OKLAHOMA GEOLOGICAL SURVEY

Governor Lee Cruce, State Superintendent R. H. Wilson,
President A. Grant Evans, Commissioners

Chas N. Gould, Director
L. C. Snider, Assistant Director

BULLETIN NO. 7

PRELIMINARY REPORT ON THE CLAYS AND CLAY INDUSTRIES OF OKLAHOMA

By L. C. SNIDER

NORMAN
JUNE, 1911

SCIENTIFIC STAFF

CONTENTS

ILLUSTRATIONS

ACKNOWLEDGMENT

Cuts for this report loaned as follows:

Iowa Geological Survey (Fig. 2.)

West Virginia Geological Survey (Fig. 14.)

C. W. Raymond Company, Dayton, Ohio (Figs. 10, 12, 15, 16 and Plate 2.)

American Clay Machinery Company, Bucyrys, Ohio (Fig. 11, Plates 4, 5 and 7.)

The Stevenson Company, Wellsville, Ohio (Plates 1 and 3.)

Anderson Foundry and Machine Company, Anderson, Indiana (Plate 8.)

Acknowedgement is due to G. H. Brown, Pittsburg, Pennsylvania, for photograph and blue print from which the cuts for plates 9 and 10 were made; and to Professor Edward Orton, Jr. of Columbus, Ohio for the use of classification of clays given in Chapter 1.

CHAPTER I.

ORIGIN AND CLASSIFICATION OF CLAYS

ORIGIN OF CLAYS.

All rocks of the earth's surface may be divided into two great classes, igneous and sedimentary; although a third class, metamorphic rocks, is sometimes recognized. The last is formed from either of the first two, but vary so much from the original rocks that a separate classification is sometimes required. However, they are not important in the clay industries, hence they need little notice in this connection. Igneous rocks are those which have been forced up from the interior of the earth in a molten condition and have cooled and crystallized into their present form, either on or below the surface. Rocks of this nature are granite, diabase and basalt. They compose the cores of most mountain ranges, and, if borings were made deep enough, would be found underlying all the other portions of the earth's surface. All sedimentary rocks, such as limestones, sandstones, shales, gravels, and clays are derived from the weathering or tearing down of igneous rocks.

Of igneous rocks, granite is probably the best known type; so it will be taken here as an example to show how the sedimentary rocks, and especially clays, may be derived from the original rock. The processes and reactions involved in the change of any igneous rock to a clay will be in general similar to those indicated for granites, varying only in detail according to the composition of the rock.

Composition of Granite.

Granite is composed essentially of three minerals; quartz or silica (SiO_2), the transparent hard crystals which form a large part of the stone; feldspar, the pink or gray material softer than the quartz; and hornblende, the dark green or black substance. Mica, a transparent mineral capable of being divided into very thin sheets, commonly known as "isinglass," is usually present in small crystals. Of these constituents quartz is chemically the most simple, being a compound of silicon and oxygen (SiO_2). The feldspars are compounds of silica and alumina with one of the alkalies—potash, or soda—or with lime, or with both soda and lime. One of the most common forms occuring in granite has the formula ($KAlSi_3O_8$) or ($K_2O—Al_2O_3$)—$(SiO_2)_6$. This is the potash feldspar or orthoclase. Hornblende is also an aluminum silicate, but iron and magnesia take the place of the alkalies.

Action of Weathering Agencies.

When an area of granite is exposed to the action of the weather several changes take place. In the first place daily and seasonal changes of temperature cause an unequal expansion and contraction of the different minerals setting up stresses in the rock which cause it to become filled with small cracks and finally to crumble to pieces. This action is greatly hastened by the freezing of water in these cracks, tending to widen them and finally causing the rocks to burst.

The rain water and oxygen of the atmosphere bring about chemical changes. When the rain falls through the air it dissolves out some carbondioxide (CO_2) and forms a weak acid. As has been said, the feldspars are chemical compounds of alumina and silica with potash, soda or lime, or with both lime and soda. When the oxygen and the rain water, carrying CO_2, attack the granite they separate the feldspar into these substances and the oxygen and carbondioxide form compounds with those that are most soluble in water. These are lime, soda and potash. As these compounds are formed they are dissolved and carried away by the water, leaving the compounds of alumina and silica behind as a solid residue, which is known as kaolin or pure clay. The hornblende is similarly acted upon, but, as it contains both iron and magnesia, the iron compounds being insoluble mostly remain behind and the magnesia is carried away. Quartz may be slightly acted upon but for the most part remains as sand. The heterogeneous mixture of the insoluble products of rock decay is called clay.

It should be borne in mind that what has been said is only a general statement for what is really a series of complex chemical changes. Many other minerals occur in the igneous rocks and take part in the reactions giving rise to kaolin, such as andalusite, epidote, leucite, nephelite, sodalite and zoisite. Other insoluble compounds besides kaolin may be formed and remain as impurities, e. g. limonite, magnetite, calcite and gypsum. Some minerals such as mica and rutile, may remain unaltered. Kaolin itself is a general term that includes several closely related compounds of aluminum. Among these are kaolinite, halloysite, cimolite, gibbsite and schrotterite. Of these kaolinite is the most important and gives the name to the group. Although the changes are so complex, the principal tendency of the reaction is to lessen the percentage of lime, soda, potash and magnesia present and to increase that of the aluminum silicates and of the iron compounds.

This change is shown by the following reactions which Van Hise[1] gives for the alteration of the feldspars to kaolinite.

Orthoclase.

$$2K\,Al\,Si_3O_8+2H_2O+CO_2=(H_4Al_2Si_2O_9)+4\;SiO_2+K_2CO_3$$

(Kaolinite)

Albite.

$$2Na\;AlSi_3O_8+2H_2O+CO_2=H_4Al_2Si_2O_9+4SiO_2+Na_2CO_3$$

Anorthite.

$$4CaAl_2Si_2O_8+3H_2O=H_2Ca_4Al_6Si_6O_{20}+H_4Al_2Si_2O_9$$

The same fact is brought out by the following data compiled[2] from G. P. Merrill's "Rocks and Rock Weathering," showing the difference in composition of fresh and weathered samples of the same kind of igneous rock.

Loss of constituent minerals in the decomposition of crystalline rocks.

Constituent	*Gneiss* *Fresh*	*Gneiss* *Decomposed*	*Phonolite* *Fresh*	*Phonolite* *Decomposed*	*Syenite* *Fresh*	*Syenite* *Decomposed*
Silica (SiO_2)	60.69	45.31	55.67	55.72	59.70	46.27
Alumina (Al_2O_3)	16.89	26.55	20.64	22.19	18.85	38.57
Iron oxide (Fe_2O_3)	9.06	12.18	3.40	3.44	4.85	1.36
Lime (CaO)	4.44	Trace	1.40	1.28	1.34	.34
Magnesia (MgO)	1.06	.89	1.42	.44	.68	.25
Potash (K_2O)	4.25	2.40	5.56	6.26	5.97	.23
Soda (Na_2O)	2.82	1.10	7.12	2.65	6.29	.37
Phosphoric acid (P_2O_5)	.25	.47	——	——	——	——
Ignition	.62	13.75	4.33	7.79	1.88	13.61
Total	100.08	99.98	98.28	99.76	99.56	101.00

1. Treatise on Metamorphism, p. 253.
2. Logan, W. N., Bull., No. 2, Miss. State Geol. Survey. p. 34.

Besides the oxygen and carbon dioxide other agents assist in weathering. One of the most important is plant growth, which acts both mechanically and chemically. The roots aid the temperature changes in breaking up the rock by wedging it apart and the acids formed by the roots and by the decay of the plants take part in the chemical reactions. Alkalies may be attacked by subterranean vapor and rock broken down in this way.

CLASSIFICATION OF CLAYS.

