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Investigating the Ancient Craftsmanship: Comprehensive Analysis of Composition and Sintering Techniques in Jiangzhai Painted Pottery

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Abstract: Delving into the past through the study of pottery, this research employs scientific techniques to explore Jiangzhai pottery from circa 3000–4000 BCE. The investigation revealed that the red and grey pottery, despite their color differences, have similar elemental compositions, suggesting that these variations are not due to elemental differences but likely due to a higher concentration of Fe^{3+} in the red pottery. Analysis of the pigments using elemental analysis, polarized light microscopy, and XRD showed that the red pigment contains ochre, the black is a mix of pyrolusite and magnetite, and the white is composed of calcite. Additionally, thermal expansion analysis determined that the firing temperature of Jiangzhai colored pottery is around 1050 °C, with similar temperatures for both red and grey pottery, suggesting that kiln operations like stacking or overlapping are likely causes of the color variations. This study not only broadens our understanding of ancient pottery-making techniques and cultural practices but also emphasizes the critical role of scientific analysis in preserving and interpreting the rich artistic and technological legacy of ancient cultures.

Keywords: painted pottery; Jiangzhai culture; pottery body; pigment; firing process

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1. Introduction

Unveiling the intricate life of ancient China, the painted pottery from the Jiangzhai site offers a vivid portrayal of the Yangshao culture. Located near the Yellow River basin, this Neolithic settlement reflects the artistic zenith of a culture that flourished approximately 4000 to 7000 years ago [1]. This period coincides with significant advancements in pottery in regions such as Japan [2,3], where Jomon pottery showcased cord markings and elaborate designs, and the Near East [4], known for painted ware and the introduction of the potter's wheel, highlighting a global context of ceramic innovation. The Yangshao culture, marking a crucial period in human history [5], witnessed the convergence of art, culture, and technology that began to shape a more sophisticated and organized society [6,7]. Renowned for its distinctive painted pottery characterized by intricate designs and vibrant colors, it symbolizes a pivotal moment in ancient Chinese cultural heritage [8]. Moreover, the elaborate decoration and fine clay quality of the pottery specifically found at Jiangzhai not only exemplify the craftsmanship of the era but also provide a deeper understanding of the daily life, beliefs, and societal structures of the Neolithic communities in this region [9].

In the context of the Jiangzhai site, located about a kilometer north of Lintong District in Xi'an, Shaanxi Province, as Figure 1 shows, we discover a profound connection to this rich cultural past. The site, covering an area of approximately 50,000 square meters with around 13,000 square meters excavated, serves as a window into the complex social structure of its inhabitants [10]. Jiangzhai, with its distinct residential areas, kilns, and burial sites, illustrates a well-organized community adept in both agricultural practices and hunting–fishing activities. The excavation of over 10,000 artifacts, including stone and bone tools, decorative items, and ceramics, paints a vivid picture of the daily life and artistic expression of this community [11]. The painted pottery unearthed here, distinct in its craftsmanship and style, is particularly notable for its contribution to our understanding of Neolithic art and societal practices.

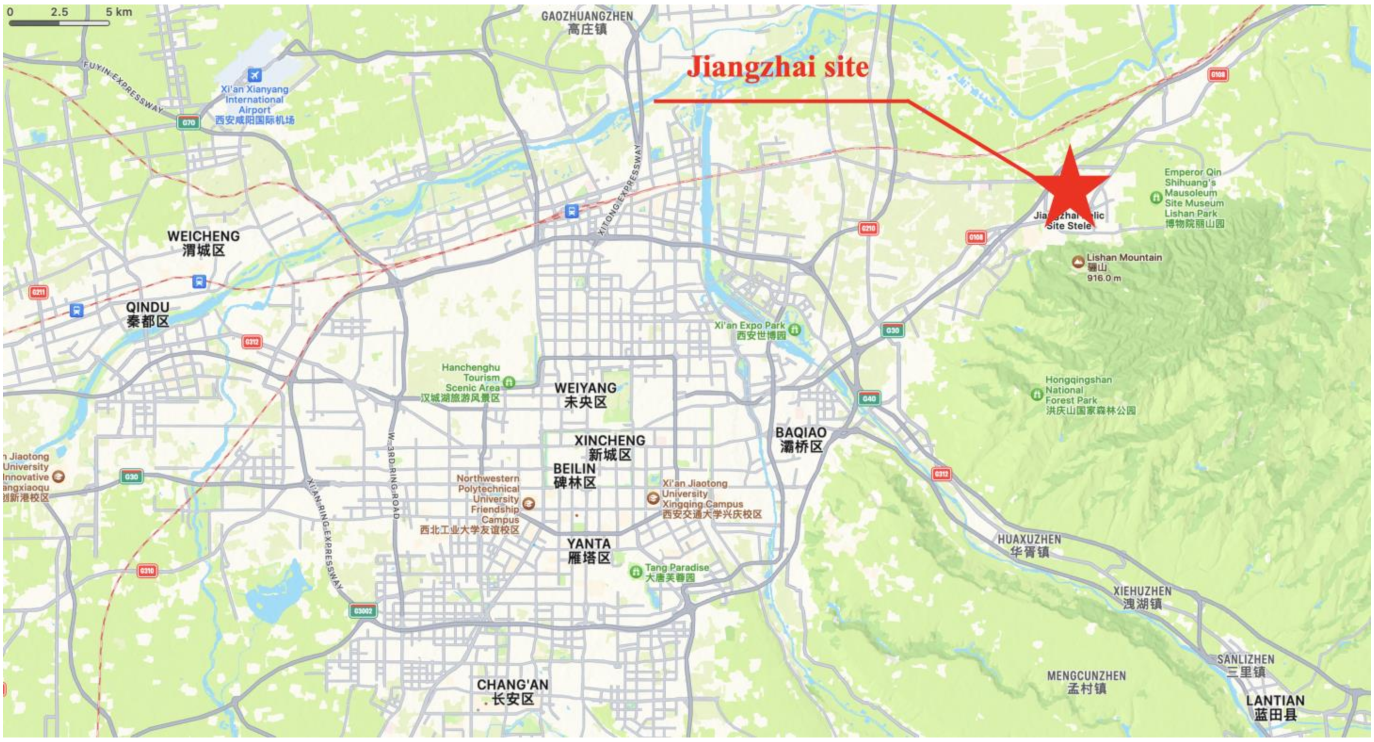

Figure 1. The Jiangzhai site is located in Xi'an, Shaanxi Province, China.

