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STATE OF ILLINOIS

DEPARTMENT OF REGISTRATION AND EDUCATION



# LONG-TERM DIMENSIONAL CHANGES IN ILLINOIS BRICKS AND OTHER CLAY PRODUCTS

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ILLINOIS STATE GEOLOGICAL SURVEY  
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CIRCULAR 405

1966

E R R A T A

Illinois State Geological Survey Circular 405, Dimensional Changes in Clay Products, by J. S. Hosking, W. A. White, and W. E. Parham.

Page 11, lines 2 and 3 should read: "The chemical and mineralogical compositions for the three mixtures of chinaware, sanitaryware, and art pottery raw materials are shown in tables 1 and 2, respectively."

Page 17, figure 7, caption: Change "Sydney semi-dry press (NM)" to "Sydney semi-dry press common (NM)," and change "Sydney semi-dry press common (SB<sub>C</sub>)" to "Adelaide wire-cut cream (SB<sub>C</sub>)."

Page 18, line 6: Change ". . kaolinite, silica, feldspar, or nepheline syenite . ." to ". . kaolinite, silica, and feldspar or nepheline syenite . ."

Page 20, line 19: Change "figure 7" to "figures 1 and 2."

Page 27, References, between "Johnson, P. V." and "Lamar, J. E." insert: "Kosanke, R. M., Simon, J. A., Wanless, H. R., and Willman, H. B., 1960, Classification of the Pennsylvanian Strata of Illinois: Illinois Geol. Survey Rept. Inv. 214, 84 p."



# LONG-TERM DIMENSIONAL CHANGES IN ILLINOIS BRICKS AND OTHER CLAY PRODUCTS

J. S. Hosking, W. A. White, W. E. Parham

## ABSTRACT

A four-year study has been made of the long-term dimensional changes in Illinois clay bricks and in laboratory test bars made from clays used in various ceramic products manufactured in Illinois. Results have been compared with those for Australian bricks and laboratory test bars that have been studied for up to ten years.

The Illinois bricks, like those in Australia, expanded when exposed to the atmosphere, after leaving the kiln, and this expansion has continued for the four years of exposure. A number of the Illinois bricks, however, have shown little change for some time, and none has reached the stage of continuous contraction after earlier expansion now shown by most of the Australian bricks.

General behavior patterns of the Illinois and Australian laboratory test bars are similar when expansions are considered in relation to the temperatures of firing. The expansions of the three varieties of Illinois brick—common, red-facing, and buff-facing—are low compared to the Australian bricks. The low expansions of the common bricks correspond with the relatively low expansion of their clays at all temperatures of firing, and in this respect the common bricks resemble the low-expanding red bricks from Adelaide, South Australia. The low expansions of the red- and buff-facing brick, compared with those in Australia, are explained on the basis of their higher industrial firing temperatures. The magnitudes of expansion of the Illinois ceramic bodies are related to the contents of kaolinite and illite as well as to those of other components of the clays.

A lower incidence of damage in Illinois brickwork, compared with that in parts of Australia, has been attributed partly to the higher firing temperatures and the consequently

lower expansion of the bricks, and partly to the more general practices of using lime-rich mortars, of allowing movement joints in the brickwork, and, in some cases, to long distance haulages that allow some expansion in the bricks before use.

## INTRODUCTION

Undesirable expansion of ceramic materials due to the sorption of moisture, sufficient to cause crazing of the glaze on whiteware, was first recognized by Merritt and Peters (1926) and Schurecht (1928) about 40 years ago. Only in the past decade, however, has certain serious damage to brickwork and tiling been accounted for by a similar expansion of structural clay products (McBurney, 1954; Hueber and Milne, 1955; Hosking et al., 1959; Hosking and Hueber, 1960a). Consequently, much effort in Australia (Hosking and Hueber, 1958, 1959, 1960a, 1960b, 1961, 1962; Hosking et al., 1959; Waters, Hosking, and Hueber, 1960; Hueber and Hosking, 1961; Hosking, 1964; Hosking, Hueber, and Holland, in press), in the United States (McBurney, 1954; Johnson and Plummer, 1958; Young and Brownell, 1959), and elsewhere (Norris et al., 1958) has been devoted to the study of the changes in length that structural clay products undergo when exposed to the atmosphere after leaving the kiln.

Studies of this nature were started in 1954 in the Division of Building Research, Commonwealth Scientific and Industrial Research Organization, in Australia. They were undertaken in order to determine how to prevent damage in structures in which ceramic products were used. Two main lines of attack have been followed: one has been the study of industrial products, and the other that of laboratory specimens prepared from clays used in making the products, but fired under controlled conditions in the laboratory. The study of the former has enabled conclusions to be drawn as to the actual behavior of products in practice, and that of the latter has enabled a better assessment to be made of the influences of various factors on the dimensional changes of various clay products, and to some extent of the causes of expansion.

Observations of buildings throughout the world have shown that damaging expansions may be apparent only a few weeks after the beginning of construction and that they can continue for years. However, it was soon realized that many years of exposure under natural conditions might pass before these expansions reached maximum values, i. e. those values upon which final expansion jointing in ceramic structures should be accurately based. The possibility of accelerating this expansion by immersing bodies in water or autoclaving them in steam was then considered. Unfortunately, though immersion increased the swelling of low-burned bodies, it did little or nothing to hasten the expansion of bodies burned at industrial temperatures (Hosking et al., 1959; Hosking and Hueber, 1960b, 1962), and the correlations between expansions at high and normal temperatures of exposure were so low as to preclude the application of autoclave data to the behavior of products exposed under natural conditions (Waters, Hosking, and Hueber, 1960; Hosking and Hueber, 1962). As a result, measurements are being continued indefinitely on products and laboratory specimens exposed at normal temperatures, and the results are analyzed periodically for long-term trends (Hosking and Hueber, 1959; Hosking et al., 1959; Hosking and Hueber, 1960a, 1961, 1962; Hosking, 1964; Hosking, Hueber, and Holland, in press).

In 1959, the senior author was invited by the Illinois State Geological Survey to inaugurate a study of the expansion of Illinois bricks similar to the Australian study. In addition to determining the long-term expansions of the local bricks, other purposes of the study were to compare the behavior of the bricks and of the bodies produced from various Illinois clays with that of Australian products, and to seek reasons why damage from expansion in brickwork did not appear as prevalent in the United States—particularly in Illinois—as in Australia.

This paper discusses the results of the first four years of the study and compares the long-term dimensional changes of Illinois bricks and laboratory specimens with those in Australia.

#### Acknowledgments

The authors wish to thank Dr. O. W. Rees of the Illinois State Geological Survey for the chemical analyses, Dr. I. E. Odom, formerly of the Survey, now with Northern Illinois University, and Mr. C. Lancucki of the Division of Building Research, Commonwealth Scientific and Industrial Research Organization, Australia, for the X-ray analyses, and Mrs. N. M. Nickson of the Division for the differential thermal and mechanical analyses of the clays. The authors are also grateful to Dr. N. R. O'Brien, now of the State University of New York, Potsdam, for assistance in preparation of the test bars.

#### BRICKS AND LABORATORY SPECIMENS

Illinois has a well established ceramic industry, which is widely dispersed throughout the state. It is well provided with clays and shales suitable for making a variety of products (White, 1959; White and Lamar, 1960), and needs to import only purer kaolins, ball clays, and other special raw materials for porcelain type whiteware and special refractories. When these studies were started in 1959, approximately 60 ceramic plants were operating in Illinois; of these, 26 were producing bricks (Busch, 1959). As it was not practicable to examine bricks or clays from all plants, a selection was made so that the bricks sampled were as representative as possible, and the clays were typical for the various products made in the state.

Bricks were collected from 10 plants, with three samples each of common, red-facing, and buff-facing building bricks and one firebrick. The common bricks were from the vicinity of Chicago, where they are mainly produced, but the facing bricks were collected from plants throughout the state. The building bricks were all formed by the extruded wire-cut or stiff-mud process and the firebricks by the semi-dry press method. The facing bricks and firebricks were fired in tunnel kilns, except when periodic round downdraft kilns were used. The common bricks were produced in large scove kilns with about 1,250,000-brick capacity. The Australian bricks, with which the Illinois bricks are being compared, were formed by one of the three processes—stiff-plastic press, semi-dry press, or wire-cut—and they were fired in a variety of kilns, which included continuous Hoffmann, Patent or tunnel kilns, and intermittent rectangular downdraft kilns.

Samples for this study were taken from the kilns while still hot, during normal drawing operations. Six adjacent bricks were taken from six sites on the tunnel kiln cars or from the setting face of the periodic downdraft or scove kilns,



with sites being chosen to represent a cross section of firing conditions in the kiln. The bricks were transported immediately to the laboratory, where the temperature and relative humidity are controlled at  $80\pm 5^\circ$  F and  $55\pm 5$  percent, respectively.

A total of 21 clays have been investigated; of these, 19 were supplied by manufacturers, and two, one a kaolin and the other an illite, were sampled in the field. The industrial clays include those from which the various bricks and firebricks were made, an additional firebrick clay, three clays for making building and drain tiles, and one clay each for making sewer pipes, sanitaryware, chinaware, stoneware pottery, and art pottery. From each of the clays, 100 laboratory specimens or test bars,  $4\frac{1}{2}$  inches by 1 inch by 1 inch, were prepared by extrusion. After air-drying, the specimens were fired in groups of eight in an electric muffle furnace. Firing temperatures ranged from  $800^\circ$  C ( $1472^\circ$  F) to either the melting point of the sample or to  $1300^\circ$  C ( $2372^\circ$  F), in  $50^\circ$  C ( $90^\circ$  F) intervals. The furnace temperature was raised to the required level at a controlled rate and held at that temperature for four hours. After firing, the furnace was allowed to cool naturally to  $400^\circ$  C ( $752^\circ$  F), and the specimens were removed and cooled rapidly to room temperature by fan draft. They were then transferred to the temperature and humidity controlled laboratory.

Each plant from which the bricks and clays were sampled is identified by a two-letter code combination, the first letter "I" for Illinois and the second for the particular unnamed plant in the state. The Australian samples are indicated by the letter "N" for New South Wales, "S" for South Australia, and "V" for Victoria.

## EXPERIMENTAL PROCEDURES

### Composition and Particle Size of the Clays

Each of the clays has been chemically analyzed and its mineral composition approximately determined from the combined chemical, X-ray, and differential thermal analyses.

X-ray diffractometer patterns of the samples were produced in the Survey, and X-ray powder diffraction photographs of six of the samples were made in the Division of Building Research of Australia. The powder photographs were taken with cameras that allowed spacings of the order of  $40\text{\AA}$  to be recorded using  $\text{Cu-K}\alpha$  radiations. Powder photographs were taken of the whole sample and of oriented aggregates of the less than  $2\mu$  fractions after various treatments, including glycerol saturation and heating to  $600^\circ$  C. After treatment with warm hydrochloric acid, the presence of chlorite was determined by X-ray diffraction methods. X-ray photographs of the heated clays were taken with a Guinier type focussing camera using monochromatic radiation.

Differential thermal analyses of the clays and their less than  $2\mu$  fractions were run with the apparatus developed by Carthew and Cole (1953) and later modified by Cole and Rowland (1961). The rate of heating was  $10^\circ$  C/min. and the inert material was calcined alumina. The less than  $2\mu$  fractions were separated by sedimentation methods, ground to pass a 70-mesh sieve, and dried overnight at  $40^\circ$  C before analysis.

For particle size analysis, samples were peptized with sodium hexametaphosphate and comminuted with high-speed stirring. The amounts of the various sized fractions were determined with a hydrometer. Curves of the particle size distribution were plotted and from these data a triangular diagram was prepared.

## Physical Properties of Bricks and Test Bars

During preparation of the test bars, losses in weight and shrinkages on drying and firing were determined. Water absorption, both after standing in water for 24 hours and after boiling for 5 hours, and saturation coefficients were determined on all bricks and test bars according to the British Standard Method of Testing Clay Building Bricks (B. S. 1257-1945). The color and condition of the specimens were assessed by visual observation before and after firing, and their hardness estimated from the ring emitted when samples were struck together or with a hammer.

## Measurement of Length and Conditions of Exposure

Measurements of dimensional changes in the bricks and test bars were determined with an adjustable comparator of the type described in the British Standard Method of Testing Clay Building Bricks (B. S. 1257-1945). Invar rods of known length were used as standards of comparison and were measured along with the specimens throughout the tests; measurements obtained are considered correct to  $\pm 0.0002$  inch.

The bricks were prepared for measuring by drilling a conical cavity of  $\frac{1}{4}$ -inch diameter in the center of each end. The cavities were drilled in the green test bars before firing. Removable steel balls were placed in these cavities, and the lengths were measured with the comparator.

The bricks and test bars were stored in the laboratory where the relative humidity is kept between 50 and 60 percent and the temperature between 75° and 85° F. The Australian samples have been standing in an air-conditioned room maintained at relative humidities between 50 and 65 percent and a temperature of about 70° F.

The bricks were measured immediately when they reached the laboratory, and the test bars were measured as soon as they cooled to room temperature. Changes in length were measured at the end of the first and second week, the first, second, and third month, at three-month intervals for the next 15 months, and at six-month intervals thereafter.

COMPOSITIONS AND PROPERTIES OF THE CLAYS, BRICKS,  
AND LABORATORY SPECIMENS

Chemical and mineral compositions, mechanical analyses, and drying and firing behavior of the Illinois clays are given in a series of figures and tables in the text and Appendix. Chemical analyses for each of the clays studied are given in table 1. Mechanical analyses of the clays and mineralogical composition of a clay typical for each type of product, determined from a combination of chemical, X-ray, and differential thermal analyses are given in table 2. The dimensional changes are given in table 3. The properties of the bricks under examination, of the green specimens produced from the clays, and of the fired test bars are given in tables 4, 5, and 6, respectively. Changes in length on firing, water sorption, saturation coefficients, and dimensional changes at the end of four years for the test bars are shown in figures 1 and 2. Curves for the three varieties of building brick, the building and drain tiles, and the firebricks are averages for the specimens examined; the other curves are for the individual clays. Relevant informa-

