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Ceramic properties of the clays of the Polo Gas Field

Clarence Arthur Lambelet

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CERAMIC PROPERTIES OF THE
CLAYS OF THE POLO GAS FIELD

by

CLARICE E. LAMBELET

A

THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the
Degree of
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1946

Approved by

Paul J. Hiestand
Professor of Ceramic Engineering
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# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acknowledgement</td>
<td>11</td>
</tr>
<tr>
<td>List of Tables</td>
<td>v</td>
</tr>
<tr>
<td>List of Graphs</td>
<td>vi</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Description of Area</td>
<td>2</td>
</tr>
<tr>
<td>Ceramic Materials in Area</td>
<td>6</td>
</tr>
<tr>
<td>Sampling of Clays</td>
<td>9</td>
</tr>
<tr>
<td>Chemical Analysis</td>
<td>10</td>
</tr>
<tr>
<td>Pyrometric Cone Equivalent</td>
<td>11</td>
</tr>
<tr>
<td>Water of Plasticity, Pore Water, and Shrinkage Water</td>
<td>12</td>
</tr>
<tr>
<td>Drying Shrinkage</td>
<td>14</td>
</tr>
<tr>
<td>Firing Behavior</td>
<td>14</td>
</tr>
<tr>
<td>Mechanical Strength</td>
<td>27</td>
</tr>
<tr>
<td>A.S.T.M. Specifications for Building Brick</td>
<td>29</td>
</tr>
<tr>
<td>Dry Pressed Gumbotils</td>
<td>33</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 1</td>
<td>35</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 2A</td>
<td>39</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 2B</td>
<td>43</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 2</td>
<td>47</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 3</td>
<td>51</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 4</td>
<td>55</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 8A</td>
<td>59</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 8B</td>
<td>62</td>
</tr>
<tr>
<td>Results of Tests on Clay No. 8</td>
<td>64</td>
</tr>
</tbody>
</table>
Results of Tests on Clay No. 5 ........................................... 67
Results of Tests on Clay No. 6 ........................................... 72
Results of Tests on Clay No. 7 ........................................... 76
Results of Tests on Clay No. 9 ........................................... 80
Discussion of Results ...................................................... 84
Conclusions ................................................................. 85
Appendix A ................................................................. 86
Bibliography ............................................................... 89
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Columnar Section of Missouri Series, Kansas City Group, Pennsylvanian</td>
<td>5</td>
</tr>
<tr>
<td>2.</td>
<td>Physical Requirements for A.S.T.M. Standard Specifications of Building Brick</td>
<td>31</td>
</tr>
</tbody>
</table>
LIST OF GRAPHS

<table>
<thead>
<tr>
<th>Graph</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Firing Shrinkage and Porosity of Clay No. 1</td>
<td>37</td>
</tr>
<tr>
<td>2. Firing Shrinkage and Porosity of Clay No. 2A</td>
<td>41</td>
</tr>
<tr>
<td>3. Firing Shrinkage and Porosity of Clay No. 2B</td>
<td>45</td>
</tr>
<tr>
<td>4. Firing Shrinkage and Porosity of Clay No. 2</td>
<td>49</td>
</tr>
<tr>
<td>5. Firing Shrinkage and Porosity of Clay No. 3</td>
<td>53</td>
</tr>
<tr>
<td>6. Firing Shrinkage and Porosity of Clay No. 4</td>
<td>57</td>
</tr>
<tr>
<td>7. Firing Shrinkage and Porosity of Clay No. 3A</td>
<td>60</td>
</tr>
<tr>
<td>8. Firing Shrinkage and Porosity of Clay No. 8</td>
<td>65</td>
</tr>
<tr>
<td>9. Firing Shrinkage and Porosity of Clay No. 5</td>
<td>69</td>
</tr>
<tr>
<td>10. Firing Shrinkage and Porosity of Clay No. 6</td>
<td>74</td>
</tr>
<tr>
<td>11. Firing Shrinkage and Porosity of Clay No. 7</td>
<td>78</td>
</tr>
<tr>
<td>12. Firing Shrinkage and Porosity of Clay No. 9</td>
<td>82</td>
</tr>
</tbody>
</table>
INTRODUCTION

In Western and Northwestern Missouri there exist many natural gas fields of such limited size and of such great dispersion that it is not economical to utilize their products by the construction of pipe lines to consuming centers. Thus a large source of natural wealth is lying idle. This wealth could be utilized, however, if some manufacturing process requiring large amounts of fuel were located in the vicinity.

The ceramics industry would appear to be ideally suited for the utilization of this fuel if the other requirements for a successful ceramics industry are present in the area. The primary requirement for any such venture is a suitable market for the finished product within economical transportation radius. Then, such a venture would require managerial and technical organization and a sufficient quantity of satisfactory labor. The final requirement is the presence of suitable raw materials, including clay or shale, fuel, and water.

Part of the first requirement— that of a suitable market—is satisfied anywhere in Northwestern Missouri. The large consuming areas of Kansas City and St. Joseph could utilize any products offered at a reasonable price. The question of adequate transportation is a much more localized problem and would require the location of the plant on a railroad and highway network.

The requirements of capital, managerial and technical organization, and labor are not of primary concern to this study. Certainly the first two would have to be imported by whoever
undertook the business venture. Presumably, labor would be available from the local inhabitants, or it could be imported from Kansas City.

Concerning the last requirement, the availability of fuel is the reason for interest in the area, though an investigation should be made to assure the quality and quantity of the fuel in any selected area. The adequacy of water supply in the area selected must be determined. The crux of the whole problem, however, is the location of suitable deposits of clay or shale within the area of one of these gas fields. This, then, is the purpose of the investigation.

The investigation must include a field trip to the area selected for study to make a survey of clay deposits available. Any clays which appear from field investigation to be suitable must be properly sampled and tests must be made on these samples to determine any uses they might have. Finally, from the results of the tests selected for the clays, an estimate of the value of the clays must be made and their probable use indicated.

DESCRIPTION OF AREA

Apparently one of the most suitable areas in Northwestern Missouri, and that selected for the investigation, is that of the Polo Gas Field. It is situated near the small town of Polo, in Caldwell County, about fifty miles Northeast of Kansas City. The field lies on the main lines of the Chicago Rock Island and Pacific and of the Chicago Milwaukee and St. Paul Railroads, both of which lead directly into Kansas City. Missouri State
Highway No. 116, an all-weather gravel road running east and west, and Missouri State Highway No. 13, a paved highway running north and south, pass through the town of Polo. The requirement of suitable transportation to a market is adequately met in this area.

The quantity and quality of the fuel here are also satisfactory. According to Greene and McQueen, twenty wells have been drilled in the field, and these have an initial gas open flow capacity of 33,000,000 cubic feet. Rock pressure is 86 pounds. The total reserve of gas in the Polo sand of the Polo Gas Field is estimated at 1,023,310,000 cubic feet. Heating value of the gas is 940 B.T.U.'s per cubic foot. Greene and McQueen also point out that there is a possibility of gas and oil being present in deeper formations in this area.

Water from shallow wells in the glacial drift of the area has always been adequate for farm and home use. One well that was analyzed had a capacity of 10,000 gallons per day. Water from the Pennsylvanian is too mineralized to be of use for industrial purposes, though it can be obtained in large quantities. The nature of the water from the Mississippian and older formations is unknown.

2. Ibid. P. 21.
3. Greene and McQueen, op. cit., pp. 6,7,8.
in the Polo area, but analysis in surrounding counties indicate that it also is too highly mineralized for industrial uses. It is most likely that the wells in the glacial drift would supply adequate water, but if not, provision would have to be made for the purification of water from deeper sources.

The area surrounding Polo is gently rolling and typically glaciated with an elevation of about 1000 feet above sea level. It is largely under cultivation or in pasturage and is populated by prosperous farms. Surface material is post Kansan Pleistocene. Outcrops are from the Kansas City Group of Missouri Series Pennsylvanian. Columnar section as given by Clair is shown in Table No. 1, page 5.

Greene and McQueen describe the Kansas City Formation as being 190 to 200 feet thick and consisting of alternating layers of shale and limestone. The shales are mainly gray, but include some red clay and black slaty shales. The latter carry some water and gas appears in some wells. Below the Kansas City is the Pleasanton Formation, which is about 100 feet thick, and below this is the Henrietta Formation which includes the Polo Sand at a depth of about 400 feet. Very few wells have been drilled into the Cherokee below.


5. Greene and McQueen, op. cit., p. 9.
<table>
<thead>
<tr>
<th>SERIES</th>
<th>GROUP</th>
<th>FORMATION</th>
<th>SECTION</th>
<th>MEMBER</th>
<th>LITHOLOGIC DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>MISSOURI</td>
<td>KANSAS CITY</td>
<td>IOLA LIMESTONE</td>
<td>Quindaro</td>
<td>Shale, yellowish, clayey to calcareous</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frisbee Limestone</td>
<td>Liberty</td>
<td>Shale, gray to blue, weathers brownish to buff, argillaceous, sandy</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frisbee Limestone</td>
<td>Memorial Shale</td>
<td>Limestone, gray, veined with calcite</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raytown Limestone</td>
<td>Muncie Creek Shale</td>
<td>Shale, black, fissile</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Raytown Limestone</td>
<td>Paola Limestone</td>
<td>Limestone, blue, dense, hard, lithographic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Union Station Shale</td>
<td>Cement City Limestone</td>
<td>Limestone, blue, gray, drab, medium to dense, hard, silty, oolitic</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quivira Shale</td>
<td>cement City Limestone</td>
<td>Shale, gray, clayey, nodular, limestone streaks.</td>
<td></td>
</tr>
</tbody>
</table>

TABLE NO. 1

COLUMNAR SECTION OF MISSOURI SERIES, KANSAS CITY GROUP, PENNSYLVANIAN
and little can be said about it. There is practically no information available concerning pre-Pennsylvanian formations.

CERAMIC MATERIALS IN AREA

The surface material of the Pleistocene Series has been left by the melting of glaciers. This rock material which was transported by glaciers consists chiefly of silicates, quartz, and some previously weathered materials. Over a very long period of time this material is acted upon by ground water containing carbonic acid and by oxygen from the air as they penetrate the surface. This action of oxygen and acid removes soluble salts, breaks down the various base forming metals, as sodium, potassium, calcium, magnesium, iron, etc., into soluble forms, and if carried to completion will leave a pure clay mineral, one of the hydrated aluminum silicates. However, this process is rarely carried to completion, and the weathered material generally contains scattered particles of quartz, chert, and lime concretions.

Pure clays formed by the above processes are rare and quite valuable, though they have long been known. There is no evidence of such clays in the Polo area. The only argillaceous material found above the shale beds of the Pennsylvanian is gumbotil. There is no record of this material having ever been used for ceramic products, but the decision was made to take samples of it and to test it to determine any possible uses it might have.

The term gumbotil was first used by Kay, in 1916, when he said that a new term was to be applied to certain gumbos which overlay

tills and appeared through field investigations and chemical analysis to be related to the tills. Gumbotil is described as a gray to dark-colored, thoroughly leached, non-laminated, deoxidized clay. It is very sticky and breaks with a starchy fracture when wet, and is very hard and tenacious when dry. Chiefly, it is the weathered product of drift. Three gumbotils are known, the Kansan, the Nebraskan, and the Illinobtan, corresponding to the glacial tills with which they are associated. This investigation is primarily concerned with the Kansan, which Kay and Pearce have described as having a maximum thickness of twenty or more feet. It is leached, but in many places contains lime concretions. There are a few scattered pebbles, predominately quartz and chert. It grades down into yellowish to chocolate colored till which merges into unleached till oxidized yellowish for several feet, and then into unoxidized, unleached, dark grayish to bluish black Kansan till.