This paper focuses on an in-depth, multidisciplinary analysis of the painted pottery from the Jiangzhai site [12]. Our research explores various aspects of these artifacts, including the investigation into the causes of the varied color changes observed in the pottery, such as the differing red and gray hues and the black speckling on the bottom of the red pottery. A comprehensive study of the surface pigments is undertaken, examining color, elemental composition, phase structure, and the origin of the pigments. This multifaceted approach is aimed at gaining a deeper understanding of the raw materials and firing techniques of these colored potteries, thereby contributing to an enhanced comprehension of the technological and artistic capabilities of the Neolithic communities at the Jiangzhai site.

2. Materials and Methods

2.1. Sample Source

The study focuses on the painted pottery excavated from the Jiangzhai site, where the predominant color scheme is a classic red adorned with black motifs. As depicted in Figure 1, these designs encompass fish, birds, and a variety of geometric patterns. Among these artifacts, a selection of potsherds exhibiting gray and red-black hues has been identified [13]. A specific subset of these potsherds, illustrated in Figure 2, was chosen for detailed examination to explore the occurrence of these unique gray and red-black pieces and to ascertain the composition of the pigments employed in the surface decorations. The color spectrum of these sherds varies, including unadulterated red, gray, and blends of red and gray. In terms of structure, the majority of the pottery fragments that exhibit both red and gray colors demonstrate a layered formation, with the red layer on the exterior and the gray layer internally. A smaller fraction of the collection reveals a distinct stratification between the top and bottom, displaying separate sections of red and gray. The analysis of the pigments used on these potteries revealed a palette consisting of three primary colors: red, black, and white, contributing to their distinctive aesthetic appeal.

Figure 2. Painted pottery excavated from the Jiangzhai Site: ((**a**) a pointed-bottom flask, (**b**) a narrow-mouthed bottle, (**c**) a jar, and (**d**) a bowl).

This paper focuses on pottery artifacts from the Jiangzhai site in Xi'an. For analysis, small painted pottery sherds were carefully selected, ensuring minimal damage. All procedures were conducted with professional care, preserving both the artifacts and the archaeological site. Post-experimentation, restoration, and preservation measures were applied to the pottery pieces.

2.2. Analytical Methods

(1) X-ray Fluorescence Spectrometry (XRF-1800, Shimadzu, Kyoto, Japan):

The spectrometer is used to determine the chemical makeup of colored pottery, analyzing both the clay material and surface colors. It operates with an Rh target X-ray tube at 60 kV and 150 mA. The device delivers both qualitative and quantitative information for elements ranging from Na to U, detecting concentrations between one part per million to pure elements. It can accommodate samples up to 250 μm thick.

(2) X-ray Photoelectron Spectroscopy (XPS, Thermo Fisher Scientific, Shanghai, China):

This device is essential for examining the valence states and Fe content in the pottery. It is equipped with Al/Mg dual anodes and operates at a 400 W power setting.

(3) Polarizing Optical Microscopy (Leica Microsystems, Wetzlar, Germany):

Used for in-depth analysis of the pottery's grain structure, especially in the painted areas. This method differentiates black pigments under transmitted light and red/white pigments under reflected light at a 50x magnification.

(4) X-ray Diffractometry (XRD, Bruker, Germany):

This technique is employed to study the phase structure of both the unpainted and painted areas of the pottery. The device scans from 5° to 90° with fine steps, using 40 kV voltage and 15 mA current, to understand the crystalline structures.

(5) Thermal Expansion Analysis (DIL 402 Expedis Supreme, Netzsch Instruments, Munich, Germany):

This analysis, involving heating up to 1200 °C at 5 °C/min in an air environment and cooling when shrinkage surpasses 2%, is key to determining the pottery's initial firing temperature.

2.3. Sample Selection

In this paper, an analysis is conducted on pottery sherds from Jiangzhai painted pottery, which exhibit both red and gray colors, as shown in Figure 3. The samples are identified as JZ-1, JZ-9, JZ-13, JZ-15, JZ-21, JZ-22, JZ-26, and JZ-28. The selected sherds are all well-preserved, uncorroded pieces, and these sherds typically have a red exterior and a gray interior. All analyses in this study were conducted on unprocessed powders obtained from sampling the surfaces of the above-mentioned samples. The analyses of the samples, following their examination, were conducted in Python, while both Python and Origin were utilized for generating the graphical representations.

