

# CERAMIC TECHNOLOGY AT PREHISTORIC BAN CHIANG, THAILAND: PHYSIOCHEMICAL ANALYSES

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## Introduction

Ban Chiang lies on Thailand's Khorat Plateau, over 500 kilometers northeast of Bangkok and about 50 kilometers south of the Mekong River which forms the border between Thailand and Laos. Although best known for documenting a recently recognized bronze-producing period in Southeast Asia, Ban Chiang is perhaps even more remarkable for its unusually long cultural sequence (White 1982). Calibrated radiocarbon dates from the site extend from the fourth millennium B.C. into the first millennium A.D. (Hurst and Lawn 1984). This time span includes pre-metal, bronze-casting and iron-forging periods. The artifactual inventory documenting this sequence is dominated by a ceramic assemblage which is characterized by highly aesthetic forms and decorations.

In the fall of 1983 the MASCA Archaeoceramics Section embarked upon a pilot study of a select sample of Ban Chiang

pottery vessels in an attempt to define the underlying ceramic technology of Ban Chiang. Technical analyses of the pottery from two other prehistoric sites in northeast Thailand have produced intriguing results. Thermal expansion measurements of pottery from Non Nok Tha indicated that the vessels had been fired at temperatures above those of an open or pit firing (Plate 1), most probably in a kiln (Meacham and Solheim 1979). A ceramic analysis of Ban Na Di pottery suggested some intraregional trade in ceramics and even higher firing temperatures (Vincent 1984a; 1984b).

The initial problem in any ceramic study is to select out a representative group of specimens from a large corpus of pottery. On the basis of macroscopic criteria (*e.g.*, vessel type, surface decoration, ware color, *etc.*) ware types can be preliminarily defined. Specific ceramic questions also emerge at



Plate 1:

Potter beginning open air firing at Ban Kham Oo in northeast Thailand. Firings employing rice straw fuel usually take less than one hour. Refiring experiments showed that the prehistoric Ban Chiang pottery was probably also fired in the open.

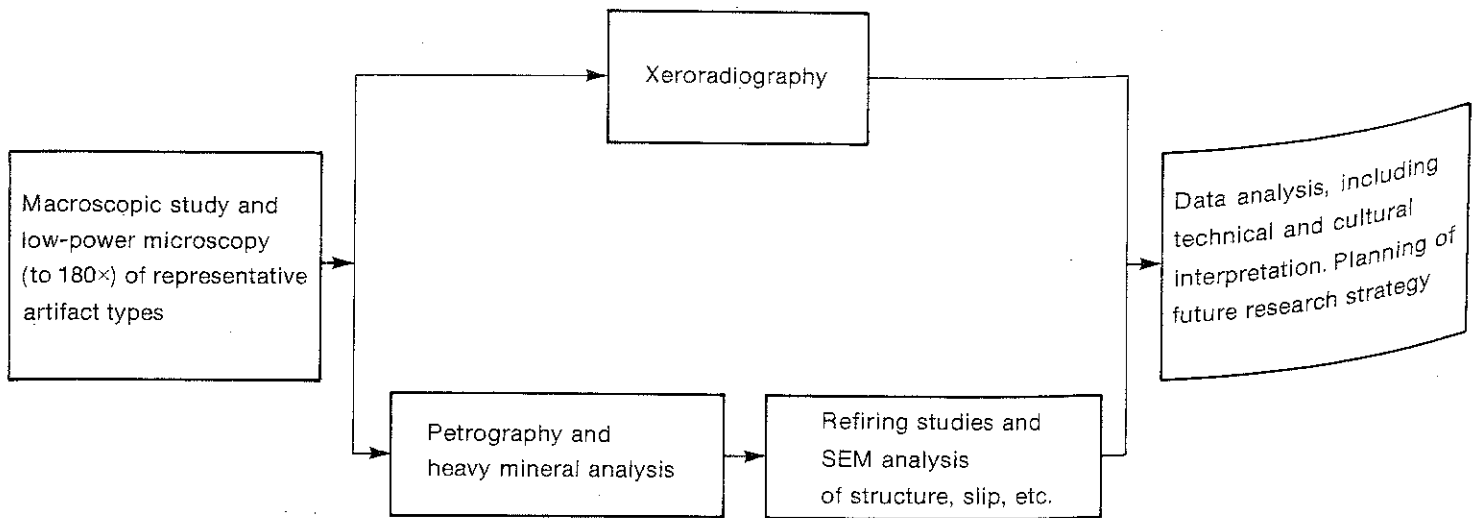


Fig. 1: MASCA archaeoceramics analytical program.

this stage, which the samples selected for more detailed analysis should begin to answer.

There were several questions that stimulated this study. Were the prehistoric pots constructed using the same paddle-and-anvil techniques observed in contemporary pottery manufacture in the area (White 1982)? Might forms or molds have been used in the manufacture of the distinctive concave surfaces of the Middle Period white carinated pots? Were firing temperatures sufficiently high to suggest interaction in the metal and ceramic pyrotechnologies during any period of the site's occupation? Was the surface color variation in the pottery, particularly the black, white, and red hues, controlled by firing conditions, by clay sources, by slips or paints, perhaps even by tempering? Was the formal variation evident in the three-thousand-year ceramic sequence accompanied by technological changes?

With these questions in mind twelve pottery vessels from secure Early, Middle, and Late Period funerary contexts were analyzed within the framework of the routine procedures now used in the MASCA archaeoceramics program (Fig. 1). Vessels were selected from each period which were considered to be of probable local manufacture either because they represented a diagnostic type of a specific phase, or because they were of undistinguished character and probably were made for domestic purposes.