Grim and Ekblaw say that gumbotil is composed essentially of beidellite \((\text{Al}_2\text{O}_3\cdot3\text{SiO}_2\cdot2\text{H}_2\text{O})\) in particles \(0.0006\) mm. in diameter or in slightly larger particles \(0.001\) to \(0.0005\) mm. in diameter which are easily reduced by slight working of the material to the finer grain size. In addition to beidellite, silty gumbotil contains a sericite-like mineral \((2\text{K}_2\cdot3\text{Mg} \cdot\text{Si}_2\cdot2\text{Si}_3\cdot2\text{H}_2\text{O})\) and quartz in

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amounts varying according to the degree of siltyness. Coarse grains of quartz and possibly large grains of other materials may be present if the gumbotil is sandy. If the till is calcareous, calcite is present in particles which may attain a minimum size of 0.001 mm. Different tills vary in relative abundance of these materials, and the relative abundance of beidellite and the sericite-like mineral are of prime importance in influencing the physical properties of the gumbotil. Beidellite has a high adsorptive ability for water, it possesses the ability to break down easily into extremely small particles, and it has exchangeable bases. It increases the plasticity, stickiness, impervious character, and shrinkage of the clay. The sericite-like mineral possesses exactly the opposite of these physical properties.

In the Polo area shales are present close to the surface and in outcrops as shown in Table No. I. Shales are sedimentary type deposits, hard, lamellar, and are commonly an impure form of kaolin. They have been laid down in water, either as offshore deposits or at some distance from the borders of lakes, estuaries, or in the ocean. Apparently they were laid down with little thickness, but the gradual sinking of the area has allowed great thicknesses to be formed. Shales have a low plasticity, are usually impure, and are quite often used for the manufacture of heavy structural clay products.

Some loess was observed within the general area of the Polo Gas Field, though it occurs more generally farther South. This material has been carried by winds and deposited in unstratified beds. It is
often used for the coarser clay products. No samples were taken since beds of sufficient thickness were not observed in the immediate vicinity of the gas field.

**SAMPLING OF CLAYS**

Samples of clays within the area were all obtained from railroad or highway cuts or stream banks. No drill cores were made. This was felt to be entirely adequate sampling in as much as the dip of the beds is sufficient that the depth of exposed faces throughout the area showed all strata of clay or shale which appear at mineable depths any place in the area. It is assumed that drill cores must be made if exploitation is contemplated after a satisfactory clay is found in order to determine the actual thickness of the clay or shale beds, the amount of overburden to be removed from the beds, and the extent of the beds. Underground mining of any clays in the area would be very unlikely.

In the selection of the samples, every effort was made to make them completely representative. The surface of the outcrop was cleared of weathered material to a depth of several inches. A trench was cut down the entire depth of the deposit in order to obtain an equal amount of sample from each layer of the bed.

Similar channel sampling of the gumbotils was not possible because they had slumped down in the exposed highway and railroad cuts to a marked extent. However, because they are a product of weathering in place rather than deposition in place as are the shales, they have a less stratified character and grade more evenly from one
composition to another without evidence of the thin strata of coal and limestone which greatly affect the shales.

Samples were gathered of five different shales and of Kansas gumbotil from four different locations. The description of the samples is given in Appendix A. Samples of approximately seventy-five pounds of each clay were taken.

Samples were prepared by drying on a steam radiator, and then by crushing and grinding in a jaw crusher and a hammer mill until all material had passed a 20 mesh sieve.

**CHEMICAL ANALYSIS**

A chemical analysis by itself is of little value in indicating the value of a clay, in as much as it gives no indication of the plastic properties of the clay, such as drying shrinkage, plasticity, ability to withstand rapid heating and cooling, etc. Therefore, chemical analysis must be used in conjunction with other tests. However, a chemical analysis does aid in the prediction of the fired properties of a clay, such as the color, fired shrinkage, fusability, blistering, etc. Discussion of the effects of chemical impurities on the properties of a clay during firing will be made in reference to the firing behavior test of the clays.

A chemical analysis was run on all the clay samples. All samples were ground to pass a 100 mesh sieve and were mixed by rolling. They were dried for twelve hours at 105 degrees Centigrade. Regular clay procedure was used, the clays being fused in sodium.

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carbonate. Silica was rerun on a one-half gram sample. Loss on ignition temperature was limited to 850 degrees Centigrade. A blank was run and subtracted and all determinations were made in duplicate.

PYROMETRIC CONE EQUIVALENT

The melting, or fusion, point of a clay designates the temperature at which it becomes sufficiently fluid to deform under definite stress. This indicates complete vitrification and is useful in predicting the firing temperature and range of the clay. The common method of determining the fusion point of a clay is by comparing its bending characteristics when made into cones of the same size and shape as standard pyrometric cones with the bending characteristics of the standard cones when both are fired in the same furnace and under the same conditions.

The Pyrometric Cone Equivalent of the clays was determined in the manner specified by the American Ceramic Society and the American Society for Testing Materials for Refractory Clays. From the entire sample a sample of suitable size was obtained by the use of a mechanical sample splitter. The clay was ground to pass a 70 mesh sieve and then calcined in a fire clay crucible at the rate of 150 degrees Centigrade per hour to 930 degrees Centigrade and held there for forty-five minutes. The purpose of this treatment was to remove the hygroscopic water and the organic materials which might cause some defer-

mation during the firing of the test cones. Test cones were made of the calcined clay in special molds using gum arabic as a binder. The cones were mounted in cone plaques with English China clay, and fired at the rate specified. Cone equivalents were taken as the results of at least two similar tests.

WATER OF PLASTICITY, PORE WATER, AND SHRINKAGE WATER

The water of plasticity is the water necessary to bring the clay from the dry state to a good working consistency, and is expressed as a percentage of the dry weight. It varies within wide limits, both for various clays and for various experimenters, for the conception of a "good working consistency" is entirely a matter of personal judgement. However, the test is of some value in determining the plasticity of a clay and in preparing proper batch mixtures of the clay. The water of plasticity is calculated by the following formula:

$$T = \frac{W_p - W_d}{W_d} \times 100$$

where, $T$ = water of plasticity  
$W_d$ = dry weight of the test piece  
$W_p$ = plastic weight of the test piece.

Shrinkage water is that portion of the water of plasticity which is given off up to the point where shrinkage ceases, and it gives an indication of the mechanical water necessary to bring the clay to a good working consistency and of the amount of drying shrinkage of the clay. Shrinkage water is given by the following formula:

$$t = \frac{V_p - V_d}{V_d} \times 100$$
where, \( t \) = per cent shrinkage water

\( V_{p} \) = plastic volume of the test piece

\( V_{d} \) = dry volume of the test piece

\( M_{d} \) = dry weight of the test piece

Pore water is that portion of the water of plasticity which is given off from the point where shrinkage ceases to the time when the test piece reaches constant weight at 110 degrees Centigrade. It is a measure of the amount of water to fill the interstices between the clay particles. Pore water and shrinkage water are always equal to the water of plasticity. Pore water is given by the formula:

\[
t_{2} = T - t
\]

where, \( t \) = per cent pore water

\( T_{2} \) = per cent water of plasticity

\( t \) = per cent shrinkage water

Procedure for these tests is given by the American Ceramic Society.

The clays are ground to pass a 20 mesh sieve, are mixed with water to a soft plastic consistency, and are thoroughly wedged and kneaded by hand. Test pieces are formed by pounding a piece of the clay, which has been roughly shaped to fit the mold, into a previously oiled brass mold. The dimensions of the mold are one and one-eighth inches in cross section and twelve inches long. The test pieces are removed from the mold, cut into two inch lengths, and the edges are rubbed lightly with the fingers to smooth them in order to prevent losses in handling. The test pieces are immediately weighed and the volume determined in a volumeter of the Seger type, using kerosene as the measuring fluid. The test pieces are dried at room temperature, then at 110 degrees Centigrade in an electric oven until they reach constant

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weight. Dry weight is measured. The dry volume is determined in
the same manner as the plastic volume in a Seger volumeter, except
that the test pieces are first soaked overnight in kerosene.

DRIYING SHRINKAGE

Drying shrinkage is one of the most important properties of a
clay if it is to be used in the manufacture of ceramic ware. Excessive
shrinkage during drying might cause cracks, warpage, and distortion
of the ware, and may be the cause of an excessive amount of waste.
Also, drying and burning shrinkages must be known in order to make
such allowances in the green shapes that the fired shapes may be of
the correct size. Drying shrinkage is attributed to the loss of
mechanical water of the plastic clay, which has acted as a matrix
between the particles of the clay and held them apart. As it dries
the clay particles move closer and closer together, and the volume
of the test piece decreases. Drying shrinkage depends upon many
factors, but the chief ones are the amount of water present and the
nature of the clay, that is, the shape of the grains, their size, etc.
High water content generally means high shrinkage.

Drying shrinkage is determined on a percentage basis of the
difference in the dry and plastic volumes of the test pieces used
in the foregoing tests, based on the dry volume.

FIRING BEHAVIOR

Firing behavior is the most important test to be run on the
clays, and for that reason it will be discussed at greater length
than the other tests. It is proper that the first tests run be
on the plastic properties of the clay to determine if ceramic ware can be properly formed from the raw clay, if so, the firing behavior test will be needed to determine the value of such ware. The firing behavior test will give an indication of the possible uses of the clays and will suggest any further tests which might be necessary to satisfy certain conditions. The firing behavior test determines progressive changes with increased firing temperature of volume, color, hardness, and absorption.

In order to understand the results of the firing behavior test on clays, a review of the reactions occurring will be helpful. These have been summarized by Austin as follows:

1. Water smoking period, removal of water
   1. mechanical and hydrosopic water
   2. water of constitution
2. Oxidation period
   1. elimination of carbon
   2. oxidation of iron compounds
   3. decomposition of carbonates and sulphates
3. Vitrification period
   1. sintering and grain growth
   2. crystal transformations
   3. formation of a liquid phase
   4. formation of new crystalline compounds
4. Cooling period
   1. crystallization of crystalline phase
   2. annealing of vitreous phase
   3. crystal inversions

The end results of the above reactions are governed by several factors including, equilibrium state of the reaction, which is determined by the temperature of the clay and the composition of the clay and

the furnace gases, and the rate of the reaction, which is influenced by the effective temperature within the clay, and the size or condition of the solid particles.

The water smoking period has little effect on the fired ware if it is properly traversed in the firing of the ware. However, detrimental effects can occur during this period unless care is taken in the firing. Uneven temperature distribution can cause condensation of moisture and sulphur gases (from the fuel) in the cooler parts of the kiln, which acts to increase the uneven temperature distribution, and the sulphur might act with the iron in the clay to form spots on the ware; while the excess water softens the ware, possibly causing deformation. With too rapid heating, insufficient oxidation of the iron and organic material in the center of the pieces results in black coring. These detrimental effects can be prevented by having a minimum amount of water in the ware, by having an excess of air passing over the ware, and by passing through the water smoking period slowly.

The primary reaction in the oxidation period is the elimination of carbon by oxidation and the removal from the kiln along with the kiln gases as CO and CO₂. Carbon may appear as vegetable matter, bituminous material, non-volatile carbon (graphite), or as minerals (carbonates). In the raw clay it may color the material gray, bluish, black, brown, or even red; though it is seldom present in amounts up to five per cent. Excessive carbon burned out of the ware may increase its

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porosity. If the ware is heated rapidly and the surface becomes vitrified before the carbon has been removed, bloating of the ware will result. Also, the reducing action of the carbon will greatly affect the color and other physical properties of the clay due to other chemical constituents of the clay unless oxygen is present in excess.

The oxidation of the iron compounds during the oxidation period is the greatest factor in the development of the properties of the fired clay product. Iron is generally, and certainly always in impure clays, the strongest coloring agent present, and it is a fluxing agent which has a great influence on the vitrification range of the clay. The amount of fluxing action and the color produced depend upon the amount of iron minerals present, their chemical combinations, the firing conditions to which they are subjected, the size of grains of the clay and of the iron mineral, the state of distribution of the iron minerals, and on the other minerals present in the clay.

Searle says that iron compounds occur in clays in the following 14 forms:

1. Free ferric oxide, \( \text{Fe}_2\text{O}_3 \)
2. Free ferric hydroxide, \( \text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O} \)
3. Magnetic iron oxide, \( \text{Fe}_3\text{O}_4 \)
4. Free ferrous oxide, \( \text{FeO} \)
5. Complex iron silicates or alumino-iron-silicates
6. Iron oxide combined with silica or with silica and alumina
7. Ferrous carbonate, \( \text{FeCO}_3 \)
8. Ferric sulphide, \( \text{Fe}_3\text{S}_2 \)

Often the color of the clay is an indication of the iron minerals present. Ferric compounds give a pale yellow to reddish brown in the raw state, whereas ferrous compounds give a bluish or greenish tint. Ferric carbonate or finely divided pyrites sometimes give a gray color.

