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Red-Burnt Clay and Early Chinese Architectural Technology: Archaeological Significance and Scientific Approaches to Firing Temperature Reconstruction

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Abstract: Red-burnt clay remains (hongshaotu) are clayey architectural and occupation deposits that were reddened, hardened, and mineralogically altered by intentional firing or incidental heating. These materials document the transition from unfired earth-and-timber construction to fired ceramic architecture in Neolithic and early Bronze Age China, yet their archaeological value has been limited by reliance on macroscopic description for temperature reconstruction. This narrative review examines published cases — including Guanmiaoshan red-burnt house remains (~600 °C), Lingjiatan red ceramic blocks (>950 °C), Sujiacun burnt soil deposits (~500–600 °C), and Qiaocun composite roof tiles — and compares archaeometric methods for estimating firing temperature, heating temperature, and thermal history. The methods reviewed include magnetic susceptibility and thermal demagnetization, colorimetry, X-ray diffraction, petrography, Fourier-transform infrared spectroscopy, differential thermal analysis, thermal expansion, and physical property testing. Each method responds to different parts of the heating process and operates within a limited temperature range; no single technique covers the full spectrum from low-temperature occupation deposits to high-fired ceramic building materials. The review proposes a multi-method workflow that begins with field screening and contextual classification, matches analytical methods to the likely temperature range, and returns temperature evidence to questions of building practice, site formation, production organization, and the diffusion of firing techniques. Future work should build regional calibration databases from local raw materials, standardize the reporting of temperature estimates, and connect thermal data with architectural and technological history.

Keywords: Red-burnt clay; hongshaotu; early Chinese architecture; archaeometry; firing temperature; thermal history; ceramic building materials.

1. Introduction

In this review, red-burnt clay remains (hongshaotu) refer to clayey architectural or occupation deposits that were reddened, hardened, and mineralogically altered by intentional firing or later heating [1, 2]. Early Chinese architecture relied for a long time on earth-and-timber construction, and fired clay materials entered this tradition through gradual changes in walls, floors, blocks, and roof components [1]. Red-burnt clay stands between unfired earthen building and later ceramic or brick construction, because it records the moment when clay used in architecture was altered by heat rather than only shaped and dried [1]. Evidence from Qiaocun shows that red fired clay roof tiles had entered large building projects on the Chinese Loess Plateau by about 2400–2200 BCE, which helps place red-burnt building materials within a longer sequence of early Chinese ceramic architecture [5].

The archaeological value of red-burnt clay does not rest in color or surface hardness alone. Well-preserved pieces can retain wall, roof, post, bamboo, thatch, rope, and floor traces that connect thermal alteration with building practice [1]. Red-burnt deposits can also record settlement activity and depositional history, as shown by studies that combine mineral, chemical, and magnetic evidence from burnt soil layers [2, 6].

Temperature evidence changes how several well-known cases are read. At Guanmiaoshan, the Daxi-period F22 house preserved red-burnt wall and roof remains with construction traces, and ceramic testing reported a firing temperature of about 600 °C [1]. At Lingjiatan, red ceramic blocks dated to about 5500 BP were linked to fired architectural materials because XRD, DTA, thermal expansion, water absorption, and compressive strength results point to firing above 950 °C [3, 4]. At Sujiacun, XRD, XRF, and magnetic susceptibility work placed burnt soil samples at about 500–600 °C and tied the white ash layer to added kaolin, which shifts the question from color description to site formation and human activity [2].

Macroscopic observation alone cannot separate intentional pre-firing, accidental burning, secondary heating, post-firing treatment, and post-depositional change. Similar red color, darkening, hardness, and sintering can arise from different heating atmospheres, surface treatments, raw materials, and burial histories [7, 8]. Thermal demagnetization work on clay-rich archaeological materials further shows that heating may occur during building destruction or nearby burning rather than during manufacture, so the archaeological setting must be tested together with the material signal [9].

This narrative review connects the architectural questions raised by red-burnt clay with archaeometric approaches for reconstructing firing temperature, heating temperature, and broader thermal history. It treats temperature estimates as evidence for production choices, building practice, site formation, labor organization, and the spread of firing techniques, not as isolated numbers [10, 11]. The review therefore compares field observation, magnetic methods, colorimetry, mineralogical and chemical analysis, FTIR, DTA, and thermal expansion by asking what each method can answer, where it fails, and how it can be combined with archaeological context [7]. While comprehensive reviews of ceramic firing reconstruction exist [7], none have focused on red-burnt architectural clay in the Chinese archaeological context, where the material ranges from lightly heated occupation deposits to high-fired building components.