FORMS DUE TO METHOD OF TRANSPORTATION.

Indigenous or residual clay. A clay formed from granite or other igneous rock in the manner just described, which remains in place is called an indigenous or residual clay. Since these can only occur in situations which are favorable to chemical disintegration and which at the same time preclude the possibility of the clay being carried away by running water, it is evident that their occurrences must be rare and of limited extent. These residual clays or kaolins, unless derived from a rock containing too much iron, are the purest type of clays. They are white and usually soft and rather greasy to the feel. They are used in the manufacture of pottery, floor tiling, and other products, requiring a high grade, white burning clay.

From the method of their formation it may be seen that they may contain fragments of undecomposed granite, feldspar and quartz, which will increase in amount as the bed rock is approached. The partially decomposed rock is called "Porzellan Erde" by the Germans and is used in the manufacture of porcelain. The kaolins are often freed from these impurities by a washing process which will be described later.

Colluvial clay. The greater part of clay does not remain in place, but is carried away by running water. If it is carried only to the foot of the hill or to the heads of small ravines and built up there, the deposit is called "colluvial" clay. Clay of this nature is usually impure and of small extent. It is sometimes used for brick, but is not an important type on account of the small size of the deposits.

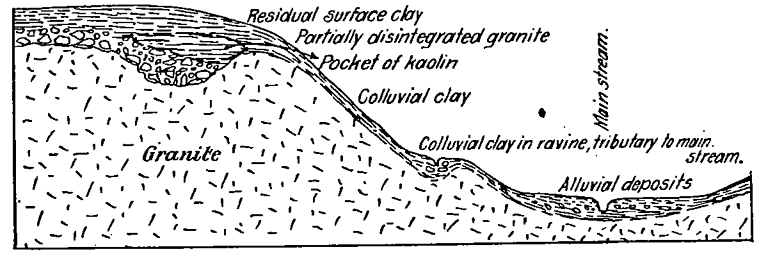


Fig. 1. Formation of kaolin, surface clay, colluvial clay and alluminal deposits from Granite.

Alluvial clay. Another type of clays is formed by streams, which have wide flood plains. In time of flood the water carries large quantities of small particles in suspension, but when the water spreads out over the flood plain and the speed of the current is checked, most of the sediment is dropped. These deposits are known as alluvial gravels, sands and clays. The clays are always impure, being mixed with sand, pebbles and organic matter. The composition and nature of the clay may differ greatly in various parts of the same deposit. Alluvial clays are not worked extensively except where other clays are hard to obtain. None are worked in Oklahoma.

Shales. The finer clay particles remain in suspension for a long period and are carried on to the ocean by the streams. Some of this material may be deposited in the form of deltas, composed of mud and sand more or less mixed. Some of the Redbeds deposits of southwestern Oklahoma and northwestern Texas seem to be delta deposits of the Permian ocean.

The finest portion of the sediment is carried for some distance into the ocean by the currents, but finally settles as a fine soft mud. This deposit increases in thickness and as other layers are deposited on it the pressure consolidates the mud into a rock. If this mud rock is elevated and becomes land it is known as shale. Shales are among the most valuable clay deposits. They usually occur as ledges which may be practically uniform in composition over an extent of many miles. They require grinding before they can be manufactured, but otherwise are easily worked. The shales, which are interstratified with the sandstones and coals of the Carboniferous system, are probably the most important. These are worked extensively for building and paving brick, sewer pipe and other products in Pennsylvania, Ohio, Indiana, Illinois, and Iowa.

Similar shales of the same age occur over most of eastern and southeastern Oklahoma. One advantage of these shales is that they are usually exposed in regions where gas or coal, or both, occur to furnish plenty of cheap fuel. It is on this account that the principal clay plants are located at such places as Muskogee, Boynton, McAlester, Cleveland and Sapulpa.

Shales are described as homogenous, fissile, laminated, slaty, concretionary, or stony according to structure and as ferruginous, calcareous, micaceous, bituminous, carbonaceous, or arenaceous, according as the principal impurity is iron, lime, mica, bitumen carbon or sand.

Residual clay from sedimentary rocks. It has been noted that shales are composed principally of clay matter, but that they may contain impurities such as iron or lime, which often act as cements holding the clay particles together. On the other hand sandstones and limestones usually contain a small per cent. of clay material, which settled w th the sand or with the calcareous sediments while the rock was forming. When these rocks are weathered most of the other substances dissolve and are carried away by the water leaving the clay as a residual deposit. Naturally, shale gives rise to the largest deposits of this residual clay, but limestones, which contain only a fraction of one per cent. of clay matter, when exposed to the weather through long periods of time form clay deposits many feet in thickness. The residual clays from limestones are very stiff, plastic, and usually of a deep red color, due to the iron oxide they contain. The clays from sandstone are very sandy. Those from shale differ from the original rock in the loss of small quantities of soluble material. Such clays are widely distributed. The red surface clays which cover most of central and western Oklahoma are of this type being derived from the shales and sandstones that form the Redbeds.

These residual clays from sedimentary rocks should not be confused with the indigenous clays from igneous rocks which have already been described. The latter are formed in place as the result of chemical reactions. Those from sedimentary rocks are simply the residue of rocks in which the clay remains unchanged while the other constituents have been removed.

Glacial clay. A glacier in passing over a region grinds up and mixes the surface rocks and on melting leaves this material, partially assorted by running water, behind as glacial drift. The clays of this formation are impure, containing many pebbles and glacier worn bowlders of rock. They are seldom uniform in thickness or composition over large areas. Those near the surface are usually leached out and oxidized forming a red bowlder clay, but deeper buried deposits are blue in color. Glacial clays cannot be used for the high-grade refractory products but are extensively used for brick and drain tile in the north-central states where the drift is often 200 to 500 feet or even more in thickness, obscuring all the other clays. No glacial clays are found in Oklahoma.

Loess. Loess is usually considered a wind-blown deposit formed after the glacial invasion and before the land was covered with vegetation. It is a fine-grained clay with a large percentage of very fine sand. It is fitted for common brick and drain tile. No deposits occur in Oklahoma, but it is an important clay in the upper Mississippi Valley, especially in Iowa.

KINDS OF CLAY WITH REFERENCE TO PROPERTIES OR USES.

Joint clays. A very plastic clay whose shrinkage is so great as to cause it to crack may be called a joint clay. When exposed to the weather joint clays break up into small blocks or cubes. Any surface clay may be a joint clay and much of the glacial clay is of this type. Sand is sometimes added to overcome the excessive shrinkage and consequent cracking. Bleininger[1] has shown that the same results may be accomplished by heating the clay to about 250° to 300°C. for several hours before making it up. This may also change the color of the clay and some of its other properties. Some of the surface clays of Oklahoma are joint clays, but there is such a variety of shales and other clays that there is no need of attempting to use those that are likely to give trouble.

Fire clays. Coal miners call all clays that underlie coal veins fire clay, but the term is only properly applied to those clays that hav marked heat-resisting powers. It is true that most of the good fire clays occur under coal veins, but all veins of such clay are not refractory. It is supposed that the growth of the plants, which formed the coal, tended to leach all the soluble salts from the soil that the roots penetrated, and to leave only the more refractory materials. Some of the best fire clays are non-plastic and have to be mixed with other clay before they can be molded.

Slip clays. Slip clays are clays that melt at low temperature and which may be used as a glaze for stone ware and pottery. They are of rare occurrence, the most important deposit in the United States is found near Albany, N. Y., and is known as the "Albany slip."

1. Uni. of Ill. Bull., Vol. VI, No. 25.

Ball clays. Ball clays are very plastic, burn to a white or buff body and are refractory. They are used in the mixture for the higher grades of stone ware and pottery to give plasticity.