Within the confines of a limited pilot study, not all the archaeological phases or types of pottery could be represented in the sample. Three chronologically coherent groups were represented by the initial twelve specimens:

- a., Early Period, phase II (*circa* 2500-2000 B.C.): two large fragmentary pots with heavily incised shoulders (BC-1, BC-2), and a small buff pot (BC-3) with a ring base and simple geometric incising.
- b., Middle Period, phase VII (*circa* 800-400 B.C.): two white carinated vessels (BC-4, BC-7), two reddish yellow vessels (BC-5, BC-8), and a small globular pot (BC-6).
- c., Late Period (*circa* 300B.C.-A.D. 200): a classic Red-on-Buff painted vessel (BC-10) from phase IX; and a Red-Burnished vessel (BC-11), a Red-on-Red painted vessel (BC-9), and a buff bowl (BC-12), all from phase X.

These were subjected to all the routine analytical procedures of our program. As an extension of the xeroradiography study (see Glanzman and Fleming, this issue) three more Early Period vessels (BC-46, BC-44, and BC-45 from phases III, IV, and V respectively) and three modern vessels were included to fill in the major time gap (*circa* 2000-1000 B.C.) and to provide a reference group of known manufacture.

#### Analytical techniques

This pilot study of the Ban Chiang pottery demonstrates the value of combining several mutually complementary techniques (McGovern *et al.* 1982). Xeroradiography and macroscopic examination are of primary importance in elucidating fabrication methods, but provide equivocal data on the provenience of the clay and the physical and chemical properties of the ware as a result of the preparation and firing. Microscopic techniques enable inferences to be made about the probable ancient firing temperature range and the possible levigation and tempering of the wares and any slips/paints. For a more detailed understanding of the raw materials of these fabrics, and the specific uses to which they were put, analytical chemical techniques are required. So as not to prejudice their outcomes, the individual studies were carried out independently of one another (except that each investigator was aware of the general problem orientation), and only brought together as the final step in the investigation. For the most part, individual findings fit together extremely well to give a composite picture of the ancient technology.

On the basis of the combined macroscopic and xeroradiographic evidence, two methods of fabrication were identified: a *coil-and-slab*, and *lump-and-slab* technique. The final shaping of the vessel was carried out with an anvil and a plain or corded paddle, though this was not always apparent on the surface of the finished vessel (see Glanzman and Fleming, this issue).

Petrographic studies were divided into two parts. The predominant inclusions in each fabric were identified in thin-section by standard techniques, and their volumetric contribution determined by the point count method (700 points in this study). The presence/absence of heavy mineral accessories

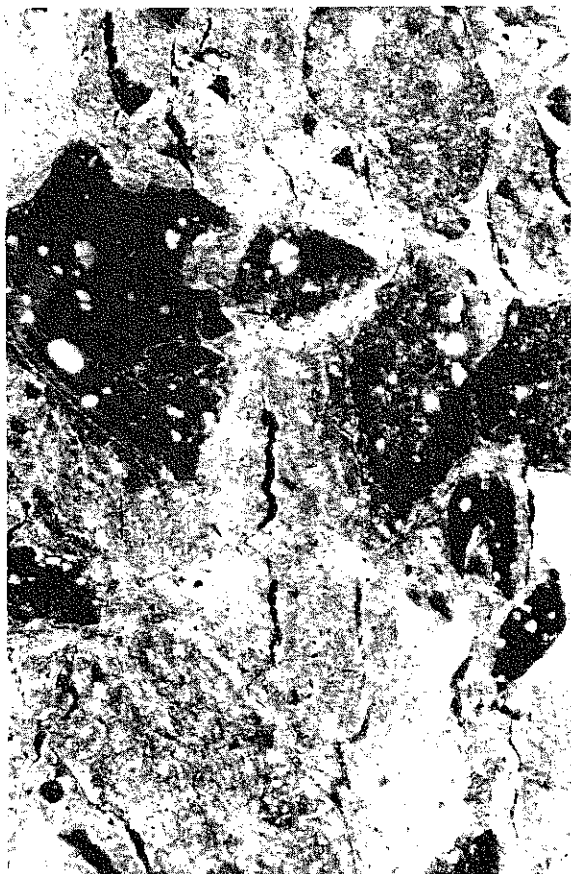
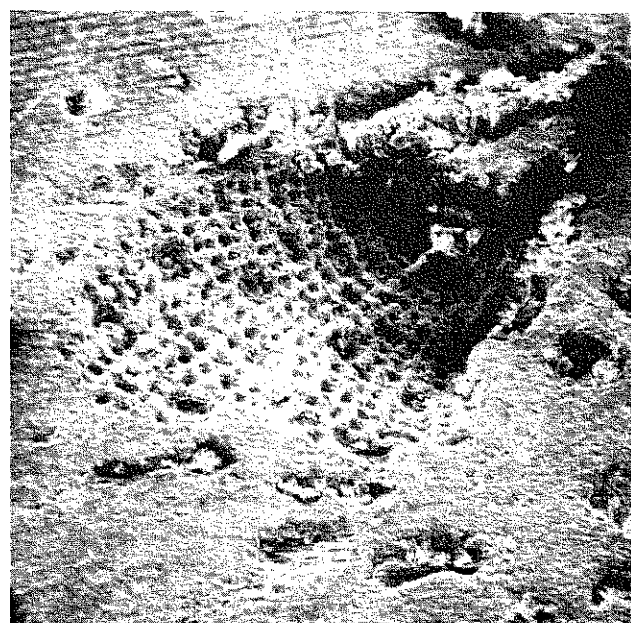


Plate 2:  
Optical photomicrograph of quartz-tempered grog inclusions, interior of BC-9 (magn., 25X).