2. Methods

This article is a narrative review rather than a new laboratory experiment. The core archaeological material comes from published studies of Guanmiaoshan red-burnt architecture, Lingjiatan red ceramic blocks, Sujiacun burnt soil, and related Chinese fired clay building materials [1, 3, 5]. The comparative method literature was selected from ceramic archaeometry, magnetic studies of baked clay, colorimetry, mineralogical analysis, FTIR, thermal analysis, and work on firing organization [7, 10].

Studies were included when they could help answer at least one of three questions. The first question is whether the material records architecture, occupation activity, or secondary burning; the second is whether the reported method can constrain a firing or heating range; the third is whether the evidence can be returned to architectural technology rather than left as an instrumental result [1, 7]. Studies limited to general ceramic typology or broad architectural description were used only when they clarified context, while unsupported claims about temperature were excluded from the synthesis.

The reviewed literature was grouped into four evidence classes. Field and morphological observation covers color, hardness, spatial position, construction traces, and architectural form [1]. Physical and engineering evidence covers water absorption, compressive strength, porosity, and related material properties [3, 19]. Mineralogical, chemical, magnetic, colorimetric, spectroscopic, and thermal methods were then compared by the question each method can answer, its usable temperature range, sample demand, destructive impact, calibration requirement, and field applicability [7].

The discussion keeps three temperature terms separate. Firing temperature is used for intentional production of clay or ceramic building materials and must be read together with raw material, atmosphere, duration, and firing structure [10, 7]. Heating temperature is used for materials exposed to fire or later burning events where manufacture is not yet demonstrated [9, 8]. Thermal history refers to the broader sequence of heating, cooling, atmosphere, duration, placement, and later alteration, so it is the preferred term when the available evidence does not support a single manufacturing temperature [7].

3. Results and Discussion

3.1. Red-Burnt Clay as Architectural Evidence

The cases considered here show that red-burnt clay should first be treated as contextual architectural evidence. At Guanmiaoshan in Zhijiang, Hubei, Li Wenjie reported 25 Daxi-period red-burnt clay house remains excavated between 1978 and 1980, with F22 preserving a square ground-level building of about 35 m², walls of equal height, and a four-sided roof form [1]. The red-burnt wall and roof pieces retained traces of posts, bamboo rafters, thatch, and rope, so the material recorded both heating and construction practice [1]. The reported firing temperature of about 600 °C is useful because it connects those architectural traces with a controlled alteration of clay rather than with color alone [1].

Guanmiaoshan also shows why field description cannot be discarded when archaeometric work begins. The value of F22 comes from the fit between temperature estimate, spatial position, surface traces, house form, and fired clay fragments [1]. If the same pieces were removed from their architectural position, a temperature around 600 °C would say much less about wall construction, roof making, or the use of heat in building work. Temperature evidence becomes archaeological evidence only after the deposit, shape, and construction marks have been recorded.

The Lingjiatan red ceramic blocks raise a different problem. They are not simply red-burnt soil deposits; they belong to the discussion of early fired ceramic building materials. The site yielded nearly 3000 m² of red-burnt remains and structures or wells built with red ceramic blocks, dated to about 5500 BP [3, 4]. Li Naisheng and colleagues reported XRD, DTA, thermal expansion, water absorption, and compressive strength results indicating a firing temperature above 950 °C, with the inner part reaching 26 MPa in compressive strength and 12.4% water absorption [3, 4]. These values place Lingjiatan closer to intentionally fired ceramic building products than to lightly heated occupation sediment.

The internal differences within the Lingjiatan blocks are as important as the high temperature itself. Li Naisheng and colleagues observed a red outer part and a bluish-grey inner part, with mineral phases interpreted as evidence of different firing atmospheres in different parts of the same block [3]. The reported gradient in water absorption and compressive strength, from outer to inner portions, also warns against treating one measured point as the property of the whole object [3]. For red-burnt architectural clay, sampling position can change the reading of firing temperature, material performance, and even manufacturing intent.

Table 1. Comparison of water absorption and compressive strength between Lingjiatan red ceramic blocks and bricks from later periods. Data from [3, 4]

Sample	Absorption / %	Strength / MPa
Lingjiatan (outer)	22.1	12
Lingjiatan (middle)	17.5	25
Lingjiatan (inner)	12.4	26
Han-dynasty brick	10.4	17.6
Ming-dynasty brick	22.0	6.9
Modern brick	17.2	12.5

The Qiaocun composite tiles add a later comparison within the long sequence of fired clay architecture. Xu and colleagues studied more than 5000 tile fragments from a single context on the Chinese Loess Plateau, dated to about 2400–2200 BCE, and described the tiles as red fired clay pieces belonging to cover-tile and pan-tile systems [5]. Their reconstruction connects tile making with thick rammed-earth walls, heavy tiled roofs, and buildings that required coordinated labor [5]. Qiaocun should not be read as direct evidence for Guanmiaoshan or Lingjiatan, but it shows that fired clay building components had entered roof and public-building practices by the Early Longshan period [5].