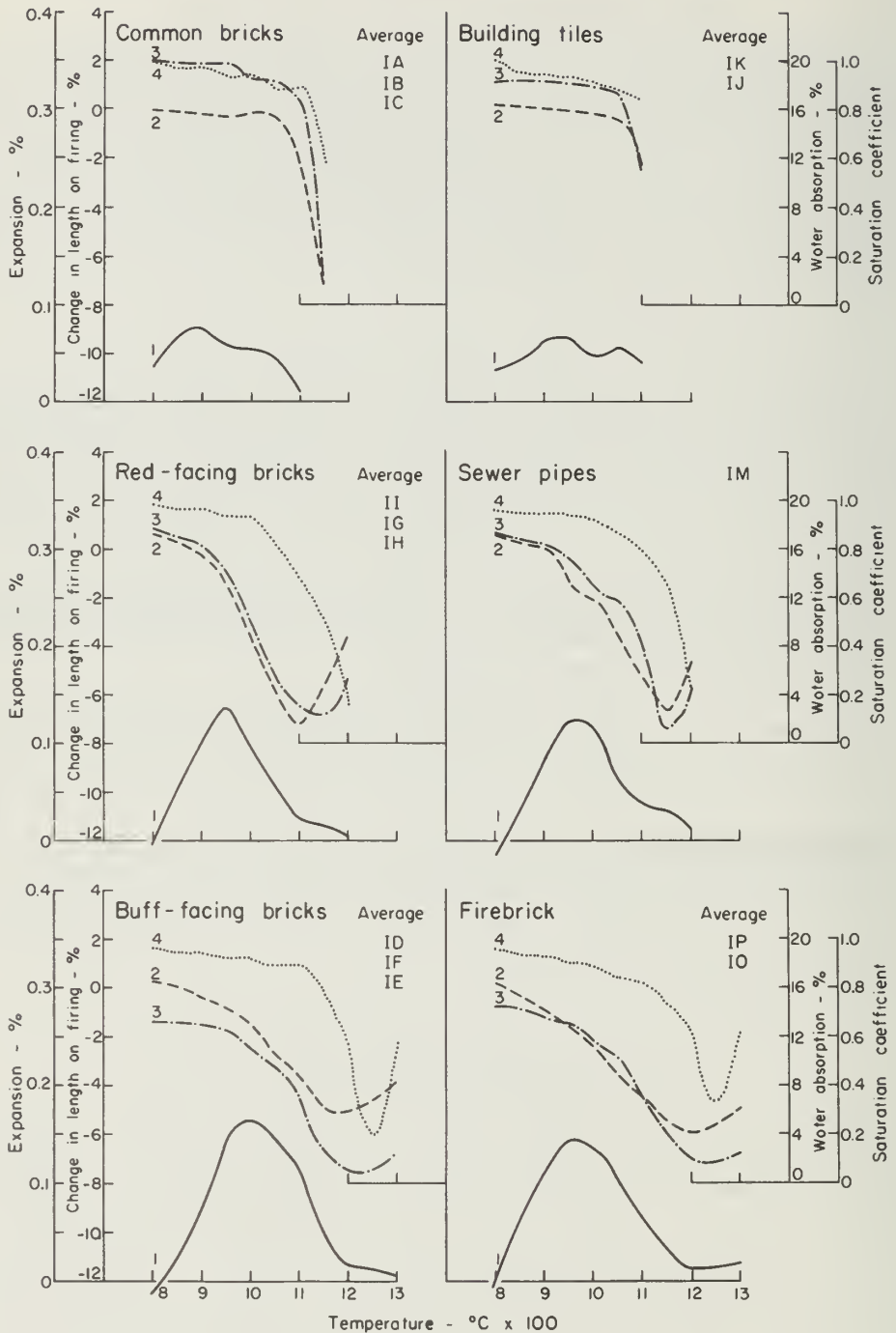


Figure 1 - Curves for (1) permanent expansion on standing in air for four years, (2) firing shrinkage, (3) water absorption after boiling for 5 hours, and (4) saturation coefficient for the Illinois brick, firebrick, building tile, and sewer pipe clays fired in the laboratory at temperatures from 800° to 1300° C.



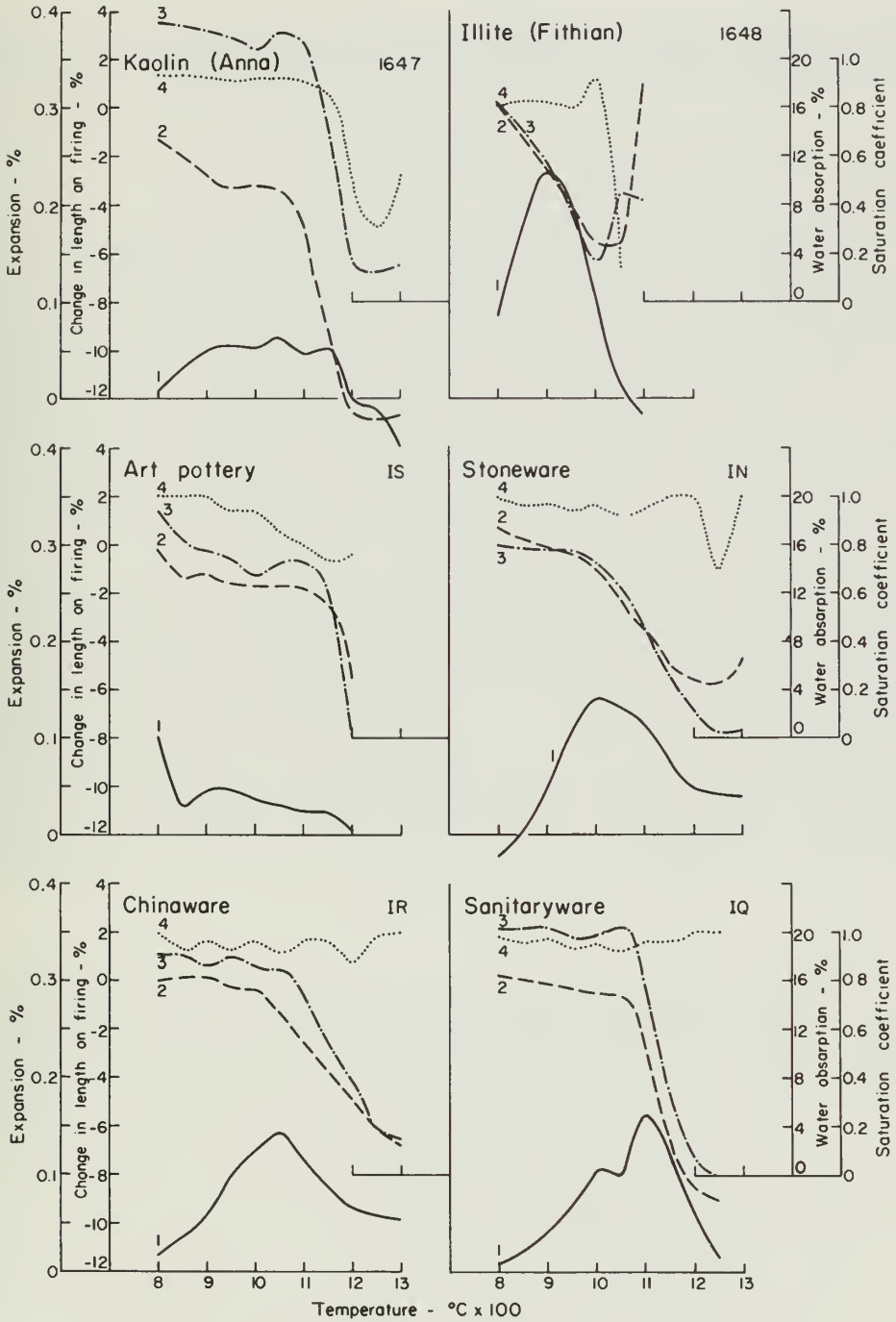


Figure 2 - Curves for (1) permanent expansion on standing in air for four years, (2) firing shrinkage, (3) water absorption after boiling for 5 hours, and (4) saturation coefficient for the Anna kaolin, Fithian illite, art pottery, stoneware, chinaware, and sanitaryware clays fired in the laboratory at temperatures from 800° to 1300° C.

tion on the Australian clays, bricks, and laboratory specimens are given by Hosking et al. (1959), Hosking and Hueber (1960a, 1962), and Cole and Segnit (1963). The various Illinois clays and laboratory specimens are discussed below.

## Bricks

### Common

Common bricks in Illinois are made from clays taken mostly from Pleistocene glacial tills, the mineralogy of which has been described by Willman, Glass, and Frye (1963). The brickmaking deposits, which contain some loess, consist of yellowish to yellowish brown surface layers over heavy gray to blue clays below. The clays are composed mainly of illite and quartz with smaller amounts of kaolinite (which may be absent in some samples), chlorite, feldspar, and iron oxides, and varying amounts of carbonate minerals. The clays are characteristically calcareous (tables 1 and 2), and carbonate minerals, with dolomite predominating over calcite, may amount to as much as 20 percent. Mechanical analyses (table 2) show the three samples examined are silty clays with clay and silt contents at 37.5 percent each and sand about 25 percent.

The clays are readily molded and shrink between 3 and 4 percent on drying (table 6). On firing to 800° C (1472° F), test bars shrink very little and have a high water absorption of 18 to 20 percent (table 6 and fig. 1). Test bars show little change between 800° and 1050° C (1472° and 1922° F), but above the latter temperature they shrink rapidly to dense, vitrified bodies at 1150° C (2102° F) and are molten at 1200° C (2192° F). The samples below 950° C (1742° F) are buff colored and underburned. Between 950° and 1100° C (1742° and 2012° F), they are pink to salmon-red, hard, and well burned, and at 1150° C (2102° F) they are dark brown and overburned. Industrial bricks are creamy pink. The carbonate in the clays is shown by the soft white or gray nodules of lime and magnesia in the bricks and test bars. On standing, the lime and magnesia become hydrated and cause spalling, or even cracking in some cases.

### Facing Bricks

The raw materials for facing bricks are drawn mainly from Pennsylvanian strata. The red or colored bricks are made from run of pit mixtures of shales, siltstones, sandstones, and clays, but for the buff- or cream-colored bricks only clays or shales of low iron content from the Spoon Formation (Kosanke et al., 1960) are used. These clays and shales have been described, and their mineralogy discussed, by Grim, Bray, and Bradley (1937); Grim, Bradley, and White (1957); Glass, Potter, and Siever (1956); Glass (1958); Potter and Glass (1958); and Parham (1964). The ceramic potentialities of the materials, particularly for buff-burning products, have been discussed by Lamar (1948), Parham (1959, 1960, 1961), Parham and White (1963), and White (1963).

The raw materials for brickmaking are essentially mixtures of kaolinite, illite, and quartz, with smaller amounts of other minerals. In the red-burning clays, illite is generally in excess of kaolinite, and other clay minerals such as chlorite and mixed-layer types are present. Feldspar is common, and iron minerals including hematite, siderite, pyrites, and hydrated oxides are characteristic. In the buff-burning clays, on the other hand, kaolinite is generally in excess of illite, quartz is higher, iron minerals are low, and there may be a little feldspar. The

predominance of kaolinite in the buff-burning clays and of illite in the red-burning clays was determined by X-ray and differential thermal methods. Raw materials giving pink- or salmon-colored bricks have mineralogical compositions intermediate between those for buff- and red-burning clays.

Table 2 shows that the red-facing brick clays, which average about 42 percent clay and 39 percent silt, are a little heavier, in the textural sense, than the common clays; the buff-burning clays are even heavier, with 50 percent clay. Both types of clay are plastic and mold readily. On the average, the clays show between 3 and 4 percent drying shrinkage; the buff-burning clays, because of their higher clay content, shrink a little more than do the red ones.

The buff-burning clays are more refractory than the red-burning ones, and this is reflected in the differences in their behavior on firing, as seen in table 6 and illustrated by the firing shrinkage and water absorption curves of figure 1. The test bars of the red-burning clays showed a slight expansion at 800° C (1472° F) and shrank slightly on further heating at 900° C (1652° F). They shrank rapidly above this temperature to reach a minimum volume at 1100° C (2012° F), after which they bloated appreciably before melting at 1250° C (2282° F). The test bars were soft to medium hard and salmon or buff-brown below 950° C (1742° F), but hard and dense and light to dark red between 1000° and 1100° C (1832° and 2012° F). On bloating, above 1100° C (2012° F) the bars opened up and the color changed to dark red-brown.

The buff-burning clays also showed an initial small expansion at 800° C (1472° F), but they shrank more slowly than the red-burning ones, reaching their highest density between 1150° and 1250° C (2102° and 2282° F). On further heating, they expanded slightly, but showed no signs of melting at 1300° C (2372° F). The test bars were soft to medium hard below 950° C (1742° F), but the hardness and density increased as the temperature was raised to 1200° C (2192° F), when they were vitrified and very hard. The bars were gray-white to pink up to 1150° C (2102° F), then stone gray. Above 1200° C (2192° F), black specks appeared on the surface.

### Building and Drain Tiles

Two of the building and drain tile clays (IK, IJ), like those for the common bricks, were obtained mainly from the Pleistocene glacial tills. The third was a mixture of surface till and underlying Pennsylvanian clays and shales. Mineralogically, therefore, the first two clays resembled those for the common bricks and the third a mixture of the common and red-facing brick clays. All were calcareous with dolomite again predominating over calcite (table 2) and were similar to the common brick clays in their particle size analyses (table 2).

As may be seen from table 6 and the firing and shrinkage curves of figure 1, fired specimens from the three clays behaved like those for the common bricks. Little change was shown by the specimens fired in the 800° to 1050° C (1472° to 1922° F) range, but beyond 1050° C (1922° F) they shrank rapidly. Two of them melted at 1150° C (2102° F), the lowest melting temperature for all the industrial clays studied, and the third at 1200° C (2192° F). The test bars were medium hard and salmon-red below 950° C (1742° F); above this temperature they were hard and darker in color. In the sample containing shale, some bloating occurred before melting, and the highest burned sample was red-brown (table 6).

### Sewer Pipes

The sewer pipe clay, like those for the red-facing bricks, was obtained from Pennsylvanian clays and shales and was therefore similar mineralogically (table 2). However, it contained a higher quartz content, and this is reflected in the larger sand and lower silt and clay fractions in the particle size analyses (table 2).

Figure 1 and table 6 show that in its firing behavior the clay also resembles that of the red-facing bricks. When fired to 800° C (1472° F), the test bars expanded a little, but the expansion was followed first by a slight and then a rapid shrinkage as the temperature was raised to 1150° C (2102° F). Bloating occurred at 1200° C (2192° F), and the clay melted at 1250° C (2282° F). Up to 900° C (1652° F), the test bar was buff colored and soft; from 1000° to 1050° C (1832° to 1922° F), it was salmon to light red and hard; from 1100° to 1200° C (2012° to 2192° F) it was red to chocolate brown, hard, and dense; and at 1200° C (2192° F) it was dark gray-brown and bloated.

### Firebricks

As the buff-burning clays of the Spoon Formation of the Pennsylvanian System, which are similar to the clays occurring below the coals, are used for making both building bricks and firebricks, it is understandable that the two clays sampled to represent the firebricks should resemble the building bricks in both their mineralogy and firing behavior (tables 2, 6; fig. 1). The samples of the firebrick clay examined had high contents of both kaolinite and quartz, a lower content of illite, and little pyrites. The mechanical analysis (table 2) shows that the sample illustrated was more sandy than the building brick clays, with corresponding lower contents of silt and clay.

Reference to figure 1 and table 6 shows the similarity in the firing behavior of the firebrick and buff-facing brick clays. The fireclays showed a gradual shrinkage over the firing range to a minimum volume at 1250° C (2282° F) and then a slight expansion at 1300° C (2372° F). The test bars were medium hard with pink or buff colors below 950° C (1742° F), but above this temperature they became creamier and hardened appreciably. Above 1200° C (2192° F) they were stone gray and vitrified.

### Stoneware

The clay used for making stoneware is also from the Spoon Formation of the Pennsylvanian sediments and in its mineralogy and firing behavior resembles both the buff-burning facing brick and firebrick clays. As shown in figure 2 and table 6, the clay shrank gradually on heating to 1250° C (2282° F) and bloated slightly at 1300° C (2372° F). The test bars below 950° C (1742° F) were soft to medium hard and pale pink, between 950° and 1150° C (1742° and 2102° F) were hard and off-white to cream, and between 1200° and 1300° C (2192° and 2372° F) were dense, hard, vitrified, and stone gray.

### Whiteware

The raw materials for the chinaware, sanitaryware, and art pottery are compounded mixtures of purer clays, silica, and fluxes. For the chinaware, they are



kaolin, ball clays, silica sand, feldspar, nepheline syenite, and ground limestone. The chemical and mineralogical compositions for the three mixtures of the sanitaryware and art pottery raw materials are shown in tables 1 and 2, respectively. The clays are ground to fine size before molding; the particle size analyses of the sanitaryware and art pottery are given in table 2.