Plate 3:  
SEM image of rice husk impression, interior of BC-5 (magn., 700X).



(e.g., green hornblende, hematite, etc.) which were poorly represented in thin section, was assessed by inclusion analysis of disaggregated 25 mg. samples.

The three major types of inclusions were as follows:

(i) Quartz, with a wide range of sizes (0.1 mm to circa 0.8 mm) and morphology (angular to rounded, mono- to polycrystalline).

(ii) Grog, with a similarly wide range of sizes (0.1 mm to circa 3 mm; see Plate 2). Colors varied from black to light gray, and from light reddish brown to light red and reddish yellow; shapes tended to be angular. Inclusions within the grog were principally fine quartz grains which were sometimes accompanied by grog grains; a small amount of plant material occasionally occurred.

(iii) Plant material, either carbonized remains or remnant impressions (Plate 3), and for the most part easily recognizable as parts of rice plants.

In addition, all the wares contained sponge spicules and fresh-water diatoms.

The ancient firing temperature range was determined for ware types of each period. The original degree of vitrification of clay particles for vessels of the same fabric was compared with that of small tiles cut from each and refired to various fixed temperatures (600° C, 700° C, 800° C, and 900° C). The tiles were

heated in a servo-controlled muffle furnace for eight hours in an oxidizing atmosphere (Chazan and McGovern 1984). According to the terminological distinctions of Tite *et al.* (1982a), an initial vitrification structure shows minimal fusion between clay particles, whereas large areas will have coalesced in an extensive vitrification structure.

The presence/absence of slips and paints was established using a scanning electron microscope (SEM), at magnifications typically in the 300X to 1000X range. The chemical composition of the single instance of a slip in the collection (on BC-11) was assessed semi-quantitatively with an attached energy dispersive system (EDS). The compositions of red paints were analyzed by proton-induced x-ray emission (PIXE) spectrometry (Swann 1982), and compared with the interior ware.

The color changes of the wares and slips/paints are denoted by their Munsell equivalents (Munsell 1975). The readings were taken under subdued natural lighting.

## Catalogue of data

For reasons of brevity, the technical observations on each vessel have been reduced, wherever possible, to description by a symbolic key. Following the MASCA laboratory number (BC no.) are the project identification number and archaeological phase (Early Period, phase II = EP II, etc.).

For *manufacturing method* as indicated by macroscopic and xeroradiographic studies, the designators are as follows: *CS* (coil-and-slab), *LS* (lump-and-slab), *cp* (corded paddle), and *pp* (plain paddle).

Individual vessels are illustrated in Fig. 3 of Glanzman and Fleming, this issue.

For *petrographic data* the designators are as follows: *gr* (grog) with an appropriate volumetric contribution and a typical size, or size range, included in parentheses; *q* (quartz) with an approximate volumetric contribution and the main grain size range included in parentheses; *pm* (plant material); and *v* (voids, some of which are burnt-out organics), with an approximate volumetric contribution in parentheses in each case.

For *heavy mineral description* the following designators are used: *il* (ilmenite), *hm* (hematite), *hb* (hornblende), *gn* (garnet), *zr* (zircon), *mn* (monazite), *bm* (brown mica), and *so* (sulfides and oxides of metal).

For the *vitrification state* of the fabric the designators are (after Tite *et al.* 1982b): *NV* (none), *IV* (initial), *V* (extensive), and *CV* (continuous).

*Munsell notations* represent the colors in parentheses: 10R 4-5/6-8 and 2.5YR 5/6 (red), 10R 6/6-8 and 2.5YR 6/6-8 (light red), 5YR 7-8/4 and 7.5YR 7-8/4 (pink), 5YR 5/4 (reddish brown), 5YR 6-7/6-8 and 7.5YR 6-8/6-8 (reddish yellow), 7.5YR 6/4 (light brown), and 10YR 8/3-4 (very pale brown).

The concentrations of elements of importance in elucidating the chemistry of the paints on certain vessels are given following each elemental symbol.

The vessels are sub-grouped and ordered chronologically. Thus rapid visual scan of some of the entries allows the reader to assess, for example, the prevalence of the usage of plant material within a particular time period, and a sense of how its presence may have changed with time.

### Early Period vessels

#### BC-1

BC B.34 A 1188

#### EP II

Fragment of a large black globular jar (H., 0.27 m).

Upper body, densely incised; lower body, cord marked. Regions of decoration separated by appliqué.

*CS*, *pp* (upper body), *cp* (lower body).

Patched on interior. Horizontal cracking along coil seams.

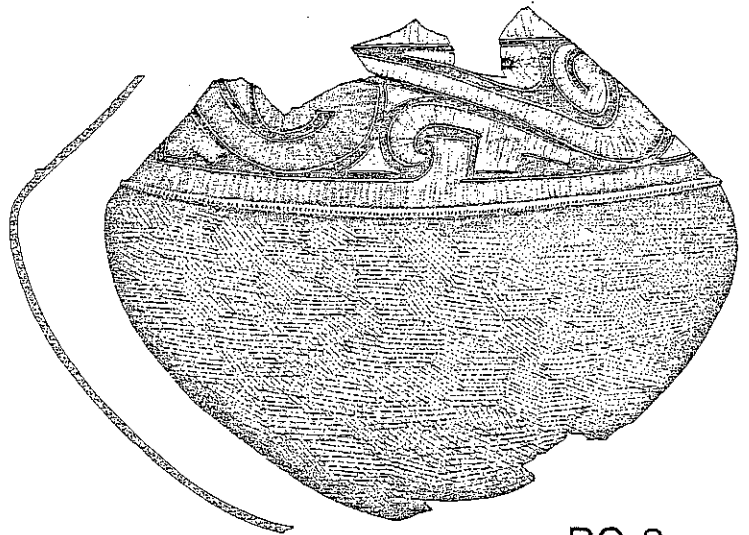
*gr* (16.1%: *circa* 1 mm), *q* (7.9%: <0.1 to *circa* 0.8 mm, bimodal at *circa* 0.2 and 0.5 mm), *pm* (6.6%), *v* (7.1%).