During the firing of the clays, the hydroxides, carbonates, sulphates, sulphides, and phosphates are decomposed yielding one or more of the complex silicates. If the firing is made under reducing conditions, ferrous silicates are formed. These are complex compounds formed only at high temperatures, and they are quite fusible. If they are melted, they produce dark green to black colors; if not, they give a greenish or black color to the ware. The more pleasing red iron colors are produced under oxidizing conditions of firing, when ferric oxide and complex ferric silicates are formed. The colors generally become lighter and brighter as the temperature of firing is increased until a maximum brilliance is reached, then they begin to darken and turn brown and black as vitrification progresses.

The distribution of iron minerals in clay is the most important factor in getting a good red color. It has been found impossible to grind iron minerals fine enough to give the proper distribution, so the clay must possess the iron in a sufficiently finely divided state naturally. 15 This is the case when the iron mineral is in a soluble state, for during the blunting of the clay it becomes adsorbed on the surface of the clay grains, giving perfect distribution. 16


Lovejoy states that the difference in optical properties of the clay grains can affect the color. Therefore, a clay containing much sand, which is hard, has a large grain size, and is smooth, will reflect a lighter and brighter color than will a surface of very small pure clay grains, which form a matte surface.

Disregarding the influence of other materials, one may say that a white burning clay has less than one per cent iron, that buff burning clays have from one to five per cent iron, and that red burning clays have about five per cent iron.

Lime may be present in clays in three forms: as the carbonate (limestone and dolomite); as the silicate (feldspar); and as the sulphate (gypsum). These three forms have different effects on the behavior of the clay during the oxidation period of the firing process. The silicate renders the clay more fusible, but has no effect on the color and never produces quicklime with the danger of its swelling and alabing if the clay is underfired. If the calcium is present as the carbonate, it can easily be detected by a colorless effervescence when treated with cold dilute hydrochloric acid. Upon sufficient heating the carbonates break down and the carbon is driven off, leaving the calcium to combine with silica, forming complex silicates which are very fusible. If the clay is underfired, and especially if the lime is present as concretions, quicklime is formed, which causes the lime to swell and the clay to burst when water penetrates it. Calcium in the form of the sulphate is the most objectionable, as the lime combines with silica to form a very fusible calcium silicate and the sulphate forms

17. Lovejoy, op. cit., p. 279.
sulphuric acid gas which might cause blistering of the ware. Lime in the form of sulphate or carbonate has a very decisive bleaching action on the coloration due to oxidized iron, forming iron-lime-silicates which have a greenish-buff color. Lime present in amounts equal to or in excess of the amount of iron, each in excess of five per cent, will notably bleach the clay. Lime greatly shortens the vitrification range of clays, often shortening it to such an extent that it is impossible to fire the ware. It decreases the firing shrinkage and increases the porosity of the clay.

Another detrimental impurity is the element magnesium, which may be present from the minerals biotite, chlorite, or dolomite. Magnesium sulphate may be present, but it is usually removed by weathering because of its great solubility. Magnesium affects the clay very much the same way as calcium, except that its action is not so strong. It is not so powerful a flux and it does not increase the rate of vitrification so much as does calcium, nor does it bleach the iron red color so strongly.

The alkalies sodium and potassium are present in all clays, though often in very small amounts. They have a great influence on the firing behavior of a clay in that they are the most powerful fluxing agents known, though they have no influence on the color or shrinkage of a clay. Sodium and Potassium may be present because of their occurrence as soluble salts in all surface water. They also occur as complex silicates, as in the micas, and as soluble silicates, as in the feldspars.

While the minerals silica, alumina, and titanium undergo no
cchanges during the oxidation period, mention should be made of their
effect on the fired properties of clays. Free silica affects the
properties very little, but if present in large amounts it will re-
duce the fired shrinkage. Titanium is usually found in such small
amounts that it has little or no effect on the clay. However, it
is thought that it exaggerates the red coloration of iron, if pre-
sent as rutile, and that it produces a buff or straw color if
present in large quantities. Alumina is rarely found in clays in
the uncombined state, but it probably would increase the melting
point, as it would combine with silica to produce the highly refractory
material mullite. Also, according to Wilson, alumina tends to bleach
iron colors somewhat.

Another element which is seldom present in clays, but which, if
present in large enough quantities, has some effect on the coloration
of the clay is manganese. It produces brown or black colorations.

The decomposition of carbonates and sulphates during the oxidation
period has already been discussed with reference to the carbonates
and sulphates of iron and calcium, which are the most common types.
These are broken down early in firing, but the evolved carbon and
sulphur gases might be disastrous in the firing and are quite detri-

York, 1921, p. 76.
mental substances when present. The gases of both of these elements may be trapped in the clay because of too early vitrification and the closing of the pores of the clay, causing bloating and blistering. Both must be removed to allow oxidizing conditions in the clay. Sulphur often forms sulphuric acid within the clay, which dissolves some of the minerals there, carrying them to the surface where it evaporates, leaving the minerals concentrated at the surface and greatly enhancing any effect they may have on the properties of the clay. This is the cause of the scums which often appear on the surface of ceramic ware. White scums are the commonest and are usually due to the presence of calcium, magnesium, potassium, sodium, ferrous, or aluminum sulphates, and occasionally to other salts, such as chlorides and nitrates. These compounds form the acid of the salt and are dissolved, carried to the surface, and reform the salt upon evaporation, giving the scummy appearance.

Whereas all the chemical reactions are considered to take place during the oxidation period, the vitrification period is considered to include the physical transformations. Parmelee says that sintering, or coalescence, is the welding together of the smaller particles and the growth of the larger particles at the expense of the smaller particles. Thus, due to the sintering action as a clay is burned, its volume diminishes, it becomes harder and more durable, and its permeability, porosity, and specific gravity change, though


there is yet no evidence of the softening of the particles and of vitrification.

It is difficult to determine just when sintering stops and vitrification commences because of the complexity of the changes taking place. However, vitrification is the development of a glassy texture in the clay. This may not be visible during early stages of firing, but observation under a microscope will show particles of the inert material surrounded by a glassy magma. As the temperature is raised, the size and number of inert particles decrease and the glassy matrix increases in volume. This action is due to the melting of more particles and to the taking into solution of material by the glass which is formed, as is shown by the rounded edges of the particles as the vitrification advances. The temperature and rate of sintering and vitrification depend upon many factors, the most important being the fusion point of the least refractory material present and the grain size of all materials present.

Parmelec describes incipient vitrification as that stage when, under a microscope, the material first shows the appearance of glass formed; whereas complete vitrification is that stage when the mass, if viewed under a microscope, shows a collection of particles of the same or different substances so completely bonded that there is no measurable porosity. When seen without magnification the mass is dense and has a fine granular or smooth conchoidal fracture, and is sometimes glassy.

With increased heating the vitrification merges into a gradual softening of the clay and increased fluidity until the clay is molten. The vitrification range is described as the time-temperature period between the incipient vitrification and the beginning of overfiring as shown by the complete lack of porosity of the clay and the subsequent deformation of the ware because of the reduced viscosity of the clay. It is very important that clays used in the manufacture of ceramic products have an extended vitrification range in order to allow firing under normal kiln conditions, which give rather uncertain control of temperature and uneven firing conditions throughout the kiln, without excessive losses.

Before complete vitrification occurs, many clays form a vesicular structure, which, as was previously described, is the result of incomplete oxidation of carbon or the incomplete decomposition of sulphates or carbonates. This result occurs only at high temperatures, after the surface had vitrified and the gases trapped in the interior of the clay continue to expand with no way for release, forming "blebs" or bubbles. This phenomenon occurs particularly in dense bodies.

One of the most important physical properties of clays in the fired state is its strength, which is dependent upon the degree of vitrification. At the start of vitrification the liquid develops only at the points of contact of the grains, thus the grains are cemented only at these points. As the vitrification develops the pores are filled and the cemented surface is much greater. This continues

to the point of complete vitrification, at which time maximum strength should be developed. However, the formation of a vesicular structure reduces the strength because of the disruption of the interior or by the bubble formation.

Although the crystal transformations and the formation of new crystalline compounds during vitrification are undoubtedly important factors in the properties of the fired clay, a complete discussion of these reactions cannot be made because of the complexity of the reactions which occur and because of the lack of general information on this subject. The formation of new crystalline compounds is affected by the presence of fluxes which melt at low temperatures and dissolve other constituents, by the grain size of the particles which affects the area of the constituents in contact, and by the degree of twinning of quartz. Some mention has already been made of the formation of complex silicates with the various fluxes, such as iron and calcium.

According to Norton,27 the chemically combined water of pure kaolinite is given off at 450 degrees Centigrade. At 950 degrees Centigrade the alumina crystallizes in the gamma form and then begins to dissolve in the glassy phase and mullite begins to crystallize. At 1200 degrees Centigrade cristobalite crystallizes from the glassy phase. Possibly the fluxing action of such materials as iron and lime will greatly affect these temperatures.

Norton also states that the lattice-breakdown for montmorillonite and illite appears at 600 degrees Centigrade and is complete at 800 degrees. A spinel phase appears at 950 degrees and is completely dissolved at 1300 degrees. Mullite appears at 1050 in montmorillonite and at 1100 in illite.

The rate of cooling and proper annealing influence the strength of the clay and its resistance to mechanical shock. Many silica compounds have a very slow crystal growth, and large size crystals are formed during slow cooling. If it is desired to retain the glassy phase, a rapid rate of cooling must be used, however, the cooling curve must be such as to give the glass which is formed a chance to anneal at the proper time. In highly siliceous compounds the crystal inversion at 250 degrees Centigrade of cristobalite with its relatively sudden change in volume might cause trouble.

The firing behavior test was run on all clays in the manner specified by the American Ceramic Society. Test pieces were made in the same manner as those for the plastic property tests. Dry weights and volumes were determined and the test bars were fired in an electric glow-bar furnace at the rate of 45 degrees Centigrade per hour from the start of firing until the point where heat treatment began, and from there at the rate of 20 degrees per hour. Heat treatment begins at the second consecutive cone below the cone at which the first draw of test pieces is to be made. Four test bars

of each sample were drawn at every other cone from cone 021 for the shales and cone 09 for the gumbotils until either the first or second cone below the P.C.E. of the clay was reached. Pieces were quenched in hot sand when withdrawn. The fired weight and volume were determined, and the weight after saturation for two hours in boiling water was measured.

Color of the fired test pieces was determined by eye, noting whether the red color was a satisfactory one for structural clay products. Hardness was determined by scratching with a steel knife blade. Volume shrinkage was calculated as a percentage of the dry volume, and the total shrinkage was obtained by adding the fired and drying shrinkages. Apparent porosity was determined by the use of the following formula:

\[
P = \frac{S_f - W_f}{V_f} \times 100
\]

where, \( P \) = per cent porosity
\( S_f \) = weight of the saturated fired test piece
\( W_f \) = weight of the fired test piece
\( V_f \) = volume of the fired test piece.

**MECHANICAL STRENGTH**

Mechanical strength of a clay is an important factor in the case of production of ceramic ware and in the value of the finished product. In the plastic state considerable strength is necessary to withstand the rigors of rough handling during the manufacturing processes and drying. In the fired state strength is necessary for any product which is to find use.
The dry strength of clays is a more or less unexplained property.

However, Norton says that it is known to be more or less due to the attractive forces between the clay mineral crystals. Certain adsorbed ions, when present in a more nearly saturated condition, increase the strength; for instance, a dialyzed clay increases greatly in dry strength when saturated with sodium ions. Dry strength also increases as the area of the clay particles increase, that is, as the particles become finer.

The fired strength of a clay is due to the bond developed by the formation of a glassy phase which cements the particles together. Thus, it will be dependent upon the degree of vitrification, the strength of the bond developed, and the strength of the clay particles themselves. Greatest strength should be developed at complete vitrification.

There are three types of strength tests: crushing strength, tensile strength, and transverse strength, which is sometimes called modulus of rupture. In this test the latter is the one used. The test was made in accordance with the specifications of The American Ceramic Society.

The clay was thoroughly dried, crushed to pass a twenty mesh sieve, and mixed to a soft plastic consistency with water. The test pieces were made in a brass mold, oiled with kerosene, and with the dimensions of seven inches long and one inch in cross section.