Each body behaved differently during firing, as may be seen in figure 2 and table 6. The sanitaryware test bars were slightly expanded at 800° C (1472° F); they shrank only slightly on heating to 1050° C (1922° F), but rapidly above this temperature, and they melted between 1250° and 1300° C (2282° and 2372° F). The bars were soft at 850° C (1562° F) but hardened at 950° C (1742° F) and were dense and vitrified at 1150° C (2102° F). The test bars of the china mix also showed a small expansion between 800° and 900° C (1472° and 1652° F); they shrank only slightly on heating to 1000° C (1832° F) and then markedly, although not as rapidly as the sanitaryware, on heating further to 1300° C (2372° F). They remained fairly soft up to 950° C (1742° F), were hard, dense, and vitrified at 1100° C (2012° F), and very dense between 1200° and 1300° C (2192° and 2372° F). The test bars of the art pottery mix, after shrinking slightly at 850° C (1562° F), showed little change to 1150° C (2102° F) but then shrank rapidly and were molten at 1250° C (2282° F).

The test bars of the three mixes were white throughout the whole firing range, although the art pottery bars had a creamy tinge between 1000° and 1100° C (1832° and 2012° F). All samples had a porcelainlike appearance at the higher temperatures.

#### Anna Kaolin

The kaolin from Anna, in southern Illinois, is a Cretaceous clay that contains about 15 percent quartz and 5 percent montmorillonite (table 2). It is extremely fine grained, containing nearly 90 percent of the clay fraction (table 2). The extremely fine grain and small amount of montmorillonite renders the clay very plastic. It molds readily and has a drying shrinkage of more than 6 percent.

On firing (fig. 2 and table 5), the test bars shrank only slightly at 800° and 850° C (1472° and 1562° F). Between 850° and 1050° C (1562° and 1922° F) they shrank at a medium rate, and then very rapidly to 1200° C (2192° F) with 13 percent total shrinkage. They expanded slightly on further heating to 1300° C (2372° F). They remained soft with a pale pink color up to 950° C (1742° F), became light cream and hard between 950° and 1100° C (1742° and 2012° F), off-white and dense to 1250° C (2282° F), and pale gray and vitreous at 1300° C (2372° F).

#### Fithian Illite

The sample of illitic shale from below a coal seam of the Bond Formation, in the Pennsylvanian sediments at Fithian, in eastern Illinois, contains about 45 percent illite, 40 percent quartz, and small amounts of feldspar, iron minerals, and gypsum. It contains no kaolinite (table 2). The sample is medium fine grained with 51 percent silt and 31 percent clay (table 2).

On firing, the test bars shrank very rapidly between 800° and 1000° C (1472° and 1832° F), but on further heating, they bloated considerably, and at 1100° C (2012° F) they were larger than at 800° C (1472° F). They melted between 1100° and 1150° C (2012° and 2102° F). The bars were soft and light brown to salmon-



red from 800° to 850° C (1472° to 1562° F) but hardened and changed color to orange over the next 100° C (180° F). The bloated bars were red-brown.

## DIMENSIONAL CHANGES

### Bricks

Dimensional changes have been measured on 108 building bricks and 12 firebricks from Illinois, while standing for four years in the laboratory. The results are summarized, along with those for several varieties of Australian brick, which have been under investigation for up to 10 years, in table 3 and figures 3 and 4.

The expansions of the Illinois bricks were small compared with those of the majority in Australia. In both their rates and amounts of expansion, the Illinois bricks (average maximum expansion 0.035 percent) were similar to the red bricks from Adelaide, South Australia (average maximum expansion 0.030 percent), a group with the second lowest movement of the varieties so far studied in Australia (fig. 4).

The general behavior pattern of the Illinois bricks was similar to that of the Australian varieties; they showed an early, relatively rapid expansion, a slower one after some months, and then a fairly steady state. Four years were evident-

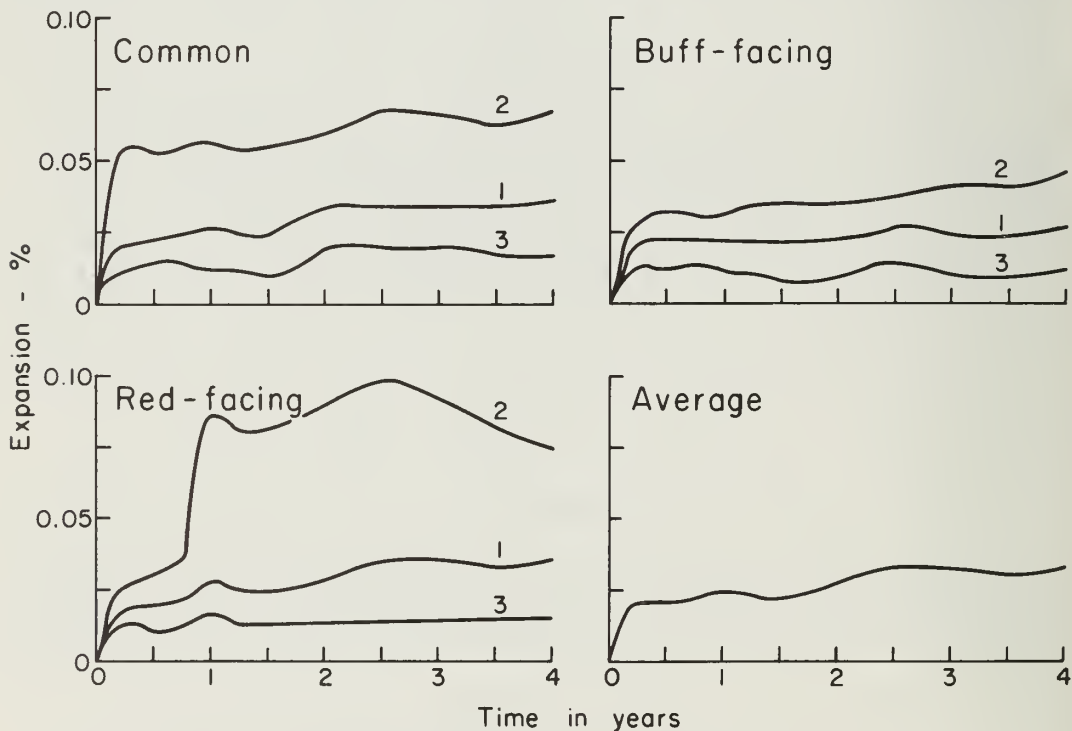


Figure 3 - Mean (1), maximum (2), and minimum (3) permanent expansion curves for the Illinois common, red-facing, and buff-facing bricks standing in the laboratory for 4 years and averages for all of the bricks.

ly too short for any contraction tendency to be noted, as now apparent for many Australian bricks (Hosking, Hueber, and Holland, in press), although a few bricks did show signs of shrinking and the average expansion of each of the three groups of bricks at the last measurement was actually slightly less than it had been earlier. Differences were noted in the rates and amounts of expansion of the bricks of each variety as well as among those from a single works, but on the whole, little difference was seen in the general behavior of the three varieties of building brick and the firebricks. The expansions of the buff-facing bricks were slightly lower on the average than those of the red-facing and common bricks, and the range between the highest and lowest expansions of the former was narrower than for the others.

Results for Australian bricks and other clay products show that although all industrial products expand on exposure to the atmosphere after leaving the kiln, and although this expansion may continue for years, expansions are by no means permanent, as was previously thought to be the case. Expansions may be followed by contractions as great as or greater than the earlier expansions (Hosking, Hueber, and Holland, in press). Figure 4 shows that the bricks expanded rapidly at first, though with considerable differences in rates and amounts of expansion for different varieties. Expansion was slower after three to six months, and beyond 12 months, marked differences in behavior of the varieties became ap-

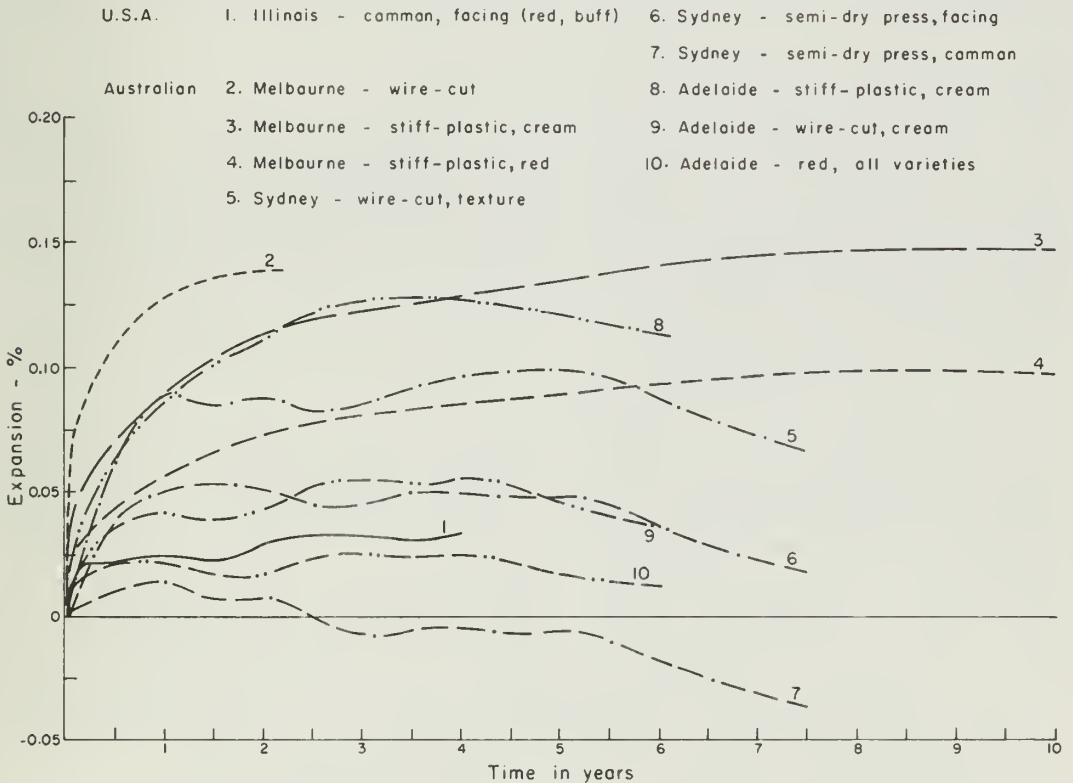


Figure 4 - Mean long-term dimensional change curves for the Illinois bricks and the varieties of bricks examined in Australia, after standing in air for up to 10 years.

parent. Some bricks continued to expand; others remained the same for several years. Others started to contract at an early age.

Of the Australian bricks, the stiff-plastic ones from Melbourne, which have been under investigation for 10 years, expanded continuously for eight years, and only recently have the cream bricks remained steady and the red variety shown signs of contracting. By contrast, the Sydney semi-dry press commons expanded only slightly before they started to contract after a few months exposure, and they have been shrinking steadily for years. Until about three years ago, the contraction of these bricks was considered exceptional, but at about that time, most other Sydney bricks, the Adelaide bricks, and the firebricks, which after expanding for a year or so had remained fairly steady for the next three or four years, also started to shrink and have been shrinking ever since. In all, about 50 percent of the Sydney and Adelaide bricks are now smaller; on the average, the Sydney bricks after expanding returned to their original lengths in seven years.

Table 3 and figure 4 show that of the Australian bricks, the cream stiff-plastic ones from Melbourne have expanded most, with an average maximum expansion of 0.15 percent in nine years, though the Sydney commons expanded least, with an average maximum expansion of only one tenth of this at about 12 months. The other bricks had maximum expansions lying between these extremes, but there was a wide spread in the expansions of the varieties from any one state.

#### Laboratory Specimens

The dimensional changes that have occurred over four years in the test bars made from the Illinois and several Australian clays are summarized in figures 5 to 13. From these it is clear that the general behavior patterns of the clays from the two countries are similar, whether the dimensional changes are considered in relation to time or to temperature of firing. Although peak and near-peak expansions for the Illinois test bars are, on the whole, lower than those for the Australian specimens, the magnitudes of these expansions are of the same order, and thus do not reflect the marked differences in the expansions of the industrial bricks. It will be shown below that the lower expansions of the Illinois facing bricks are, in fact, related to their higher temperatures of firing.

Several conclusions regarding the influence of such factors as time of exposure, temperature of firing, and raw materials or body composition on expansion, which have been drawn from the study of Australian clays (Hosking et al., 1959; Hosking and Hueber, 1960a, 1962; Cole, 1962), are confirmed. Other conclusions regarding the more specific roles of kaolinite, illite, and fluxing components are presented.

#### Time of Exposure

In figures 5, 6, and 7 the movements of the test bars are plotted against time for eight Illinois and six Australian clays. The clays selected illustrate the range in expansions between maximum and minimum values for various clays and in the temperatures of firing at which the maximum expansions occur.

On the whole, the behavior of the test bars was similar to that of the bricks, except that expansions were much higher for specimens burned at intermediate temperatures, and for some clays, the specimens burned at the highest and lowest temperatures contracted rather than expanded at the start. After four years, some of the

test bars were still expanding appreciably, while others, particularly those burned at the extreme temperatures, have shown little movement for some time. None of the bars has yet shown any marked tendency to contract after expanding. Some of the bars that shrank to begin with have since expanded; others have remained contracted, although there has been little movement in the last few years.

The movement versus time curves show that generally the differences in expansion for most of the test bars were determined by differential rate of expansion in the first few months to a year or more. Since then, the movements of the test bars for individual clays have settled down to fairly steady and similar rates so that the families of curves for each clay are roughly parallel. However, for some test bars of one clay, different rates of movement may persist for some time, as shown by the crossing of curves in figures 5, 6, and 7.

Temperature of Firing

The influence of the temperature of firing on dimensional changes, while evident in figures 5, 6, and 7, is brought out more clearly in figures 8 to 11, where movements of the test bars at 6 months and 4 years are plotted against the temperature of firing for the 21 Illinois and 9 Australian clays. From these figures, it is seen that at low temperatures, dimensional changes were usually small and the test bars either expanded or shrank at the beginning. As the firing temperature was

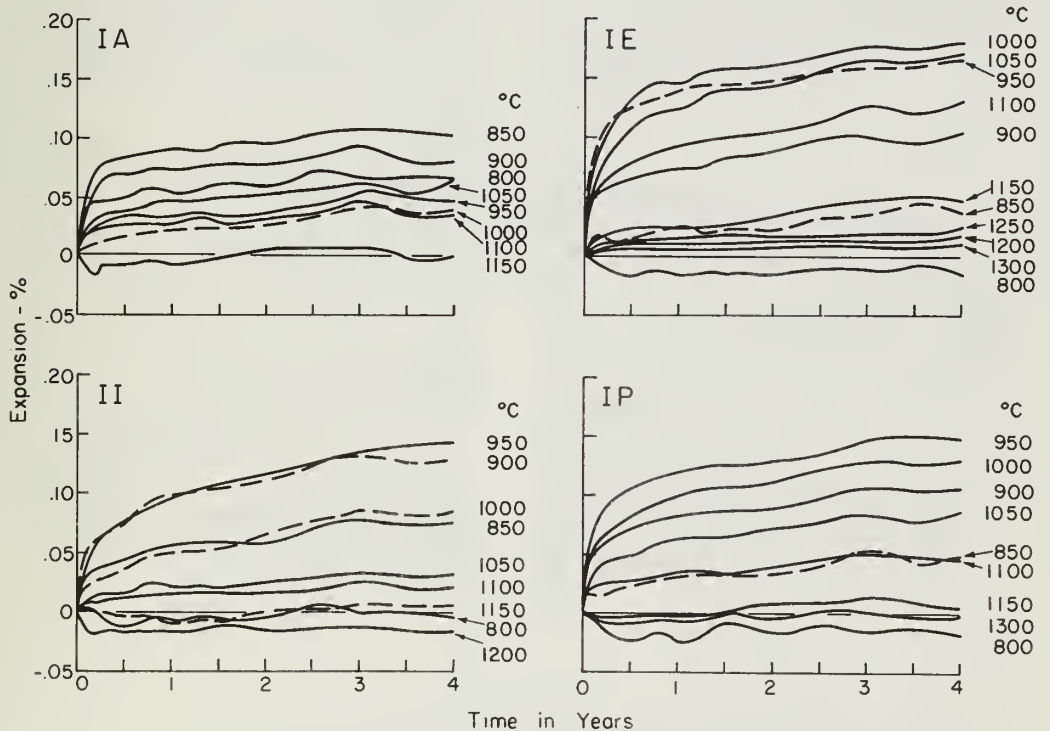


Figure 5 - Long-term dimensional change curves according to temperature of firing for laboratory specimens of four Illinois brick clays: common (IA), red-facing (II), buff-facing (IE), and firebrick (IP).

raised, the test bars all expanded and the expansion increased to a maximum and then decreased, until at the highest temperatures of firing, as at the lowest, only low expansions or even shrinkages were again evident.