Other clays. Stoneware clay, sagger clay, terra-cotta clay, brick clay, glass-pot clay, paper clay etc., are terms applied to clays fitted to the manufacture of the different clay products. They are not used very strictly and the same term may be applied to clays of different appearance and properties

CLASSIFICATIONS BY DIFFERENT AUTHORS.

From the facts which have been noted several classifications of clays based upon origin and, in some cases, uses and properties have been made by different authors. Three of the most important are given below.

Ladd's[1.] *classification.* (Based on origin and occurrence.)

Indigenous.

A. Kaolins.
- a. Superficial sheets.
- b. Pockets.
- c. Veins.

Foreign or Transported.

A. Sedimentary.
- a. Marine.
  - 1. Pelagic (deep water).
  - 2. Littoral (shore deposits).
- b. Stream.

B. Meta-sedimentary.
C. Residual
D. Unassorted

Buckley's[1.] *classification,* (Based on origin.)

I. Residual, derived from
- A. Granitic or gneissoid rocks
- B. Basic igneous rocks
- C. Limestone or dolomite
- D. Slate or shale
- E. Sandstone

1. Geol. Survey of Ga., Bull. No. 6, 1898.
1. Wisconsin Geol. Survey, Bull. VII. Part. II, 1901.

II. Transported by
- A. Gravity assisted by water.
  Deposits near the heads and along the slopes of ravines.
- B. Ice. Deposits resulting mainly from the melting of the ice of the Glacial epoch.
- C. Water. 1. Marine, 2. Lacustrine, 3. Stream.
- D. Wind. Loess.

Orton's[2.] *classification.* (Major divisions on basis of origin, some of the minor divisions on basis of uses and properties.)

CLAYS

Clays are rocks in which the mineral "Kaolinite" is present in sufficient quantity to impart its characteristics to the mass to a sensible degree; and in which no other mineral is present in sufficient quantity to become a source of its commercial supply. Kaolinite is a secondary or derivative mineral formed by the weathering and hydration of various igneous silicates.

FIRST GROUP—PRIMARY OR RESIDUAL

Primary clays are mixtures of kaolinite and other minerals which have been formed on the spot where they now occur by the weathering or "breaking down" of igneous rocks. The proportions of the minerals left, therefore, depend on the composition of the original rock, the extent to which the chemical alteration has progressed, and the opportunities for removal of the products of the weathering process.

A. MASSIVE, OR DERIVED FROM THE WEATHERING OF MASSIVE ROCKS.

I. WHITE OR LIGHT BURNING.

1. **Still hard and preserving a more or less rocky structure.**
   Felspathic rocks which have partially weathered and lost some of their alkali, without becoming clay-like. Example-Corn wall Stone used by English potters. Fusible or vitrifying to a porcelain-like body. Insoluble in ordinary acids. Non-plastic.

2. This classification is a rearrangement of that used by Prof. Edward Orton, Jr., in his classes in Ceramics at Ohio State University, and is published here by his permission.

2. Soft and clay-like.

Kaolins, china-clays and "paper-clays." These occur only when igneous rocks rich in felspathic minerals occur in a situation favorable to decay and also unfavorable to erosion. Such clays are therefore relatively rare and valuable. Their alkali has been almost wholly removed. Infusible, insoluble in ordinary acids, and usually soft and crumbling. When worked up with water, they are generally not very plastic or tough. Shrinkage in firing excessive. When any mineral detritus is left undecomposed, it generally consists of angular grains of quartz or flakes of white mica.

II. COLORED BURNING, RED OR YELLOW.

1. Hard and rock-like.

Not used as an ingredient of clay mixtures and hence not discussed here.

2. Soft and clay-like.

The product of the weathering of rocks originally containing ferrous silicates. These clays are stained in all degrees by ferric hydroxide. They are usually more fusible than kaolins, give up iron readily to acid solvents. Are not very plastic and show high shrinkage in firing. Frequently contain much coarse mineral detritus. These clays are not often valuable for practical purposes.

B. FAINTLY STRATIFIED OR DERIVED FROM THE WEATHERING OF STRATIFIED LAYERS OF COMMINUTED IGNEOUS ROCKS.

Volcanic ash beds, frothy tuff, and scoriae, which are ejected in separate eruptions, and fall in successive showers. They are sedimented and to some extent sorted by the atmosphere, the finest portions being carried to great distances. When they settle they weather to clays with exceptional ease and rapidity, and often still show the roughly stratified character of the original beds. Frequently contain soluble silicic acid. Sometimes light-colored or white, oftener containing enough iron to prevent their use for other than common purposes. When they contain any coarse or unweathered minerals, these show the volcanic nature of the original material, as they are angular, generally glassy, and but little crystallized. These deposits are of large extent in Texas, and in the Northwestern States, and Canada.

SECOND GROUP—SECONDARY

Secondary clays are mixtures of kaolinite and other minerals in which the assortment and proportions are due to the transportation and sedimentation. They do not often represent the product of decay of any single rock, but are generally the blended products of decay from many rocks and from large areas, assembled chiefly by water and sorted while in transit.

A. TRANSPORTED BY AIR, OR WIND-BLOWN CLAYS.

1. LOESS. Believed to be formed by the gradual shifting of fine clays and sands by winds in arid districts. This view is contested by some who consider them of sedimentary origin. All loess clays are not adequately explained by either theory, but the first has the most adherents. Fine, very sandy clays, fragments usually somewhat sharp and not water-worn. Occurring in beds of great thickness without horizontal stratification planes. Remains of land animals and plants frequently found embedded at all levels. Clays form vertical or bluffy banks, when cut by streams. In some places the streams form canons with vertical walls. Vegetation leaves vertical root casts filled with lime or fire clay, perforating the clay in great numbers. Largest occurrence in China, and in West and Northwestern prairies of the United States.

B. TRANSPORTED AND SORTED BY RUNNING WATER AND DEPOSITED AS SEDIMENTS FROM STILLER WATERS.

I. DEPOSITED FROM COMPARATIVELY STILL, QUIET WATERS LIKE THE OCEANS, LAKES, AND PONDS.

I. Light Burning Clays—White or Buff (excepting the calcareous variety.)

a. Ball clays.

Kaolins in composition but secondary in origin. Have been transported and sorted by water, but without contamination with ferruginous sediments.

Generally the distance over which they have been moved is small.

a_1. PLASTIC.

Impure or Semi-Ball Clays.

Diluted with other minerals contained in the original kaolins. Contain 50 to 90% Kaolinite. Balance usually pure white quartz or white mica. Prepared for commerce by washing i. e. sedimentation and concentration of clay substance. Color, white, opaque. Fracture, earthy. Plasticity generally good but inferior to next group. Difficult to vitrify. Illustrations: Florida Kaolin bed and S-E. Missouri kaolins.

Pure or Real Ball Clay.

Separated by sedimentation from practically all other minerals. Contain 90 to 98% kaolinite. Characteristics: Highly refractory but can be vitrified at white heat. Most plastic of all clays. Great strength and bonding power. Frequently colored with organic matter. Fracture conchoidal but not consolidated to point of loss of plasticity. Illustrations: English No. 4 Ball Clay, and Mayfield, Kentucky Ball Clay.

a_2. PLASTICITY REDUCED OR ENTIRELY WANTING.

Hard or Semi-Flint Clays.

Modified kaolinite or clays in which the clay base consists of a mixture of kaolinite and other allied silicates of alumina like Pholerite, Halloysite, Rectorite, Newtonite, Allophane, and Indianaite. These silicates modify the structure, making the fracture conchoidal and often making the clay translucent on thin edges. Plasticity generally reduced tho' some become eminently plastic if finely ground with water. Shrinkage in drying, often great, in burning, always great. Not usually valuable except as refractories. Illustration: Hard kaolins of Alabama. Indianaite, etc.

b. Fire clays.