Great care was taken in the formation of the test pieces to prevent laminations. The test pieces were dried, at first under a damp cloth, then in air, and finally at 110 degrees Centigrade to constant weight. During drying the test pieces were turned to allow even drying on all sides. The dry test pieces were broken on a Reihle testing machine with knife edges five inches apart. The depth and breadth of the bar at the point of breakage were measured. Five bars of each clay which was tested were broken.

Five bars of each clay that was tested were made in the same manner as were those for the dry modulus of rupture, but were fired to cone 04, which is within the firing range of all the clays tested as was shown by the firing behavior test. Firing was done in an electric glow-bar furnace at the rate of 150 degrees Centigrade per hour, and the fired bars were broken in the same manner as were the dry bars.

Modulus of Rupture was calculated by the following formula:

\[ M = \frac{3FL}{2bd^2} \]

where,
- \( M \) = modulus of rupture in pounds per square inch
- \( F \) = breaking load in pounds
- \( l \) = distance between the knife edges in inches (five)
- \( d \) = depth of the bar at point of breakage in inches
- \( b \) = breadth of the bar at point of breakage in inches.

A.S.T.M. SPECIFICATIONS FOR BUILDING BRICK

It was evident from the firing behavior tests that some of the clays might be useful for common building brick. Therefore, an investigation of the specifications for such materials under the standards of the American Society for Testing Materials would be necessary. The grades of building brick made from clay or shale which
are specified by A.S.T.M. are: Grade SW, which includes bricks intended for a high degree of resistance to the action of frost and which are expected to sustain freezing when permeated with water; Grade NW, which includes bricks intended for use where exposed to temperatures below freezing, but not when permeated with water, or when a moderate and somewhat uniform resistance to frost action is permissible; and Grade NW, which includes bricks intended for backup or interior masonry, or if exposed, for use where no frost action occurs, or if frost occurs, where the average annual precipitation is less than twenty inches. Physical requirements for these designations are given in Table No. 2, page 31.

According to A.S.T.M. Standards, compressive strength is to be obtained on a three and three-quarter by four inch face of the brick when placed flatwise by applying load mechanically at a uniform rate until crushing, relieving the strain, takes place. In this test stresses far above those experienced in masonry walls are realized. However, the test is valuable as an indication of the strength of the material and forms an excellent means for comparison of different bricks.

Since neither full size bricks nor equipment to crush them were available for the test, the test pieces of the firing behavior test were used. These test pieces were approximately two inches by one inch by one inch, and were tested on the two by one inch surface.

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>MINIMUM COMPRESSIVE STRENGTH p.s.i. gross area</th>
<th>MAXIMUM WATER ABSORPTION Five hours boiling, %</th>
<th>MAXIMUM SATURATION Coefficient</th>
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<td></td>
<td>Ave. 5 brick</td>
<td>Individual</td>
<td>Ave. 5 brick</td>
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<tr>
<td>Grade NW</td>
<td>1500</td>
<td>1250</td>
<td>no limit</td>
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</table>

**Table No. 2**

**Physical Requirements for A.S.T.M. Standard**

**Specifications of Building Brick**
which if compared to the four by three and three-quarter inch surface of a standard brick would give about the same ratio of surface area to thickness, thus making the tests comparable. Samples were bedded in one-quarter inch celotex and were crushed in a small laboratory hydraulic press by applying load slowly until the test piece failed and increased load did not increase pressure. Crushing strength in pounds per square inch was calculated.

Maximum water absorption and saturation coefficient may be grouped under the property of durability of the brick. If the compressive strength of the brick is sufficient to withstand the masonry pressures of construction, the resistance to the deleterious action of freezing and thawing will be the criterion of the durability of the brick. The ideal test for this property would be continuous cycles of freezing and thawing of the brick. However, this is an impractical test, and other physical properties have been correlated to the resistance of bricks to freezing and thawing. The one chosen by the A.S.T.M. is the saturation coefficient, which is the ratio of the absorption after twenty-four hours of submersion in cold water to the absorption after five hours of submersion in boiling water, and may be defined as the ratio of the total fillable pore space to the easily fillable pore space. The theory of the test is that when only part of the total space is occupied by water there is room for expansion during freezing and thawing into the remaining pore space without disruption of the material. Data indicates that, with bricks subjected to excessive moisture, if the easily fillable pore space does not exceed eighty per cent of the total space, the remaining space will relieve
the pressure due to expansion on freezing, and the brick will not
be seriously broken when subjected to freezing.

Tests were made on the firing behavior test pieces of the shales.
The stiff and formed gumbolils were considered as not usable because
of excessive drying shrinkage. Pieces were weighed dry, after being
submerged twenty-four hours in cold water, and after being sub-
merged for five hours in boiling water.

DRIED PRESSED GUMBOLILS

From the results of the plastic property tests, which showed
excessive drying shrinkage for the gumbolils, it was apparent that
the gumbolils were unsuited to manufacture by soft or stiff mud
methods. However, their fired properties seemed more desirable, and
it was decided to make tests on bricks formed by dry pressing to
determine the feasibility of their use in this manner.

Approximately three per cent water was added to the air dry
gumbolils and full size bricks were dry pressed at about 1200 pounds
per square inch pressure. Bricks were carefully dried and then fired
to cone 4, which appeared from the firing behavior tests to produce
the optimum properties in the clay. Above this temperature a very
poor dirty dark color appeared, and below it vitrification was not
sufficiently advanced.

The bricks were tested for hardness, color, crushing strength,
and saturation coefficient. Crushing strength and saturation coef-
icient. Crushing strength and saturation coefficient were measured
on segments of the full size bricks. This probably produced erroneous
results because of the difference in surfaces, but the errors would
give less favorable properties to the clay, so they would tend to raise the standards required.
RESULTS OF TESTS ON CLAY NO. 1

CHEMICAL ANALYSIS:
Loss on ignition 7.00%
SiO₂ 57.40
Fe₂O₃ 6.94
TiO₂ 1.00
Al₂O₃ 22.06
CaO 1.85
MgO 1.81
S 0.17
Total 99.23%

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 5

WATER OF PLASTICITY: 19.9%

SHRINKAGE WATER: 9.3%

PORE WATER: 10.6%

VOLUME DRYING SHRINKAGE: 18.0%

FIRING BEHAVIOR:
<table>
<thead>
<tr>
<th>No. to cone</th>
<th>Shrinkage</th>
<th>Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
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Test pieces fired below this temperature are soft, have very high porosity, and the colors are unsatisfactory.
MODULUS OF RUPTURE:

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<tr>
<th>Bar No.</th>
<th>Fired M of R</th>
<th>Average M of R</th>
<th>Bar No.</th>
<th>Dry M of R</th>
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A.S.T.M. SPECIFICATIONS:

<table>
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<th>Bar No.</th>
<th>Fire to cone</th>
<th>Absorption cold water</th>
<th>Absorption boiling water</th>
<th>Saturation coefficient</th>
<th>Crushing Strength</th>
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</tbody>
</table>
Graph No. 1  Clay No. 1

Relationship of Firing Shrinkage and Porosity to Temperature
to Which Clay id Fired.
The location and extent of the shale bed which comprises Clay No. 1 appears satisfactory. It was sampled along state highway No. 116 about a mile from the railroad. The bed is about ten feet thick and is on the Northern edge of the gas pool.

Its chemical analysis shows that the clay is high in silica and iron and low in alumina and that it had a medium amount of flux. This would indicate a red burning clay with a medium vitrification range, probably one which would be useful for structural clay products.

The clay has good plasticity and plastic properties and is easily worked. The volume drying shrinkage appears high, but the stiff and mix tested was probably high in water content. The dry strength is high. This clay can easily be worked and formed in the plastic state.

The firing behavior test shows a relatively short firing range between cones 03 and 2. This span of five cones is considered the minimum satisfactory for commercial kiln conditions. The fired color is a good deep red, the clay is harder than steel, and the appearance is satisfactory for face brick. The crushing strength and absorption coefficient are well within the A.S.T.M. specifications for grade SW brick. The fired modulus of rupture is very high.

This clay is considered satisfactory for face brick or common building brick of any A.S.T.M. specification.
RESULTS OF TESTS ON CLAY NO. 2A

CHEMICAL ANALYSIS:

loss on ignition 11.30%
SiO₂ 48.20
Fe₂O₃ 6.71
TiO₂ 1.00
Al₂O₃ 20.09
CaO 8.39
MgO 2.01
S 0.56
Total 99.16%

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 1

WATER OF PLASTICITY: 26.7%

SHRINKAGE WATER: 8.2%

FIRE WATER: 18.7%

VOLUME DRYING SHRINKAGE: 15.1%

FIRING BEHAVIOR:

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<th>Remarks</th>
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</tr>
<tr>
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<td>7.3</td>
<td>28.1 20.0</td>
<td>same</td>
</tr>
<tr>
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</tr>
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<td>27.2 18.9</td>
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</tr>
<tr>
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<td>30.9 19.9</td>
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</tr>
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<td>same</td>
</tr>
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<td>7.2</td>
<td>32.2 22.2</td>
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</tr>
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<td>Plus</td>
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<td>31.0 17.0</td>
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<td>31.2 19.5</td>
<td>same</td>
</tr>
<tr>
<td>16 09</td>
<td>Plus</td>
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<td>same</td>
</tr>
<tr>
<td>18 09</td>
<td>Plus</td>
<td>29.2 17.0</td>
<td>red, soft</td>
</tr>
</tbody>
</table>

Below this temperature there was no shrinkage. The clay expanded when placed in water and the colors were extremely ugly dirty yellowish red. The clay was soft.
MODULUS OF RUPTURE:

This test was not made on clay No. 2A because of its other qualities which obviously make it unsuitable for use.

A.S.T.M. SPECIFICATIONS:

<table>
<thead>
<tr>
<th></th>
<th>Bar Fired</th>
<th>Absorption</th>
<th>Absorption</th>
<th>Saturation</th>
<th>Crushing strength</th>
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</table>
Graph No. 2    Clay No. 2A

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 2A is from a bed of gray shale eight feet thick and separated from Sample No. 2B above it by a thin coal streak. It is located in a wall of a creek bed near a secondary road southwest of Polo. The sample was taken from a point about three hundred yards from the railroad and near the center of the gas field.

The large calcium and magnesium content as shown by the chemical analysis indicated that the clay might not possess good firing properties. The loss on ignition is high, pointing to the presence of carbonates. The low P.C.E. shows up the fluxing influence of these impurities.

The plastic properties are good, with high plasticity, good workability, and medium shrinkage.

The firing behavior test indicates no definite firing range though the temperature of the test was carried to a point just one cone below the P.C.E. of the clay. Evidently the high calcium and magnesium content have reduced the vitrification range to a point undetectable by the test.

The high porosity and saturation coefficient indicate that the clay would be worthless for products which are exposed to weathering. The crushing strength is high enough for back-up bricks, but the difficulties of firing would probably preclude the use of this clay.

The clay is considered worthless.
RESULTS OF TESTS ON CLAY NO. 2B

CHEMICAL ANALYSIS:
Loss on Ignition 7.20%
SiO₂ 58.40
Fe₂O₃ 6.75
TiO₂ 1.00
Al₂O₃ 22.25
CaO 0.92
MgO 2.17
S 0.29
Total 98.96

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 3

WATER OF PLASTICITY: 23.4%

SHRINKAGE WATER: 6.1%

PORE WATER: 17.2%

VOLUME DRYING SHRINKAGE: 11.3%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>Bar No. to cone</th>
<th>Fired Burning Shrinkage</th>
<th>Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
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</tr>
<tr>
<td>3 6</td>
<td>17.6</td>
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<td>30.9</td>
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</tr>
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<td>28.6</td>
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</tr>
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</tr>
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<td>1.3</td>
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</tr>
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<td>35.5</td>
<td>same</td>
</tr>
<tr>
<td>8 4</td>
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<td>2.5</td>
<td>58.3</td>
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<tr>
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<td>13.2</td>
<td>39.5</td>
<td>red, some scum, hard</td>
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<tr>
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</tr>
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<tr>
<td>25 07</td>
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Below cone 05 the test pieces were soft, had a very high porosity, low shrinkage, and an unsatisfactory yellowish red color.