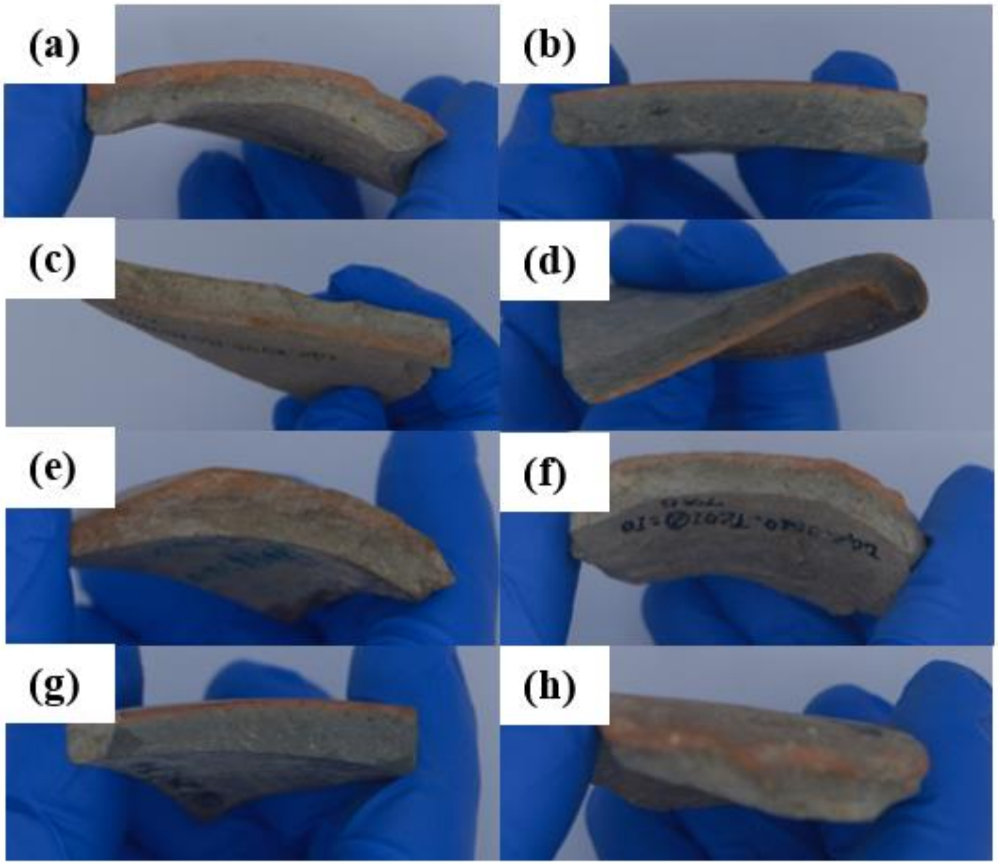

Figure 3. Jiangzhai painted pottery sherds (labeled as (**a**–**h**), corresponding to samples JZ-1, JZ-9, JZ-13, JZ-15, JZ-21, JZ-22, JZ-26, and JZ-28.

3. Result and Discussion

3.1. Pottery Body Composition Analysis

From these eight samples, 40 spots each from the red and gray sections were analyzed to explore the types and quantities of elements contained in the clay body of Jiangzhai painted pottery. The objective is to determine whether the red and gray colors in the pottery are due to the firing of different clays, or the same clay fired under different atmospheric conditions. Figure 4 shows a box plot of its elemental composition. To further enhance the understanding of the elemental composition within the pottery samples, statistical analyses were extended. These analyses are comprehensively detailed in Table 1, which displays a range of statistical measures including the maximum, minimum, median, standard deviation, and mean values for each element evaluated. Additionally, this table now includes the average values of each element specifically for the red and gray sections of the pottery, offering a nuanced view of the elemental distribution within these distinct color zones.

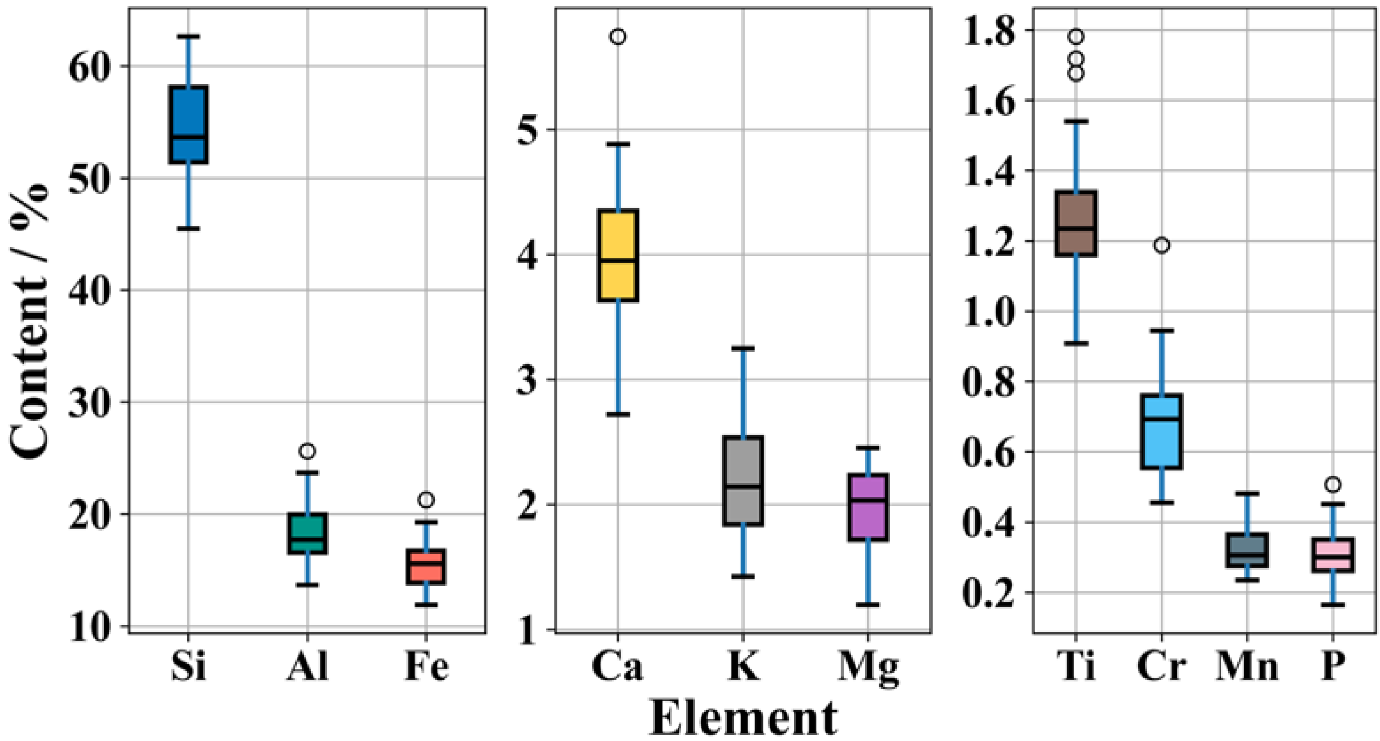

Figure 4. Box plot of the elemental content in the clay body of painted pottery.