*hm*, *mn*.

Original firing: 500°-700°C, *IV*, surfaces (black with areas of 5YR 6/6), subsurfaces (5YR 6/6), thick core (black).

Refiring: 600°C, *IV*, entirely black.

No slip.



BC-2

BC-2 (Fig. 2 a, above)

BCES 2593

#### EP II

Part of a large black globular jar (H., 0.28 m).

Upper body, densely incised; lower body, cord marked. Regions of decoration separated by appliqué.

*CS*, *pp* (upper body), *cp* (lower body).

Patched on interior. Horizontal cracking along coil seams.

*gr* (21.9%: *circa* 0.25 to 1.0 mm), *q* (7.3%: <0.1 to *circa* 0.3 mm), *pm* (0.1%), *v* (2.4%).

*il*, *hm*, *gn*, *bm*.

Original firing: 500°-700°C, *IV*, surfaces (black), subsurfaces (2.5YR 6/6), medium thick core (black).

Refiring: 800°C, *V*, surfaces (5YR 5/4), interior ware (2.5YR 6/8 with some areas of 5YR 5/4).

No slip.

#### BC-3

BC B.42 B 1346

#### EP II

Buff ring-based vessel (H., 0.20 m).

Geometric incising on the shoulder; cord marked on lower body.

*CS*, *pp* (upper body), *cp* (lower body).

No patching. Horizontal cracking along coil seams.

*gr* (16.0%: *circa* 0.2 mm), *q* (11.1%: *circa* 0.1 to 0.3 mm), *pm* (9.3%), *v* (4.7%).

*il*, *zr*, *bm*, *so*.

Original firing: 500°-700°C, *IV*, surfaces (7.5YR 7/4-8), thick core (black).

Refiring: 900°C, *V* (plus surface cracking), surfaces (10YR 8/4 and 5YR 7/8), interior ware (5YR 7/8).

No slip.

#### BC-46

BCES B.49 A 2251

#### EP III

Mottled tan beaker, with flanges (H., 0.12 m).

No surface treatment.

*LS*, *pp* (upper body), *cp* (lower body).

No patching. Irregular vertical cracking, and break at junction of lump and slab. All outer surfaces wet-smoothed.

Petrography and heavy mineral content, not examined.  
No studies of firing conditions, or of slips/paints were made.

BC-44

BCES B.31 B 1990

EP IV

Mottled tan, straight-sided deep bowl (H., 0.13 m).

Heavily cord marked body, with a distinct band of vertical cord marking just below the rim.

CS, cp.

No patching. Horizontal cracking along coil seams and junction of coil to basal slab.

Petrography and heavy mineral content, not examined.

No studies of firing conditions, or of slips/paints were made.

BC-45

BCES B.56 C 2215

EP V

Buff globular vessel, with everted rim (H., 0.15 m).

Cord marked over entire outer body.

LS, cp.

No patching. Irregular vertical cracking.

Petrography and heavy mineral content, not examined.

No studies of firing conditions, or of slips/paints were made.

Middle Period vessels

BC-4 (Fig. 2 b, below)

BCES B.19/24 C 1443

MP VII

White carinated vessel (H., 0.28 m).

Red-painted rim.

LS, pp (upper body), cp (lower body).

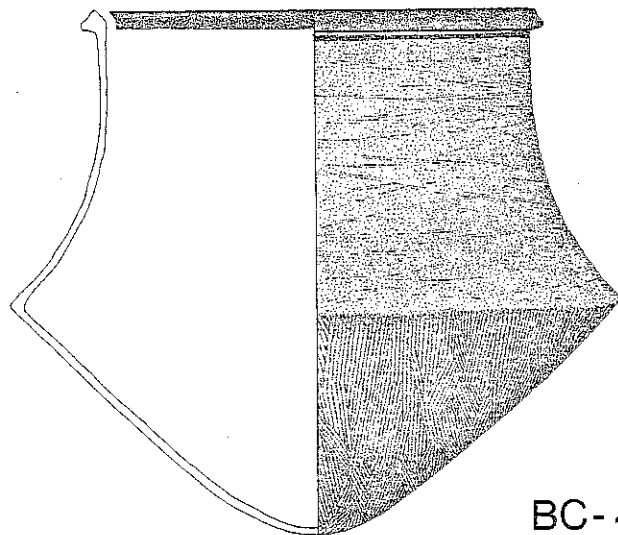
Patching (and cracking) at the carination seam. Irregular cracking, otherwise.

gr (12.0%: circa 1 mm), q (15.0%: circa 0.1 to 0.2 mm), pm (30.3%), v (4.0%).

gn.

Original firing: 500°-700°C, IV, exterior surface (white), interior surface and thick core (black), paint (10R 5/6).

PIXE: core (CaO, 1.17%; Fe<sub>2</sub>O<sub>3</sub>, 1.03%); paint (CaO, 2.72%; Fe<sub>2</sub>O<sub>3</sub>, 14.5%).



BC-4

Refiring: 600°C, IV, exterior surface (white) penetrates interior ware (gray), interior surface (gray), paint (2.5YR 5/6).