In figure 12, maximum expansions attained at four years by the test bars are plotted against the temperatures of firing at which they occurred, for each Illinois and 15 Australian clays. The firing temperatures corresponding to maximum expansion cover a wide range, from 800° to 1100° C (1472° to 2012° F), although they lie mostly in the narrower range, between 900° and 1050° C (1652° and 1922° F). The three Illinois clays, with their firing temperatures of maximum expansion outside the latter range, are the art pottery clay at 800° C (1472° F), a common brick clay at 850° C (1562° F), and the sanitaryware clay at 1100° C (2012° F). The art pottery clay, which had its maximum expansion in the sample burned at the lowest temperature of firing, showed a second but smaller peak expansion in the sample burned at 950° C (1742° F).

Raw Materials and Body Composition

Although the patterns of dimensional changes of the clays of figures 5 to 11 are broadly similar, they differ in important detail, which must result from differ-

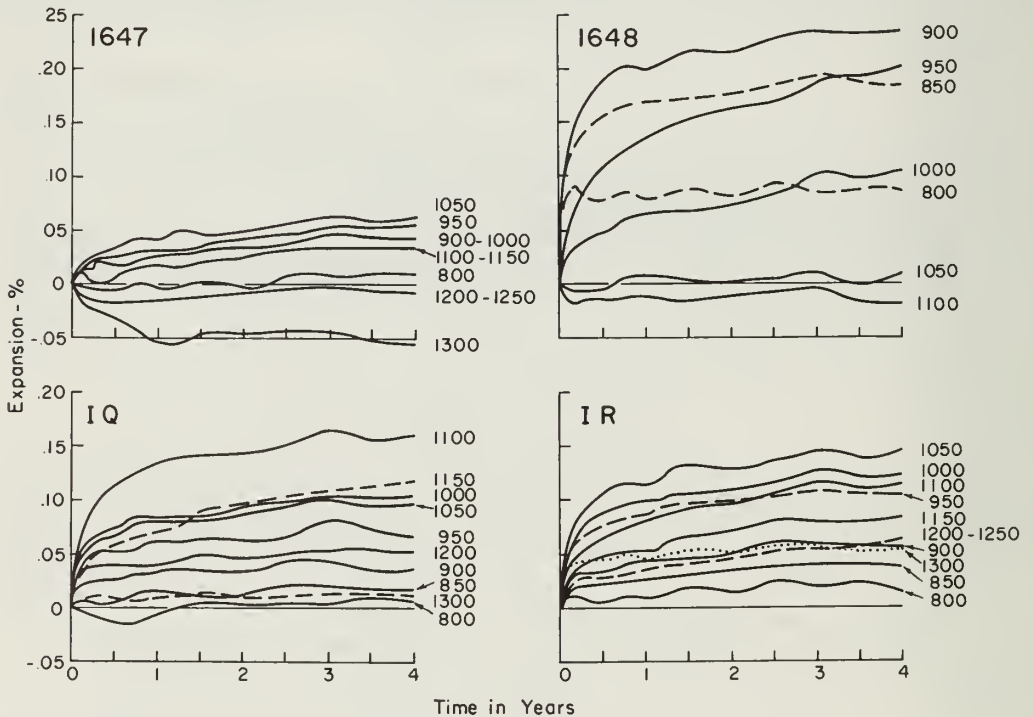


Figure 6 - Long-term dimensional change curves according to temperature of firing for laboratory specimens of four Illinois clays: Anna kaolin (1647), Fithian illite (1648), sanitaryware (IQ), and chinaware (IR).



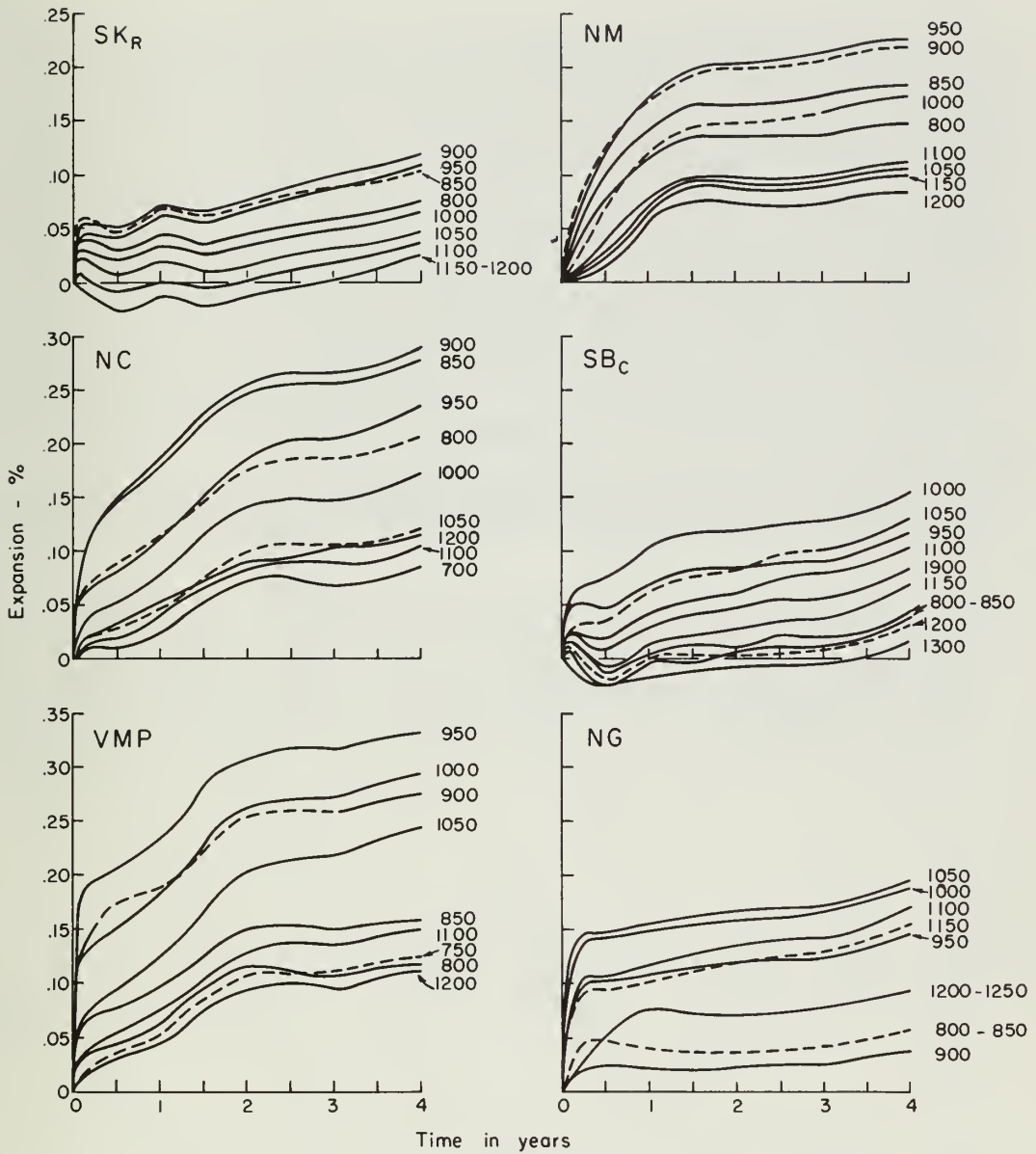


Figure 7 - Long-term dimensional change curves according to temperature of firing for laboratory specimens of six Australian brick clays: Adelaide wire-cut red (SK<sub>R</sub>), Sydney wire-cut texture (NC), Melbourne stiff-plastic cream (VMP), Sydney semi-dry press (NM), Sydney semi-dry press *Adelaide wire-cut cream (SB<sub>c</sub>)*, and Sydney semi-dry press facing (NG).  
*Common (SB<sub>c</sub>)*

ences in composition, as has already been shown for Australian clays (Hosking et al., 1959; Hosking and Hueber, 1960a, 1962; Cole, 1962; Cole and Segnit, 1963). All the clays were natural mixtures of kaolinite, mica or illite, and quartz, with smaller amounts of other clay minerals, iron oxides, feldspars, and carbonates, except for the whiteware mixes, the raw materials for which were artificial mixtures of kaolinite, silica, <sup>and</sup> feldspar, or nepheline syenite, with minor contents of other components. The proportions of the constituents varied widely in the clays, those with the higher contents of illite, feldspars, iron oxides, and lime being the less refractory. Apart from the Anna kaolin and the Fithian illite, the natural Illinois clays fall mineralogically into three groups (tables 1 and 2): (1) light-colored, refractory Pennsylvanian clays and shales used for buff-facing bricks, firebricks, and stoneware; (2) red-burning, mixed Pennsylvanian clays and shales, rich in illite and kaolinite, with fluxes such as feldspar, siderite, and iron oxides, used for red-facing bricks and pipes; and (3) Pleistocene tills and surface clays, rich in illite and carbonates but low in kaolinite, used for red commons and building and drain tiles.

Several mechanisms have been suggested for the expansion of clay bodies. The phenomenon has been attributed to the hydration of noncrystalline components

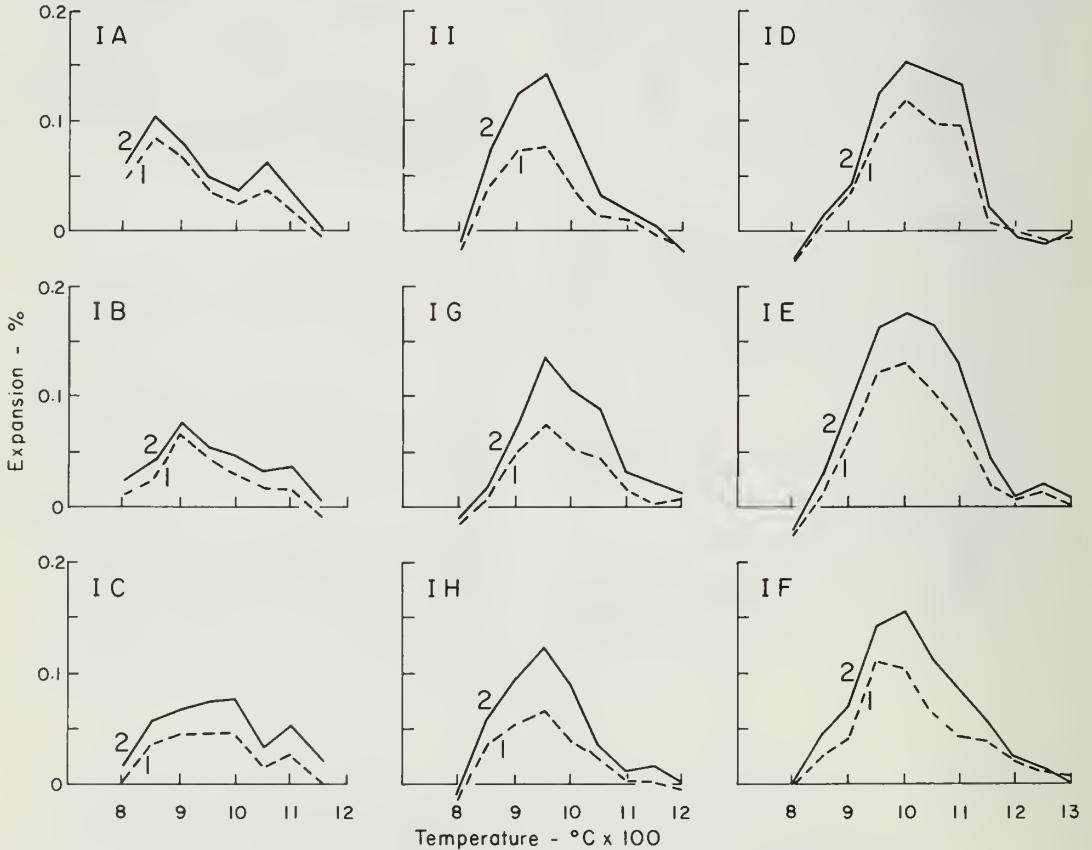


Figure 8 - Curves of long-term dimensional change in air versus temperature of firing for laboratory specimens of nine Illinois brick clays exposed for 6 months (1) and 4 years (2): common (IA, IB, IC), red-facing (II, IG, IH), and buff-facing (ID, IE, IF).

(Hill, 1953; Hueber and Milne, 1955; Dal, Zueleger, and Berden, 1956; Hosking and Hueber, 1958; Hosking et al., 1959; Demediuk and Cole, 1960; Cole, 1962), to physical adsorption of water (Norris et al., 1958), or to a combination of physically and chemically sorbed water (Smith, 1955; Young and Brownell, 1959). Hosking and Hueber (1961, 1962) have suggested that stress release in and between components of the bodies, and atomic rearrangements in these components, could also contribute. Specifically, expansion has been related to the formation of amorphous aluminosilicates, amorphous silica,  $\gamma$ -alumina, and glass (Demediuk and Cole, 1960; Cole, 1962), as well as to the presence of dehydrated clay minerals (Hill, 1953), free lime, and hydrateable salts (Hosking et al., 1959). The relative proportions of these constituents could account for the differences in rates and amounts of expansion in different bodies and at different firing temperatures (Hosking and Hueber, 1962), and the maximum development of nonvitrified amorphous material at a particular temperature could be responsible for peak expansion at that firing temperature (Cole, 1962).

Consideration of firing shrinkages and water absorption of the Illinois clays now leads to some further general conclusions on the relationships between expansion and vitrification, and the behavior of the Anna kaolin, Fithian illite, and related clays gives evidence as to the influence of particular constituents of the clays on expansion.