**MODULUS OF RUPTURE:**

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**A.S.T.M. SPECIFICATIONS:**

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Graph No. 3  Clay No. 25

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 2B is from a shale bed five feet thick and separated from Sample No. 2A below by a thin coal streak. It was taken from a wall of a creek bed on a secondary road Southwest of Polo and about three hundred yards from the railroad.

Its chemical analysis appears satisfactory for a high iron content red burning shale. Calcium is low and magnesium fairly so. The P.C.E. is relatively high evidencing the lack of fluxes other than iron.

The plastic properties are very good, with high plasticity and relatively low drying shrinkage.

Firing properties are good, with a firing range of seven cones from 03 to 4 producing satisfactory fired ware. It is hard and of a dark red color. Some scum appears, possibly from the magnesium, but it is not too prominent and probably would not be too offensive. Cone six appeared to be overfired as is shown by the increased porosity and decreased shrinkage and strength. The test pieces fired in the range of cone 03 to 4 meet A.S.T.M. standards for first grade building brick.

This clay is considered satisfactory for first grade face brick or any other red firing structural clay products.
RESULTS OF TESTS ON CLAY NO. 2

Sample No. 2 is a mixture of one half Clay No. 2A and one half Clay No. 2B.

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 3

WATER OF PLASTICITY: 25.4%

SHRINKAGE WATER: 3.4%

PORE WATER: 17.0%

VOLUME DRYING SHRINKAGE: 15.8%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>No. to one</th>
<th>Burning Shrinkage</th>
<th>Apparent Shrinkage</th>
<th>Porosity</th>
<th>Total Shrinkage</th>
<th>Color, hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>19.6</td>
<td>2.1</td>
<td>35.4</td>
<td>dark red, scum, hard</td>
</tr>
<tr>
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<td>2</td>
<td>18.4</td>
<td>3.6</td>
<td>34.2</td>
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</tr>
<tr>
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<td>39.6</td>
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<td>9</td>
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<td>03</td>
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<td>14</td>
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<td>17</td>
<td>07</td>
<td>4.0</td>
<td>26.4</td>
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<td>red, much scum, medium soft</td>
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<tr>
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<td>07</td>
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<td>25.3</td>
<td>22.9</td>
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<td>21.0</td>
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Test pieces fired below this temperature were very obviously underfired, being a light reddish yellow, soft, and having considerable scum.
### Modulus of Rupture:

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<th>Bar Dry</th>
<th>Average</th>
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<td>4</td>
<td>2435</td>
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<td>9</td>
<td>682</td>
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| 5   | 2531      | 2590    | 10     | 591     | 670

### A.S.T.M. Specifications:

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<th>No.</th>
<th>Bar to cone</th>
<th>Absorption Cold water</th>
<th>Absorption Boiling water</th>
<th>Saturation Coefficient</th>
<th>Crushing Strength</th>
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<td>.85</td>
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</table>
Graph No. 4 - Clay No. 2

Relationship of firing shrinkage and porosity to temperature to which clay was fired.
Sample No. 2 is a composite of one half clay No. 2A and one half clay No. 2B. Since these two clay beds are separated only by a thin streak of coal, which would prove harmless during firing, a considerably greater thickness of shale could be mined if the combination of the two clays together would give satisfactory results.

The plastic properties are satisfactory, with good workability and high plasticity. The drying shrinkage is somewhat high, but this is possibly due to too wet a mixture for the test. The dry modulus of rupture is high.

The F.C.B. of 3 for this mixture indicates the action of the fluxes from clay No. 2A.

The firing behavior definitely shows the deleterious action of Clay No. 2A. A satisfactory color is produced, but the scum is greater than in Clay No. 2B, and possibly it would prevent the use of the mixture for face brick. No definite firing range appears, but any bricks fired between cone 65 and cone 2 would probably be satisfactory for back-up brick. The fired modulus of rupture is satisfactorily high and the crushing strength between the cones mentioned is satisfactory for Grades NM and NW brick. The saturation coefficient appears irregular with several high values which definitely prohibit the use of this mixture for first grade brick.

The mixture is considered satisfactory for second grade building brick. The increased thickness of the bed of clay when both clays are mined as a mixture and the resulting savings in mining probably would justify the use of Clay No. 2B in this manner.
# RESULTS OF TESTS ON CLAY NO. 3

**CHEMICAL ANALYSIS:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
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<td>Loss on ignition</td>
<td>9.00%</td>
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<tr>
<td>SiO₂</td>
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</tr>
<tr>
<td>Fe₂O₃</td>
<td>7.91</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.00</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>21.29</td>
</tr>
<tr>
<td>CaO</td>
<td>3.46</td>
</tr>
<tr>
<td>MgO</td>
<td>1.96</td>
</tr>
<tr>
<td>S</td>
<td>1.06</td>
</tr>
<tr>
<td>Total</td>
<td>98.08%</td>
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</table>

**PYROMETRIC CONE EQUIVALENT:** P.C.E. No. 5 - 6

**WATER OF PLASTICITY:** 23.2%

**SHrinkage Water:** 9.5%

**Pore Water:** 14.4%

**VOLUME DRYING SHRINKAGE:** 18.8%

**Firing Behavior:**

<table>
<thead>
<tr>
<th>Bar Fired</th>
<th>Burning Shrinkage</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Color, hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 4</td>
<td>plus .7</td>
<td>19.1</td>
<td>18.1</td>
<td>very dark red, hard</td>
</tr>
<tr>
<td>2 4</td>
<td>plus .7</td>
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<td>10.9</td>
<td>same</td>
</tr>
<tr>
<td>3 4</td>
<td>plus .0</td>
<td>18.3</td>
<td>17.3</td>
<td>same</td>
</tr>
<tr>
<td>4 4</td>
<td>plus .8</td>
<td>19.4</td>
<td>17.0</td>
<td>same</td>
</tr>
<tr>
<td>5 2</td>
<td>11.4</td>
<td>1.8</td>
<td>30.2</td>
<td>dark red, hard</td>
</tr>
<tr>
<td>6 2</td>
<td>18.0</td>
<td>2.2</td>
<td>36.8</td>
<td>same</td>
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<td>7 2</td>
<td>11.7</td>
<td>4.4</td>
<td>30.5</td>
<td>same</td>
</tr>
<tr>
<td>8 2</td>
<td>15.1</td>
<td>1.8</td>
<td>33.9</td>
<td>same</td>
</tr>
<tr>
<td>9 01</td>
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<td>0.9</td>
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<td>same</td>
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<td>12 01</td>
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<tr>
<td>13 03</td>
<td>21.9</td>
<td>6.0</td>
<td>40.7</td>
<td>bright red, hard</td>
</tr>
<tr>
<td>14 03</td>
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<td>6.3</td>
<td>39.2</td>
<td>same</td>
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<td>15 03</td>
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<td>6.1</td>
<td>40.3</td>
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<td>same</td>
</tr>
<tr>
<td>17 05</td>
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<td>17.9</td>
<td>36.1</td>
<td>bright red, hard</td>
</tr>
<tr>
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<td>22 07</td>
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<td>23 07</td>
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<tr>
<td>24 07</td>
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<td>bright red, medium soft</td>
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</table>
Test pieces fired to temperatures below this were a yellowish red
with white scum and softer than a knife blade. The shrinkage was positive
and the porosity high.

MODULUS OF RUPTURE:

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<tr>
<th>No.</th>
<th>M of R</th>
<th>Fired M of R</th>
<th>No.</th>
<th>M of R</th>
<th>Dry M of R</th>
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Bar Fired Average Bar Dry Average

<table>
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<tr>
<th>No.</th>
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<th>Fired M of R</th>
<th>No.</th>
<th>M of R</th>
<th>Dry M of R</th>
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A.S.T.M. SPECIFICATIONS:

<table>
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<tr>
<th>Bar Fired</th>
<th>Absorption Cold water</th>
<th>Absorption Boiling water</th>
<th>Saturation Coefficient</th>
<th>Crushing Strength</th>
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Graph No. 5    Clay No. 3

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Clay No. 3 is a dark gray shale taken from a creek bed several hundred yards from Sample No. 2. Little thickness was sampled because most of the bed appeared to be covered by the creek bottom.

The chemical analysis indicates an average red burning shale which is low in calcium and magnesium.

The plastic properties are satisfactory, the clay having good workability and high plasticity. The dry strength is high, indicating ease in handling green ware made from this clay. The dry shrinkage is rather high, possibly due in part to excessive water in the mixture which was tested.

The firing behavior test indicates a firing range of seven cones between cones 05 and 2. The color developed is a good bright red. The fired clay is hard. The fired modulus of rupture indicates that the clay would develop sufficient strength when fired. Tests on the saturation coefficient and crushing strength of the test pieces fired within the range of cones 05 to 2 indicate values of these properties which are within the A.S.T.M. standards, except for the pieces fired to cone 05 which has much too high a saturation coefficient for first grade brick. This indicates that the ware would have to be fired within the well controlled limits of cone 05 to 2. The crushing strength is very high throughout the entire range.

This clay is considered satisfactory for any type of building brick if it is fired within the range of cone 05 to 2.
RESULTS OF TESTS ON CLAY NO. 4

CHEMICAL ANALYSIS:

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<th>Analysis</th>
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<td>Al₂O₃</td>
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<td>CaO</td>
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<td>MgO</td>
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</tr>
<tr>
<td>S</td>
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<tr>
<td>Total</td>
<td>99.32%</td>
</tr>
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PYROMETRIC CONE EQUIVALENT: P.C.E. No. 2

WATER OF PLASTICITY: 27.6%

SHEENKAGE WATER: 15.6%

PORE WATER: 15.0%

VOLUME DRYING SHEENKAGE: 23.5%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>Bar Fired</th>
<th>Burning</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. to cone</td>
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<td></td>
<td>Shrinkage</td>
<td>Color, hardness</td>
</tr>
<tr>
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<td>21</td>
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<td>25.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>medium soft, cracks.</td>
</tr>
</tbody>
</table>

Test pieces fired below this temperature were badly cracked, had a very poor color, and were soft.
MODULUS OF RUPTURE:

The modulus of rupture was not determined for this clay because of its obvious defects which assured that it could not be utilized in any way.

**A.S.T.M. SPECIFICATIONS:**

<table>
<thead>
<tr>
<th>No.</th>
<th>to core</th>
<th>cold water</th>
<th>Boiling water</th>
<th>Coefficient</th>
<th>Crushing Strength</th>
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<td>01</td>
<td>16.0</td>
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<td>19.0</td>
<td>.83</td>
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</table>
Graph No. 6 Clay No. 4

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 4 occurs as a gray shale bed with an outcrop of more than twelve feet thickness at a road cut on highway 13 about four miles north of Polo. Several hundred yards distant, about ten feet of ferruginous limestone, or clay ironstone, was observed above the shale. This would make mining very difficult. The nearest railroad connection is at Polo.

Chemical analysis of the clay shows over twelve per cent CaO and two per cent MgO, indicating that trouble can be expected during the firing of the clay.

The tests on the plastic properties of the clay show it to be sticky and to have a high drying shrinkage.

The firing behavior test shows no apparent firing range, with all the test bars having nearly uniformly high porosity and low firing shrinkage. The fired color is a dirty red with white specks. Cracks appear much too often in the test pieces. The saturation coefficient and crushing strength are satisfactory for grades Mw and NW building brick according to A.S.T.M. Standards when the clay is fired within the range of cones 09 to 03, however, the poor firing properties indicated by the poor color and the cracks would probably preclude any use of this clay.

This clay is considered worthless for fired ceramic products.
RESULTS OF TESTS ON CLAY NO. 8A

**CHEMICAL ANALYSIS:**

<table>
<thead>
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<th>Loss on ignition</th>
<th>9.00%</th>
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<tr>
<td>SiO₂</td>
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<tr>
<td>MGO</td>
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<tr>
<td>S</td>
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<tr>
<td>Total</td>
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</table>

**PYROMETRIC CONE EQUIVALENT:** P.C.E. No. 5

**WATER OF PLASTICITY:** 20.5%

**SHRINKAGE WATER:** 9.1%

**PORE WATER:** 11.4%

**VOLUME DRYING SHRINKAGE:** 18.4%

**FIRING BEHAVIOR:**

<table>
<thead>
<tr>
<th>Bar</th>
<th>Fired</th>
<th>Burning</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
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<tbody>
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<td>No.</td>
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<td>07</td>
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<td>23.3</td>
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</tbody>
</table>
Graph No. 7    Clay No. 8A

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 84 was taken from the south side of a creek bed about one mile west of Polo on highway 116. It is a bed of gray shale about six feet thick and separated from Sample No. 83 above it by ten inches of lime fossils which are included in Sample No. 83. The shales are covered by the Raytown limestone, and stripping would include two different limestone caps, one of which would be in excess of one foot thick.