Table 1. Statistical composition table of Jiangzhai painted pottery body (%).

Element	Maximum	Minimum	Median	Standard Deviation	Mean	Red Pottery Mean	Gray Pottery Mean
Si	62.64	45.48	53.57	4.67	53.96	54.62	53.39
Al	25.63	13.70	17.74	2.67	18.24	18.07	18.42
Fe	21.29	11.91	15.62	2.23	15.53	15.09	15.93
Ca	5.74	2.72	3.95	0.58	4.00	3.98	3.97
K	3.25	1.42	2.14	0.44	2.22	2.18	2.22
Mg	2.45	1.20	2.03	0.32	1.98	2.01	1.93
Ti	1.78	0.91	1.23	0.21	1.24	1.27	1.22
Cr	1.19	0.46	0.69	0.15	0.68	0.66	0.69
Mn	0.48	0.24	0.31	0.07	0.33	0.32	0.33
P	0.51	0.16	0.30	0.08	0.31	0.29	0.32

Figure 4 presents the elemental composition of 40 pottery samples from Jiangzhai, divided into red and gray categories. Each sample's composition is quantified in percentages of elements such as Si, Al, Fe, Ca, K, Mg, Ti, Cr, Mn, and P. Analyzing the elemental composition of the Jiangzhai pottery samples, we observe that Si, typically the dominant element in pottery, has a mean value of 53.96%, indicating a primary matrix of silica-based clay. Al, with a mean of 18.24%, suggests a significant clay mineral component, crucial for the workability of the pottery material. Fe content, with a mean of 15.53% and a standard deviation of 2.23, varies considerably across samples, potentially affecting the pottery's color after firing. Ca and K have means of 3.99% and 2.22%, respectively, their variations reflecting different tempering materials or the presence of various non-clay minerals. Minor elements Mg and Ti, with means of 1.98% and 1.24%, could provide insights into the firing temperatures and local geological influences. Trace elements Cr, Mn, and P, with means of 0.68%, 0.33%, and 0.32%, are indicative of specific sourcing and processing conditions. The range of values for each element, such as Fe varying from 11.91% to 21.29%, points to diversity in raw materials or craftsmanship techniques. In addition, the occurrence of contamination from biological acids in archaeological contexts is noted [14], indicating an awareness of such phenomena in our study. Despite this, the inherent phosphorus pentoxide in the soil ensures minimal influence on the phosphorus analysis of our pottery samples. This understanding allows us to maintain focus on the intrinsic properties of the artifacts under investigation.

When comparing the two categories, the elemental composition of red and gray pottery exhibits remarkable similarity. This observation suggests that the color differences between the red and gray pottery might not be primarily due to their elemental make-up. Despite the apparent uniformity, minor variations do exist, which may contribute to the color differences on a subtler level. To further investigate whether these elemental compositions are responsible for the color variations, a more in-depth analysis like principal component analysis (PCA) would be beneficial. PCA is a statistical method that converts correlated variables into uncorrelated "principal components." These components, formed by linear combinations of the original variables, are arranged so the first few retain most of the original variation. This research begins by standardizing the elemental data to eliminate variations in scale across different elements and simultaneously computes the covariance matrix to understand the inter-element relationships. The process is encapsulated in a single combined step, represented by the following formula:

$$\sigma_{jk} = \frac{1}{m-1}\sum\nolimits_{i=1}^{m}\left(\frac{x_{ij}-\overline{x}_j}{s_j}\right)\left(\frac{x_{ik}-\overline{x}_k}{s_k}\right) \quad (1)$$

In Formula (1), σ_{jk} is the covariance between the j-th and k-th elements across all pottery samples, where m is the total number of pottery samples. x_{ij} and x_{ik} represent the elemental contents of the j-th and k-th elements in the i-th sample, respectively. $\overline{x}_j$ and $\overline{x}_k$ are the mean elemental contents for the j-th and k-th elements across all samples, while s_j and s_k denote the standard deviations of these elements' contents. This unified approach not only simplifies the data processing but also enhances the efficiency of preparing the dataset for PCA. It enables us to discern and interpret the complex interrelationships among the various elemental compositions in red and gray pottery more effectively. Following data standardization, we compute the covariance matrix σ_{jk} for these standardized variables using the following formula:

$$PC_k = v_{k1}z_{i1} + v_{k2}z_{i2} + \ldots + v_{kn}z_{in} \quad (2)$$

In Formula (2), PC_k is the k-th principal component, v_{kj} represents the weight associated with the j-th element in the k-th principal component, and z_{ij} represents the standardized value of the j-th element for the i-th sample. In the raw dataset, a sample contains eight elements: Si, Al, Fe, Ca, K, Ti, S, and Mn. Through PCA, only the first two principal components, PC1 and PC2, were calculated for a two-dimensional data representation. These two principal components are linear combinations of the original eight variables, with the coefficients determined by the eigenvectors of the data covariance matrix corresponding to the largest eigenvalues. This reduction allows us to project the data into a two-dimensional space for a more accessible visual interpretation while still preserving the core structure and relationships within the data. The obtained results are plotted as illustrated in Figure 5, where the large circle represents the 95% confidence interval, i.e., two standard deviations.