Burn yellow and buff, never white. Believed (a) to be clay once impure and ferruginous but since purified by growth and decay of vegetation. (b) Sediments similar to (1) but contain a little more iron and not enough alumina to wholly mask its color.

b_1. NON-PLASTIC REAL FLINT CLAYS.

Allied by appearance and behavior with white burning clays of conchoidal fracture. Exactly similar to Halloysite but lacking the pearly luster and translucency. Plasticity either wholly lacking or so low as to require the use of other clays as a bond. Composition: Practically pure Kaolins. Often 95 to 99% clay substance. Shrinkage very great—crack badly in burning—none at all in drying. Highly valuable as a refractory material. Occur in Ohio and Penna. interstratified with coal measures. In Missouri—in pockets and sinkholes in limestone of various ages. Ascribed by Wheeler to presence of Pholerite replacing Kaolinite.

b_2. PLASTIC OR BOND CLAYS.

Clays of high plasticity and bonding power without inordinate shrinkage. Fracture, stony or earthy, never conchoidal. Occur commonly interstratified with coal measures, but sometimes occurring in large beds independently of the carboniferous formation.

1. Refractory or Fireclays Proper: Composed principally of clay substance mixed with quartz and hence vitrify slowly and only at very high

temperature. They are similar to ball clays, except that their clay substance is invariably yellow-burning. Believed to have been brot to present purity by leaching out of impurities from an originally impure mass, while ball clays have never been impure. Amount of iron may be same in both, but its distribution or effect is different which suggests different origin.

2. Non-refractory or No. 2 Fireclays—Composed of clay substance with variety of minerals which make vitrification easy at low temperatures. Iron may be present plentifully but always disseminated in granules or concretions which appear as specks or blotches on burning but which never change the buff matrix of the clay. Occur chiefly as under clays of coal veins in Carboniferous, but in some cases occur massive in beds unassociated with coal strata.

2. Red or Pink-Burning Clays including those calcareous clays which burn yellow or greenish-yellow

a. Shales.

Clay sediments, generally of considerable geological age deposited in still deep waters and generally in beds of great extent and thickness. They compose the largest clay masses in existence, generally much hardened by heat and pressure. Highly developed fissile structure. Initial plasticity small, but develops by working. Generally fine-grained and homogeneous, but sometimes full of concretions which lower their value greatly. They vitrify at low temperature to dense bodies, becoming exceedingly tough and strong if properly annealed in cooling. Otherwise, they become brittle and glassy. The shales are of very great importance as a source of wealth and industrial development.

a_1. Schists.

Metamorphic, crystalline, non-hydrous rocks supposed to have been derived from shales by heat and pressure. Bonded structure is only remaining tie to sedimentary origin. Valueless as a clay material.

a_2 Slates.

Hard, stony shales, partially by heat and pressure but still retaining some clay nature. Fissile structure most perfectly developed. Used as a roofing material without burning. Not used in clay working except in very small degree. Composition like shales but almost deficient in plasticity. Burning properties like shales.

a_3 Shales (proper). Classified according to the nature of their chief diluting material; as:

1. *Clay shales.*

High in kaolinite, but not pure enough for use as kaolins. Composition that of fire clay, but structure that of shale. Rather rare. Rakonitz shale, of Silesia. is best example.

2. *Sandy or Siliceous Shales.*

The commonest group of all. All degrees of sandiness from soft plastic clay like shales to hard stony rocks of the variety known as "Freestones" which contain only a few per cent clay.

3. *Calcareous Shales.*

Varying from 1 or 2 per cent lime in Carboniferous formations to shaly limestones in the Silurian and Devonian formations in Ohio. Usually valueless if the lime exceeds 4 or 5 per cent.

4. *Ferruginous Shales.*

The iron in ordinary shales runs from 4 to 7 per cent and is very constant, representing the average or blend of the component minerals of which the shale is made. By concentration or chemical pre cipitation it may increase till the shale becomes an ore of iron. The "clay-iron-stone" of England is an example.

5. *Bituminous Shales.*

Ordinary shales contain from 1-2 to 2 per cent carbon. "Black" shales contain 4 to 6 per cent as a minimum and increasing to 60 or 80 per cent in "bone-coal." This carbon may be granular in which case it does not much affect the character of the shale; or bituminous, when it hardens the shale greatly and makes it like a slate; or graphitic, when it makes the shale soft and flaky, but not brittle.

a_4 Bedded or Joint Clays.

Soft plastic clay strata whose deposition has been like that of shales but which are too recent to have been hardened by heat or pressure. "Young" shales. Chemical hardening also less than shales but may be present to some extent. Working properties fine. Burn like shales. Valuable, but generally rather rare.

b. Bog Clays.

Impure clay-sediments, collected in shallow or stagnant waters and marshes. Generally of recent geological age. Beds generally of small extent and non-continuous. Clays soft and unconsolidated except where acted upon by chemical agencies. Massive, without fissile structure. More influenced by chemical precipitation than any other class of clays. Precipitates may be diffused or concretionary. Working properties and behavior in burning variable with composition and generally poor. Small economic value.

b_1 Ferruginous.

Ochery Deposits. Red or yellow, raw and after burning. If Manganese is present, color

is brown forming Umber or Sienna. Iron sometimes becomes so high as to make "bog-iron ores." Clays of this class, generally worthless, except for paints and colors.

b_2 Calcareous.

Containing marly or concretionary deposits of lime and magnesium carbonates. Generally useless, but occasionally burn to even buff color and used for porous bodies, filters, etc. Gypsiferous clays, containing large crystals of Selenite.

b_3 Carbonaceous.

Spongy, peaty, or lignitic clays. Full of partially decomposed vegetable remains. Generally undesirable.

c. Residual Clays.

c_1 Left from limestone, saline, and gypsum beds after removal of soluble portions by percolating waters. Full of debris indicating kind of rock removed. Usually red. Worthless as clays. Good soils.

c_2 Shales and hard clays weathered into soft clays and soils. Former structure obliterated. Valuable as clays. Poor soils.

d. Alluvial Clays.

Recent clays deposited along present drainage systems. Soft unconsolidated and generally massive-fissile structure slight if any. Plastic, easily workable, burning much like shales. Very little chemical precipitation or concretionary growth. Valuable compared to shales but of small extent.

II. DEPOSITED FROM RUNNING WATER.

1. *Sandy Clays.*

Generally plastic clays which are weak when dry and easily crumble. Burn red or dark and vitrify at low heats and melt at high temp. When they contain vegetable mold are called loam.

2. *Clayey Sands.*

Generally plastic but are without cohesion when wet or dry. Wares made from them lose their shape. Burns red or dark and stands great heat.

C. TRANSPORTED BY ICE WITHOUT OPPORTUNITY FOR SORTING.

I. SEMI-GLACIAL

Glacial debris which has been more or less transported or sorted by water. Along the edge of an area where glacial agencies are at work there are usually numerous lakes, ponds, rivers, etc., whose existence is temporary and shortlived. By those the glacial debris is more or less reworked and sorted and classified into clays, sands, gravels, bowlders, etc. The clays vary from the finest possible sediments, like the famous Albany slip, up to sediments so coarse and sandy as to be no longer called clays. They cannot always be identified as glacial clays by studying a hand sample but can be identified as glacial by observing their geological occurrence and the nature of the other rocks among which they occur. Even the finest-grained glacial clays, often contain occasional coarse pebbles or boulders, dropped into them by floating ice, while in similarly fine-grained sedimentary clays this would be very unusual.

II. GLACIAL

Bowlder Clay or Till.—A mixture of all sorts of mineral debris; angular rock fragments, worn or rounded boulders, gravel and fine clay sediments, together with remains of vegetable or animal life. In some places, chemical reactions have produced new minerals in the mass which were not present in the original deposit.