The wider high-firing context also needs careful boundaries. Fan and colleagues examined 160 stamped hard pottery sherds from the Nanshan and Yanzaidong sites in southeastern China, dated broadly to 5300–4300 cal BP and 5000–4300 cal BP, using water absorption, Vickers hardness, petrography, ED-XRF, thermodilatometry, XRD, and SEM-EDS [20]. They argued that some groups used high-alumina clay with low fluxing elements and reached about 1100–1250 °C, producing properties comparable with stoneware [20]. This is not evidence for red-burnt architecture, but it matters because Lingjiatan should not be isolated from other Late Neolithic Chinese experiments with high-temperature clay technology.

Sujiacun gives a third type of evidence. The burnt-soil layer at Zhangqiu, Shandong, belongs to a sequence from the late Dawenkou to early and middle Longshan periods, and the fifth layer formed a 20–60 cm thick burnt deposit across the site [2]. Li Xiang and colleagues combined XRD, XRF, and magnetic susceptibility experiments and placed the heating temperature of the burnt soil at about 500–600 °C, while interpreting the white ash deposit as artificially added kaolin [2]. Here the problem is not a finished building component but a site-formation question involving burning, raw material addition, and settlement activity.

These cases separate three levels of inference. Morphological evidence links clay pieces to walls, roofs, floors, tiles, blocks, or deposits; material evidence describes strength, porosity, water absorption, mineral phases, and chemical composition; thermal-history evidence asks how heat, atmosphere, duration, and later alteration produced the observed material [1, 7]. A red surface, a hardened body, or a high magnetic response can belong to intentional pre-firing, in situ burning, later fire damage, or post-depositional change. The category red-burnt clay is more informative tied to formation process than treated as a single material type.

3.2. Limits of Conventional Observation

Field observation gives the first control on interpretation. At Guanmiaoshan, the careful cleaning, numbering, drawing, and reconstruction of red-burnt clay fragments allowed Li Wenjie to infer wall structure and roof form from the position and traces of the pieces [1]. This type of work cannot be replaced by laboratory analysis, because the laboratory sample does not carry the full spatial relation between post trace, roof trace, floor surface, and collapsed deposit. The problem is narrower. Field observation alone cannot reliably convert color, hardness, or surface preservation into firing temperature or heating temperature [1].

Typological comparison faces the same limit. House plans, roof forms, tile forms, and block shapes help place a find within an architectural sequence, and they are needed for comparing Guanmiaoshan houses, Lingjiatan blocks, and Qiaocun tiles [1, 5]. Yet a typological category does not determine whether clay was fired before use, heated during occupation, burnt during abandonment, or altered after burial. The same form may have different thermal histories, and similar red-burnt fragments may come from different formation processes.

Physical properties add more information but do not remove the need for cross-checking. The Lingjiatan blocks show that lower water absorption and higher compressive strength can mark a high degree of firing or sintering, especially when these results agree with mineralogical and thermal evidence [3]. Buchner and colleagues, however, show in modern fired-brick materials that pore structure requires several methods, including micro-CT, SEM, mercury intrusion porosimetry, Archimedes measurements, and helium pycnometry, because each method captures different parts of the pore system and has its own measurement bias [19]. Strength and absorption therefore describe material performance, but they do not by themselves define a firing temperature.

Equifinality is the main risk. Gliozzo emphasizes that maximum firing temperature alone is not enough to infer firing methods, since raw material, placement, soaking time, atmosphere, fuel arrangement, and firing structure can vary within one firing event [7]. Drieu and colleagues show from post-firing treatment experiments that blackened surfaces, altered edges, and molecular thermal markers may be small, easily missed, or misread when only macro- and microscopic observations are used [8]. A red-burnt or darkened clay surface can therefore record several different processes, and the visual signal must be tested before it becomes a technological argument.

Secondary heating adds another difficulty. Vaknin and colleagues used laboratory-heated mud bricks and archaeological burnt clay to show that thermal demagnetization can separate unheated material from material heated to at least about 190 °C and can estimate a minimum heating temperature [9]. Their Tell es-Safi/Gath case also shows that burnt clay can record the location and direction of a destruction fire rather than a manufacturing event [9]. For red-burnt clay studies, this means that heating temperature should be used when manufacture is not demonstrated, while firing temperature should be reserved for intentional production of a clay or ceramic building material.