Observations from Figure 5 reveal that the areas representing the elemental compositions of red and grey pottery, within the 95% confidence interval of the first two principal components, display similarity. This similarity suggests that the color differences between the red and grey pottery from the Jiangzhai site are not attributable to variations in their elemental compositions. This is consistent with findings from the Miaodigou site, where the color differences in the pottery are also not caused by variations in the elemental types and their concentrations [15].

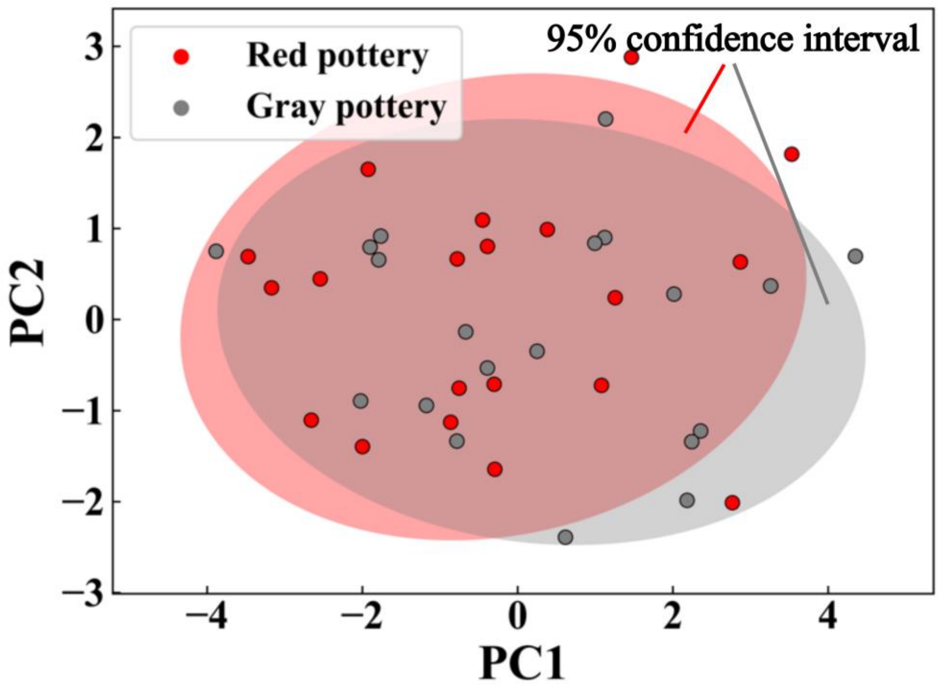

Figure 5. Principal component analysis plot of painted pottery body elements.

3.2. Iron Oxidation State Analysis

Iron, frequently influencing coloration in pottery, has a significant impact on the final color of ceramics. To explore the color variations in the pottery bodies from the Jiangzhai site, this study employs XPS. This technique specifically focuses on analyzing the role of the iron (Fe) element within the pottery matrix, aiming to shed light on the factors contributing to the distinct color stratification observed [16]. We pressed the powder samples taken from the pottery sherds into pellets for the XPS analysis. The detailed findings of the XPS analysis, as depicted in Figure 6, provide a comprehensive overview of the iron states and their correlation with the varied hues present in the Jiangzhai pottery.

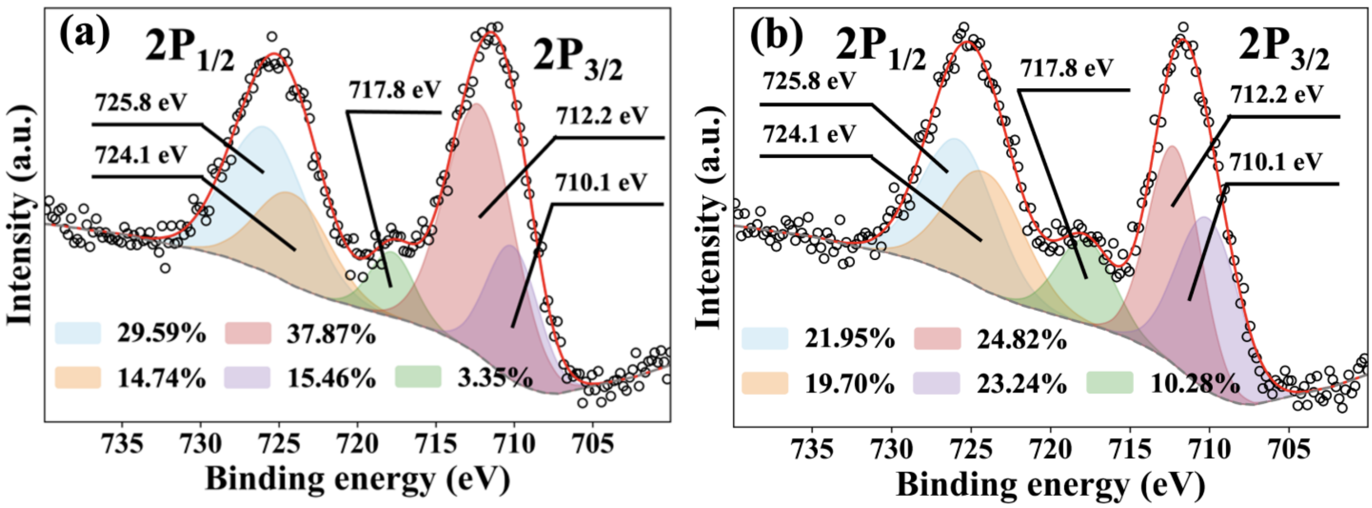

Figure 6. XPS spectrum of Fe element in painted pottery body ((**a**) for the red part and (**b**) for the gray part).