The chemical analysis of the clay indicates a CaO and MgO content which is equal to the iron content. This indicates that the clay will not have good firing properties.

The plastic properties are fair, with satisfactory workability and plasticity, however, the drying shrinkage is high.

The firing behavior test proved that the clay is worthless. Nearly all the bars cracked, and many broke, during the firing. The burning shrinkage, when it could be determined, was low, but the porosity was high. The fired color was a dirty red with white specks. The clay was not considered worth testing for A.S.T.M. specifications for building brick.

This clay is considered worthless for fired clay products.
RESULTS OF TESTS ON CLAY NO. 88

CHEMICAL ANALYSIS:
Loss on ignition 12.00%
SiO₂ 50.00
Fe₂O₃ 5.48
TiO₂ 1.00
Al₂O₃ 18.22
CaO 10.06
MgO 2.03
S 0.25
Total 99.14%

PYROMETRIC CONE EQUVALENT: P.C.E. No. 2

WATER OF PLASTICITY: 20.1%

SHRINKAGE WATER: 6.4%

POROUS WATER: 13.7%

VOLUME DRYING SHRINKAGE: 12.6%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>No. to cone</th>
<th>Fired</th>
<th>Burning</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
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<td>18.2</td>
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<tr>
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<tr>
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<td>19.4</td>
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<td>dirty light red, scum, specks, hard</td>
</tr>
<tr>
<td>6</td>
<td>03</td>
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</table>

The test pieces, when fired to temperatures below this, were a dirty light red with white specks. The scum was bad. The test pieces were badly broken up, and because of this, it was impossible to carry out any more tests on this clay.
Clay No. 8B was taken from the same location as Sample No. 8A, it being the upper four feet of the shale bed, and being separated from Sample No. 8A below it by about ten inches of lime fossils. These lime fossils are included in this sample.

The chemical analysis shows the CaO and MgO content to be twice that of the iron, pointing to difficulties in firing.

The plastic properties would be satisfactory as to plasticity, workability, and drying shrinkage. Modulus of rupture was not determined.

However, the firing behavior test proves the worthlessness of this clay. The fired clay had a dirty light red color with white specks. So many bars were broken during firing that it was impossible to get bars which had been fired over a sufficient range to give a graph of the firing behavior, and little indication is observed concerning the type of curve which would be produced.

This clay is considered worthless for any fired ceramic products.
RESULTS OF TESTS ON CLAY NO. 8

CHEMICAL ANALYSIS:

Sample No. 8 is a mixture of one half Sample No. 3A and one half Sample No. 3B.

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 4

WATER OF PLASTICITY: 25.1%

SHINKAGE WATER: 9.7%

PORE WATER: 15.4%

VOLUME DRYING SHINKAGE: 19.0%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>Bar</th>
<th>Fired</th>
<th>Burning</th>
<th>Apparent Shrinkage</th>
<th>Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>to cone</td>
<td>Shrinkage</td>
<td>Porosity</td>
<td>Total Shrinkage</td>
<td>Color, hardness</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>5.4</td>
<td></td>
<td>24.4</td>
<td></td>
<td>Broke in water</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>61</td>
<td>4.5</td>
<td>14.0</td>
<td>23.5</td>
<td>dark red, hard, cracked broken</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>01</td>
<td></td>
<td></td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>01</td>
<td>9.1</td>
<td>12.4</td>
<td>28.1</td>
<td>dark red, hard broken</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>01</td>
<td></td>
<td></td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>03</td>
<td>4.8</td>
<td>18.2</td>
<td>23.8</td>
<td>red, hard</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>03</td>
<td>3.4</td>
<td>16.1</td>
<td>22.4</td>
<td>red, hard, cracked</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>03</td>
<td>1.9</td>
<td>17.4</td>
<td>20.3</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>03</td>
<td>0.4</td>
<td>17.2</td>
<td>19.6</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>05</td>
<td>1.5</td>
<td>14.8</td>
<td>20.5</td>
<td>red, hard, scum, specks</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>05</td>
<td>7.0</td>
<td>17.5</td>
<td>24.5</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>05</td>
<td>2.3</td>
<td>23.0</td>
<td>25.3</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>05</td>
<td>2.2</td>
<td>20.9</td>
<td>23.1</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>07</td>
<td>1.2</td>
<td>21.7</td>
<td>22.9</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>07</td>
<td>plus</td>
<td>21.8</td>
<td></td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>07</td>
<td>3.0</td>
<td>21.1</td>
<td>22.0</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>07</td>
<td>3.1</td>
<td>21.3</td>
<td>22.4</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>09</td>
<td></td>
<td></td>
<td></td>
<td>broken</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>09</td>
<td>2.3</td>
<td>23.6</td>
<td>21.9</td>
<td>red, hard, cracked</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>09</td>
<td>3.4</td>
<td></td>
<td>22.4</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>09</td>
<td>0.4</td>
<td>23.7</td>
<td>19.4</td>
<td>same</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>011</td>
<td>plus</td>
<td>24.0</td>
<td></td>
<td>same</td>
<td></td>
</tr>
</tbody>
</table>

Test pieces fired below this temperature expanded upon being placed in water. The porosity was high and the color a dirty red with white specks.
Graph No. 8    Clay No. 8

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 8 is a mixture of one half Clay No. 8A and one half Clay No. 8B. The clay was tested in this manner because it was felt that separation of the layer of lime fossils which separated the two clays from the clays would be difficult, and the increased thickness of the bed, if both layers of shale could be used together, would increase the value of the deposit.

The plastic properties are average with high plasticity, fair workability, and high shrinkage. The modulus of rupture was not tested.

The firing behavior test shows that this clay has all the bad qualities of both of its components and it is as worthless as either of them. Nearly all the test pieces broke or cracked during the firing or cooling. The color was a dirty red with white specks. A.S.T.M. Standard tests were not run.

This clay is considered worthless for all fired ceramic products.
RESULTS OF TESTS ON CLAY NO. 5

CHEMICAL ANALYSIS:

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss on ignition</td>
<td>3.90%</td>
</tr>
<tr>
<td>S10</td>
<td>75.40</td>
</tr>
<tr>
<td>Fe2O3</td>
<td>3.36</td>
</tr>
<tr>
<td>TiO2</td>
<td>1.00</td>
</tr>
<tr>
<td>Al2O3</td>
<td>14.84</td>
</tr>
<tr>
<td>CaO</td>
<td>0.93</td>
</tr>
<tr>
<td>MgO</td>
<td>0.94</td>
</tr>
<tr>
<td>S</td>
<td>0.07</td>
</tr>
<tr>
<td>Total</td>
<td>100.49</td>
</tr>
</tbody>
</table>

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 14 - 15

WATER OF PLASTICITY: 26.0%

SHRINKAGE WATER: 15.3%

POROSITY WATER: 10.7%

VOLUME DRYING SHRINKAGE: 31.0%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>Bar Fired</th>
<th>Burning Shrinkage</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. to cone</td>
<td></td>
<td></td>
<td></td>
<td>Color, hardness</td>
</tr>
<tr>
<td>1</td>
<td>12 plus</td>
<td>19.7</td>
<td></td>
<td>dirty red, vesicular</td>
</tr>
<tr>
<td>2</td>
<td>12 plus</td>
<td>20.6</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>3</td>
<td>12 plus</td>
<td>21.6</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>4</td>
<td>12 plus</td>
<td>20.8</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>5</td>
<td>10 plus</td>
<td>10.9</td>
<td></td>
<td>blackish gray, hard</td>
</tr>
<tr>
<td>6</td>
<td>10 plus</td>
<td>11.4</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>7</td>
<td>10 plus</td>
<td>15.5</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>8</td>
<td>10 plus</td>
<td>17.9</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>9</td>
<td>8 plus</td>
<td>12.3</td>
<td>38.4</td>
<td>very dark red, hard</td>
</tr>
<tr>
<td>10</td>
<td>8 plus</td>
<td>14.1</td>
<td>39.8</td>
<td>same</td>
</tr>
<tr>
<td>11</td>
<td>8 plus</td>
<td>10.6</td>
<td>40.6</td>
<td>same</td>
</tr>
<tr>
<td>12</td>
<td>8 plus</td>
<td>10.1</td>
<td>36.8</td>
<td>same</td>
</tr>
<tr>
<td>13</td>
<td>6 plus</td>
<td>13.4</td>
<td>36.7</td>
<td>dark red, hard</td>
</tr>
<tr>
<td>14</td>
<td>6 plus</td>
<td>17.1</td>
<td>38.7</td>
<td>same, cracked</td>
</tr>
<tr>
<td>15</td>
<td>6 plus</td>
<td>17.2</td>
<td>35.7</td>
<td>same</td>
</tr>
<tr>
<td>16</td>
<td>6 plus</td>
<td>15.3</td>
<td>35.5</td>
<td>same</td>
</tr>
<tr>
<td>17</td>
<td>4 plus</td>
<td>20.0</td>
<td>31.4</td>
<td>same</td>
</tr>
<tr>
<td>18</td>
<td>4 plus</td>
<td>18.3</td>
<td>32.2</td>
<td>same</td>
</tr>
<tr>
<td>19</td>
<td>4 plus</td>
<td>13.7</td>
<td>34.2</td>
<td>same</td>
</tr>
<tr>
<td>20</td>
<td>4 plus</td>
<td>23.1</td>
<td>33.9</td>
<td>same</td>
</tr>
<tr>
<td>21</td>
<td>2 plus</td>
<td>19.5</td>
<td>32.7</td>
<td>red, hard (very good color)</td>
</tr>
<tr>
<td>22</td>
<td>2 plus</td>
<td>17.5</td>
<td>35.3</td>
<td>same</td>
</tr>
<tr>
<td>23</td>
<td>2 plus</td>
<td>20.8</td>
<td>38.1</td>
<td>same</td>
</tr>
<tr>
<td>24</td>
<td>2 plus</td>
<td>19.0</td>
<td>34.1</td>
<td>same</td>
</tr>
<tr>
<td>25</td>
<td>01</td>
<td>21.8</td>
<td>33.0</td>
<td>good red, hard</td>
</tr>
<tr>
<td>26</td>
<td>01</td>
<td>21.4</td>
<td>34.5</td>
<td>same</td>
</tr>
</tbody>
</table>
Bar Fired Burning Apparent Total Remarks
No. to cone Shrinkage Porosity Shrinkage Color, hardness
27 01 3.4 21.2 34.4 good red, hard
28 01 3.5 20.3 34.5 same
29 03 2.1 20.6 33.1 red, hard, yellowish
30 03 3.2 21.7 34.2 same
31 03 2.3 20.3 33.3 same
32 03 1.2 18.7 32.2 same
33 05 plus 22.5

Clay test pieces fired to temperatures below this expanded when immersed in water. The color was a yellowish red.

MODULUS OF RUPTURE:

The modulus of rupture was not determined on this clay because equipment was not available to make proper test bars by the dry press method, which was deemed to be the only practicable method because of the excessive drying shrinkage with the stiff or soft mud method.

A.S.T.M. SPECIFICATIONS:

These tests were made on a segment of one full size dry press brick which was fired to cone 04.

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Absorption</th>
<th>Saturation</th>
<th>Crushing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold water</td>
<td>Boiling water</td>
<td>Coefficient</td>
<td>Strength</td>
</tr>
<tr>
<td>12.0</td>
<td>13.2</td>
<td>.31</td>
<td>4000</td>
</tr>
</tbody>
</table>

DRY PRESS SHRINKAGE:

<table>
<thead>
<tr>
<th>Per cent water</th>
<th>Linear Drying Shrinkage</th>
<th>Linear Fired Shrinkage</th>
<th>Total Shrinkage</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.25</td>
<td>1.25%</td>
<td>0.73%</td>
<td>1.98%</td>
</tr>
</tbody>
</table>
Graph No. 9       Clay No. 5

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 5 is Kansas gumbotil taken from a road cut on highway No. 13 south of Polo about four miles. The gumbotil occurs within a few feet (in this case ten feet) of the surface of the non-eroded areas. It is missing in the eroded areas. The thickness was not accurately determined because of slumping of the material, and would vary, in any case, over the area.