A further limit is calibration. Color, magnetic susceptibility, mineral phase development, and porosity all depend on the local clay body, grain size, iron mineralogy, carbonate content, atmosphere, and heating duration [7, 14]. Without local raw-material tests, two samples with the same apparent red color or similar hardness may not have reached the same temperature. Conventional field and typological work remains necessary, but it should define the question and sampling context rather than carry the whole temperature reconstruction.

3.3. Archaeometric Approaches to Temperature Reconstruction

Magnetic methods are useful because many clay-rich materials change their magnetic response during heating. Wu and colleagues heated clay from Guanghan in the Chengdu Plain and found that magnetic susceptibility increased sharply when firing temperature exceeded about 800 °C, a change linked to newly formed ferrimagnetic minerals [12]. Chen and colleagues used χ-T curves on burnt clay from the Maidiping Neolithic site in Fujian and estimated a firing temperature of about 620 °C from the reversibility and irreversibility of heating and cooling curves [6]. Li Xiang and colleagues applied stepwise refiring and magnetic susceptibility to Sujiacun samples, supporting a heating temperature of about 500–600 °C [2].

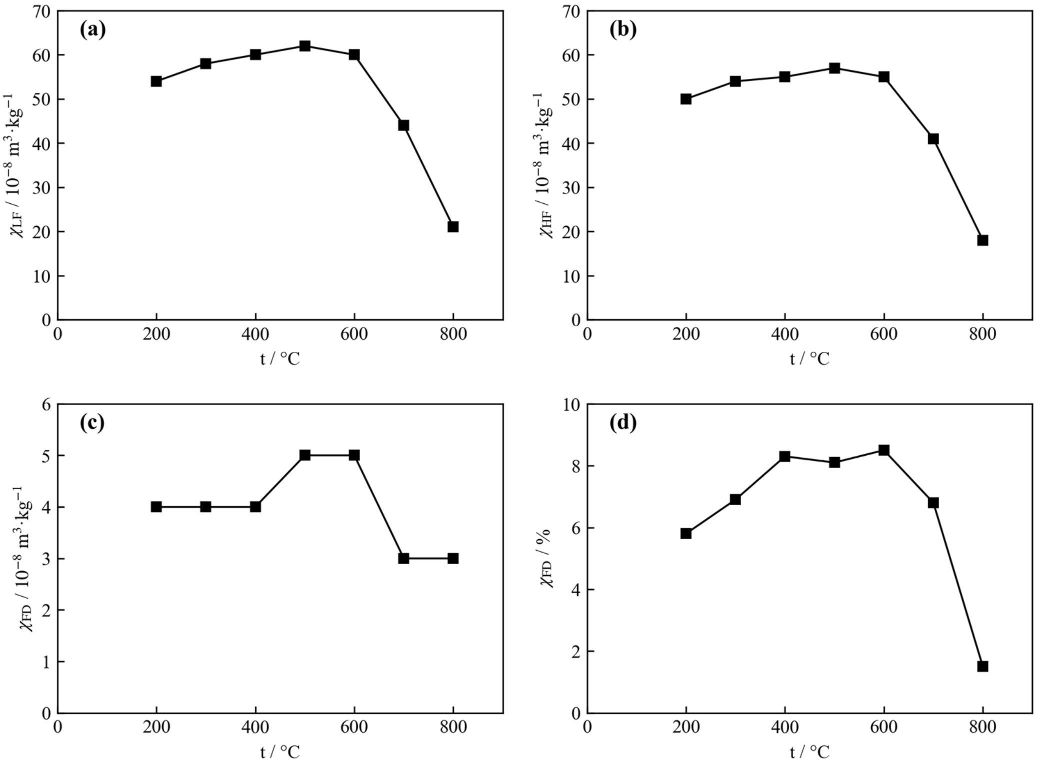

Figure 1. Magnetic susceptibility parameters of Sujiacun burnt soil samples as a function of refiring temperature: (a) low-frequency susceptibility χLF; (b) high-frequency susceptibility χHF; (c) frequency-dependent susceptibility difference χFD; (d) percentage frequency-dependent susceptibility χFD%. Redrawn after [2].

The magnetic signal is strongest when the relevant iron minerals have changed enough to alter susceptibility. Tema and Ferrara caution that single heating below about 300–400 °C may produce weak magnetic changes, while repeated heating or heating above about 400 °C gives more reliable magnetic behaviour [14]. This limit matters for red-burnt clay, because many architectural or occupation deposits may have been heated below the range where magnetic susceptibility responds clearly. Magnetic work is therefore better read as part of a thermal-history reconstruction than as a universal thermometer.

Thermal demagnetization answers a different question. Vaknin and colleagues tested 49 miniature mud bricks heated between 100 and 700 °C and showed that the method can identify materials heated to at least about 190 °C and recover a minimum heating temperature [9]. For oriented samples, the method can also help reconstruct cooling orientation and distinguish clay heated in place from material moved after burning [9]. This makes thermal demagnetization especially useful where the archaeological question is whether a burnt deposit comes from an internal fire, nearby burning, or construction-related firing.

