ternary plot includes all other petrographic groups signified by symbol shape and surface treatment identified by color.

vessels with cord or fiber-point cord-marks, were imported to the site from a different geological region. Smaller numbers of cord and fiber-point cord marked sherds were also produced with paste recipes that are available locally. At least two scenarios could explain these data. First, like basket-marked sherds, there could have been a dominant local production group that imported or otherwise acquired Metamorphic Lithic tempering materials for production at Shimao. Alternatively, these vessels could have been produced elsewhere and imported to the site. Locations with this specific raw material are currently unknown. Regular exchange of cord-marked vessels is known from other areas of northwestern China at this time (Womack et al. 2019). Either way, production of vessels with these surface treatments also took place using other paste recipes, speaking to apparent diversity in production.

Aside from the likely importation of metamorphic group vessels or temper, only a single other distinctly nonlocal sherd was discovered during this study. In this case SM074, which has amphibole inclusions that are not known in any local rock types. Amphibole-bearing rocks are relatively common in igneous and metamorphic geology, which are both common in other regions of China, making the origins of this sherd difficult to determine. Nevertheless, if direct long-distance exchange was happing between peoples at Shimao and more distant regions, it does not seem that pottery was a regular focus of this exchange. Based on the characteristics of the sherd, the vessel it came from was likely relatively small and light one-handled tripod (see Fig. 2, B2), meaning that it was likely relatively easy to transport. How it arrived at Shimao, exactly where it came from, and why it was brought there, remain unclear.

In summary, despite the lack of wider contextual information on ceramic production and use at Shimao, we can already draw some preliminary conclusions about pottery from the site. First, it seems that ceramic production for sampled vessel types was not highly standardized or regulated. In nearly every case, groups of sherds representing the same vessel type were produced using a variety of paste recipes. While there is typically a dominant recipe, perhaps indicating a single large production group, often three or four other recipes are also present. This is likely indicative of concurrent production of particular types of vessels by multiple production groups. How this production was coordinated or organized, however, is currently unknown.

Second, it appears likely that most ceramic production took place at the site itself utilizing the abundant local raw materials. It is also possible that production took place at other sites with similar raw materials, however sampling at other sites is needed before we can hypothesize further on this possibility. Additionally, as with the example of sherds with the Metamorphic Lithic paste, it is likely that certain pottery types were imported from regions with different geological resources, or the materials necessary to produce them were brought to the site from elsewhere. However, a more formal geological assessment of the site area, as well as of surrounding sites, is needed to confirm the presence or absence of additional tempering materials.

Finally, ceramic vessels do not seem to have been a major long-distance import to Shimao. While it is clear that some form of exchange network was bringing exotic goods such as jade and shells to Shimao, and to many other sites across the region, pottery does not seem to have been a major long-distance trade item, at least compared to the total amount of pottery sampled for this study. Given the weight and bulkiness of ceramic vessels, this is not entirely surprising. Based on the presence of the Metamorphic lithic group as well as the composition of SM074, it does appear that pottery from distant areas was occasionally brought to the site (16% of the total amount analyzed), however more research is needed to better understand both the origins of these imports and how unique they are among the wider pottery assemblage at Shimao.

6. Conclusion

Turning back to current discussions of political and economic organization and reach at Shimao, much like the material in Owlett et al.'s study (2018), our data do not point to a highly regulated system of production at the site. While it seems likely that most of the pottery discarded in the area of the citadel from which our sample was derived was produced locally at Shimao, it is not especially homogeneous. Aside from sherds with applique decoration, sherds with most other surface treatments were made using a variety of paste types and inclusion amounts. While most of these paste types are made of components available at the site, others, such as the Metamorphic paste group, may not have been, pointing to potential contribution from more distant communities of potters. Even within specific paste groups and vessel types, amounts of silt and sand can vary significantly, indicating a lack of highly standardized clay preparation processes.