CHAPTER II.

CHEMICAL PROPERTIES OF CLAYS

Complexity of Composition

From what has been said regarding the origin of clays it is easily seen that they must be of complex nature. Any clay may be regarded as at some stage of decomposition of the rock from which it has been derived. The process may have gone only far enough to break down the more easily altered constituents of the parent rock while the more resistant remain practically unchanged. Or the process may have continued until all the minerals have been more or less affected.

Transported clays have been mixed with mineral matter foreign to the parent rock and also contaminated with organic matter. Under these circumstances it is not surprising that most clays and shales are mixtures of several mineral constituents and that different clays or shale from the same area differ very much in composition.

Mineral Constituents.

The following substances are not all of the constituents that may be found in clays but are those which are the most common and which affect the working or burning properties of the clays.

Kaolin. This substance is a hydrated silicate of alumina, expressed by the formula $Al_2\ O_3$, $2Si\ O_2$, $2H_2O$. This formula represents the mineral kaolinite. There are other closely related minerals which may be grouped with kaolinite under the term kaolin. Kaolinite is a white to gray colored mineral of earthy texture. It crystallizes into plates, but is seldom found in the crystallized form in nature. Kaolinite may be regarded as the essential constituent of clays since the property of plasticity seems to be directly connected with this mineral and since it is also responsible for most of the refractory properties.

As a rule the clays having the highest percentage of kaolinite are the purest and most refractory and are white burning. Kaolinite is regarded as being present in all clays, although it is usually in such a finely divided condition that it cannot be detected with the microscope and, owing to the complex composition of clays, it cannot be separated in the pure state by chemical methods.

Water. After the clay has been thoroughly dried in air there always remains a small percentage of water mechanically held by the clay. This is called hygroscopic water and is driven off at 100° to 110°C. If the clay is exposed to the air again it takes up the same amount as it gave off. Water also exists in the combined state in kaolinite and some other minerals such as gypsum and the hydrated oxides of iron. This is not driven off until a temperature of 500° to 600°C. is reached and it cannot be taken up again.

Silica. Silica (SiO_2) is present in clays in two forms, free as quartz or sand, and combined as various silicates as kaolinite, feldspar. hornblende and mica. Sand may be present in proportions varying from 2 to 3 per cent in fire clay to 30 or 40 per cent in impure brick or tile clays. It is derived from the quartz grains of the parent igneous rock. Sand in coarse grains lessens the plasticity and shrinkage of clays and increases the porosity of the dry and burned ware. When added to very pure clays it acts as a flux and lowers the fusion point. When added to impure clays it usually has the opposite effect.

Feldspars. The feldspars have been discussed in connection with the origin of clays. They are more abundant in clays in which the parent rock has not been completely decomposed, but they are present in small quantities in almost all clays. They furnish the alkalies, soda and potash, which act as the most active fluxes in burning.

Mica. Mica occurs commonly in two varieties; the white mica, muscovite, and the black mica or biotite. Muscovite is a silicate of potash and alumina and biotite a silicate of iron, magnesia and alumina. Biotite is rather easily decomposed and is seldom found in transported clays on account of the length of time during which such clays have been subjected to the weathering agencies, while muscovite is very resistant and occurs very commonly in shales and other transported clays as bright, shiny flakes. Muscovite in burning, decomposes and furnishes alkali which acts as a flux. In some way the alkali deepens the red color in iron bearing clays and produces very dark reds.

Iron Compounds. Iron may occur in clays in several minerals. In the ferrous state it occurs principally as the carbonate, siderite ($FeCO_3$). This may occur disseminated evenly through the clay or as kidney-shaped concretions. In burning the carbonate liberates carbon

dioxide and sets free the ferrous oxide (FeO), which is a very active flux.

In the ferric state iron may occur as the oxides, hematite, and magnetite; the hydroxide, limonite; the sulphide, pyrite or marcasite; the silicates, mica and hornblende; and with titanium as the oxide ilmenite or menaccanite.

Magnetite rarely occurs in clay. Hematite is responsible for the red color of most of the red clays and shales and for the deep red color of burned clays. Limonite gives the yellowish and brownish color to raw clays. During the burning, the combined water is driven off and limonite is converted into hematite. The sulphides, pyrite and marcasite, occur as aggregates of cubical crystals. They give off part of the sulphur at rather low temperatures and are converted into the ferrous sulphide, (FeS). This is an extremely active flux. If the clays containing pyrite or marcasite are exposed to the weather, the minerals are oxidized to form iron sulphate. This is soluble and if sufficient water is present it will be carried away in solution. If it is not entirely removed it will be brought to the surface and upon the evaporation of the water will remain behind as a white incrustation. This may often be seen upon the exposed surfaces of ledges of shale containing pyrite where there is considerable evaporation.

Iron sulphide exerts an extremely bad influence during the burning process. When it is necessary to use shales containing pyrite in considerable quantities some method of removal is ordinarily resorted to.

This may be accomplished by exposing the shale to the weather for some time—several months—before it is used. The removal may be hastened by wetting the clay at frequent intervals. This not only hastens the oxidation of the sulphide to the sulphate, but also carries away the latter as fast as it is formed. In addition it removes other soluble salts which may be present.

Ilmenite or menaccanite seems to have no pronounced action. The action of the different iron compounds in burning is considered more fully in the succeeding chapter.

Calcium Compounds. Calcium occurs as the silicate in the plagioclase feldspars and other minerals; as the carbonate ($Ca\ CO_3$) as calcite or limestone; as the sulphate, gypsum, ($Ca\ SO_4\ 2H_2O$) and as the phosphate $Ca_3\ (PO_4)_2$. The carbonate may be formed by the precipitation from solution or it may be present as fragments of limestone, or, in shales and marls, may be found as fragments of the shells of the sea animals that settled to the bottom as the shale or marl was formed. It would appear that residual clays from limestone should contain appreciable quantities of the carbonate, but it is usually so completely removed that the clay contains none or only a trace. The phosphate is not important as a constituent of clays for industrial purposes, but is an essential constituent of soils as it supplies the phosphoric acid, which is required by plant growth.

In burning, the carbonate is broken down into the oxide (Ca O) or lime and carbon dioxide. When the burned ware becomes wet the lime slakes and swells. If the lime is well disseminated this causes no damage, but if it is in large pieces, and is near the surface of the burned ware, it produces a spalling or peeling off of the surface. If sufficiently large pieces of lime are deeply imbedded in the body of the ware the stress set up when they take on moisture may be great enough to disrupt the burned ware. At higher temperatures lime acts as an active flux, and combines to form a complex silicate with iron and alumina. This silicate is yellow in color and, if the lime in the clay is in excess of the iron, this yellow or buff color may mask the red due to the iron.

Calcium sulphate or gypsum is a common constituent of many of the clays in western Oklahoma. It is slightly soluble in water and is carried to the surface of the ware in the drying process and deposited as a scum or efflorescence on the surface. This causes a white discoloration of the burned ware known as "whitewash."

Magnesium Compounds. The occurrence of magnesium is very similar to that of lime. It occurs as the silicate in mica and hornblende, and as the carbonate and the sulphate. The action in burning is very similar to the corresponding calcium compounds except that magnesium is a less active flux and its compounds do not shorten the vitrification range so much as the lime compounds.

Alkalies. Soda and potash are never found free in clays but are usually combined as silicates in the feldspars and micas.

Titanium Compounds. Titanium has been mentioned as occurring with iron in ilmenite or menaccanite. It also occurs as the oxide, ($Ti\ O_2$) rutile. Neither of these compounds play an important part in the drying or burning of the clays.

Manganese Compounds sometimes occur in clays in the form of the oxide, pyrolusite. It seldom occurs in sufficient quantity to have any marked effect during the burning. Occasionally, however, there

is enough present to produce a noticeable brown coloration in the burned ware. This is true of some of the sandy clays of southeastern Oklahoma.