Colorimetry offers rapid and relatively low-cost measurement, but it is safe only when calibrated. Wu and colleagues used portable colorimetry with magnetic susceptibility and proposed that changes in Δa*/Δb* can help separate low, middle, and high heating ranges in Guanghan clay [12]. Zhou's review of color measurement in cultural heritage also supports the use of instrumental color data to reduce the subjectivity of visual description [15]. For field archaeology, this gives a practical screening tool, especially when many suspected red-burnt fragments need to be sorted before destructive sampling.

Table 2. Segmented criteria for estimating heating temperature from Δa*/Δb* ratios. After [12]

Δa*/Δb* range	Inferred heating temperature
<0.3	Unheated or very low temperature
0.3–0.55	Approx. 300–800 °C
0.55–0.7	Approx. 300–800 °C
>0.7	Approx. 800–1000 °C

Color cannot be treated as a simple temperature scale. Zhang and colleagues studied Tang-period plain pottery from the tomb of Liu Jing with replica firing experiments and found that color saturation C* increased and then decreased with firing temperature, with the inflection point corresponding to glass-phase formation [16]. Their fitted relation worked for that sample set and agreed with XRD, optical microscopy, and porosity evidence, but it depends on comparable raw materials and firing conditions [16]. Su and colleagues further show in Yangshao pottery experiments that firing atmosphere and iron valence can produce strong red, black, and grey differences under the same broad temperature programme [17]. Colorimetry is useful for screening; it becomes temperature evidence only after local calibration and independent checks.

Mineralogical methods help constrain the middle and high temperature ranges. XRD can identify the disappearance or formation of phases related to kaolinite dehydroxylation, quartz transformation, cristobalite, spinel, feldspars, hematite, and other products of heating [7]. In the Lingjiatan red ceramic blocks, XRD detected quartz, cristobalite, tridymite, feldspar, Fe-Mn spinel, and abundant amorphous material, and Li Naisheng and colleagues used these results to support firing above 950 °C [3]. In Sujiacun, XRD comparisons between archaeological samples and refired samples helped support the 500–600 °C heating estimate [2].

Petrography and thin-section observation add a different scale of evidence. Travé Allepuz examined biotite changes in greyware pottery thin sections from 700 to 1000 °C after XRD had provided temperature groups [18]. The study is not about Chinese red-burnt clay, but it shows how a mineral inclusion can act as a thermal marker when its colour, birefringence, and texture are tied to an experimentally or analytically defined range [18]. For architectural clay remains, this type of observation may help test whether a fragment's internal fabric agrees with a proposed firing or heating range.

FTIR picks up some low-temperature changes that XRD and magnetic susceptibility miss. Yan and colleagues developed an FTIR absorbance-ratio method using potassium ferricyanide as an internal standard, so the Si–O–Si band in clay minerals could be compared while reducing preparation errors [13]. Applied to early Shang bronze-casting moulds and cores from Zhengzhou Shang City, the method gave firing temperatures of only about 200–300 °C, much lower than earlier thermal-expansion estimates of 900–1050 °C [13]. Although the case concerns casting moulds rather than red-burnt architecture, it warns that high values derived from unsuitable methods can distort low-temperature materials.

Chemical and microstructural methods mostly answer questions about raw material, additives, and internal organization. XRF helped Li Xiang and colleagues distinguish the mineral source of Sujiacun burnt soil and the white ash deposit, supporting the interpretation that kaolin was artificially added [2]. In high-fired stamped hard pottery, Fan and colleagues used ED-XRF and SEM-EDS with petrography, thermodilatometry, and XRD to connect physical quality with high-alumina clay and low fluxing elements [20]. In fired bricks, Buchner and colleagues show that SEM and micro-CT can characterize pore shape, pore distribution, and thickness variation, but those measurements need other evidence before they become firing-temperature estimates [19].

DTA and thermal expansion are especially useful when the research question concerns whether an original firing had already passed a transformation threshold. Li Naisheng and colleagues compared Lingjiatan red ceramic block samples with clay samples and found that reactions around 950 °C were absent or changed in the archaeological material, supporting a firing temperature above that level [3]. Thermal expansion on an inner Lingjiatan sample gave an inflection near 960 °C, agreeing with XRD and DTA [3]. These methods are powerful in high-fired materials, but their sample-size and destructive demands limit their routine use on small or rare architectural fragments.