Our current hypothesis for ceramic production organization points to a large, but not highly regulated local production group or groups, potentially organized at the household level, that produced a variety of ceramic forms using multiple paste recipes derived from locally available materials. At least one group of potters working outside of the local geological area potentially also produced vessels that were similar to those being produced at Shimao, although the mechanism by which these pots may have been moved to and used at the site are currently unknown. Overall, much like animal rearing at Shimao, and pottery production in other areas of China around this time (Bonomo, 2017; Womack et al. 2019), pottery at Shimao appears to have mostly been produced locally to suit local needs.

Now, additional research is needed to fill in the many gaps in our understanding of vessel production, forms, and function at Shimao. First, geological and ceramic sampling is needed at other sites in the same region as Shimao in order to better understand variability in raw materials and/or production techniques. Macroanalysis of sherds is needed to further refine our understanding of the wide variety of vessel types used at the site, while use-alteration and residue analysis can provide insight into the function of these goods. Finally, additional petrographic analysis and geological survey is planned at Shimao in order to better understand variation in ceramic production and consumption over time and in different parts of the site.

Declaration of Competing Interest

The authors have no competing interests to declare.

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References

Arnold, D.E., Neff, H., Bishop, R.L., 1991. Compositional analysis and "sources" of pottery: an ethnoarcheological approach. Am. Anthropol. 93, 70–90.
Bernardini, W., 2000. Kiln firing groups: inter-household economic collaboration and social organization in the Northern American Southwest. Am. Antiq. 65, 365–377.
Bonomo, M.F., 2017. Ceramic production and provenance in the Yiluo Basin (Henan, China): Geoarchaeological interpretations of utilitarian craft production in the Erlitou state. Archaeol. Res. Asia 14, 80–96.
Bowser, B.J., Patton, J.Q., 2008. Learning and transmission of pottery style: women's life histories and communities of practice in the Ecuadorian Amazon. In: Stark, M.T.B., Horne, L. (Eds.), Cultural Transmission and Material Culture: Breaking Down Boundaries. Arizona University Press, Tuscon, pp. 105–129.
Campbell, R.B., Li, Z.P., He, Y.L., Yuan, J., 2011. Consumption, exchange and production at the great settlement Shang: bone-working at Tiesanlu, Anyang. Antiquity 85 (330), 1279–1297.
Costin, C.L., 1991. Craft specialization: issues in defining, documenting, and explaining the organization of production. Archaeol. Method Theory 3, 1–56.
Cui, T., 1991. Zhukaigou yi zhi tao qi shi qi (analysis of pottery from the Zhukaigou site). Kaogu (Archaeology) 361–371.
Dai, X., 2006. Pottery Production, Settlement Patterns and Development of Social Complexity in the Yuanqu Basin, North-Central China, Archaeopress, Oxford, England.
D'Ercole, G., Budka, J., Sterba, J.H., Garcea, E.A., Mader, D., 2017. The successful 'recipe'for a long-lasting tradition: Nubian ceramic assemblages from Sai Island (Northern Sudan) from prehistory to the New Kingdom. Antiquity 91, 24–42.
Druc, I., Underhill, A., Wang, F., Luan, F., Lu, Q., 2018. A preliminary assessment of the organization of ceramic production at Liangchengzhen, Rizhao, Shandong: Perspectives from petrography. J. Archaeol. Sci. Rep. 18, 222–238.
Druc, I., Underhill, A., Wang, F., Luan, F., Lu, Q., Hu, Q., Guo, M., Liu, Y., 2020. Late Neolithic white wares from southeastern Shandong, China: the tricks to produce a white looking pot with not much kaolin. Results from petrography, XRD and SEM-EDS analyses. J. Archaeol. Sci. Rep. 35. https://doi.org/10.1016/j.jasrep.2020.102673.