Figure 6 displays the XPS analysis of iron in the Jiangzhai painted pottery. This analysis distinctively differentiates the iron states, predominantly as ferric oxide (Fe_2O_3), in both the red and gray segments of the pottery. The spectrum reveals that for Fe^{3+}, the

2p1/2 and 2p3/2 levels are located at approximately 725.8 eV and 712.2 eV, respectively. In contrast, the Fe^{2+} states exhibit peaks at around 724.1 eV for 2p1/2 and 710.1 eV for 2p3/2, with an additional satellite peak, termed 'Sat', identifiable between 717 eV and 721 eV [17]. The quantification of these peaks provides insights into their proportional presence. The data indicates that the reddish section of the Jiangzhai pottery contains a significantly higher proportion of Fe^{3+}, approximately 67.46%, compared to 46.77% in the grey areas. Moreover, the increased concentration of trivalent iron (Fe^{3+}), predominantly in the form of ferric oxide (Fe_2O_3), plays a pivotal role in the coloration of the pottery. Ferric oxide is known for its reddish pigment, and its presence is a key factor in imparting the red hue to ceramic materials. When Fe_2O_3 is present in higher quantities, it influences the light absorption and reflection properties of the pottery, leading to a more pronounced red appearance. This is due to the specific way in which Fe^{3+} within the ferric oxide interacts with light, reflecting wavelengths that give rise to the red color.

Consequently, the reddish coloration of the Jiangzhai painted pottery's body can be directly attributed to its higher Fe^{3+} content. The XPS analysis confirms that the reddish sections of these ancient ceramics contain a significantly greater proportion of Fe^{3+}, primarily in the form of Fe_2O_3 This composition is responsible for the distinct and characteristic reddish tint of the Jiangzhai painted pottery, a hue that not only adds to the aesthetic appeal but also provides insights into the material composition and manufacturing techniques of these historical artifacts.

3.3. Analysis of Black Speckles on Painted Pottery

Fragments of painted pottery unearthed from Jiangzhai are illustrated in Figure 7, showing three pigment colors: red, black, and white. The card behind the sherds serves as a color comparison chart. The pigment samples were meticulously scraped off layer by layer using a scalpel, followed by a series of purification processes to remove any impurities. Finally, the purified samples were pressed into thin pellets. This pellet-pressing step is critical, as it prevents laser penetration beyond the pigment layer during analysis, ensuring that the experimental results are solely attributed to the pigment itself, without interference from the underlying material. To investigate the raw materials of these three pigments, five samples of each pigment were collected from various painted pottery sherds. An analysis of the elemental composition was performed, and the average results of this analysis are presented in Table 2. Subsequently, these three pigments were examined under a polarizing microscope to observe their crystal structures. The images of these pigments at 50× magnification under both plane-polarized and cross-polarized light are shown in Figure 8.

In the Jiangzhai painted pottery, the composition of pigments reveals much about the materials and methods used, as Table 2 shows. The Fe content in the red pigment is as high as 54.32%, indicating the use of iron-rich materials, commonly hematite or ochre at that time [18]. Hematite's specific crystalline structure and ochre's amorphous nature, as shown in Figure 8, are discernible under polarized light, indicating their likely presence in the pigment [19]. The black pigment's composition in pottery potsherds, marked by 37.34% Mn and 27.43% Fe, aligns with the Yangshao culture's historical use of minerals like pyrolusite and magnetite. The coexistence of these minerals [20,21] suggests a predominance of pyrolusite with some magnetite. Identifying the white pigment in pottery poses challenges due to the limitations of EDX, particularly in detecting elements like C and O. The pigment's high Ca, 44.34%, and Si, 31.69%, levels indicate the possibility of calcite, a calcium-rich mineral, and potentially other calcium or silicon-based compounds [18]. Polarized light microscopy could offer additional clues, especially if the pigment's optical properties resemble those of calcite [19].

In summary, the red and black pigments in Jiangzhai pottery likely contain hematite or ochre, and a mix of pyrolusite and magnetite, respectively. The white pigment, while not definitively identified due to EDX constraints, could be a blend of calcite and other related minerals or compounds, as suggested by its high Ca and Si content.

Table 2. Chemical composition average table of painted pottery pigments (%).

Red Pigment	Element	Fe	Si	Ca	K	Mn	Mg	Ti
	Content	54.32	31.34	5.23	2.62	2.43	1.95	0.56
Black Pigment	Element	Mn	Fe	Si	Ca	Ba	Al	Mg
	Content	37.34	27.43	13.13	9.42	5.42	4.35	1.35
White Pigment	Element	Ca	Si	Fe	K	Mg	Mn	Ba
	Content	44.34	31.69	9.24	6.42	3.15	2.52	1.55

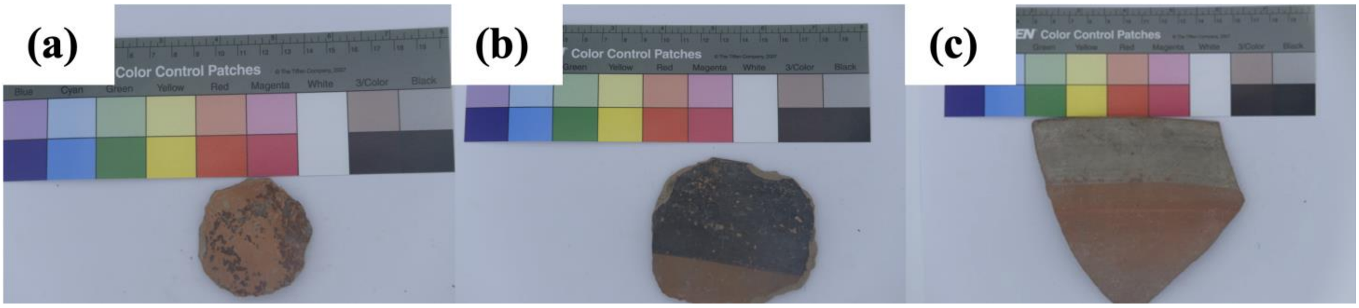

Figure 7. Painted pottery potsherds from Jiangzhai site ((**a**) for potsherds with red painting, (**b**) for black, and (**c**) for white).