Taken together, these methods do not compete for a single best answer. Magnetic susceptibility is sensitive to iron mineral changes in certain ranges; thermal demagnetization can detect heating and minimum heating temperature; colorimetry is fast but local; XRD and petrography work best when mineral transformations are clear; FTIR can help in lower temperature ranges; DTA, thermal expansion, and physical properties are strongest when high-fired ceramic material is suspected [7, 12]. The value of the method set lies in its uneven coverage of the heating process. Different methods respond to different parts of raw material, temperature, atmosphere, duration, and later alteration.

Table 3. Comparison of major archaeometric methods for reconstructing heating or firing temperature of red-burnt clay

Method	Principle	Sensitive range	Sample requirement	Main limitations
Magnetic susceptibility	Iron mineral phase transitions increase susceptibility	Sensitive above ~800 °C	Small amount of powder	Insensitive at low temperatures
Thermal demagnetization	Stepwise decay of thermoremanent magnetization	≥190 °C	Oriented block	Requires controlled laboratory conditions
Colorimetry	Iron oxide changes alter color parameters	>100 °C	Non-destructive or micro-destructive	Affected by weathering and burial
XRD	Mineral phase identification	>550 °C	Small amount of powder	Ambiguous at low temperatures
FTIR	Si–O–Si absorbance ratio decreases with heating	≥200 °C	Trace powder	Requires internal standard calibration
DTA	Absence of exothermic peaks indicates prior heating	>500 °C	Powder	Indirect inference
Thermal expansion	Inflection point on refiring expansion curve	Full range	Larger block	Highly destructive

3.4. Toward a Multi-Method Workflow

A workable study of red-burnt clay should begin with field screening, not with instrument choice. Recording should include spatial position, stratigraphic relation, association with walls, roofs, floors, hearths, pits, fill, or collapse deposits, and visible traces such as wood, bamboo, thatch, rope, surface vitrification, cracking, and color zoning [1, 5]. Portable colorimetry and magnetic susceptibility can then sort large numbers of suspected red-burnt pieces and identify samples that deserve laboratory work [12, 15]. Screening is not final interpretation; it is a way to choose samples without losing context.

The second step is contextual classification. A fragment attached to a house wall, a tile from a collapsed roof, a burnt occupation deposit, a fill with mixed fired clay, and a later fire-damaged object should not be grouped before their formation processes are considered [1, 9]. This step decides whether the next question concerns firing temperature, heating temperature, or broader thermal history. It also prevents a common error in which all hard red clay is folded into a single technological narrative.

Formation-process screening should then ask whether the material records manufacturing, use, destruction, post-firing treatment, or burial alteration. Thermal demagnetization is useful where orientation and minimum heating temperature can test in situ burning [9]. Macro- and microscopic observation, together with molecular or chemical checks where appropriate, can guard against misreading post-firing blackening or surface treatment as a primary firing signal [8]. Color and magnetic readings should be interpreted with atmosphere in mind, because iron valence and redox conditions can change the surface and core without changing the maximum temperature in a simple way [7].

Laboratory validation should match the likely temperature range. For low-temperature or uncertain heating, FTIR, thermal demagnetization, and calibrated colorimetry can be more informative than methods designed for high-fired ceramics [13, 9]. For middle and high temperature ranges, XRD, magnetic refiring experiments, DTA, and thermal expansion can test whether mineral transformations or curve inflections have already occurred [3, 7]. For high-fired blocks, bricks, and tiles, physical properties and pore analysis should be read beside mineralogical evidence rather than used as an independent temperature scale [3].

The Lingjiatan and Sujiacun studies illustrate two different combinations. Lingjiatan works because XRD, DTA, thermal expansion, water absorption, and compressive strength all point to a highly fired ceramic building material, so firing temperature is a justified term [3, 4]. Sujiacun works differently. XRD, XRF, and magnetic susceptibility point to a 500–600 °C heating range and to the addition of kaolin in the white ash deposit, so the interpretation concerns burnt soil formation and settlement activity more than ceramic building production [2]. These two cases should not be forced into one explanatory model.

Table 4. Summary of published heating or firing temperature estimates for red-burnt clay and related archaeological materials

Site	Period / Culture	Methods used	Temp. / °C	Reference
Lingjiatan	~5500 BP	XRD + DTA + thermal expansion	>950	[3]
Guanmiaoshan	Daxi culture	Ceramic testing	~600	[1]
Sujiacun	Late Dawenkou–Longshan	XRD + XRF + magnetic susceptibility	500–600	[2]
Maidiping	Neolithic	χ-T thermomagnetic curves	~620	[6]
Zhengzhou Shang City	Early Shang	FTIR absorbance ratio	200–300	[13]
Tell es-Safi/Gath	Iron Age	Thermal demagnetization	≥190	[9]
Santhià	Archaeological site	Magnetic measurements	Uncertain	[14]
Guanghan clay	Experimental	Magnetic susceptibility + colorimetry	Full range	[12]

Regional calibration is the main condition for comparison. Gliozzo notes that clay composition, mineral grain size, atmosphere, soaking time, placement, and raw material all affect thermal transformations [7]. Zhang's color-temperature curve was built from replicas tied to a specific pottery and raw-material set, and Wu's color and susceptibility criteria were built from Guanghan clay [16, 12]. Such results can guide red-burnt clay research, but their numerical thresholds should not be transferred directly to Guanmiaoshan, Lingjiatan, Sujiacun, or other regions without refiring local raw materials.