No slip; paint present.

BC-5

BCES B.19/24 F 1442

MP VII

Rim, shoulder, and a portion of body from a large, reddish yellow, globular vessel (D., 0.31 m, at rim).

No decoration.

LS, pp (upper body), cp (lower body).

No patching. Irregular cracking.

gr (0%: -), q (2.4%: circa 0.1 to 0.2 mm, some 0.5 mm), pm (25.2%), v (6.1%).

so.

Original firing: 500°-700°C, IV and organic residue still present; exterior surface and subsurface (5YR 7/6), interior surface and thick core (black).

Refiring: 800°C, V, exterior surface and interior ware (5YR 7/6), interior surface (5YR 8/4).

No slip.

BC-6

BCES B.19/24 M 1442

MP VII

Portions of rim and body from a buff, globular vessel (H., 0.19 m).

Plain, except for red paint trim just below rim.

LS (but no basal region), cp (all over).

Traces of patching. Horizontal cracking above and below maximum diameter, otherwise irregular. Cracking at sharp neck turn obscures whether or not rim is an additional coil.

gr (0%: -), q (3.4%: circa 0.1 to 0.2 mm, some 0.5 mm), pm (36.7%), v (5.3%).

No accessories found.

Original firing: 500°-700°C, IV, exterior surface and subsurface (7.5YR 6/4), interior surface and thick core (black).

Refiring: 900°C, V (plus surface cracking), exterior surface and subsurface (7.5YR 6/8 with 2.5YR 6/8 mottling), interior ware and surface (7.5YR 6/8).

No slip.

BC-7

BCES B.40 G 1927

MP VII

Tall, white, carinated vessel (H., 0.45 m).

Plain, except for red lines painted under rim.

LS, pp (upper body), cp (lower body).

Patching (and cracking) at the carination seam. Patching on interior of base. Irregular cracking, otherwise.

gr (9.3%: 0.1-4 mm), q (6.0%: <0.1 to circa 0.3 mm), pm (17.0%), v (1.1%).

il, hm.

Original firing: 500°-700°C, IV, exterior surface (white), exterior subsurface (5YR 7/6), interior surface and thick core (black), paint (10R 4/8).

PIXE: core (CaO, 0.84%; Fe<sub>2</sub>O<sub>3</sub>, 1.14%); paint (CaO, 1.21%; Fe<sub>2</sub>O<sub>3</sub>, 23.6%).

Refiring: 700°C, V, exterior surface (white), exterior subsurface (5YR 7/6), interior surface and thick core (light gray).

No slip; paint present.

BC-8

BCES B.40 D 1935

MP VII

Reddish yellow, carinated vessel (H., 0.35 m).

Incised and painted design on shoulder.

*LS*, *pp* (upper body), *cp* (lower body).

Patching (and cracking) along carination. Irregular cracking, otherwise.

*gr* (0%: -), *q* (2.7%: <0.1 to circa 0.3 mm), *pm* (36.6%), *v* (2.0%), *il*, *hm*, *gn*.

Original firing: 500°-700°C, *IV*, exterior surface and subsurface (5YR 7/6), interior surface and thick core (black), paint (10R 4/8).

Refiring: 700°C, *V*, exterior surface (5YR 7/6), interior surface (10YR 8/4), interior ware (5YR 7/4).

No slip; paint present.

Late Period vessels

BC-10

BCES B.9 I 2554

LP IX

Portion of buff, high-shouldered vessel, with a flaring rim (H., 0.52 m).

Red-painted with various curvilinear designs over all the outer surface except close to the base.

*CS*, *pp*.

Patch-strengthening achieved by smearing the inner edge of each coil downwards over the coil below. Horizontal cracking along coil seams, and at the neck constriction. Base scraped on interior.

*gr* (11.7%: 1 to 2 mm), *q* (13.4%: <0.1 to 0.4 mm), *pm* (0%), *v* (1.7%).

*hm*, *gn*, *hb*.

Original firing: 500°-700°C, *IV*, exterior surface (7.5YR 7/6 and grayish white), exterior subsurface (7.5YR 7/6), interior surface and ware (10R 6/8), thick core (2.5YR 8/2), paint (2.5YR 5/6).

PIXE: interior ware (CaO, 0.95%; Fe<sub>2</sub>O<sub>3</sub>, 1.02%); paint (CaO, 0.69%; Fe<sub>2</sub>O<sub>3</sub>, 5.79%).

Refiring: 700°C, *V*, exterior surface (7.5YR 8/6 and gray), exterior subsurface (7.5YR 8/6), interior surface and ware (mottled 10R 6/6), paint (10R 5/6).

No slip; paint present.

BC-9 (Fig. 2 c, above right)

BCES B.2 B 494

LP X

Red, high-shouldered vessel with a broad, flaring rim (H., 0.34 m).

Red painted design.

*CS* (coils pinched on by hand), *pp*.

No patches. Irregular cracking, with no preferential breakage along coil seams.