Expansion and Physical Properties.—Curves for firing shrinkage and water absorption are closely parallel for each clay (figs. 1, 2; Hosking and Hueber, 1960a, fig. 5). From the curves, it is seen that low-fired bodies have a low shrinkage and high water absorption, indicating a porous, low density body in which there has been little reaction between the constituents. With increasing temperature, there was little change to begin with, but then a sharp increase in shrinkage and

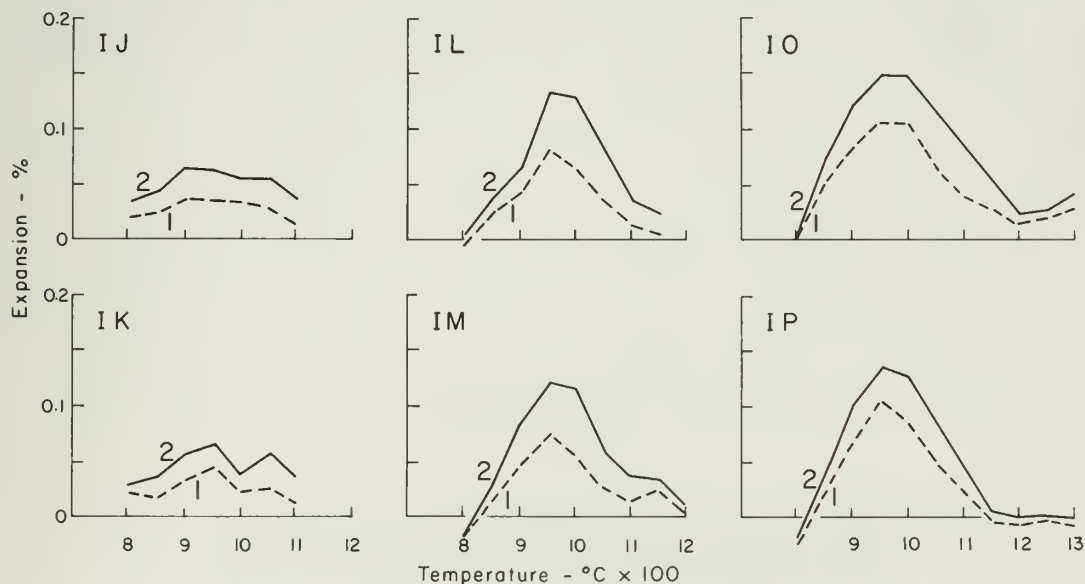


Figure 9 - Curves of long-term dimensional change in air versus temperature of firing for laboratory specimens of six Illinois clays exposed for 6 months (1) and 4 years (2): building tile (IJ, IK, IL), sewer pipe (IM), and firebrick (IO, IP).

decrease in water absorption indicated the start of vitrification and the beginnings of crystallization of new phases. Finally, a high shrinkage and low absorption indicated a dense body and reflected strong vitrification and crystallization; a subsequent expansion and increase in water absorption in some clays resulted from bloating with partial melting.

The Anna kaolin and Fithian illite differed markedly in their firing and expansion behaviors (figs. 2, 6). The illite had a marked maximum expansion of 0.23 percent at 900° C (1652° F). The kaolinite, on the other hand, had its maximum expansion at about 1050° C (1922° F) and was only a fraction of that observed for the illitic clay. For both clays, expansion fell when shrinkage and water absorption indicated the beginnings of vitrification.

The firing temperatures of maximum expansion and the average maximum expansion of the bodies from the buff-burning Pennsylvanian clays, the red-burning mixed Pennsylvanian clays, and the Pleistocene tills were 950° to 1000° C (1742° to 1832° F) and 0.16 percent, 950° C (1742° F) and 0.14 percent, and 850° to 900° C (1562° to 1652° F) and 0.07 percent, respectively. In all cases, peak expansions were associated with the temperature at which vitrification began, and hence, at which there was maximum development of amorphous aluminosilicates. The parallelism of the curves in figure 10 indicates that the rate of decrease in expansion beyond the peak expansion followed the rate of vitrification. With rapid

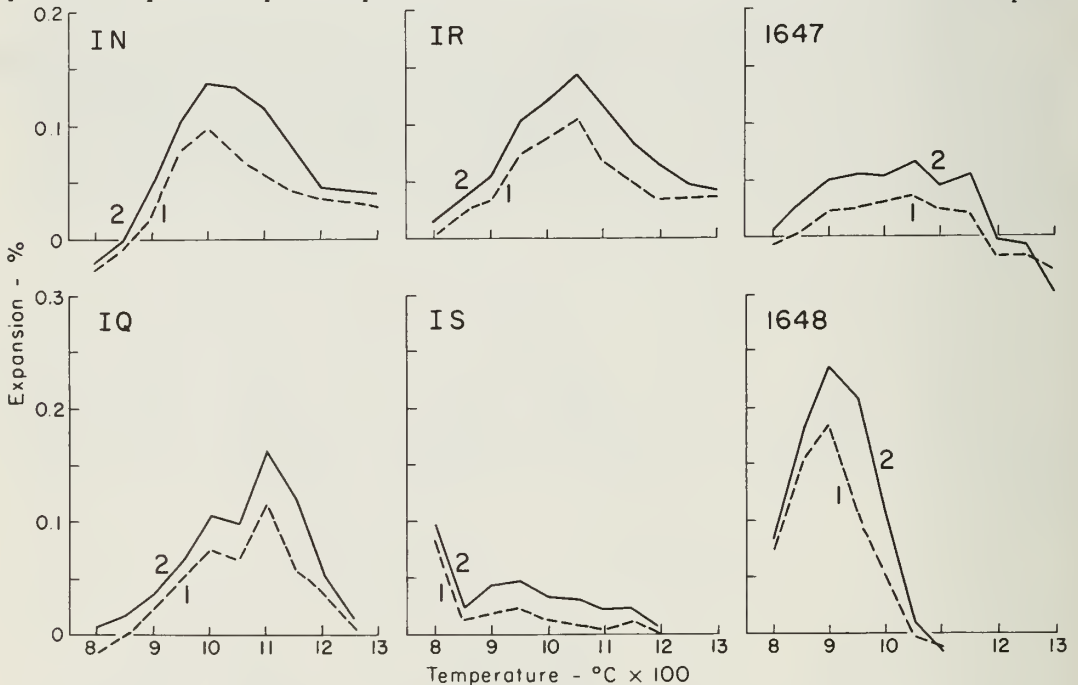


Figure 10 - Curves of long-term dimensional change in air versus temperature of firing for laboratory specimens of six Illinois clays exposed for 6 months (1) and 4 years (2): stoneware (IN), sanitaryware (IQ), chinaware (IR), art pottery (IS), Anna kaolin (1647), and Fithian illite (1648).

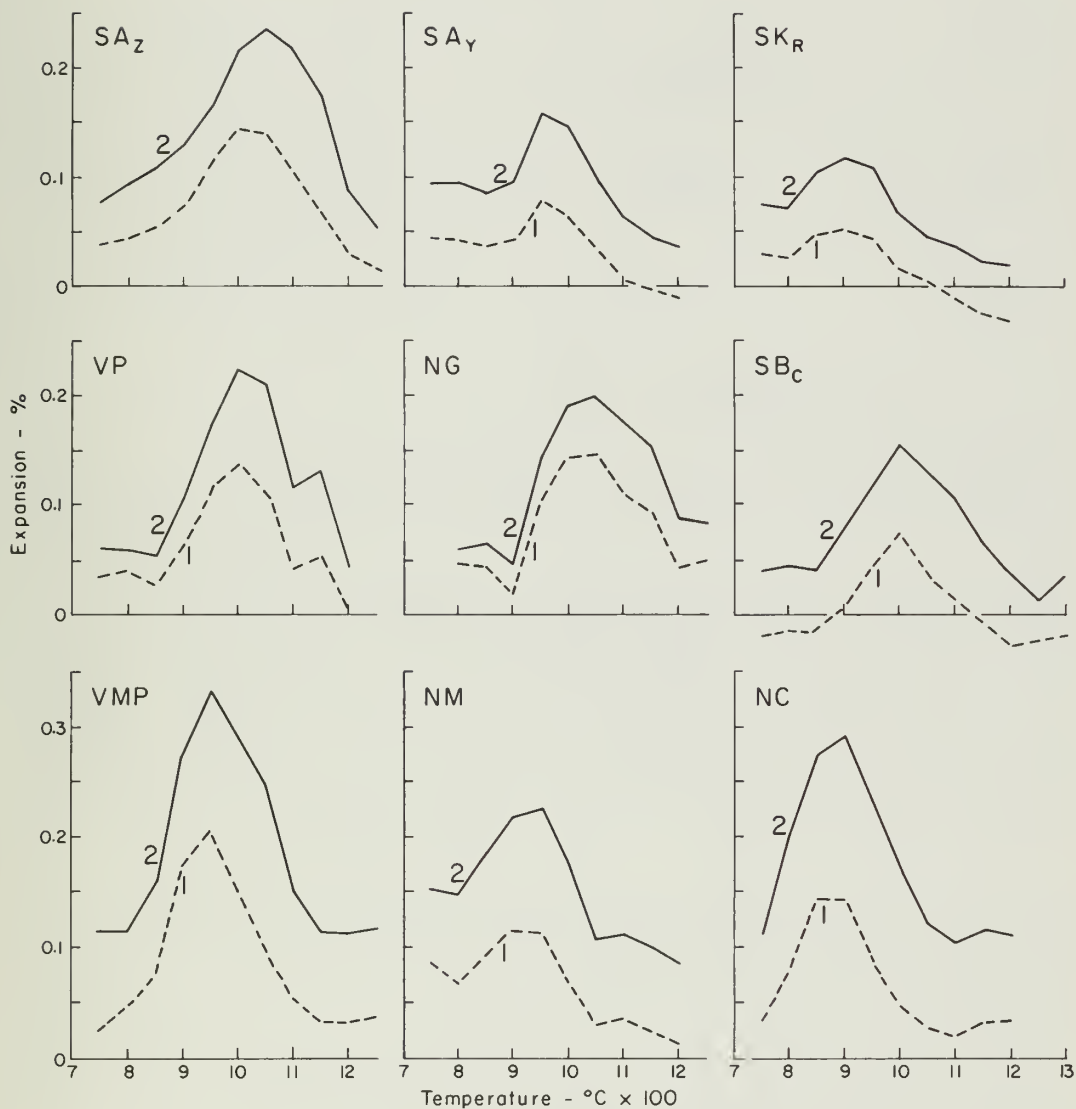


Figure 11 - Curves of long-term dimensional change in air versus temperature of firing for laboratory specimens of nine Australian brick clays exposed for 6 months (1) and 4 years (2): stiff-plastic (SA<sub>Z</sub>, VP, VMP), semi-dry press (SA<sub>Y</sub>, NG, NM), and wire-cut (SK<sub>R</sub>, SB<sub>C</sub>, NC).



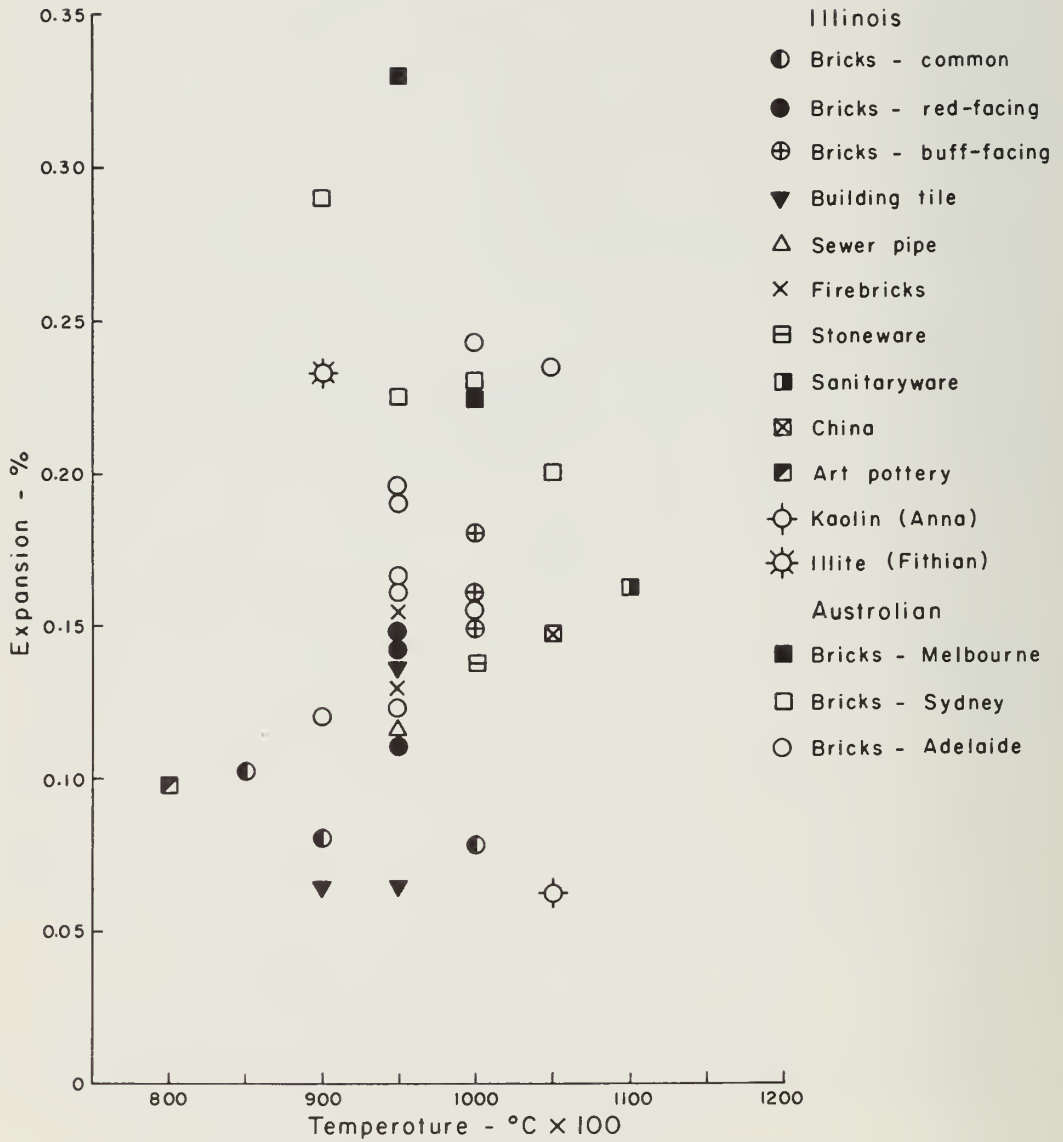
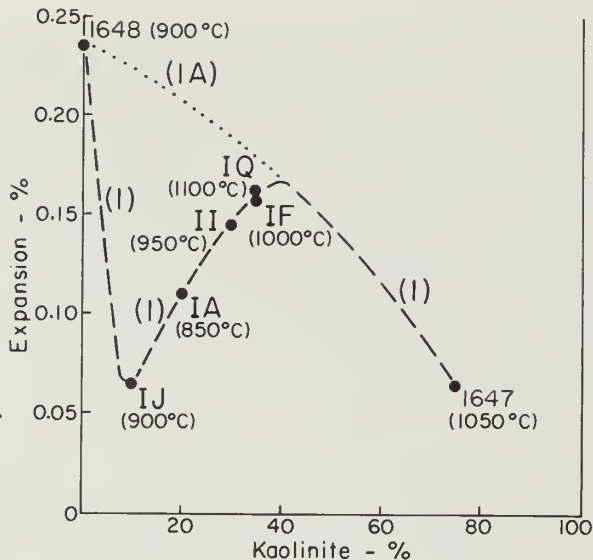


Figure 12 - Maximum expansion after four years exposure in air, plotted against the temperature of firing at which it occurs, for the laboratory specimens of the 21 Illinois clays and 15 Australian brick clays examined.

Figure 13 - Relationship between the maximum expansion of the fired specimens of seven Illinois clays after four years exposure in air and the kaolinite content of the raw clays: Anna kaolin (1647), Fithian illite (1648), common (IA), buff-facing (IF), red-facing (II), building tile (IJ), and sanitaryware (IQ). The temperature at which maximum expansion occurs for each clay is shown in parentheses.



vitrification, decrease in expansion was rapid, with a consequent narrow expansion peak (fig. 1, red-facing bricks; fig. 2, Fithian illite); where initial vitrification was slow, a broader expansion peak resulted (fig. 1, buff-facing bricks; fig. 2, stoneware).

Of the compounded clays, the expansion behavior of the chinaware and sanitaryware varieties conformed to those of the natural clays, but that of the art pottery clay was different. The small changes in the physical state of the chinaware and sanitaryware test bars between 800° and 1100° C (1472° and 2012° F) are reflected in the more gradual rise in the expansion to the maxima at the high temperatures of 1050° and 1100° C (1922° and 2012° F), respectively. Unlike these, the art pottery test bars showed their maximum expansion at 800° C (1472° F) with a second weak peak at 950° C (1742° F). This behavior could be due to the presence of the talc, which is also added to wall tile bodies to reduce long-term expansion (Lintz, 1938; Sproat, 1936).