The reporting format also needs to change. A useful publication should give sample context, sampling position, raw-material comparison, atmosphere inference, method parameters, temperature interval, uncertainty, and the reason for choosing firing temperature, heating temperature, or thermal history [7, 14]. Without this information, the same temperature value may be read as evidence for production skill, house destruction, post-depositional burning, or laboratory artefact. Standard reporting would make future cross-site comparison possible without hiding the uncertainty that belongs to each method.

The final interpretation should return to architecture and social practice. Tite's review of ceramic technology stresses that raw material choice, forming, surface treatment, firing method, and production organization are linked, not separate technical details [10]. Padovani's study of firing structures in Southwest Asia likewise argues that firing structures should be read through production space, labor organization, and diffusion of firing techniques, rather than through maximum achievable temperature alone [11]. For red-burnt clay, the same principle applies. A temperature estimate matters because it helps explain how people built walls, roofs, floors, blocks, and tiles, how they managed heat, and how fired clay entered architectural practice.

A multi-method workflow does not promise a single precise temperature for every red-burnt deposit; it keeps field context, method selection, and archaeological interpretation connected [7, 1].

4. Conclusions

Red-burnt clay sits at the junction of early architectural history and high-temperature technology. The cases reviewed here show that red-burnt deposits, blocks, and tiles document the transition from unfired earth-and-timber building to intentionally fired ceramic architecture in Neolithic and early Bronze Age China [1, 3, 5]. Whether the material in question is a Guanmiaoshan wall fragment fired at about 600 °C, a Lingjiatan block fired above 950 °C, or a Qiaocun roof tile from the Early Longshan period, each case ties thermal alteration to a specific building practice and production context [1, 5]. Read alongside contemporary high-firing experiments in stamped hard pottery and broader accounts of ceramic technology, red-burnt clay is better understood as a record of how communities learned to use heat in construction than as a marginal or residual category [20].

Conventional observation remains the first step in any study of red-burnt clay. Field recording of spatial position, construction traces, and architectural form supplies the context that laboratory measurements alone cannot recover [1]. At the same time, this review shows that macroscopic description and typological comparison cannot carry the task of temperature reconstruction. Color, hardness, and surface preservation are affected by raw material, atmosphere, duration, secondary heating, post-firing treatment, and burial conditions, so the same visual signal can arise from different formation processes [7]. Conventional methods should therefore define the archaeological question and guide sampling, while temperature reconstruction should rest on independent analytical evidence.

The archaeometric methods compared in this review — magnetic susceptibility, thermal demagnetization, colorimetry, XRD, petrography, FTIR, DTA, thermal expansion, and physical property testing — each respond to different parts of the heating process and operate within different temperature ranges [12, 14]. No single method covers the full range from low-temperature occupation deposits to high-fired ceramic building materials. Complementarity among methods matters more than the precision of any one technique. The main source of error is the mismatch between a method's sensitive range and the actual thermal history of the sample, not measurement noise itself. A workflow that matches method choice to contextual classification and likely temperature range will produce more reliable results than repeated application of a single favored instrument.

Three priorities stand out for future work. First, regional calibration databases built from local raw materials and controlled refiring experiments are needed so that magnetic, colorimetric, mineralogical, and thermal thresholds can be compared across sites rather than transferred without adjustment [7, 12]. Second, standardized reporting of sample context, method parameters, temperature intervals, uncertainty, and the choice among firing temperature, heating temperature, and thermal history would make cross-study comparison possible and reduce the ambiguity that currently surrounds many published temperature values. Third, temperature data should be returned to questions of architectural technology, production organization, labor coordination, and the diffusion of firing techniques across regions and periods [11]. Red-burnt clay research is most productive when temperature is read as evidence for how early communities built, managed heat, and passed on construction knowledge, rather than as a number to be extracted and reported.