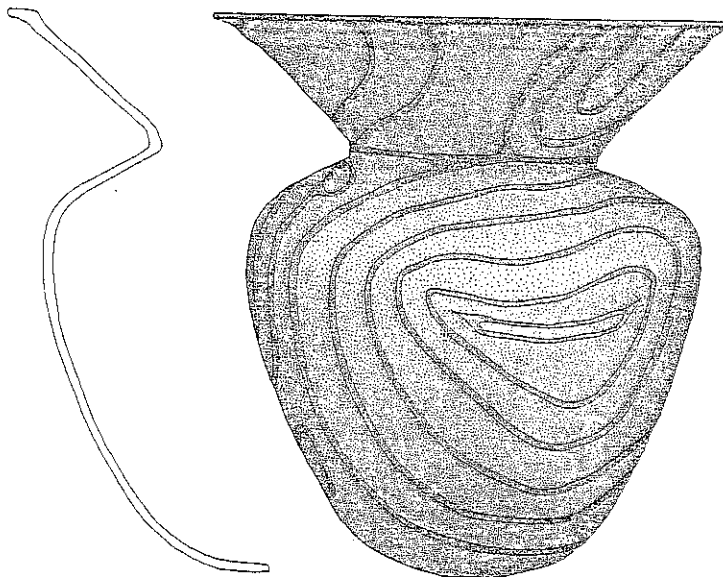
*gr* (17.6%: 1 to 4 mm), *q* (7.0%: <0.1 to circa 0.4 mm), *pm* (0%), *v* (3.1%).

*il*, *hm*, *zr*, *hb*, *so*.

Original firing: 500°-700°C, *IV*, exterior surface (5YR 7/6 with black mottling), interior surface and thick core (black).

Refiring: 600°C, *IV*, exterior surface (5YR 7/6), interior surface (7.5YR 8/4), interior ware (7.5YR 7/4).

No slip; paint present.



BC-9

BC-11

BCES B.2 D 495

LP X

Upper part of a red burnished vessel with a broad, everted and ridged rim (H., 0.19 m, upper body).

No further surface treatment.

*CS*, *pp*.

Patch-strengthening achieved by smearing the inner edge of each coil downwards over the coil below. Horizontal cracking along coil seams, and at the neck constriction. Base scraped on interior.

*gr* (25.3%: <2.5 mm), *q* (1.6%: <0.1 to circa 3 mm), *pm* (0.1%), *v* (2.4%).

*hm*, *zr*, *hb*.

Original firing: 500°-700°C, *IV*, exterior surface (10R 4/8), exterior subsurface (5YR 7/6), interior surface and thick core (black).

Refiring: 800°C, *V*, exterior surface (10R 5/8), interior ware and surface (5YR 7/6).

Slip present.

BC-12

BCES B.2 E 523

LP X

Buff, open-faced, footed bowl (H., 0.12 m).

No decoration.

*CS* (?).

Heavy wet-smoothing, inside and out, that now obscures any signs of possible paddle or anvil marks, and of any patching used.

*gr* (14.6%: <3 mm), *q* (6.4%: circa 0.1 mm), *pm* (0.1%), *v* (1.4%).

*il*, *hm*, *hb*.

Original firing: 500°-700°C, *IV*, exterior surface (5YR 7/6 with areas of white and 2.5YR 6/8), exterior subsurface (white), interior surface (black with areas of white), thick core (black).

Refiring: 900°C, *V* (plus surface cracking), exterior surface (7.5YR 8/6), interior surface (7.5YR 8/6) interior ware (7.5YR 7/8).

No slip.

## Discussion

The complementary analytical techniques used in this pilot study of the Ban Chiang pottery enabled many aspects of the industrial sequence from raw materials to the finished decorated form to be reconstructed. The study of samples from discrete time periods, covering approximately 2500 years, also provided a time depth which is unusual in ceramic studies. As a contemporary point of reference, ethnographic comparisons for the ancient technology could be drawn from modern potters in the Ban Chiang area.

### a. Technological change

The catalogue of data reveals certain distinct trends. There are, for example, changes in petrographic characters from one period to the next (Fig. 3). EP II pottery was tempered primarily with grog (Plate 2) and quartz (averaging 18.0% grog and 10.6% quartz, by volume), along with varying amounts of plant material. The latter was largely derived from rice plants (Yen 1982). Plant material was the preeminent temper of the Middle Period pottery, averaging 29.2%. It was combined with a reduced amount of quartz, which in three instances was below the arbitrary lower limit (5%) that has been suggested for intentional tempering, as opposed to the inclusions being derived from the clay or another additive (Rye 1976). Grog was used for only two MP examples (BC-4 and BC-7), and in reduced amounts (average content of 10.7%). By contrast, in the LP vessels, plant material was scarcely used at all, while grog once again became the principal temper (averaging 17.3%). The use of quartz was quite variable, ranging from 1.6% to 13.4%.

Comparable but less dramatic shifts were apparent in the accessory mineral assemblages. MP pottery was depleted in heavy minerals compared to the wide spectrum of associated minerals found in the EP II pottery. The LP pottery again showed considerable variability, but differed from the EP pottery in lacking monazite and brown mica. Most notably, all

the LP examples were found to contain hornblende, which was totally absent in earlier pottery.

As another difference between the groups, slips occurred only in the Late Period. The only slipped vessel studied (BC-11) had a relatively thin layer (10-50 microns) of fused clay. Semi-quantitative chemical determination by EDS indicated that the iron level of the slip was elevated and its calcium content slightly depressed in comparison to the interior ware. Red painted vessels were present in the Middle Period (BC-4, BC-7, BC-8) and the Late Period (BC-9 and BC-10); although they occurred in the Early Period, they were not represented in the pilot study. According to the PIXE results, the LP red paint was quite comparable to the slip of the same period, with higher iron and lower calcium levels. The MP red paints, on the other hand, differed in having much higher iron contents and a somewhat increased amount of calcium (*cf.*, BC-4 and BC-7).