Expansion and Mineralogy.—Any attempt to relate expansion data to the mineralogy of the clays at this stage indicates that more detailed studies are needed before the influence of specific constituents on the long-term expansion of fired bodies can be clearly defined. More detailed data will be available in a later paper. Nevertheless, certain trends appear from this work regarding the influence of kaolinite, illite, and other minerals, which act as fluxes. In ceramic bodies there are three main groups of components—free silica (usually quartz or flint), clay minerals, and fluxes. The free silica is more or less inert and provides the skeleton of the body. The clay minerals give rise to the nonvitrified, amorphous aluminosilicates on firing, and peak expansion generally can be attributed to maximum development of these materials. Fluxes, such as feldspar and carbonate, appear to modify these effects.

The maximum expansion of the test bars from the Fithian illite was the highest of the clays examined and that of the test bars from the Anna kaolin the lowest. Test bars from mixtures of illite and kaolinite therefore could be expected to have intermediate expansions related to the contents of the two minerals. However, for test bars from industrial clays containing both kaolinite and illite this is not nec-

essarily true. In figure 13, expansion versus kaolinite content is plotted for the illite, the kaolin, and five industrial clays for which mineralogical data are available. For the industrial clays, the maximum expansion increases with the kaolinite content, indicating that more complex relationships than those involving kaolinite and illite alone exist for the group of clays concerned. It is therefore evident that other constituents are playing an important part in the expansion behavior of fired clays. Of the clays represented in figure 13, only IF can be considered to be essentially an illite-kaolinite clay, and it is perhaps significant that it has an intermediate expansion that lies close to the line joining the expansions of illite and kaolinite. The expansion of the sanitaryware body IQ also lies close to this line, despite the low amount of illite. The high feldspar content in this case may affect the nature of the breakdown products of the kaolin and thus influence the expansion.

The effect of the other fluxes is seen in the results for the remaining three clays, all of which have a high carbonate content (siderite in II and dolomite in IA and IJ). The apparent result of decreasing kaolinite in the mixed clays is a reduction in expansion. However, at the same time, the flux content (carbonates, together with the illite) is increased markedly. This results in earlier vitrification with the formation of a more rigid body, and evidently inhibits the formation of non-vitrified, amorphous aluminosilicates and other phases that strongly adsorb water and expand in the process.

In summary, it is clear that all the components of the clays play some role in determining the amount of the expansion of fired bodies on exposure. For the Illinois clays that are essentially mixtures of kaolinite, illite, and quartz, the maximum expansions of the fired bodies might be expected to conform approximately to the curve ABC of figure 14. In general, therefore, the portion of the curve AB may represent the expansion behavior of light- or buff-burning clays in which the kaolinite content ranges down to about 35 or 40 percent. However, as the kaolinite content decreases further in the other Illinois clays, the flux content increases and apparently has a greater influence in decreasing expansion than the increasing illite content has in increasing it. Beyond the point B (fig. 14), clays with an increasing content of fluxes other than illite could thus conform approximately to the curve BD, and the composite curve ABD could express the overall relationship between expansion and kaolinite for the Illinois industrial clays under examination.

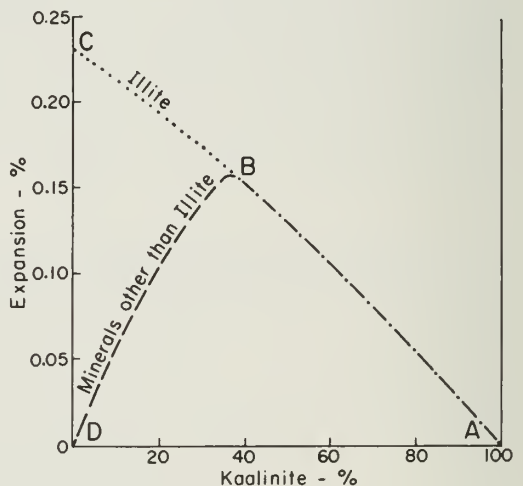


Figure 14 - Theoretical curves showing the relationships between maximum expansion of the fired specimens of figure 13 after four years exposure in air and the kaolinite content of Illinois industrial clays.

## CONCLUSIONS

From the present study it is clear that Illinois ceramic bodies, when

exposed to the atmosphere, exhibit the same patterns of expansion behavior as their Australian counterparts. All continue to expand for years. The maximum expansions of the bodies, and the firing temperature at which they occur, vary markedly from one clay to another, and these variations are undoubtedly related to the mineral or chemical compositions of the bodies and in turn to those of their raw materials.

For clays that are essentially mixtures of kaolinite, illite, and quartz, and little else, the magnitudes of maximum expansion appear to be related to the relative amounts of kaolinite and illite in them. Highly kaolinitic clays have low expansions. Expansions increase with decreasing kaolinite and reach the highest values when illite is probably the sole clay mineral. For industrial clays, however, this relationship appears to hold only for kaolinite contents down to about 35 or 40 percent. Below these percentages, fluxes other than illite increase in amounts, and they play such a role that the trend toward increasing expansion with decreasing kaolinite is reversed. As these fluxes increase, expansions decrease to very low values.

The Illinois bricks all expanded after leaving the kilns, but the long-term expansions for all three groups, common and red- and buff-facing, were uniformly low compared with the bricks in Melbourne, Australia. At four years, like most Australian bricks at the same period of exposure, none of the Illinois specimens has yet reached a stage where marked contractions following expansion are apparent, although many of them have remained steady for some time.

The low expansions of the Illinois bricks can be explained two ways: first, the firing temperature is high, and second, the mineralogical composition of the clay is such that the fired body has low expansion. For both Australian and Illinois bricks, industrial firing temperatures are above those that are responsible for maximum expansions for the various clays and, hence, with few exceptions, the expansions of the bricks decrease with increasing firing temperatures. In Australia, firing temperatures are usually 950° to 1050° C (1742° to 1932° F), and these are, unfortunately, only slightly above those at which maximum expansions occur. This accounts in part for the relatively high expansion of many Australian bricks. In Illinois, facing bricks are fired to higher temperatures than those in Australia—the buff bricks in particular—to between 1100° and 1200° C (2012° and 2192° F). This is the major reason for the low expansion of these two varieties. The Illinois common bricks, which are made from clays containing appreciable amounts of calcium and magnesium carbonates, are fired at about the same temperatures as the Australian bricks. However, test pieces, when fired at temperatures that result in maximum expansion, show a much lower percentage expansion than do Australian bricks and Illinois facing bricks. This low expansion is probably attributable to the presence in abundance of calcium and magnesium carbonates.

Examination of many brick buildings throughout Illinois shows that damage due to expansion is much less apparent than in some cities in Australia, and this low incidence can be explained as due to the higher firing temperature of the facing bricks. Bearing in mind that brick walls may be expected to expand about 40 percent more than the bricks they contain (Hosking et al., 1959; Hosking and Hueber, 1962; Hosking, Hueber, and Holland, in press), brick walls in Illinois may be expected to move about 0.5 to 0.7 inches per 100 feet compared with 0.5 to 2.8 inches per 100 feet for Australian bricks. Other factors that reduce the liability to damage in brick walls in the United States are the common practices of allowing  $\frac{1}{4}$ -inch movement joints to every 10 feet of brickwork; the use of lime-rich mortars, which take up expansion through compression, rather than straight, more rigid cement



mortars; and the long distance haulages of many bricks, which allows time for some expansion to take place before use.

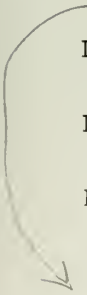
Unfortunately, not all bricks or building tiles in the United States have the low expansions of the Illinois bricks tested, for reports of damage by McBurney (1954, and private communications) and others and personal observations in Pennsylvania, Texas, Indiana, and even in Illinois indicate that the expansions of many bricks in the United States may be much higher than those examined. However, to reduce the chances of damage, the following five precautions should be taken: (1) use well burned bricks or tiles only; (2) allow all bricks or tiles to stand as long as possible before use; (3) use lime-rich mortars only, instead of strong cement mortars; (4) include enough effective movement joints at suitable intervals in brickwork, ceramic veneer, and tiling to take up all expansion; and (5) design all structures in which ceramic products are used so that the effects of expansion of these products and the effects of differential movement between them and other building material, particularly concrete, are minimized.

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APPENDIX



TABLE I - CHEMICAL ANALYSES OF CLAY SAMPLES (IN PERCENT)

Product	Sample identi- ficator	SiO <sub>2</sub>	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	Loss on ignition	Total	H <sub>2</sub> O+	H <sub>2</sub> O-	CO <sub>2</sub>	SO <sub>2</sub>	Organic carbon
Bricks, common	IA	52.36	0.56	12.50	2.50	2.30	4.91	7.48	0.71	3.20	12.81	99.33	3.92	0.75	8.40	1.00	1.80
	IB	49.58	0.58	12.65	1.69	2.50	5.45	8.76	0.72	3.32	13.91	99.16	3.68	0.48	10.35	1.70	1.29
	IC	49.77	0.56	11.90	1.65	2.24	5.67	9.23	0.70	3.01	14.89	99.62	3.45	0.34	11.61	1.46	1.16
Bricks, red-facing	IG*	55.26	—	21.57	4.74	4.60	2.29	0.53	1.21	3.43	6.37	100.00	—	0.63	—	—	—
	IH*	49.00	—	24.67	5.44	5.79	2.36	0.49	0.74	3.50	8.16	100.15	—	0.79	—	—	—
	II*	53.40	—	22.89	1.22	6.29	2.04	0.64	0.86	3.52	8.91	99.78	6.17	0.85	—	—	—
Bricks, buff-facing	ID	59.34	1.33	25.44	2.00	0.48	0.69	0.37	0.14	1.21	9.13	100.13	8.66	1.11	0.00	2.80	0.19
	IE	62.05	1.29	22.29	0.94	1.54	0.74	0.35	0.18	2.09	8.55	100.02	7.43	0.59	0.51	0.87	0.94
	IF	64.46	1.18	21.40	1.01	1.45	0.70	0.30	0.26	1.57	7.69	100.02	7.03	0.40	0.34	1.30	0.39
Building and drain tiles	IJ	56.46	0.62	12.30	3.09	1.45	4.10	6.57	0.75	3.11	11.75	100.20	4.00	0.89	7.36	0.20	0.93
	IK	57.47	0.62	12.02	3.16	1.31	3.80	6.42	0.74	3.12	11.36	99.98	3.92	0.70	7.11	0.08	0.83
	IL*	55.78	—	20.28	4.72	5.32	2.03	0.50	1.17	2.81	7.30	99.91	—	—	—	—	0.46
Sewer pipes	IM	60.32	1.01	18.32	1.11	5.41	2.04	0.85	1.16	3.17	6.71	100.10	4.75	0.06	2.46	0.24	0.25
Firebricks	IO	66.18	1.35	22.00	1.25	0.58	0.59	0.22	0.17	1.85	5.98	100.17	5.50	0.23	0.00	1.16	0.33
	IP	55.90	1.35	29.55	1.19	0.54	0.69	0.52	0.13	1.59	9.22	100.68	8.64	1.45	0.00	0.62	0.30
Stoneware	IN	65.46	1.43	21.87	0.62	0.63	0.64	0.23	0.23	2.29	6.78	100.18	6.28	0.81	0.20	0.17	0.36
Chinaware	IR	72.09	0.87	18.49	0.34	0.19	0.11	0.26	1.17	0.97	5.88	100.37	5.72	0.40	0.00	0.04	0.33
Sanitaryware	IQ	67.32	0.56	20.35	0.15	0.44	0.40	0.49	1.00	3.71	6.22	100.64	5.59	0.38	0.41	0.08	0.59
Art pottery	IS	47.22	0.60	20.84	0.43	—	8.78	6.90	—	2.65	11.88	99.30	—	—	—	—	—
Kaolin, Anna	1647	50.27	1.60	34.43	1.05	0.26	0.28	0.47	0.06	0.14	12.11	100.67	—	—	—	—	—
	1648	52.90	0.76	26.06	2.02	2.92	1.66	1.14	0.45	5.23	7.35	100.49	6.22	2.73	0.02	—	—

\* Analysis shown is not that of the clay under investigation but of an earlier one from the same source (White, 1959).



TABLE 2 - MINERALOGICAL AND PARTICLE SIZE ANALYSIS OF REPRESENTATIVE CLAYS

Product	Sample Identification	Mineralogy*												Particle size				
		Kaolinite	Mica-illite	Chlorite	Montmorillonite	Talc	Quartz	Feldspar	Hematite	Boehmite	Siderite	Anatase	Calcite	Dolomite	Gypsum	Clay, < 2 $\mu$	Silt, 2 to 20 $\mu$	Sand, > 20 $\mu$
Bricks, common	IA	20	25	5	-	-	25	5	5	-	-	P	5	13	-	37	38	25(a)
Bricks, red-facing	II	30	30	<5	-	-	25	5	P	-	5-10	-	-	-	42	39	19(b)	
Bricks, buff-facing	IF	35	25	-	-	-	35	Tr	-	-	-	1	-	-	50	33	17(c)	
Building and drain tiles	IJ	10	P	P	-	-	P	P	-	-	-	-	4	12	-	38	37	25(d)
Sewer pipes	IM	P	P	P	-	-	P	P	P	-	-	-	-	-	31	32	37	
Firebricks	IP	P	P	-	-	-	P	P	-	-	-	1	-	-	42	23	35	
Stoneware	IN	P	P	-	-	-	P	P	-	-	-	1	-	-	-	-	-	
Chinaware	IR	P†	-	-	-	-	P	P†	-	-	-	-	-	-	-	-	-	
Sanitaryware	IQ	35†	5-10	-	-	-	35	20	-	-	-	Tr	-	-	35	43	22	
Art pottery	IS	53†	P	-	-	32	-	12***	-	-	-	-	3	-	37	42	21	
Kaolin, Anna	1647	75	-	-	6	-	16	Tr	-	Tr	-	1	-	-	89	5	6	
Illite, Fithian	1648	Tr	45	-	-	-	40	<5	<5	-	-	1	-	-	31	51	18	

\* Percentages are only approximate and do not necessarily add up to 100% for each sample.  
 † Kaolin plus ball clays.  
 ‡ Feldspar plus nepheline syenite.  
 \*\* Nepheline syenite.  
 †† Average of samples IA, IB, and IC.  
 ‡‡ Average of samples IG, IH, and II.  
 ††† Average of samples ID, IE, and IF.  
 †††† Average of samples IJ, IK, and IL.