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References

[1] Li W J. How to establish red-burnt clay architectural archaeology [J]. Wenwu Chunqiu (Cultural Relics), 2018 (6): 3-14. (in Chinese)

[2] Li X, Wu Y J, Mao L J, Wu X T, Song Y B. Study on firing temperature of burnt clay samples from Sujiacun site [J]. Sciences of Conservation and Archaeology, 2022, 34(1): 63-70. (in Chinese)

[3] Li N S, Zhang J G, Mao Z W, Feng M, Hu Y W, Wang C S. Testing study on ceramic building materials from 5000 years ago [J]. Sciences of Conservation and Archaeology, 2004, 16(2): 13-20. (in Chinese)

[4] Li N S, Zhang J G, Mao Z W, Feng M, Wang C S. The earliest ceramic building materials in China: Lingjiatan "red pottery blocks" [J]. Journal of Building Materials, 2004, 7(2): 127-132. (in Chinese)

[5] Xu Y J, Zhou J, Zhao J L, Chen G K, Li W, Ma M Z, Monteith F, Liu S Y, Peng M H, Bevan A, Zhang H. Reconstructing the earliest known composite-tiled roofs from the Chinese Loess Plateau [J]. Scientific Reports, 2023, 13(1): 8163.

[6] Chen G S, Li G H, Liu M M, Ge W, Wu G B, Zhan C F. The firing temperatures of burnt clay from the Chinese neolithic cultural relics and its paleoenvironmental imprints [J]. Heliyon, 2023, 9(10): e20838.

[7] Gliozzo E. Ceramic technology. How to reconstruct the firing process [J]. Archaeological and Anthropological Sciences, 2020, 12(11): 260.

[8] Drieu L, Lepère C, Regert M. The missing step of pottery chaîne opératoire: Considering post-firing treatments on ceramic vessels using macro- and microscopic observation and molecular analysis [J]. Journal of Archaeological Method and Theory, 2020, 27(2): 302-326.

[9] Vaknin Y, Shaar R, Lipschits O, Eliyahu Behar A, Maeir A M, Ben-Yosef E. Applying thermal demagnetization to archaeological materials: A tool for detecting burnt clay and estimating its firing temperature [J]. PLoS ONE, 2023, 18(10): e0289424.

[10] Tite M S. Ceramic production, provenance and use: A review [J]. Archaeometry, 2008, 50(2): 216-231.

[11] Padovani C. Kilns and potters: Measuring pyrotechnology diversity to assess dynamics of firing techniques diffusion within Southwest Asia communities, 6500-4700 BCE [J]. Journal of Archaeological Science: Reports, 2023, 52: 104273.

[12] Wu Q, Xiang F, Guo Y M, Huang M, Liu J C, Sun X. Rapid identification of suspected red-burnt clay and its firing temperature at ancient Shu sites using portable magnetic

susceptibility meter and colorimeter [J]. Kuangwu Yanshi (Mineral Petrology), 2025, 45(3): 11-23. (in Chinese)

[13] Yan B C, Liu S R, Chastain M L, Yang S G, Chen J L. A new FTIR method for estimating the firing temperature of ceramic bronze-casting moulds from early China [J]. Scientific Reports, 2021, 11: 3316.

[14] Tema E, Ferrara E. Magnetic measurements as indicator of the equivalent firing temperature of ancient baked clays: New results, limits and cautions [J]. Journal of Cultural Heritage, 2019, 35: 64-75.

[15] Zhou H, Qian W, Zhou W R. Application of color measurement in cultural relics and archaeology [J]. Sciences of Conservation and Archaeology, 2021, 33(1): 125-132. (in Chinese)

[16] Zhang B, Wang H, He X L, Zhu J F, Luo H J, Liu D Y, Wang F, Zhao X C, Fei G Q, Shi P. Correlation study on firing temperature and color of plain pottery excavated from the Tang Dynasty tomb of Liu Jing in Shaanxi, China [J]. Heritage Science, 2024, 12(1): 61.

[17] Su X Y, Wen R, Xing H P, Liu H F, Xu N, Chao X L. Formation mechanism of "inner black, outer red" in Yangshao pottery: The role of firing atmospheres and temperatures [J]. Journal of Archaeological Science: Reports, 2025, 67: 105442.

[18] Travé Allepuz E. Colour transformation and textural change in biotite: Some remarks for the interpretation of firing technology in greyware pottery thin-sections [J]. Minerals, 2021, 11(4): 428.

[19] Buchner T, Kiefer T, Zelaya-Lainez L, Gaggl W, Konegger T, Füssl J. A multitechnique, quantitative characterization of the pore space of fired bricks made of five clayey raw materials used in European brick industry [J]. Applied Clay Science, 2021, 200: 105884.

[20] Fan Z X, Zhou Z Y, Liu S R, Cui J F, Fan X C, Lin W, Huang Y M, Deng Z H. The earliest stamped hard pottery and high-firing technology dating back to 5000 BP: Evidence from two sites in southeastern China [J]. Journal of Archaeological Science, 2024, 166: 105977.