The manufacturing techniques used in forming the vessel shapes followed a similar pattern, and can be briefly summarized here (see Glanzman and Fleming, this issue). In phase II of the Early Period, various pottery types were coil-and-slab built, and formed by the paddle-and-anvil method. By the end of the Early Period, the lump-and-slab method was being employed. In two instances, a corded paddle had been employed over the entire body (except the rim); only the lower body of another four examples had been cord-marked, whereas the upper body had been worked with a plain paddle. In the Middle Period both the lump-and-slab and coil-and-slab techniques were attested, and four specimens had cord-marked lower bodies and plain upper bodies. In the Late Period, the coil-and-slab method with overall plain paddling predominated. The modern potters of the area use a single lump of clay, which is entirely plain-paddled.

Unique to the Middle Period were carinated forms (BC-4 and BC-7) with intense white surfaces. Only these sustained the EP tradition of the use of quartz as grog. Slips were not observed on

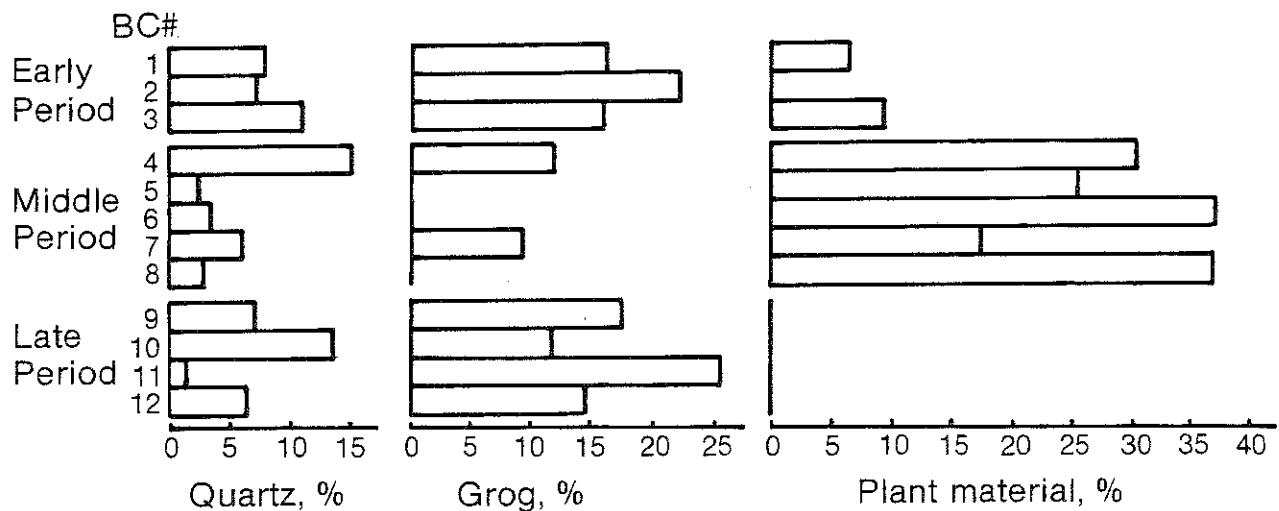


Fig. 3: Histogram of temper percentages (by volume) for Ban Chiang pottery examples.





Plate 4 a:  
SEM image of interior of BC-7 (magn., 800X). Individual clay particles are visible.

these specimens, and the interiors changed to the same color as the exterior upon refiring. According to the PIXE results, the clay is closer to a kaolinite (lower levels of aluminum, iron, magnesium, and titanium) rather than a smectite, which was generally used in making the Ban Chiang pottery of all periods. Metakaolinite ( $\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$ ) forms from kaolinite when it is heated above  $550^\circ\text{C}$  (Heimann and Franklin 1979), and it is most likely responsible for the vessels' white coloration (Noll *et al.* 1975).

#### b. Technological continuity

In contrast to the tempering, fabrication, and employment of slips/paints, the firing of the Ban Chiang pottery appears to have been carried out in much the same way over the three millennia. Comparison of the degree of vitrification of the ancient pottery with refired tiles of the same specimens revealed that the pottery of the three periods had been fired at uniformly low temperatures (*circa*  $500^\circ\text{C}$ - $700^\circ\text{C}$ ). All the original pieces exhibited an initial vitrification structure in which the clay particles were minimally fused together (Plate 4 a). The corresponding refired pieces which had been heated above  $700^\circ\text{C}$  had an intermediate vitrification structure (Plate 4 b), whereas those that had been refired below this temperature retained the features of an incipient stage of fusion. The prevalence of exterior oxidation and reduction spots on examples from each period indicates that the firing process was

poorly controlled. In view of the low firing temperatures, it may be proposed that the pottery was fired in the open by piling the fuel up and around the vessels, as is still done today (see Plate 1). Ancient firing installations have not been excavated, but kilns would normally have been fired to higher temperatures— $800^\circ$  to  $1000^\circ\text{C}$  (Mayes 1961, 1962; Bryant 1970, 1978). Since refiring to  $900^\circ\text{C}$  caused surface cracking on the tiles, higher temperature firings may have been purposely avoided.

Black surface coloration, which was observed only on EP II examples (BC-1 and BC-2), could have been achieved by close packing of the fuel, thus cutting off the flow of oxygen. Upon refiring in an oxidative atmosphere, the color of the smectite clay generally changed from black to gray to various shades of red, pink, yellow, and brown, dependent upon the amount of remaining oxidizable organic material, the iron content of the fabric, and the temperature and duration of the firing. This color development can be observed for the cores and interior wares of MP and LP ceramics, as well as the EP surfaces and interiors. Wares with higher iron contents, particularly in the Late Period (*e.g.*, BC-10) sometimes had large red surface areas, probably as a result of lesser compaction of the fuel and extensive oxidative gradients. In the case of the kaolinitic clay bodies of the Middle Period, black went to gray and then white. Since the cores generally disappear with eight hour refirings,



Plate 4 b:  
SEM image of interior of BC-7 (magn., 800X), after refiring to  $700^\circ\text{C}$ . Note the extensive areas of sintering.



short duration ancient firings can be inferred. Modern potters in the area have been observed to fire their vessels for less than an hour. In general, the surface color variations in the Ban Chiang corpus can be explained as due either to firing in a more reducing atmosphere (as in phase II of the Early Period) or to the use of a different clay (e.g., more iron rich bodies in the Late Period).