Organic Matter. All transported clays become mixed with more or less organic matter. Residual clays often contain roots of plants. Shales are often bituminous due to the decomposition of the plant and animal matter, which settled to the bottom of the ocean and was included in the mud which forms the shale. The organic matter may mask the color due to the iron and usually gives the deep black colors although some reds are due to organic material. Organic matter burns out in the early stages of the burning of the clays and if present to the extent of several per cent., may give rise to much difficulty.

CHEMICAL ANALYSIS

In the ordinary chemical analysis of clays the different constituents are broken down into and reported as, the oxides of the metals or bases present. On this account it is called the ultimate analysis. The following constituents are usually reported in an analysis of this kind:

Silica ($Si\ O_2$)	Magnesia ($Mg\ O$)
Alumina ($Al_2\ O_3$)	Potash ($K_2\ O$)
Ferric Oxide ($Fe_2\ O_3$)	Soda ($Na_2\ O$)
Lime ($Ca\ O$)	Loss on ignition.

The loss on ignition comprises the hygroscopic and combined water, any carbon dioxide present in carbonates and the organic matter. In some clays it is necessary to estimate the sulphur trioxide (SO_3) which is contained in the sulphates of calcium ond magnesium. Occasionally determinations are made of the oxides of titanium ($Ti\ O_2$) and of manganese ($Mn\ O_2$), but the amounts of these are usually small and are ordinarily included with the iron. Sometimes a distinction is made between ferrous and ferric iron. The methods of analysis may be found in several of the reports upon clays issued by the Federal and State Geological Surveys. Among them may be mentioned Vol. XIV of the Iowa Geological Survey and Bulletin 176 of the United States Geological Survey.

Value of chemical analysis. The ultimate chemical analysis has usually been regarded as of value in determining the properties of clays and much time and money have been expended, especially by the state surveys, in having such analyses made.

Ries gives the following as the facts to be obtained from the ultimate analysis of a clay[1].

"1. The purity of the clay, showing proportions of silica, alumina, combined water and fluxing impurities. High grade clays show a percentage of silica, alumina, and water, approaching quite closely to those of kaolin.

"2. The refractoriness of the clay, for other things being equal, the greater the total sum of fluxing impurities the more fusible the clay.

"3. The color to which the clay burns. This may be judged approximately, for clays with several per cent. or more of ferric oxide will burn red, provided the iron is evenly and finely distributed in the clay, and there is no excess of lime. The above conditions will be effected by a reducing atmosphere in burning, or the presence of sulphur in the fire gases.

"4. The quantity of water. Clays with a large amount of chemically combined water sometimes exhibit a tendency to crack in burning ad may also show high shrinkage. If kaolinite is the only mineral present containing chemically combined water, the percentage of the latter will be approximately one-third that of the percentage of alumina, but if the clay contains much limonite or hydrous silica the percentage of chemically combined water may be much higher.

"5. Excess of silica. A large excess of silica indicates a sandy clay. If present in the analysis of a fire clay, it indicates low refractoriness.

"6. The quantity of organic matter. If this is determined separately, and it is present to the extent of several per cent., it would require slow burning if the clay was dense.

"7. The presence of several per cent. of both lime (Ca O) and carbon dioxide (CO_2) in the clay indicates that it is quite calcareous."

On the other hand many prominent ceramists do not put any trust in the chemical analyses of clays except of the purest fire clays and kaolins[1].

The principal objection is that the impure clays are very complex mixtures of different minerals and that the chemical analysis in which these minerals are broken down into and reported as the simplest oxides

1. Geol. Survey of N. J., Vol. 6, 1904, pp. 50-51.
1. Purdy, R. C., Ill. State Geol. Survey, Bull. No. 9. 1908, pp. 200 et seq.

has no value in revealing the true mineralogical composition of the clay.

For example it cannot be determined how much of the alumina was present in the kaolin, and how much in feldspar, mica, or other aluminous silicates: the potash and soda may have been present in mica or in various feldspars and would have different effects according to the compound in which it was held, but the ultimate analysis does not reveal this; the iron is reported as ferric oxide while it may have been present as the hydroxide, ferrous oxide, ferrous carbonate, pyrites, or in mica or other silicates and the effect of the iron would depend very largely upon its compounds. Each of the constituents can be taken up in a similar way.

Even if the mineralogical composition were known, the fluxing effect of so many constituents upon each other could scarcely be prophesied with our present knowledge. The effect of the different proportions of minerals upon the melting point of a mixture has been worked out for several simple cases, but nothing is known which would lead to an accurate forecast of the melting or vitrification point of such heterogeneous mixtures as the impure brick or tile clays and shales.

While the statements given by Ries are certainly true there are so many conditioning factors and approximations that it seems not worth while to make chemical analyses to judge the fitness of clays for the ordinary clay products.

Certainly no ceramist or practical clay worker would attempt to prophesy any of the following points from the ultimate analysis of the clay:

1. Actual temperature of maturity, vitrification, and fusion.
2. The exact drying and burning shrinkages.
3. The color (with any degree of accuracy as to shade).
4. The rate of drying.
5. The porosity or absorption of the burned ware.
6. The rate at which ware must be fired.
7. The actual difficulties encountered such as cracking and warping in drying and burning.

Since all of these points are of great importance in the working of a clay and since an accurate knowledge of them cannot be gained by chemical analysis, but can be by making test pieces and burning them in a kiln or small furnace, the value of the ultimate chemical analysis is certainly not commensurate with the expense and labor which it entails.

CHAPTER III.

PHYSICAL PROPERTIES OF RAW CLAYS

Introduction.

The physical properties of raw clay, which may effect its working or burning qualities, are as follows: plasticity, bonding power, specific gravity, tensile strength, shrinkage, porosity, slaking, fineness of grain. feel and color. In this chapter these qualities will be noted together with the different tests applied to clays to determine them.

PLASTICITY.

Definition

The chief quality which separates clay from other mineral substances, is its plasticity. By this term is meant the clay's power to be moulded into any shape while wet and the retention of this shape in the dry condition with sufficient strength to permit its being handled without breaking. It is this property that gives clay its value in the various industries and without which it would be worthless for most purposes to which it is put. The plasticity varies with several factors, but seems to be absolutely controlled by none of them. Among these factors are fineness of grain, amount of sand or other impurities present, amount of working or kneading which the clay has undergone in wet condition (irrespective of fineness of grain thus obtained), and the shape of the clay particles.

THEORIES OF PLASTICITY.

As this property is so important in clay working it seems worth while to go into the various theories of its origin at some length. The theories advanced base the plasticity of the clay on one or more of the following causes:

(a) Molecular attraction between the particles.
(b) Presence of chemical or combined water.
(c) Fineness of grain.

(d) Shape of the clay or kaolinite particles.
(e) Presence of non-crystalline inorganic compounds or colloids.
(f) Presence of adsorbed salts. This may be regarded as one phase of (e).

(a) The Molecular Attraction Theory.

This theory briefly stated is: in the wet condition the clay is plastic because the molecular attraction between the grains is sufficient to act through the film of water which separates them and to hold them in a definitely shaped mass; further, the molecular attraction of the clay molecules for those of the water renders the water film viscous, and causes it to act as a lubricant allowing the clay particles free motion with respect to each other. When the clay dries the removal of the water from between the grains allows them to come closer together thus increasing the force of the molecular attraction. This accounts for the greater tensile strength of the clay in the dry condition.

The theory supposes that the strength of the molecular attraction varies with the composition of the molecule, so as to account for the difference of plasticity in primary and secondary clays. This reasoning is evidently closely related to the fineness of grain theory as the grains must be very small for the molecular attraction to act between them with sufficient force to produce the observed effects.