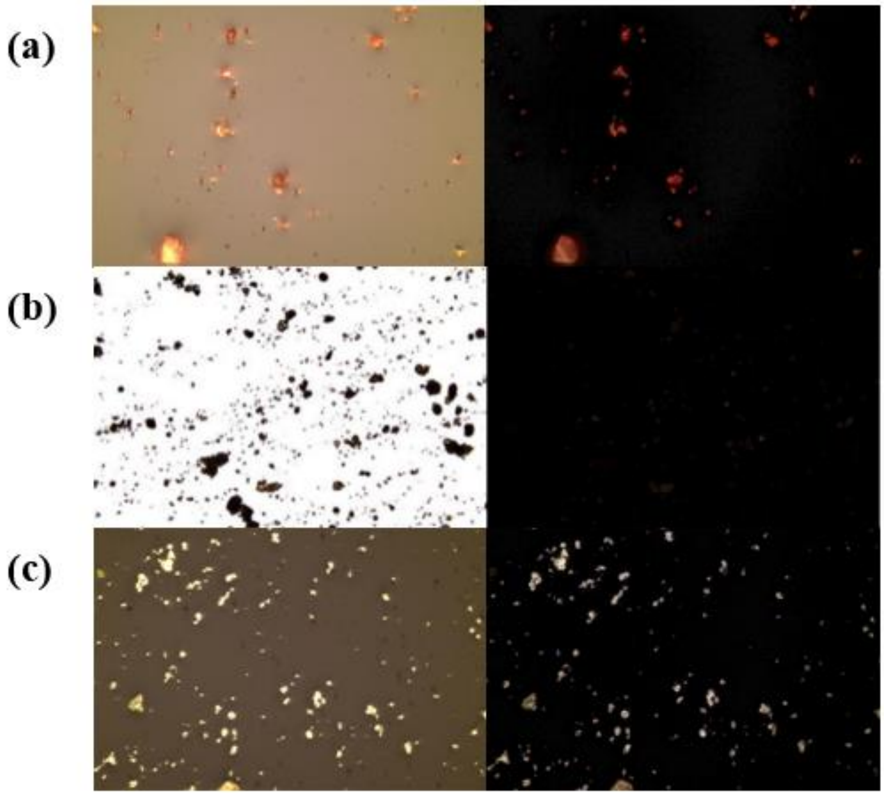

Figure 8. Images of painted pottery pigments under polarized light microscopy ((**a**) for red pigment, (**b**) for black, and (**c**) for white; left image is single-polarized light, and right image is orthogonally polarized light).

3.4. Pigment Structural Analysis

Building on the previous analysis of the elemental composition and polarized microscopy images of the pigments used in Jiangzhai painted pottery, this section aims to further investigate the original pigments on the pottery surface. To validate whether the pigments correspond to the minerals identified earlier, particularly in light of the inconclusive results for the white pigment, XRD analysis is now employed, offering a precise examination of the phase structure of the pigments crucial for accurately identifying their sources, and the results of the XRD are presented in Figure 9. This step is instrumental in enhancing our understanding of the pigments' origins and confirming the hypotheses drawn from earlier analyses.

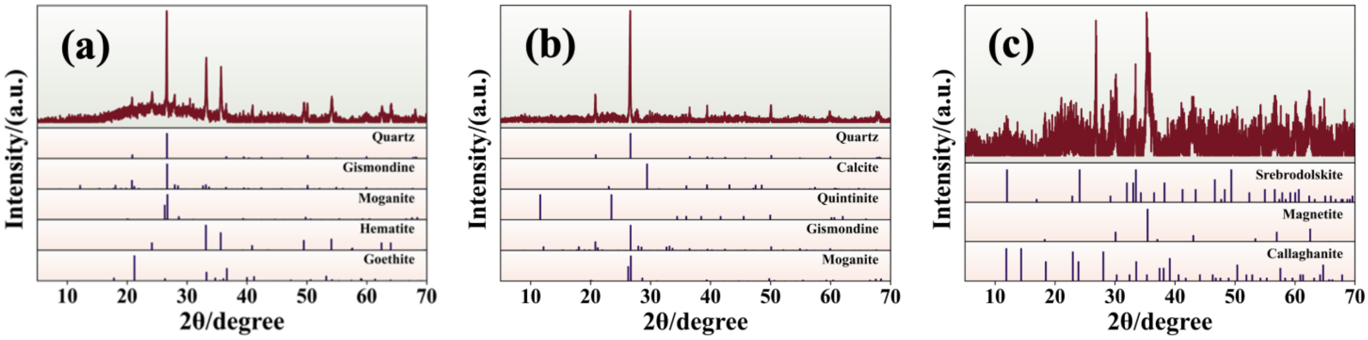

Figure 9. XRD patterns of Banpo painted pottery ((**a**) for red pigment, (**b**) for black pigment, and (**c**) for white pigment).

The XRD analysis images from Figure 9 reveal that the red pigment in Jiangzhai pottery contains ochre, corroborating the initial hypothesis that suggested the red pigment could be either ochre or hematite. This analysis solidifies the belief that ochre is the primary component of the red pigment. The black pigment is identified as comprising both pyrolusite and magnetite, aligning with the results of previous analyses. As for the white pigment, it was found to be calcite, which was one of the anticipated outcomes. Although calcite was not commonly used as a white pigment in prehistoric times, its presence has been noted in archaeological sites like Majiayao [22,23], Dawenkou [24], and Shuangdun [25], with similar findings in Romanian [26] white pigments, indicating its broader historical utilization.