Flad, R.K., 2012. Bronze, jade, gold, and ivory: valuable objects in ancient Sichuan. Const. Value Ancient World 306–335.
Gosselain, O.P., 1992. Bonfire of the enquiries. Pottery firing temperatures in archaeology: what for? J. Archaeol. Sci. 19, 243–259.
Gosselain, Olivier P., 2000. Materializing identities: an African perspective. J. Archaeol. Method Theory 7, 187–217.
Jaang, L., Sun, Z., Shao, J., Li, M., 2018. When peripheries were centres: a preliminary study of the Shimao-centred polity in the loess highland, China. Antiquity 92, 1008–1022.
Jaffe, Y., 2016. The continued creation of communities of practice – finding variation in the Western Zhou expansion (1046-771 BCE). Harvard University, Cambridge, Mass.
Li, M., 2016. Settling on the ruins of Xia: Archaeology of social memory in early China. In: Emberling, G. (Ed.), Social Theory in Archaeology and Ancient History. Cambridge University Press, Cambridge, pp. 291–327.
Linduff, K.M., 1995. Zhukaigou, steppe culture and the rise of Chinese civilization. Antiquity 69, 133–145.
Liu, L., 2003. "The products of minds as well as of hands": Production of prestige goods in the Neolithic and early state periods of China. Asian Perspect. 42, 1–40.
Michelaki, K., Braun, G.V., Hancock, R.G.V., 2014. Local clay sources as histories of human–landscape interactions: a ceramic taskscape perspective. J. Archaeol. Method Theory 22, 783–827.
Neimenggu, Zizhiqu Wenwu Kaogu Yanjiusuo, E 'erduosi, Bowuguan, 2000. Zhukaigou: Qing Tong shi Dai Zao Qi Yi Zhi Fa Jue Bao Gao (Zhukaigou: Excavation Report on the Early Bronze Age Site). Wenwu Chubanshe (Cultural Relics Publishing House), Beijing.
Owlett, T.E., Hu, S., Sun, Z., Shao, J., 2018. Food between the country and the city: the politics of food production at Shimao and Zhaimaoliang in the Ordos region, northern China. Archaeol. Res. Asia 14, 46–60.
Ownby, M.F., Huntley, D.L., Peeples, M.A., 2014. A combined approach: using NAA and petrography to examine ceramic production and exchange in the American southwest. J. Archaeol. Sci. 52, 152–162.
Quinn, P.S., 2013. Ceramic Petrography: The Interpretation of Archaeological Pottery & Related Artefacts in Thin Section. Archaeopress.
Quinn, P., Day, P., Kilikoglou, V., Faber, E., Katsarou-Tzeveleki, S., Sampson, A., 2010. Keeping an eye on your pots: the provenance of Neolithic ceramics from the cave of the Cyclops, Youra, Greece. J. Archaeol. Sci. 37, 1042–1052.
Rawson, J., 2017. Shimao and Erlitou: new perspectives on the origins of the bronze industry in Central China. Antiquity 91, 1–5.
Rice, P.M., 1984. Change and conservatism in pottery-producing systems. In: Van Der Leeuw, S.E. (Ed.), The Many Dimensions of Pottery: Ceramics in Archaeology and Anthropology. Albert Egges van Giffen Instituut voor Prae-en Protohistorie, pp. 231–289.
Rice, P.M., 1987. Pottery Analysis. University of Chicago Press.
Rice, P.M., 1996. Recent ceramic analysis: 1. Function, style, and origins. J, Archaeolog. Res. 4 (2), 133–163.
Roux, V., 2015. Standardization of ceramic assemblages: transmission mechanisms and diffusion of morpho-functional traits across social boundaries. J. Anthropol. Archaeol. 40, 1–9.
Rye, O., 1981. Pottery Technology: principles and reconstruction. Taraxacum.
Sassaman, K.E., Rudolphi, W., 2001. Communities of practice in the early pottery traditions of the American Southeast. J. Anthropolog. Res. 57 (4), 407–425.
Shaanxi, Sheng Kaogu Yanjiusuo, Yulinshi, Wenwu Baohu Yanjiusuo, 2005. Shenmu Xinhua. Kexue Chubanshe (Scientific Publishing House), Beijing.
Shao, J.S., 2016. Shi lun Shimao chengzhi de niandai xiujian guocheng (On the age and construction of the Shimao site). Kaogu yu Wenwu (Archaeology and Cultural Relics) 4, 102–108.