This theory of molecular attraction has been worked out most completely by Grout[1], who has proved in the case of the fine-grained clays that the molecular attraction is more than sufficient to hold the amount of water necessary to develop plasticity. Purdy[2] summarizes Grout's arguments as follows:

"1. Attraction varies with the nature of the grains, i. e. their chemical constitution, or in other words, molecular structure.

"2. Films become viscous as a result of molecular attraction, the more strongly attracted film being the more viscous.

"3. Organic colloids increase plasticity by rendering the water film viscous.

"4. The tendency for tensile strength to vary with plasticity is explained by molecular attraction between grains.

"5. Change in viscosity or in thickness of film is beyond the region of experiment."

1. Jour. Am. Chem. Soc., Vol. XXVII, No. 9, Sept. 1905, and West Virginia Geol. Survey. Vol. III, 1905.
2. Ill. State Geol. Survey, Bull. No. IX, 1908, p. 179.

Purdy makes the objection that if other than the finest grained clays are taken, the amount of water, which can be held by molecular attraction, is much less than that required to develop plasticity. This is shown by determining the fineness of grain by mechanical analysis and calculating the amount held by the particles by the law of molecular attraction. Only one clay of several to which the scheme was applied showed a calculated amount of water sufficient to develop plasticity.

(b) Chemical or Combined Water.

Since kaolin is a hydrous aluminum silicate, and since when the chemical water is driven off by heat, the plasticity of the clay is destroyed and cannot be restored, it has been suggested the combined water is the source of the plasticity. If this were the case, however, other hydrous aluminum silicates and other minerals containing combined water should develop plasticity. Experiments have been performed by many investigators and none of these hydrous minerals have developed true plasticity. Wheeler[1] obtained plasticity in brucite, the hydrate of magnesia, by fine grinding, but Cushman[2] failed to obtain similar results with the same mineral. Crystallized gypsum, hydrous calcium, sulphate, also becomes plastic when ground and shows a high tensile strength when dry, but this is undoubtedly due in a large measure to the solution of some of the gypsum in the water and its recrystallization when the water evaporates.

From all the evidence it seems that the presence of combined water cannot be the prime cause of plasticity and that the destruction of plasticity with the loss of the combined water is not due to the loss of the water but to other changes that take place at about the same temperature.

(c) The Fineness of Grain Theory.

This theory has arisen from the fact that in the mechanical analysis the finer material is reported as clay substance while the coarser is reported as sand. Since the plasticity of the fine material greatly exceeds that of the coarser it was supposed that it was due primarily to the fineness of grain. However, it has been proved that the coarser materials contain much clay matter not disintegrated by the process of mechanical analysis. When this coarser material is ground in a mortar or when it is worked and kneaded it develops plasticity. This

1. Mo. Geol. Survey, Vol. XI.
2. Trans. Am. Cer. Soc., Vol. VI, 1904.

seems to strengthen the idea that the plasticity is due to the fineness of grain, but, as will be shown later, it probably only brings about conditions in which the real cause may come into play.

The strongest argument against the theory and one that seems to prove conclusively that fineness of grain alone cannot cause plasticity is that materials other than clays, no matter how finely ground, do not develop true plasticity. Glass has been ground so fine that it remained suspended in water for several hours and yet when collected show no plasticity. Similar experiments have been tried with many other substances but only in kaolinite substances is true plasticity developed. Although the finer grained clays are usually the more plastic and although clays are usually rendered more plastic by fine grinding, the fact that there are many exceptions to both rules seems to prove that fineness of grain is not the sole cause of plasticity but is a conditioning factor.

(d) Plate Structure Theory.

It has long been recognized that clays are partially made up of particles having a plate like or lamellar form. Owing to the extremely small size of these plates their mineralogical character cannot be determined even with the highest powers of the microscope, but it has been assumed that these plate like particles are kaolinite and that the other particles, which are too small to show definite shape under the microscope, still possess the plate structure. In many cases, however, it is probable that the plates are micaceous.

The adherents of this theory hold that particles having this shape would move over each other with less resistance and would also lie closer to each other and thus produce a greater molecular attraction than they would if the grains were angular or spherical. It has been observed that the more plastic clays had a greater percentage of the plate-like particles and that the particles were smaller than in the less plastic clays.

Wheeler[1] has also shown that minerals possessing a plate-like structure, such as feldspars, gypsum, calcite or slate when finely ground developed some plasticity and possessed considerable strength when dried.

In the case of the calcite and gypsum part of this strength, as already mentioned, is due to the slight solubility of the substance and

1. Mo. Geol. Survey, Vol. XI.

to the formation of interlocking crystals as the water dries out. The feldspars must be ground wet to develop plasticity[1] as dry ground feldspar simply wetted is not plastic. The water in which the feldspar is ground becomes alkaline, showing that chemical changes take place during the grinding. The resulting plasticity may be due more largely to the nature of the substances resulting from these changes than to the plate structure of the feldspars. Slate is itself a consolidated clay and the grinding probably restores it to its original condition. It may be that the plate structure of the particles increase the plasticity and that the presence of angular grains lessens it, but it is not apparent that plates themselves are the principal cause of plasticity. From these considerations it seems that the plate structure is, like the fineness of grain, a conditioning factor rather than the cause of plasticity, and that the wearing down of angular or spherical grains to plates has accompanied the building up of another condition which will be considered in the following paragraphs.

(e) The Colloidal Theory[2].

This theory holds that the plasticity of clays is due to the presence of non-crystalline substances which form a coating over each of the clay particles.

The presence of colloids in clays was first shown by Schloesing[3] in 1874. He removed the carbonates by digestion with weak hydrochloric acid and washing, and then observed the portions that settled in different lengths of time. He found that at the end of 27 days 0.69 grams out of a sample of 40 grams remained in suspension. When this matter had stood 29 hours after being precipitated, it occupied a volume of 146 c. c. When dried over calcium chloride it became a "broken film, horny, slightly translucent, adhering strongly to the porcelain." There was very little cohesion in the other portions of the sample. Similar results have been attained many times since by different investigators.

Nature and Forms of Colloids.

Colloids are non-crystalline or amorphous bodies. They may be either organic or inorganic; examples of the first sort are gelatine, glue, and humic acids; of the second are hydrated silicates, silicic acid, and

1. Cushman, A. S., Trans. Am. Cer. Soc., Vol. VI, 1904.
2. For the most complete reviews of the literature on this theory see Bull. 388, U. S. Geol. Survey, by Harrison Everett Ashley.
3. The Constitution of Clays, Compt. Rend., Vol. 79, 1874.

water glass. Bodies ordinarily crystalline may take on colloidal form and those ordinarily colloidal may crystallize.

Colloids may exist in one of two conditions: (1) the sol, a homogeneous suspension in a liquid, (2) the gel, a continuous jelly with pore walls and pores filled with liquid. In some colloids these two forms are reversible and the colloid may pass from one to another and back any number of times. The process of changing from sol to gel is called coagulation and from gel to sol is deflocculation. An example of a reversible colloid is ordinary gelatine, which will change from the gel to sol form on heating and back to the gel form cooling any number of times.

Irreversible colloids are those, which may pass from sol to gel, but which cannot be made to resume the sol form. This process is called setting and the result is a set gel.

Ashley[1] mentions the following colloids as occurring in clays: hydrated, gelatinous aluminum silicates; gelatinous silicic acid; organic colloids; hydrated ferric oxide, and, rarely, aluminum hydrate.

On drying, colloids decrease greatly in bulk, yet still retain their sponge-like structure and some water. The latter can be driven off by heating, but is again taken up on cooling. This accounts for the hygroscopic water of clays.

Application of the Colloidal Theory to the Behavior of Clays.