A uniformly low original firing temperature was also borne out by unburnt organic residues, since organics begin to burn out at around 450°C. This was further confirmed by the presence of brown mica in EP II pottery, and green hornblende in LP pottery. The optical properties of the mica suggest a temperature well below 800°C, and green hornblende is transformed to brown hornblende around 750°C (Kozu *et al.* 1927; Barnes 1930). Upon refiring in an oxidative atmosphere at 600°C and above, the organics gradually burned off (*cf.* the color changes of BC-1 and BC-2).

### Conclusions

Based on the results of this admittedly limited sampling of three periods of Ban Chiang ceramics, representing several thousand years, the pottery industry of the area appears to have been highly conservative. Thus, some fabrication techniques that were used throughout this period and up to the present day were already being employed in the earliest period available for study. Similarly, the various tempering materials (quartz, grog, and plant remains) were all being used in the EP II phase. These continued to be used in later periods, but in different combinations and amounts. Low temperature, open air firings especially illustrate the conservatism of Ban Chiang potting traditions. Indeed, village potters today fire their vessels by a method which is probably quite comparable to prehistoric practice.

When changes occurred in petrography, clay types, the use of paints and slips, and fabrication techniques, these appear to have been minor departures from the well-founded tradition. Nevertheless, they are of potential importance in understanding the evolution of the industry, and by extension, at least one component of Ban Chiang culture.

The differences in heavy minerals would imply that different clay sources were being exploited in each period. The relative paucity of such minerals and quartz in the MP ceramics, in conjunction with a kaolinitic clay, suggests that the clay was better levigated or that purer clay deposits were being worked. MP pottery also stands apart from the other two groups in its consistently high levels of plant material as temper, which was most often used alone (small amounts of quartz were most likely introduced via the clay). The fabrics of the two white, carinated vessels, being tempered with a combination of quartz, grog, and organics, are very different from those of the other MP vessels, and perhaps provide evidence for a carry-over of technological tradition from the EP II phase. In particular, the grog of all the groups is quite similar, having been tempered with fine quartz. Modern potters prepare and grind up fired clay balls for grog, but these are rice-tempered (White 1982; Vincent 1984a).

The red paints of the Middle Period could be distinguished from later red paints and slips by their extremely high iron contents and somewhat elevated calcium levels. Nevertheless, the MP paint represents a precedent for later developments, when potters might have appreciated the advantages (in particular for adherence of the slip) of using a less calcareous slip/paint on a more calcareous body (see Tite *et al.* 1982a, 1982b).

The swings back and forth between the various fabrication techniques that have been documented by Glanzman and Fleming (this issue) are difficult to understand within a continuous tradition. Perhaps future study will show whether this is a result of a sampling bias. Another possibility is that each technique continued to be employed in at least one area of the plateau, and that the changes at Ban Chiang resulted from culture contact or population movements. The temporal overlap in the use of a plain paddle on the upper body and a corded paddle on the lower body for both the EP and MP pottery may be significant in this regard.

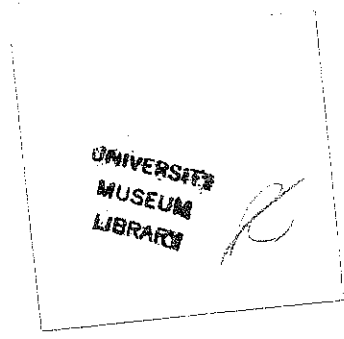
While some parameters of the production of Ban Chiang pottery (e.g., the firing temperature range) were well defined in this study, more detailed analysis and/or a larger sample is desirable in resolving a number of issues. Neutron activation analysis of more than sixty vessels and several modern clays from the Ban Chiang area has been initiated (in collaboration with R.G.V. Hancock at the University of Toronto's SLOWPOKE Reactor facility) to characterize the raw materials of the ancient pottery tradition more closely. By extension of the petrographic studies, it should be possible to document more precisely the change in tempering that must have occurred toward the end of the Early Period or the beginning of the Middle Period. The statistical base for the xeroradiographic study (Glanzman and Fleming, this issue) also needs to be expanded to determine the extent and timing of substantive developments in fabrication techniques.

Pending a more detailed study, several preliminary observations may be made about the relationship of the Ban Chiang pottery industry to that of other northeastern Thai sites. Even though there are some similarities in vessel forms, the fabrics of Ban Na Di (Vincent 1984a, 1984b) are clearly different from the wares included in this study. Much farther to the southwest, the Non Nok Tha pottery, which is contemporary with the Middle Period, is almost exclusively tempered with quartz (Bayard 1977). Higher firing temperatures (above 800°C), possibly using a kiln, were also attested for pottery from Non Nok Tha of EP and MP date (Meacham and Solheim 1979) and from Ban Na Di of MP date (Vincent 1984b).

The ceramic technological evidence from the Ban Chiang pilot study thus supports the hypothesis that a number of relatively isolated centers of pottery manufacture, of which Ban Chiang was one, probably existed on the Khorat Plateau from the third to the first millennium B.C. (Bayard 1977; Solheim 1984). The study of material earlier than the EP pottery might help to elucidate the common origins, if any, of the various industries.

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Volume 3 Number 4

June, 1985

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