Shao, J., 2019. Chulun Shaanbei diqu Longshan qianqi yicun (Preliminary Discussion on the Remains of Early Longshan in Northern Shaanxi). Kaogu yu Wenwu (Archaeology and Cultural. Relics) 4, 61–65.
Shao, J., 2020. Shimao yi zhi yu Taosi yi zhi de bi jiao yan jiu (research comparing the Shimao site and the Taosi site). Kaogu (Archaeology) 65–77.
Stahl, A.B., Dores Cruz, M.D., Neff, H., Glascock, M.D., Speakman, R.J., Giles, B., Smith, L., 2008. Ceramic production, consumption and exchange in the Banda area, Ghana: insights from compositional analyses. J. Anthropolog. Archaeol. 27 (3), 363–381. https://doi.org/10.1016/j.jaa.2008.04.001.
Stark, M.T., 2006. Glaze ware technology: The social lives of pots, and communities of practice in the late prehistoric southwest. In: Habicht-Mauche, J., Eckert, S., Huntley, D. (Eds.), Social Lives of Pots: Glaze Wares and Cultural Dynamics in the Southwest, AD1250–1680. The University of Arizona Press, Tuscon, pp. 17–33.
Stoltman, J.B., 1989. A quantitative approach to the petrographic analysis of ceramic thin sections. Am. Antiq. 147–160.
Stoltman, J.B., 1991. Ceramic petrography as a technique for documenting cultural interaction: an example from the upper Mississippi Valley. Am. Antiq. 56, 103–120.
Stoltman, J.B., 2001. The Role of Petrography in the Study of Archaeological Ceramics. Springer, Earth sciences and archaeology, pp. 297–326.
Sun, Z., Yuan, Shaanxi Sheng Kao Gu Yan Jiu, Dui, Yulin Shi Wen Wu Kao Gu Kan Tan Gong Zuo, Ju, Shenmu Xian Wen Ti Guang Dian, 2016. Shaanxi Shenmu xian Shimao yi zhi han jia ge dan di dian fa jue jian bao (excavation report from the Hanjiagedan area of the Shimao site, Shenmu County, Shaanxi). Kaogu yu Wenwu (Archaeology and Cultural Relics) 14–24.
Sun, Z., Yuan, Shaanxi Sheng Kao Gu Yan Jiu, Dui, Yulin Shi Wen Wu Kao Gu Kan Tan Gong Zuo, Chu, Shenmu Xian Shimao Yi Zhi Guan Li, 2017. Shaanxi Shenmu xian Shimao yi zhi huang cheng tai di dian (excavations of the Huangchengtai area at Shimao). Kaogu (Archaeology) 46–56.
Sun, Z., Shao, J., Liu, L., Cui, J., Bonomo, M.F., Guo, Q., Wu, X., Wang, J., 2018. The first Neolithic urban center on China's north loess plateau: the rise and fall of Shimao. Archaeol. Res. Asia 14, 33–45.
Sun, Z., Shao, J., Di, N., 2020a. Shimao yi zhi de kao gu fa xian yu yan jiu zong shu (a summary of research and discoveries at the Shimao site). Zhongyuan Wenwu (Central Plains Cultural Relics) 39–62.
Sun, Z., Shao, J., Di, N., 2020b. Shimao wenhua de mingming, fanwei ji niandi (the name, age, and scope of Shimao). Kaogu (Archaeology) 2020 (8), 101–108.
Underhill, A.P., 2015. What is Special about Specialization? In: Scott, R.A., Buchmann, M.C. (Eds.), Emerging Trends in the Social and Behavioral Sciences: An Interdisciplinary, Searchable, and Linkable Resource. Wiley.
Wang, R., 2011. Progress review of the scientific study of Chinese ancient jade. Archaeometry 53, 674–692.
Womack, A., Horsley, T., Wang, H., Zhou, J., Flad, R., 2019. Assessing site organization and development using geophysical prospection at Dayatou, Gansu, China. J. Archaeolog. Sci. Rep. 27, 1–12.
Womack, A., Wang, H., 2020. Formation and function of majiayao and qijia pottery: analysis of manufacturing Marks and use-alteration on vessels from the Tao River valley. Asian Perspect. 59, 2–32.
Yan, H., 2010. Shenmu Shimao Yizhi Taoqi Fenxi (analysis of Pottery at the Shimao Site, Shenmu County). Wenbo 2010, 3–9.