The appearance of the gumbotil is that of a very sticky gray clay which becomes somewhat friable when dry. Streaks of impurities are apparent, particularly iron staining. Small grains of impurities also appear and the clay is obviously sandy.

The clay is rather difficult to mix with water as it forms a sticky mass. The water of plasticity is high and the drying shrinkage of thirty one per cent is very high. These properties evidence the clay mineral beidellite.

With such a high drying shrinkage, cracks appear in drying, and drying troubles with this clay would surely be great. It is doubtful if the clay could ever be used if it were to be formed by stiff or soft mud methods. However, the firing behavior tests were made on these bars which were formed by the stiff mud method in order to determine the fired properties of the clay. The high P.C.E. of 14 - 15 is very likely due to the excess silica, for at temperatures considerably below this the clay becomes vesicular and the iron has reacted to form dark colored complex silicates. It is difficult to decide on a definite firing range because the porosity is nearly uniformly high and the shrinkage low during the entire range tested. However, color considerations would indicate cone six as the top
limit because of the formation of the complex iron silicates and the resulting dark brown or black colors above this temperature, and cone 01 as the lower limit because below this temperature the iron color is undeveloped and an ugly yellowish red results. Between these limits the color is a good deep red and the hardness satisfactory, although the clay still has a somewhat sandy (grainy) character.

Because of the good color which was developed it was thought that even though the clay cannot be formed by the soft or stiff mud processes, it might have value if it could be dry pressed. This method definitely removes any shrinkage problems, as the total shrinkage is negligible. The clay handles satisfactorily in a dry press when mixed with about six per cent water. Probably less could be used. However, the absorption of the fired clay is too high for any except Grade NW brick, and the saturation coefficient of 0.91 is extremely high. The crushing strength is adequate for any grade brick. Some cracks appeared in the fired brick and this might cause trouble. More tests should be made on the dry pressed bricks to check this tendency to crack.

Since the clay is so plentiful and lies practically at the surface, mining costs would be cut to a minimum, and the use of the clay is enticing. It does appear possible that some use of it can be made for building materials which are not to be exposed to weathering. Also, the high silica content might take very well to salt glazing or some other type of cheap glaze for building bricks. Further investigation should be made in this direction.
### RESULTS OF TESTS ON CLAY NO. 6

#### CHEMICAL ANALYSIS:

<table>
<thead>
<tr>
<th>Loss on ignition</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>S</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00%</td>
<td>74.80</td>
<td>2.99</td>
<td>1.00</td>
<td>15.21</td>
<td>0.30</td>
<td>0.87</td>
<td>0.07</td>
<td>99.74</td>
</tr>
</tbody>
</table>

#### PYROMETRIC CONE EQUIVALENT: P.C.E. No. 15

WATER OF PLASTICITY: 24.7%

SHRINKAGE WATER: 14.5%

PORE WATER: 10.2%

VOLUME DRYING SHRINKAGE: 26.9%

#### FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>Bar Fired</th>
<th>No. to come</th>
<th>Burning Shrinkage</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>plus</td>
<td>13.0</td>
<td></td>
<td>tan, hard, bloated</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>plus</td>
<td>13.1</td>
<td></td>
<td>tan</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>plus</td>
<td>13.1</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>plus</td>
<td>13.1</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>plus</td>
<td>12.6</td>
<td></td>
<td>grayish tan, cracks, hard</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>plus</td>
<td>12.8</td>
<td></td>
<td>same</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
<td>2.5</td>
<td>5.6</td>
<td>31.2</td>
<td>same</td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>4.8</td>
<td>6.0</td>
<td>35.7</td>
<td>same</td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>10.2</td>
<td>7.2</td>
<td>39.1</td>
<td>grayish tan with reddish</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>blotches, hard</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>11.4</td>
<td>8.3</td>
<td>40.3</td>
<td>same</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
<td>9.2</td>
<td>12.1</td>
<td>33.1</td>
<td>same</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>9.5</td>
<td>11.9</td>
<td>33.4</td>
<td>same</td>
</tr>
<tr>
<td>13</td>
<td>6</td>
<td>5.9</td>
<td>15.9</td>
<td>34.8</td>
<td>dark red, hard</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>5.9</td>
<td>17.1</td>
<td>34.8</td>
<td>same</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>4.3</td>
<td>18.1</td>
<td>33.2</td>
<td>same</td>
</tr>
<tr>
<td>16</td>
<td>6</td>
<td>5.1</td>
<td>17.4</td>
<td>34.0</td>
<td>same</td>
</tr>
<tr>
<td>17</td>
<td>4</td>
<td>4.3</td>
<td>18.9</td>
<td>33.2</td>
<td>same</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>4.1</td>
<td>18.7</td>
<td>33.0</td>
<td>same</td>
</tr>
<tr>
<td>19</td>
<td>4</td>
<td>3.5</td>
<td>19.2</td>
<td>32.4</td>
<td>same</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>4.0</td>
<td>19.5</td>
<td>32.9</td>
<td>same</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>3.1</td>
<td>19.7</td>
<td>32.0</td>
<td>medium red, hard</td>
</tr>
<tr>
<td>22</td>
<td>2</td>
<td>3.2</td>
<td>18.4</td>
<td>32.1</td>
<td>same</td>
</tr>
</tbody>
</table>
Bar Fired Burning Apparent Total Remarks
No. to cone Shrinkage Porosity Shrinkage Color, hardness
23 2 3.5 20.4 32.5 Medium red, hard
24 2 3.1 20.6 32.0 same
25 01 1.6 19.9 30.5 red, hard
26 01 3.0 20.6 31.9 same
27 01 plus 21.8 same
28 01 2.3 21.3 31.2 same
29 03 2.3 22.9 31.2 same
30 03 4.6 22.5 33.1 same
31 03 1.1 22.3 30.6 same
32 03 4.3 22.6 33.2 same
33 05 0.0 22.3 28.9 same
34 05 2.2 22.5 31.1 light yellowish red, medium soft
35 05 4.4 22.7 29.1 same
36 05 0.4 22.2 29.6 same
37 07 0.7 23.3 29.6 light yellowish red medium soft.

Test pieces fired below this temperature were soft and had a most unsatisfactory yellowish color.

MODULUS OF RUPTURE:

Modulus of rupture was not determined for this clay for the same reasons as were given for Clay No. 5.

A.S.T.M. SPECIFICATIONS:

These tests were made on a segment of one full size dry pressed brick which was fired to cone 4.

Absorption Absorption Saturation Crushing
cold water boiling water Coefficient Strength
12.3% 15.3% .36 3000

DRY PRESS SHRINKAGE:

Per cent Linear Drying Linear Fired Total
water shrinkage shrinkage shrinkage
5.48% 0.62% 1.34% 1.96%
Graph No. 10  Clay No. 6

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 6 is a Kansan gumbotil taken from a road cut on highway No. 13 a few hundred yards north of the preceding sample. It occurs in the same manner and appeared to consist of a bed a little over three feet thick. The color is a darker gray and quartz pebbles are numerous.

The plastic and fired properties are very similar to those of the preceding clay. The firing range which produces a good color is from cone 03 to cone 6. The dry press body proves to be very satisfactory for grade NW brick.

The same discussion applies to this gumbotil as to the preceding one.
RESULTS OF TESTS ON CLAY NO. 7

CHEMICAL ANALYSIS:

<table>
<thead>
<tr>
<th>Component</th>
<th>Loss on ignition</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.00%</td>
<td>77.80</td>
<td>2.33</td>
<td>0.50</td>
<td>14.57</td>
<td>1.11</td>
<td>0.33</td>
<td>100.54</td>
</tr>
</tbody>
</table>

PYROMETRIC CONE EQUIVALENT: P.C.E. No. 16

WATER OF PLASTICITY: 22.1%

SHRINKAGE WATER: 11.9%

PORE WATER: 10.2%

VOLUME DRYING SHRINKAGE: 24.2%

FIRING BEHAVIOR:

<table>
<thead>
<tr>
<th>No. to cone</th>
<th>Burning</th>
<th>Shrinkage</th>
<th>Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>plus</td>
<td>19.6</td>
<td>27.3</td>
<td>dark tannish red, bloated</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>plus</td>
<td>22.8</td>
<td>25.0</td>
<td>same</td>
</tr>
<tr>
<td>3</td>
<td>12</td>
<td>plus</td>
<td>22.8</td>
<td>25.0</td>
<td>same</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>plus</td>
<td>19.9</td>
<td>27.4</td>
<td>black, hard</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>plus</td>
<td>7.1</td>
<td>25.0</td>
<td>same</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
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<td>6.2</td>
<td>25.0</td>
<td>same</td>
</tr>
<tr>
<td>7</td>
<td>10</td>
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<td>10</td>
<td>plus</td>
<td>12.3</td>
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</tr>
<tr>
<td>9</td>
<td>8</td>
<td>3.6</td>
<td>16.7</td>
<td>27.3</td>
<td>reddish black, hard</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>4.1</td>
<td>17.2</td>
<td>28.3</td>
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</tr>
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<td>11</td>
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<td>12</td>
<td>8</td>
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<td>15.3</td>
<td>31.0</td>
<td>same</td>
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<tr>
<td>13</td>
<td>6</td>
<td>1.4</td>
<td>21.2</td>
<td>25.6</td>
<td>deep dark red, hard</td>
</tr>
<tr>
<td>14</td>
<td>6</td>
<td>1.5</td>
<td>22.2</td>
<td>25.7</td>
<td>same</td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>2.4</td>
<td>21.4</td>
<td>26.6</td>
<td>same</td>
</tr>
<tr>
<td>16</td>
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<td>0.7</td>
<td>20.5</td>
<td>24.9</td>
<td>same</td>
</tr>
<tr>
<td>17</td>
<td>4</td>
<td>plus</td>
<td>23.1</td>
<td>24.2</td>
<td>dark red, hard</td>
</tr>
<tr>
<td>18</td>
<td>4</td>
<td>plus</td>
<td>22.7</td>
<td>24.2</td>
<td>same</td>
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<tr>
<td>19</td>
<td>4</td>
<td>plus</td>
<td>22.4</td>
<td>24.2</td>
<td>same</td>
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<tr>
<td>20</td>
<td>4</td>
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<tr>
<td>21</td>
<td>2</td>
<td>0.4</td>
<td>22.5</td>
<td>24.6</td>
<td>deep red, hard</td>
</tr>
<tr>
<td>22</td>
<td>2</td>
<td>plus</td>
<td>22.9</td>
<td>24.6</td>
<td>same</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>plus</td>
<td>23.0</td>
<td>24.6</td>
<td>same</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>plus</td>
<td>23.0</td>
<td>24.6</td>
<td>same</td>
</tr>
</tbody>
</table>
Bar: Fired Burning Apparent Total Remarks
No. to cone Shrinkage Porosity Shrinkage Color, hardness
25 01 plus 23.5 deep red, hard
26 01 plus 23.1 same
27 01 plus 23.8 same
28 01 plus 23.5 same
29 03 plus 23.5 dark red, yellowish tint, medium hard.

Test pieces fired below this temperature had a high porosity, expansion, and an unsatisfactory color.

MODULUS OF RUPTURE:

Modulus of rupture was not determined for this clay was not determined for the same reasons as were given for Clay No. 5.

A.S.T.M. SPECIFICATIONS:

These tests were made on a segment of a full size brick which had been dry pressed and fired to cone 4.

Absorption Absorption Saturation Crushing
Cold water boiling water Coefficient Strength
12.3% 12.5% .98 5500
12.3% .98 1700

The crushing strength was determined on two separate segments because of the low results on the first one tried. This could have been due to invisible cracks produced in cooling in the particular segment of the brick first selected.

DRY PRESS SHRINKAGE:
Per cent Linear drying Linear firing Total
water Shrinkage Shrinkage Shrinkage
5.34% 0.62% 0.0% 0.62%
Graph No. 11  Clay No. 7

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 7 is a Kansan gumbotil from a roadcut on highway No. 13 about one and a half miles north of Polo. Its occurrence is the same as that of the preceding gumbotils. This gumbotil, however, appears sandier than the others.