In summary, the combined use of elemental analysis, polarized microscopy, and XRD has not only affirmed the initial speculations about the pigments used in Jiangzhai pottery but also enriched our understanding of ancient pottery-making practices. The identification of ochre in the red pigment, pyrolusite and magnetite in the black, and calcite in the white sheds light on the artistic and technological choices of the period.

3.5. Pottery Firing Temperature Analysis

Numerous methods exist for determining the firing temperature of ancient ceramics, primarily focusing on the expansion or shrinkage of ceramic materials during heating. These methods can be categorized based on the equipment or techniques used, such as XRD [27], Differential Thermal Analysis–Thermogravimetry (DTA-TG) [28], Laser Raman Spectroscopy, Electron Paramagnetic Resonance (EPR) [29,30], Infrared Spectroscopy (IR) [31,32], Mössbauer Spectroscopy [33–35], Fe^{3+}/Fe^{2+} ratio method [36], magnetization rate [37], and the thermal expansion method [38]. The thermal expansion method is often preferred by most researchers for its high precision and accuracy [39]. Consequently, this paper employs the thermal expansion analysis to ascertain the initial firing temperature of Jiangzhai colored pottery.

Small fragments from both red and grey Jiangzhai pottery were taken and shaped into cylindrical forms, approximately 20 mm in length and 5 mm in diameter. After being thoroughly cleaned and dried, these samples were placed in a thermal expansion meter. The temperature was increased from room temperature at a rate of 5 degrees per minute up to 1200 degrees, and the heating was stopped and the test concluded if a contraction in length of 0.5% was detected. The results of this analysis are presented in Figure 10.

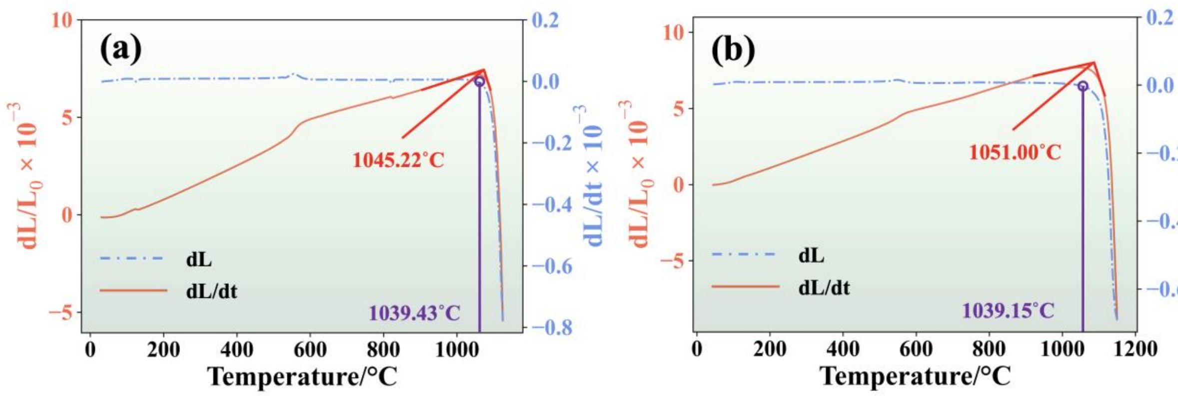

Figure 10. The thermal expansion analysis graph of Jiangzhai pottery ((**a**) represents red pottery and (**b**) represents grey pottery).

The firing temperature of pottery can be determined from the thermal expansion curve, which represents the lengthwise expansion and contraction of the pottery sample. When this is not easily discernible from the curve, it can also be inferred from the point where the first derivative of the thermal expansion curve starts to decrease [40]. From Figure 10, it is apparent that the firing temperature can be directly obtained from the original curve, so the firing temperature for the red pottery is approximately 1045 °C, while for the grey pottery, it is about 1051 °C. Additionally, for both red and grey pottery, the points of decline on their original curves are very close to those on their first derivative curves, which affirms the reliability of these data. More importantly, the similar firing temperatures of the red and grey pottery suggest that their color differences are not due to the firing temperatures, instead, it is likely that they were produced from the same batch of pottery making. Furthermore, the reason for the color differences might be attributed to variations in the oxygen levels of the gases in contact with different pottery pieces or different areas of the same piece during firing. This could be a result of practices like stacking or overlapping pottery in the kiln, leading to uneven exposure to gases and, consequently, to color variations.

4. Conclusions

In this study, we investigated the composition and techniques used in Jiangzhai pottery, focusing on both the pottery matrix and the pigments. PCA showed that the elemental compositions of red and grey pottery are similar, suggesting that color differences are not due to elemental variations. However, XPS analysis indicated that the red coloration in the pottery is mainly due to a higher concentration of Fe^{3+}.

For the pigments, elemental analysis, polarized light microscopy, and X-ray diffraction (XRD) revealed that the red pigment contains ochre, the black pigment is a mixture of pyrolusite and magnetite, and the white pigment is composed of calcite. These findings not only confirm the hypothesized pigment compositions but also provide insights into the ancient pottery-making practices of the Jiangzhai culture, highlighting the role of iron oxidation in coloration and the specific minerals used for pigmentation.

The firing temperatures for both red and grey Jiangzhai pottery, as determined from the thermal expansion curves, are 1045 °C and 1051 °C, respectively. The color differences in the pottery bodies may be due to variations in oxygen levels during firing, likely caused by uneven gas exposure from kiln practices like stacking or overlapping of the pottery.

This research significantly enhances our understanding of ancient pottery-making techniques and cultural practices, offering crucial insights into the technological sophistication and artistic choices of the Jiangzhai culture.

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