TABLE 3 - DIMENSIONAL CHANGES IN ILLINOIS AND AUSTRALIAN BRICKS STANDING IN AIR

Product	Country	State, city	Method of manufacture	Variety	Number examined	Expansion and contraction†									
						Maximum expansion			Movement to date†						
						Year attained	Mean (%)	Range (%)	Period of exposure (yrs.)	Mean (%)	Range (%)				
Building bricks	United States	Illinois	Wire-cut (stiff-mud)	Common	36	2 to 4	0.037	0.068 to 0.020	4	0.035	0.069 to 0.016				
				Facing, red	36	1/4 to 4	0.038	0.099 to 0.017	4	0.036	0.075 to 0.014				
				Facing, buff	36	1/3 to 4	0.029	0.046 to 0.014	4	0.027	0.046 to 0.010				
	Australia	Victoria, Melbourne	All	Wire-cut	All	108	1/4 to 4	0.035	0.099 to 0.014	4	0.033	0.075 to 0.010			
					Stiff-plastic press	Cream	27	9	0.149	0.217 to 0.071	10	0.149	0.216 to 0.070		
			Red	24		8½	0.100	0.195 to 0.036	10	0.099	0.194 to 0.036				
			All	Wire-cut	All	51	8½ to 9	0.124	0.217 to 0.037	10	0.123	0.216 to 0.036			
					Pink, red	18	—	—	—	2	0.134	0.178 to 0.087			
						Semi-dry press	Facing	38	1 to 5	0.058	0.162 to 0.010	7½	0.019	0.113 to -0.048	
			New South Wales, Sydney	Common	42		1/4 to 4	0.015	0.050 to 0.001	7½	-0.035	0.031 to -0.076			
Wire-cut	26	1 to 5			0.064	0.146 to 0.005	7½	0.023	0.103 to -0.048						
	Firebricks	United States	Illinois	All	All	106	1/4 to 5	0.043	0.162 to 0.001	7½	-0.001	0.113 to -0.076			
Stiff-plastic press					Cream	6	3	0.134	0.152 to 0.121	6	0.120	0.125 to 0.103			
					White	6	2 to 4	0.032	0.053 to 0.018	6	0.016	0.040 to -0.001			
Wire-cut					Cream	21	1/2 to 4	0.058	0.107 to 0.010	6	0.048	0.080 to -0.024			
					Red	52	1/2 to 4	0.030	0.069 to 0.007	6	0.017	0.065 to -0.037			
All					Semi-dry press	All	85	1/2 to 4	0.044	0.152 to 0.007	6	0.024	0.125 to -0.037		
						Illinois	12	2 to 4	0.032	0.052 to 0.020	4	0.027	0.048 to 0.017		
Australia					New South Wales and South Australia	All	Semi-dry press	All	12	1/2 to 4	0.032	0.053 to 0.018	6	0.000	0.040 to -0.024

† Negative value indicates contraction.

TABLE 4 - PROPERTIES OF BRICKS EXAMINED\*

Type	Sample identification	Kiln		Color	Brick sample no.	Dimensions			Weight (lb)	Water absorption		
		Type	Maximum firing temperature (°C)			Length (in.)	Width (in.)	Thickness (in.)		24-hr soak (%)	5-hr boil (%)	Saturation coefficient
Common	IA	Scove	—	Creamy pink	A	8.00	3.68	2.25	4.03	14.64	18.36	0.80
					B	7.98	3.13	2.18	3.90	19.50	22.82	0.85
					C	7.93	3.65	2.25	4.02	13.18	17.16	0.77
					D	7.93	3.63	2.25	4.04	11.88	15.34	0.77
					E	7.88	3.61	2.22	4.10	10.73	13.90	0.77
					F	8.05	3.73	2.27	4.04	20.80	23.27	0.90
	Mean	7.96	3.66	2.24	4.02	15.12	18.47	0.81				
	IB	Scove	—	Creamy pink	A	7.96	3.79	2.29	4.14	20.29	22.95	0.89
					B	7.99	3.77	2.30	4.07	22.11	24.57	0.90
					C	8.00	3.71	2.28	4.16	18.51	21.63	0.86
					D	8.08	3.73	2.30	4.12	21.85	24.76	0.88
					E	8.00	3.73	2.32	4.14	21.74	23.19	0.94
					F	7.92	3.75	2.29	4.22	19.67	22.28	0.88
	Mean	7.99	3.75	2.30	4.14	20.70	23.23	0.89				
	IC	Scove	—	Creamy pink	A	8.02	3.64	2.25	4.12	8.50	12.38	0.69
					B	8.13	3.68	2.28	4.24	16.51	19.34	0.85
					C	8.00	3.68	2.27	4.18	14.11	17.70	0.80
					D	8.08	3.67	2.26	4.16	15.14	19.23	0.79
					E	8.15	3.68	2.27	4.18	19.38	21.53	0.90
					F	8.07	3.64	2.25	4.08	12.50	16.42	0.76
	Mean	8.07	3.66	2.26	4.16	14.36	17.77	0.80				
Facing, red	IG	Tunnel	1030	Dark red	A	7.86	3.62	2.26	4.61	0.87	1.30	0.67
					B	7.75	3.55	2.20	4.59	0.22	0.22	1.00
					C	7.86	3.53	2.20	4.70	0.85	1.07	0.80
					D	7.83	3.54	2.22	4.60	0.22	0.22	1.00
					E	7.80	3.55	2.21	4.58	0.87	1.09	0.80
					F	7.83	3.56	2.20	4.67	1.72	1.93	0.89
	Mean	7.82	3.56	2.21	4.63	0.79	0.94	0.86				
	IH	Tunnel	1030	Red	A	8.03	3.67	2.23	4.11	5.84	7.54	0.77
					B	8.03	3.66	2.23	4.12	5.34	7.04	0.76
					C	8.00	3.67	2.22	4.09	4.65	6.36	0.73
					D	8.04	3.66	2.24	4.13	6.05	7.99	0.76
					E	7.97	3.60	2.19	4.10	3.66	4.63	0.79
					F	7.97	3.58	2.20	4.09	5.13	6.60	0.78
	Mean	8.00	3.64	2.22	4.11	5.11	6.69	0.77				

\* The data given are the average for two bricks taken in contact with the bricks tested for expansion.

TABLE 4 - Continued

Type	Sample identification	Kiln		Color	Brick sample no.	Dimensions			Water absorption			
		Type	Maximum firing temperature (°C)			Length (in.)	Width (in.)	Thickness (in.)	Weight (lb)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient
Facing, red (contd.)	II	Tunnel	1015	Red	A	8.12	3.80	2.35	4.43	11.29	12.64	0.89
					B	8.14	3.78	2.33	4.44	11.04	12.39	0.89
					C	8.00	3.75	2.29	4.47	10.96	12.30	0.89
					D	8.11	3.81	2.33	4.46	11.44	12.78	0.89
					E	7.99	3.73	2.30	4.56	9.67	11.40	0.85
					F	7.86	3.69	2.29	4.44	7.66	9.46	0.80
					Mean	8.04	3.76	2.31	4.47	10.34	11.83	0.87
Facing, buff	ID	Beehive	1130	White, speckled, brown flash	A	7.92	3.69	2.22	4.44	0.90	1.80	0.50
					B	7.94	3.70	2.22	4.49	2.00	3.34	0.60
					C	7.95	3.69	2.20	4.51	1.77	3.10	0.57
					D	7.96	3.67	2.20	4.46	2.47	3.57	0.69
					E	7.94	3.65	2.20	4.48	4.24	4.91	0.86
					F	7.99	3.70	2.22	4.49	5.57	6.46	0.83
					Mean	7.95	3.68	2.21	4.48	2.83	3.86	0.67
Firebrick	IE	Tunnel	1100	Buff, speckled white	A	7.90	3.69	2.24	4.54	3.52	3.52	1.00
					B	7.96	3.69	2.24	4.41	4.77	4.99	0.95
					C	7.98	3.69	2.24	4.47	4.25	4.25	1.00
					D	7.92	3.64	2.19	4.52	3.10	3.10	1.00
					E	7.97	3.69	2.24	4.49	4.01	4.23	0.95
					F	7.94	3.64	2.23	4.55	4.18	4.18	1.00
					Mean	7.94	3.67	2.23	4.50	3.97	4.04	0.98
Firebrick	IF	Tunnel	1175	White-buff	A	7.70	3.77	2.30	4.39	4.79	6.61	0.72
					B	7.67	3.76	2.30	4.41	4.77	6.58	0.72
					C	7.67	3.75	2.29	4.39	4.33	5.70	0.76
					D	7.66	3.75	2.30	4.46	4.04	5.38	0.75
					E	7.71	3.75	2.29	4.53	5.88	0.77	0.75
					F	7.67	3.72	2.29	4.40	4.09	5.23	0.78
					Mean	7.68	3.75	2.30	4.41	4.43	5.90	0.75
Firebrick	IO	Tunnel, round	1150	Stone gray	A	8.31	4.13	2.53	7.01	4.71	6.00	0.79
					B	8.30	4.12	2.53	6.99	3.72	5.00	0.74
					C	8.35	4.14	2.54	6.96	3.73	5.30	0.70
					D	8.30	4.10	2.51	6.99	5.14	6.30	0.82
					E	8.31	4.10	2.54	6.96	5.60	6.61	0.85
					F	8.40	4.16	2.55	6.92	5.20	6.50	0.80
					Mean	8.33	4.12	2.53	6.97	4.68	5.95	0.78

TABLE 5 - PROPERTIES OF GREENWARE FROM CLAYS EXAMINED

Product	Sample identification	Clay < 2 $\mu$ (%)	Temper-ing water (%)	Drying shrinkage* (%)	Length <sup>†</sup>			Properties of dried greenware*			
					in.	cm	Volume (ccm)	Weight (g)	Density (g/ccm)	Color	
Bricks, common	IA	37	16.0	3.89	4.325	10.986	65.47	138.41	2.11	Greenish gray	
	IB	39	17.5	3.79	4.329	10.996	65.66	137.50	2.09	Gray	
	IC	33	16.5	3.39	4.348	11.043	66.50	143.70	2.16	Gray	
Bricks, red-facing	IG	36	15.0	2.85	4.372	11.104	67.61	144.07	2.13	Light gray	
	IH	46	21.0	4.56	4.295	10.910	64.11	131.09	2.05	Greenish gray	
	II	43	16.0	3.58	4.339	11.021	66.10	142.62	2.16	Light gray	
Bricks, buff-facing	ID	48	12.0	4.56	4.295	10.910	64.11	144.93	2.26	Gray	
	IE	53	14.5	4.00	4.320	10.973	65.24	143.21	2.20	Gray	
	IF	47	12.0	3.43	4.346	11.038	64.41	147.67	2.22	Gray	
Building and drain tiles	IJ	37	20.0	5.94	4.233	10.751	61.36	134.35	2.19	Light greenish gray	
	IK	38	17.0	5.12	4.270	10.845	62.99	138.44	2.20	Light greenish gray	
	IL	40	20.0	4.08	4.316	10.964	65.08	140.26	2.16	Greenish gray	
Sewer pipes	IM	31	14.0	2.41	4.391	11.154	68.54	143.95	2.10	Gray	
Firebricks	IO	--	16.5	3.61	4.338	11.018	66.04	137.21	2.08	Light gray	
	IP	42	13.5	3.67	4.335	11.011	65.92	141.06	2.14	Light gray	
Stoneware	IN	--	19.0	7.42	4.166	10.582	58.51	115.32	1.98	Gray-white	
Chinaware	IR	--	24.0	6.64	4.201	10.671	60.01	121.73	2.03	White	
Sanitaryware	IQ	35	22.5	4.34	4.305	10.933	64.55	123.63	1.92	Off-white	
Art pottery	IS	37	22.0	4.75	4.286	10.887	63.73	128.43	2.02	White	
Kaolin, Anna	1647	89	31.5	6.36	4.214	10.703	60.55	103.67	1.71	Creamy white	
Illite, Fitchian	1648	31	21.5	5.15	4.268	10.841	62.93	129.77	2.06	Gray-black	

\* Average of eight samples.

† Dimensions of freshly extruded samples 4½ in. x 1 in. x 1 in.



TABLE 6 - BEHAVIOR OF THE CLAYS ON FIRING, AND PROPERTIES OF THE FIRED PRODUCTS

Product	Sample identification	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient		
Bricks, common	IA	800	12.55	0.10	3.99	19.94	19.94	1.00	Buff-salmon	Medium hard
		850	12.37	0.10	3.99	19.16	20.06	0.96	Buff-salmon	Medium hard
		900	12.31	0.17	4.05	17.28	18.01	0.96	Buff-salmon	Medium hard
		950	12.68	0.48	4.35	17.95	19.94	0.90	Buff-pink	Medium hard
		1000	12.78	0.20	4.08	16.82	18.02	0.93	Salmon-red	Hard
	1050	13.17	0.49	4.36	15.78	17.77	0.89	Salmon-red	Hard	
	1100	13.18	3.76	7.50	11.36	12.49	0.91	Salmon-red	Hard	
	1150	13.50	5.50	7.18	0.64	1.23	0.51	Red-brown speckled	Vitrified, signs of melting	
	IB	800	12.20	0.10†	3.69	21.37	21.37	1.00	Buff	Medium hard
		850	12.64	0.15	3.94	18.70	19.12	0.98	Buff	Medium hard
		900	12.60	0.00	3.79	17.61	17.94	0.98	Buff	Hard
		950	12.58	0.37	4.15	17.20	18.18	0.95	Buff	Hard
		1000	12.81	0.17	3.96	16.16	16.79	0.96	Buff-pink	Hard
	1050	13.74	0.23	4.02	16.90	18.52	0.91	Pink (scummed)	Hard	
	1100	14.07	1.10	4.85	16.76	17.64	0.94	Pink (scummed)	Hard	
1150	14.23	8.10	11.59	1.86	2.47	0.75	Gray, speckled	Vitrified, signs of melting		
IC	800	13.79	0.11	3.50	18.27	18.36	1.00	Buff	Medium hard	
	850	13.86	0.45	3.83	18.47	19.62	0.94	Buff	Medium hard	
	900	13.81	0.45	3.83	17.19	17.50	0.98	Buff	Medium hard	
	950	13.71	0.40	3.78	19.15	20.65	0.93	Buff	Hard	
	1000	13.79	0.15	3.54	18.52	20.49	0.93	Buff-pink	Hard	
1050	15.08	0.40	3.78	15.83	18.55	0.85	Pink (scummed)	Hard		
1100	15.65	1.66	4.99	16.57	18.95	0.87	Pink (scummed)	Hard		
1150	15.78	7.86	10.98	0.57	1.15	0.50	Gray-brown speckled	Vitrified, signs of melting		

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 50° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample identification	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Bricks, red-facing	IG	800	5.78	0.60†	2.27	—	—	—	Brown-buff	Soft		
		850	5.76	0.50†	2.36	15.73	16.67	0.95	Brown-buff	Soft		
		900	6.10	0.17†	2.68	14.70	15.18	0.97	Brown-buff	Soft		
		950	6.37	1.06	3.88	14.28	15.53	0.92	Brown-buff	Medium hard		
		1000	6.40	2.17	4.96	11.95	12.82	0.93	Salmon	Hard		
		1050	6.55	4.20	6.98	8.40	9.88	0.85	Salmon	Hard		
		1100	6.55	6.20	8.87	7.07	8.03	0.88	Salmon-red	Hard		
		1150	0.38	4.85	7.56	0.34	0.40	0.82	Red-brown	Hard, bloated		
		1200	6.39	1.31	4.12	0.52	2.88	0.18	Dark red-brown	Hard, bloated		
			IH	800	7.32	0.26†	4.31	19.60	20.06	0.98	Salmon	Soft
				850	7.41	0.23†	4.34	18.65	19.06	0.97	Salmon	Medium hard
				900	7.73	0.40	4.94	18.55	19.42	0.96	Salmon	Medium hard
950	8.01			2.25	6.71	14.35	15.36	0.93	Salmon-red	Medium hard		
1000	8.07			4.23	8.60	9.48	10.19	0.93	Salmon-red	Hard		
1050	8.30			7.51	11.73	1.78	2.67	0.67	Red	Hard and dense		
1100	8.18			8.76	12.92	0.12	0.33	0.37	Dark red	Hard and dense		
1150	8.23			5.85	10.04	0.72	6.05	0.12	Red-brown	Hard, bloated		
1200	8.25			5.01	9.34	0.74	7.00	0.11	Dark red-brown	Hard, bloated		
	II			800	7.17	0.64†	2.97	15.24	15.59	0.98	Salmon	Soft
				850	7.10	0.10†	3.48	13.98	14.67	0.95	Salmon	Soft
				900	7.43	0.52†	4.08	13.17	13.72	0.96	Salmon-red	Medium hard
		950	7.54	2.10	5.61	10.61	11.44	0.93	Salmon-red	Hard		
		1000	7.60	3.52	6.98	7.10	7.68	0.93	Orange	Hard		
		1050	7.73	6.18	9.54	2.94	3.48	0.85	Red	Hard		
		1100	7.69	6.78	10.12	0.46	0.70	0.67	Dark red	Hard and dense		
		1150	7.64	6.10	9.46	0.23	0.42	0.55	Red-brown	Hard, bloated		
		1200	7.60	4.49	7.91	0.87	5.30	0.16	Dark brown	Hard, bloated		