The drying shrinkage is the lowest of that of any of the gumbotils, but it is still too great to allow its use by stiff mud forming.

Good color is produced between cones 01 and 6 and this can be considered as the firing range of the clay. The dry press firing shrinkage is zero, the ideal condition. However, this gumbotil falls the farthest short of any of the clays in meeting the A.S.T.M. Standards. The clay is, of course, satisfactory for grade NW brick.

The same discussion applies for this clay as is given for Sample No. 5.
### Results of Tests on Clay No. 9

#### Chemical Analysis:

<p>| | |</p>
<table>
<thead>
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<tbody>
<tr>
<td>Loss on ignition</td>
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<tr>
<td>SiO₂</td>
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<td>Fe₂O₃</td>
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<td>TiO₂</td>
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<td>MgO</td>
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<td>S</td>
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<tr>
<td>Total</td>
<td>100.39%</td>
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</table>

#### Pyrometric Cone Equivalent: P.C.E. No. 13

- Water of plasticity: 25.7%
- Shrinkage Water: 14.6%
- Pore Water: 10.9%
- Volume Drying Shrinkage: 23.2%

#### Firing Behavior:

<table>
<thead>
<tr>
<th>No. to cone</th>
<th>Burning</th>
<th>Apparent Porosity</th>
<th>Total Shrinkage</th>
<th>Remarks</th>
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</thead>
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<tr>
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<td>13.6</td>
<td>tannish red, bloated</td>
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<tr>
<td>2</td>
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<td>plus</td>
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<td>same</td>
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<tr>
<td>3</td>
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<td>same</td>
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<td>same</td>
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<td>10</td>
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<tr>
<td>9</td>
<td>8</td>
<td>11.5</td>
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<td>reddish black, hard</td>
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<td>10</td>
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<td>8.3</td>
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<td>dark red, hard, cracked</td>
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<td></td>
<td></td>
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<tr>
<td>16</td>
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<td>18.9</td>
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<tr>
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<td>7.2</td>
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<td>same</td>
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<td>24</td>
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<td>Total Shrinkage</td>
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<tr>
<td>-----</td>
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<td>---------</td>
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</tr>
<tr>
<td>25</td>
<td>01</td>
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<td>26</td>
<td>01</td>
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<td>27</td>
<td>01</td>
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<td>28</td>
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<td>plus</td>
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<td>7.4</td>
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<tr>
<td>37</td>
<td>07</td>
<td>plus</td>
<td>22.5</td>
<td></td>
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</tbody>
</table>

Test pieces fired to temperatures below this had a very unsatisfactory color and high porosity. They had expanded.

**Modulus of Rupture:**

Modulus of rupture was not determined for this clay for the same reasons as were given for Clay No. 5.

**A.S.T.M. Specifications:**

These tests were made on a segment of a full size brick which was made by dry pressing and was fired to cone 4.

<table>
<thead>
<tr>
<th>Absorption</th>
<th>Absorption</th>
<th>Saturation</th>
<th>Crushing Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold water</td>
<td>Boiling water</td>
<td>Coefficient</td>
<td>.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DRY PRESS SHRINKAGE:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per cent Linear drying Linear firing Total</td>
</tr>
<tr>
<td>water Shrinkage Shrinkage Shrinkage</td>
</tr>
<tr>
<td>7.1% 1.25% 1.35% 2.60%</td>
</tr>
</tbody>
</table>
Graph No. 12  Clay No. 9

Relationship of firing shrinkage and porosity to temperature to which clay is fired.
Sample No. 9 is a Kansan gumotil from a railroad cut several miles west of Polo. The clay has slumped down greatly but appears to be about ten feet thick.

This clay is slightly higher in iron, CaO, and MgO content than the other gumotils, and this shows up in the lower P.C.E. The plastic properties are similar to those of the other gumotils. The test pieces fired between cones 6 and 01 appeared to have the best color, but all the test pieces cracked badly. The clay is the nearest satisfactory for the standards of the A.S.T.M., for the saturation coefficient of .85 is within the limits of grade 2W brick according to these standards. This clay can therefore be used for dry pressed building brick of grades 2W or 3W if the cracking can be controlled.

The same discussion applies for this gumotil as for Clay No. 5.
DISCUSSION OF RESULTS

The plastic properties of all the shales can be considered as satisfactory. They all possess some measure of plasticity and green strength. Certainly this factor would not be of much influence in a choice between these particular clays. While the drying shrinkage of all of the shales might be considered too high, it could be due to the fact that too wet a mixture was used in making the clay trials. Certainly the shales could be dry pressed if this factor were objectionable.

The firing behavior test showed that only shales No. 1, 2B, and 3 can be considered as useful for any type of fired ceramic product. The mixture of Clays 2A and 2B, which is called Sample No. 2, is satisfactory for low grade building brick. These three shales are average high iron, low lime, shales, and their fired colors, appearance, and absorption are good. They have a firing range which is long enough for commercial conditions. From a preliminary surface examination of their location and occurrence, they all appear to be satisfactory for commercial development.

Four of the shales, Clays No. 2A, 4, 8A, and 2B, were found to be completely worthless for any fired ceramic products. All of them developed white specks on a dirty yellowish red background when fired and were broken and cracked during firing. A definite firing range was not detectable in any of them. In all cases this can be traced to an exceptionally high calcium and magnesium content, affirming the contention that lime is the single most harmful impurity in shales.
The gumbo-tills were more of a satisfaction than a disappointment, for little had been expected of them. To the writer's knowledge, they have been neglected completely in all ceramic uses, yet the tests on the dry pressed samples show that they could find limited use for building brick where porosity and absorption are not factors. They have a most pleasing fired color, and have sufficient strength for any use when they are fired to cone 4. Certainly their abundance and accessible location make them enticing from an economic viewpoint.

CONCLUSIONS

The supply of natural gas in the Polo area, which is unused at the present time, could profitably be used if a ceramics industry for the manufacture of common building brick were located in the area. All the requirements for such a project are fulfilled.

There are three different shales which would make satisfactory building brick of all grades, and any of the gumbo-tills would make satisfactory dry press brick of the lowest grade. While none of the clays which were tested occur in deposits of great thickness, they are relatively widespread and the cheapness of fuel would probably balance the slightly higher cost of mining from a thin bed of clay. However, were it not for the cheapness of fuel in this area, the clay of the area would never be used.
APPENDIX A.

LOCATION OF SAMPLES SELECTED

Sample No. 1:

Location: S.E. 1/4, S.W. 1/4, Sec. 19, T 55 N, R 29 W, North side of road cut West of Polo on highway No. 116.

Stratigraphy:

Frisbee:
9. Limestone; gray, shaly, fossiliferous 6 in.
6. Limestone, brown, weathers yellowish 1 ft. 10 in.

Liberty Memorial Shale:
7. Shale, weathers brown 5 ft. 6 in.
6. Coal streak, impure 1 in.
5. Clay, buff 2 in.
4. Coal streak; impure 1 in.
3. Shale, gray, thin bedded, finely micaceous 5 ft. 4 in.
2. Coal; impure 4 in.
1. Clay, buff, structureless 1 plus

Samples beds three to seven as a composite.

Sample No. 2:

Location: S.E. 1/4, S.W. 1/4, Sec. 19, T 55 N, R 28 W. Bank in West wall of creek on Mike Fowler's farm.

Stratigraphy:

Liberty Memorial Shale:
3. Covered, partly shale, slabby sandstone float; 1 ft. 15 in.
7. Shale, hard, gray (sample No. 2-B) 5 ft.
6. Coal, dirty, impure (No. 2 of preceding) 3 ft.
5. Shale, gray, weathers brown, (Sample No. 2-A) 8 ft.
4. Covered interval, probably shale 3 ft.

Raytown:
3. Limestone, gray, fossiliferous 4 ft.

Muncie Creek Shale:
2. Slate, black, fissile 2 ft.
1. covered in creek bottom below

Bed No. 7 is sample 2 B and bed No. 5 is sample 2A. Sample No. 2 is a composite of samples 2A and 2B.

Sample No. 3:

Location: S.E. 1/4, S.E. 1/4, Sec. 29 T 55 N, R 28 W, Draw Northwest of the preceding sample.
Stratigraphy:
Shale under sandstone float, at base six to ten inches are 
black and granular. Probably same shale as in the preceeding 
sample but higher in section.

Sample No. 4:

Location: N.W. Corner, Sec 4, T 55 N, R 28 W, 5"shows in road 
cut on Highway 13 North of Polo.

Stratigraphy:
Section shows more than twelve feet of the twenty five to 
thirty feet of the Cherryvale Shale which occurs in this 
vicinity, of which eight feet were sampled.  Up the road to the 
South, ten feet or more of lens of ferruginous limestone or 
clay ironstone appears in road cut over the shale.

Sample No. 5:

Location: N.W. 1/4, S.W. 1/4, Sec 3, T 54 N, R 28 W. In Ray County, 
6 of a mile south of the Caldwell-Ray County line, on Highway 
No. 13 south of Polo. Taken from road cut, poorly exposed.

Stratigraphy:
Post Kansan:
5. Soil and brown loess 5 ft.
Kansan Gumbotil:
4. Clay, brown, sticky, slight tendency to 
    starchy fracture 3 ft.
3. Clay, brown, gray to white, mottled 1 - 2 ft.
2. Clay, light gray, very plastic, starchy 
    fracture, sandy in places, quartz grains 
    and pebbles numerous in places, grades 
    into till below 2 - 3 ft.
Kansan Till:
1. Till, gray, oxidized and leached.
Sample No. 2 is bed No. 2.

Sample No. 6:

Location:S.E. 1/4, N.E. 1/4, Sec 4, T 54 N, R 28 W. Road cut 
on Highway No. 13 North of preceding sample.

Stratigraphy:
Similar to the preceeding. Gumbotil not much more than three 
feet thick. Darker gray than the preceeding. Quartz pebbled 
numerous.
Sample No. 7:

Location: S.W. ¼, N.W. ¼, Sec 15, T 55 N, R 28 W. Road cut on east side of Highway No. 13 one and one half miles North of Polo.

Stratigraphy:
Similar to the preceding. The sumpotil is sandy.

Sample No. 8:

Location: S.W. ¼, S.W. ¼, Sec 21, T 55 N, R 28 W. South side of draw about a mile west of Polo.

Stratigraphy:
Raytown Limestone:
6. Limestone 1 ft. plus
Muncie Creek Shale:
5. Shale, Black 1.5 ft.
Paola Shale:
4. Limestone, fossiliferous 4 in.
Union Station Shale:
3. Shale with limestone in small masses, fossiliferous in lower ten inches.
(Sample No. 8 B) 4 ft.
2. Shale, gray (Sample No. 8 A) 6 ft.
Cement City:
1. Limestone, buff, upper surface very uneven, fossiliferous. 5 ft. plus.

Sample No. 9:

Location: S.W. corner, N.E. ¼, N.E. ¼, Sec 31, T 55 N, R 28 W. Railroad cut west of Polo.

Stratigraphy:
Sumpotil with same relations as elsewheres. Slumped section, ten feet plus or minus. Bottom poorly exposed.
BIBLIOGRAPHY


VITAL

Clarence Arthur Lambelet was born in Cuba, Missouri, on May 2, 1923, the son of Emile Otto Lambelet and Mabel Meule Lambelet. He attended the Oak Grove District School and the Cuba High School, Cuba, Missouri, graduating from the latter in May, 1939.

He entered the Missouri School of Mines in September, 1939, and graduated with the degree of Bachelor of Science in Ceramic Engineering in January, 1943.

In February, 1943, he entered the Engineer Officer Candidate School, Ft. Belvoir, Virginia, of the United States Army and was commissioned a 2nd Lt. in May, 1943. Army service was with the 249th Engineer Combat Battalion in the United States, and with the 992nd Engineer Treadway Bridge Company and the 1104th Engineer Combat Group in the European Theater of Operations. He was discharged in March, 1946, in the grade of Captain.

He reentered the Missouri School of Mines in January, 1946, to pursue work on a Master of Science degree under a fellowship sponsored by the Missouri Geological Survey.