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 500° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample identification	Firing temp.* (°C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Bricks, buff-facing	ID	800	8.83	0.10	4.66	11.47	12.39	0.92	Gray-white	Soft		
		850	9.15	0.23	4.78	11.33	12.37	0.92	Gray-white	Soft		
		900	9.66	0.35	4.90	11.54	12.73	0.91	Gray-white	Medium hard		
		950	10.03	1.13	5.65	10.95	12.59	0.91	Gray-white	Medium hard		
		1000	10.13	1.80	6.28	10.12	11.50	0.88	Gray-white	Hard		
		1050	10.29	3.07	7.49	8.48	10.06	0.84	Gray-white	Hard		
		1100	10.27	3.14	7.56	7.58	8.53	0.89	Gray-white	Hard		
		1150	10.36	5.69	9.99	1.00	1.57	0.64	Stone gray	Vitrified, dense		
		1200	10.17	5.27	9.59	0.23	0.89	0.26	Stone gray	Vitrified, dense		
		1250	10.02	5.00	9.33	0.00	0.00	0.00	Stone gray	Vitrified, dense		
		1300	10.27	4.50	8.86	1.07	1.72	0.62	Stone gray	Vitrified, bloated		
		IE		800	8.44	0.23†	3.78	13.60	13.94	0.98	Pale pink	Soft
				850	8.46	0.45†	3.57	13.05	13.65	0.96	Pale pink	Medium hard
900	8.65			0.37	4.36	13.06	13.56	0.96	Pale pink	Medium hard		
950	8.90			0.72	4.69	12.24	13.23	0.93	Pale pink	Hard		
1000	8.95			1.27	5.22	10.71	11.47	0.94	Pale pink	Hard		
1050	9.00			2.47	6.37	9.05	9.94	0.91	Pale pink	Hard		
		1100	9.03	3.55	7.41	6.38	6.80	0.94	Pale pink	Hard		
		1150	9.16	4.88	8.68	1.10	1.58	0.71	Stone gray	Hard, vitrified		
		1200	8.90	4.75	8.56	0.48	0.92	0.55	Stone gray	Hard, dense, vitrified		
		1250	8.88	4.37	8.20	0.35	1.58	0.22	Stone gray, speckled	Hard, vitrified, bloated		
		1300	9.18	3.44	7.30	1.09	2.40	0.45	Stone gray, speckled	Hard, vitrified, bloated		

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 500° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample Identification	Firing temp.* (°C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Bricks, buff-facing (contd.)	IF	800	7.48	0.46†	2.99	12.30	12.70	0.97	Pink	Soft		
		850	7.69	0.00	3.43	12.35	12.95	0.95	Pink	Soft		
		900	7.80	0.35	3.77	11.83	12.24	0.96	Pink	Medium hard		
		950	8.15	0.70	4.11	11.14	12.00	0.93	Pink	Medium hard		
		1000	8.11	1.41	4.79	9.83	10.42	0.94	Pink	Hard		
		1050	5.28	2.73	6.07	7.86	8.50	0.93	Pink	Hard		
		1100	8.18	3.77	7.07	6.08	6.34	0.96	Pink	Hard		
		1150	8.26	4.42	7.70	4.42	4.56	0.97	Pink-buff	Hard		
		1200	8.18	5.24	8.49	1.22	1.35	0.86	Stone gray	Hard and dense		
		1250	7.98	4.47	7.75	0.51	1.53	0.33	Stone gray, speckled	Hard, vitrified, bloated		
				3.73	7.03	2.06	3.32	0.63	Stone gray, speckled	Hard, vitrified, bloated		
		Building and drain tiles	IJ	800	11.81	0.00	5.94	17.77	17.77	1.00	Buff-salmon	Medium hard
				850	11.78	0.10	6.03	17.64	18.88	0.93	Salmon	Hard
				900	11.76	0.15	6.08	17.60	18.70	0.94	Salmon	Hard
				950	11.62	0.06	6.00	16.45	17.93	0.92	Salmon	Hard
1000	11.54			0.06	6.00	15.85	17.42	0.91	Salmon	Hard		
1050	11.61			0.41	6.33	15.36	17.74	0.86	Salmon	Hard		
1100	11.84			2.72	8.50	7.18	8.06	0.84	Salmon-red	Hard		
				0.12†	5.00	18.29	18.29	1.00	Buff-salmon	Medium hard		
850	11.36			0.20†	4.91	16.68	17.75	0.94	Salmon	Hard		
900	11.39			0.07	5.19	17.40	17.74	0.95	Salmon	Hard		
950	11.38			0.10	5.22	17.00	18.39	0.93	Salmon	Hard		
1000	11.51			0.50	5.59	16.36	18.00	0.91	Salmon	Hard		
1050	11.70			0.50	5.59	15.04	17.20	0.87	Salmon	Hard		
1100	11.70			2.00	7.02	11.27	13.42	0.83	Salmon	Hard		

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 500° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample identification	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Building and drain tiles (contd.)	IL	800	6.55	0.44†	3.66	15.88	16.04	0.99	Salmon	Soft		
		850	6.66	0.15†	3.94	14.56	15.54	0.94	Salmon	Medium hard		
		900	6.80	0.11	4.19	16.59	16.20	0.96	Salmon-red	Medium hard		
		950	7.02	0.93	4.97	15.02	15.94	0.94	Red	Medium hard		
		1000	7.04	2.00	6.00	13.13	14.13	0.93	Red	Hard		
		1050	7.07	4.21	8.12	10.89	12.28	0.88	Dark red	Hard		
		1100	7.12	6.30	10.12	5.33	5.95	0.90	Dark red	Hard		
		1150	7.07	5.22	9.09	0.88	3.49	0.25	Red-brown	Hard, bloated		
		Sewer pipes	IM	800	6.10	0.65†	1.78	16.69	17.13	0.98	Buff	Soft
				850	6.05	0.15†	2.25	16.16	16.74	0.96	Buff	Soft
900	6.19			0.15†	2.25	15.89	16.57	0.96	Buff	Medium hard		
950	6.45			1.51	3.88	14.23	15.38	0.93	Salmon	Medium hard		
1000	6.37			2.08	4.44	11.79	12.78	0.92	Salmon	Hard		
1050	6.57			3.64	5.96	10.16	11.75	0.86	Light red	Hard		
1100	6.47			5.31	7.59	6.45	8.14	0.79	Red-brown	Hard and dense		
1150	6.39			6.70	8.96	0.70	1.11	0.65	Chocolate-brown	Hard and dense		
1200	6.46			4.69	6.99	0.85	4.32	0.20	Dark gray-brown	Hard, bloated		
Firebricks	IO			800	6.27	0.20†	3.42	14.88	15.19	0.98	Pink	Soft
		850	6.48	0.00	3.61	14.42	15.12	0.96	Pink	Soft		
		900	5.93	0.60	4.19	13.67	14.28	0.95	Pink	Medium hard		
		950	6.22	0.72	4.31	13.14	14.03	0.94	Pale pink	Medium hard		
		1000	6.11	1.53	5.08	12.12	12.97	0.93	Pale pink	Hard		
		1050	6.22	2.96	6.46	10.39	11.63	0.89	Pale pink	Hard		
		1100	6.24	3.99	7.46	8.06	9.00	0.90	Cream-pink	Hard		
		1150	6.08	5.45	8.86	4.65	5.72	0.81	Cream	Hard		
		1200	6.00	6.29	9.67	1.53	2.08	0.74	Stone gray	Hard, vitrified		
		1250	5.75	5.65	9.06	0.62	1.60	0.39	Stone gray	Hard, vitrified		
1300	6.25	4.92	8.35	1.69	2.51	0.67	Stone gray	Hard, vitrified, bloated				

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 500° C interval above that given in the table.

† Figure indicates an expansion of the value shown.



TABLE 6 - Continued

Product	Sample identification	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Firebricks (contd.)	IP	800	10.18	0.49	4.14	12.20	13.60	0.92	White-buff.	Medium hard		
		850	10.23	0.63	4.28	12.74	14.14	0.90	White-buff.	Medium hard		
		900	10.50	1.57	5.19	11.60	12.68	0.91	White-buff.	Medium hard		
		950	10.67	2.24	5.83	10.10	11.94	0.85	White-buff.	Hard		
		1000	10.70	3.28	6.82	8.76	10.43	0.84	Cream	Hard		
		1050	10.71	4.20	7.72	6.79	8.75	0.78	Cream	Hard		
		1100	10.52	4.73	8.23	4.10	5.14	0.80	Cream	Hard		
		1150	10.60	5.61	9.07	1.07	2.07	0.65	Stone gray	Stone gray, vitrified		
		1200	10.42	5.60	9.06	0.91	1.82	0.50	Stone gray	Stone gray, vitrified		
		1250	10.38	5.48	8.95	0.45	1.67	0.27	Stone gray	Stone gray, vitrified		
		1300	10.68	4.94	8.43	1.23	2.23	0.55	Stone gray	Stone gray, vitrified, bloated		
		Stoneware	IN	800	6.93	0.73†	6.74	15.59	15.74	0.99	Pale pink	Soft
				850	6.82	0.10†	7.33	15.03	15.65	0.96	Pale pink	Soft
900	6.89			0.15	7.56	14.87	15.38	0.97	Pale pink	Medium hard		
950	7.29			0.36	7.76	14.61	15.56	0.94	Off-white	Medium hard		
1000	7.17			0.84	8.20	13.92	14.48	0.96	Off-white	Hard		
1050	7.26			2.34	9.59	11.52	12.60	0.92	Cream	Hard		
1100	7.29			3.50	10.66	8.95	9.14	0.97	Cream	Hard		
1150	7.37			5.01	12.06	5.02	5.02	1.00	Creamy gray	Hard		
1200	7.14			5.55	12.56	2.13	2.13	1.00	Stone gray	Hard, dense, vitrified		
1250	6.98			5.79	12.78	0.32	0.45	0.70	Stone gray	Hard, dense, vitrified		
1300	7.42			4.90	11.96	0.63	0.63	1.00	Stone gray	Hard, dense, vitrified		

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 500° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample identification	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Saturation coefficient				
Chinaware	IR	800	6.10	0.00	6.64	17.73	17.95	0.99	Off-white	Soft		
		850	6.06	0.10†	6.53	16.84	18.02	0.93	White	Soft		
		900	5.95	0.15†	6.50	16.62	17.24	0.96	White	Soft		
		950	6.24	0.30	6.92	16.62	18.02	0.92	White	Medium hard		
		1000	6.09	0.24	6.86	16.55	17.24	0.96	White	Hard		
		1050	6.11	1.35	7.91	15.45	17.06	0.91	White	Hard		
		1100	6.17	2.44	8.92	14.48	15.14	0.96	White	Hard, vitrified		
		1150	6.23	3.81	10.20	10.26	10.62	0.96	White	Hard, vitrified		
		1200	6.03	4.79	11.11	6.92	7.85	0.87	White	Hard, dense, vitrified		
		1250	6.05	6.21	12.44	3.42	3.50	0.98	White	Hard, dense, vitrified		
		1300	6.29	6.72	12.91	2.96	2.96	1.00	White	Hard, dense, vitrified		
		Sanitaryware	IQ	800	5.77	0.24†	4.11	19.86	20.26	0.98	Off-white	Soft
				850	5.67	0.00	4.34	19.26	20.24	0.95	White	Soft
900	5.89			0.11	4.45	19.91	20.47	0.97	White	Medium hard		
950	5.89			0.32	4.65	18.20	19.56	0.93	White	Hard		
1000	5.71			0.52	4.84	18.84	19.79	0.95	White	Hard		
1050	5.79			0.57	4.89	18.60	20.30	0.92	White	Hard		
1100	5.76			2.47	6.70	15.55	16.16	0.96	White	Hard		
1150	5.85	6.80	10.85	6.20	6.46	0.96	Porcelain-white	Hard, vitrified				
1200	5.63	8.55	12.52	1.11	1.11	1.00	Porcelain-gray	Hard, vitrified				
1250	5.56	9.00	13.05	0.00	0.00	1.00	Porcelain-gray	Vitrified, signs of melting				

\* Maximum temperature of firing 1300° C; where top firing temperature is less than this, the samples melted at the 50° C interval above that given in the table.

† Figure indicates an expansion of the value shown.

TABLE 6 - Continued

Product	Sample Identifi- cation	Firing temp.* (° C)	Weight loss on firing (%)	Shrinkage		Water absorption			Color	Condition		
				Firing (%)	Total (%)	24-hr soak (%)	5-hr boil (%)	Satura- tion coeffi- cient				
Art pottery	IS	800	10.08	0.23	4.97	18.66	18.66	1.00	Off-white	Soft		
		850	10.57	1.41	6.10	16.10	16.10	1.00	White	Soft		
		900	10.53	1.28	5.98	15.30	15.30	1.00	White	Medium hard		
		950	10.64	1.68	6.35	13.90	14.77	0.94	White	Hard		
		1000	10.63	1.68	6.35	12.56	13.43	0.94	Creamy white	Hard		
		1050	11.08	1.69	6.36	12.27	14.45	0.85	Creamy white	Hard, dense		
		1100	11.41	1.89	6.55	11.50	14.44	0.80	White	Hard, dense		
		1150	11.35	2.27	6.91	9.79	13.18	0.73	White	Hard, vitrified		
		1200	11.22	5.70	10.18	0.09	0.14	0.75	Porcelain-white	Vitrified		
		1250	—	—	—	—	—	—	—	Melted		
		Kaolin, Anna	1647	800	12.96	1.45	7.72	21.49	23.05	0.93	Pale pink	Soft
				850	13.00	1.85	8.10	21.04	22.74	0.93	Pale pink	Soft
				900	13.25	2.82	9.00	20.57	22.30	0.92	Pink	Soft
950	13.54			3.38	9.53	19.87	21.88	0.91	Pink	Soft		
1000	13.61			3.20	9.36	15.97	20.64	0.92	Light cream	Hard		
1050	13.00			3.49	9.63	22.08	24.14	0.91	Light cream	Hard		
1100	12.93			4.94	10.99	19.45	21.41	0.91	Light cream	Hard		
1150	13.00			9.58	15.34	12.11	14.36	0.85	Off-white	Hard		
1200	12.71			12.58	18.14	1.32	2.89	0.46	Off-white	Hard and dense		
1250	12.86			12.82	18.37	0.74	2.41	0.31	Off-white	Hard and dense		
1300	13.13			12.71	18.26	1.43	2.72	0.52	Pale gray	Hard and dense		
Illite, Fithian	1648			800	9.31	0.24†	4.92	13.84	16.23	0.79	Light brown	Soft
				850	9.59	1.25	6.36	11.70	14.22	0.82	Salmon-red	Soft
		900	10.25	2.14	7.18	9.41	11.43	0.82	Orange	Hard		
		950	10.58	4.13	9.08	5.61	7.04	0.74	Orange	Hard		
		1000	10.39	5.54	10.41	3.39	3.65	0.92	Red	Hard, bloated		
		1050	10.73	5.67	10.53	0.60	8.81	0.16	Red-brown	Hard, bloated		
		1100	10.53	1.00†	4.20	0.48	8.11	0.07	Red-brown	Hard, strongly bloated		

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Illinois State Geological Survey Circular 405  
44 p., 14 figs., app., 1966

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