Bleininger[1] in working on methods for the utilization of the very plastic joint clays of Illinois found that the plasticity and shrinkage were greatly decreased by heating the clay at 200° to 300°C. for some time before making up. This may be explained by supposing that some of the colloids are "set" while others are unaffected at this temperature. Such a temperature is not sufficient to drive off any of the combined water or to cause any chemical change in the clay, and it certainly cannot affect either the fineness of grain or the plate structure in any way.

If the colloid is dried and then subjected to great pressure the moisture ordinarily retained in the pores is driven out. The water is taken up again very slowly just as a sponge that becomes perfectly dry must be immersed and "worked" in a liquid before it will absorb it.

1. U. S. Geol. Survey, Bull. 388, p. 9.
1. Uni. of Ill. Bull., Vol. VI, No. 25, 1909.

This is supposed to be the case of the flint fire clays. They have been consolidated under such pressure that the water ordinarily remaining in the colloids is pressed out and is not readily taken on again. The theory is strengthened by the fact that flint fire clays will become plastic if ground in water for a sufficiently long time. Another fact bearing on this theory is that feldspar if ground dry and then made wet shows very little plasticity, while if ground in water it develops true plasticity. In the latter case the water acting on the finely ground feldspar for some time forms a hydrated silicate or silicic acid in the colloidal form.

The ageing of clays for use in some industries also illustrates this point. The clay used for making glass pots is pugged carefully, thrown into pits and tramped in, then allowed to stand for months to develop its best plasticity. It is well known that shales allowed to weather are usually more plastic than when brought fresh from the bank.

The colloids of clay are irreversible, that is, when they take on the gel form they cannot be turned back into the sol. This change from the sol to the set gel is supposed to take place at about the temperature at which the combined water is given off. This explains why clays heated above that temperature lose their plasticity and cannot regain it. It is difficult to see how heating the clay to this temperature could change the fineness of grain or plate structure or molecular attraction as to totally destroy the plastic properties.

On the whole, the trend of research in the past few years seems to show that the prime cause of plasticity in clays is the presence of colloids. The fineness of grain and plate structure may be important conditioning factors since besides increasing the molecular attraction, they would regulate the amount of surface to be covered by colloids, and consequently the amount of water with adsorbed salts which can be held by the clay. The fineness of grain is also a measure of the amount of mechanical disintegration which the clay has undergone. The greater part of this disintegration has taken place in the presence of water, the condition which is favorable for the production of the colloidal forms of the aluminum silicates and the gelatinous silicic acids.

The mineral substances, which easily take on the collodial form, are hydrated compounds. This fact may account for the theory that the presence of chemical water is the cause of plasticity. However, as has been already mentioned, many hydrated compounds, those which do not readily pass into the colloidal form, do not develop plasticity e. g. brucite, analcite and thomsonite.

(f) The Adsorption Theory.

Adsorption is that property of clays and other colloidal substances which enables them to take crystalline salts from solutions and hold these salts in themselves with such tenacity as to prevent their being washed out with water. It is this property which enables soils to hold the ammonia, phosphate, etc., from being washed away before it is given up as demanded by plant growth.

All clays contain appreciable quantities of adsorbed salts. As is well known, the presence of salts renders water more viscous and it is believed by many that these adsorbed salts increase the viscosity of the water films surrounding the clay particles to such an extent that it is true cause of plasticity.

The theory that adsorbed salts cause plasticity is closely related to the colloidal theory, since it is the colloidal substances which possess the power of adsorption.

Measures of Plasticity.

The ordinary way of judging of the plasticity of clay is by the feel of the wet material between the fingers. This method is in continual use in practice, but unfortunately gives no definite standard for the comparison of different clays.

Some experimenters have undertaken to show that the tensile strength of the dry clay is directly proportional to the plasticity. This is true in general, but there are many instances where a moderately plastic clay will give abnormally high tensile strength and very plastic clays will give lower values than would be expected. The latter may be due to the great shrinkage of very plastic clays and consequent tendency to crack in drying.

Ladd[1] used an arrangement consisting of two sheet iron troughs with perforated bottoms through the center of which are test-tube brushes. The troughs, which are mounted on wheels, are brought so the brushes touch and then clay is sifted on the wet brushes until a bar is formed. The pull necessary to break the bar is measured by weights attached to a pan connected to one of the troughs. This

1. Clays of Georgia, p. 52.

method takes no account of the amount of water added and is of little value for this reason.

Ashley[2] has worked out a method of measuring the colloid matter of clay by the adsorption of dyes, (malachite green.) He found that the plasticity of high grade clays varied with the colloid matter present. This has not been tried on the impure brick and tile clays.

Bleininger[3] has investigated the viscosity of slips made by mixing different percentages of clay and water. He found that the addition of very small amounts of clay actually decreased the viscosity of the water, but further additions increased the viscosity. The rate of increase in viscosity depends upon the plasticity of the clay, i. e. the addition of a given amount of a plastic clay will cause a greater viscosity than the addition of an equal amount of a less plastic clay. This property, when fully worked out may give a definite standard for the comparison of the plasticity of different clays but so far this has not been done.

Grout[1] considers plasticity as involving two variable factors: (1) Amount of possible flow before rupture and (2) Resistance to flow or deformation.

In determining plasticity the clay was mixed, tempered and forced through a cylindrical die 2 c. m. in diameter, and cut into 5 c. m. lengths. These cylinders were placed vertically under a movable plate capable of being loaded with weights as desired. The amount of weight (in 100 grams) necessary to shorten the cylinder one-half centimeter was taken as the factor representing the resistance to flow or deformation. The compression was continued until cracks at about 45° from the vertical axis appeared and the weight (in 100 grams) necessary to produce the cracks was taken as the measure of amount of possible flow before rupture. The product of the two factors represented the measure of plasticity. By this method the clays of West Virginia were found to have plasticities of from 1 to 30.

SPECIFIC GRAVITY.

If the specific gravity of a lump of clay is taken as a whole, it is evident that it will vary with the method of formation of the lump, the degree of saturation, etc. Specific gravity taken of the clay lump

2. U. S. Geol. Survey, Bull. 388, 1909.
3. Trans. Am. Cer. Soc., Vol. 10, 1908.
1. W. Va. Geol. Survey, Vol. III, 1905, p. 41.

is called the apparent specific gravity. If the specific gravity of the particles themselves is taken the result is the true specific gravity.. The apparent specific gravity of a piece of dry clay is equal to the weight divided by the volume.

There are several methods of determining the true specific gravity. The following method is used in the laboratory of the clay products division of the Bureau of Standards at Pittsburg, Pa.

Heat the clay (screened through 10 mesh sieve) at 100°C. for one and one-half hours, and weigh out 50 gr. in a closed cylinder.

Determine the weight of dry Kjeldahl flask, with a mark on the neck to show volume of about 150 c. c. and with a wire to attach it to the balance. Fill with water up to the mark, take temperature and weigh.

Put 50 grams of clay slowly into the flask one-half filled with water. Attach the flask to a suction (Bunsen pump) and boil the contents for five minutes by immersing the flask in a beaker of warm water. Cool under tap and fill up to mark with cold water. Dry the outside of the flask carefully and weigh. Take the temperature of the water immediately after weighing.

Calculations. Weight of (flask+50 gr. of clay+water)—(weight of flask+50 gr. of clay)=weight water required to fill flask to mark when clay is present=(a). (Weight of flask+water to mark)—(weight of flask)=weight water required to fill flask to mark=(b). (a) and (b) after corrections for temperature may be regarded as volumes of water. Then b—a equals the true volume of the clay particles—Call this c.

$$b - a = c \qquad \frac{50}{c} = \text{sp gr. of clay.}$$

The apparent specific gravity is usually regarded as having no value in indicating any of the working properties of a clay. The true specific gravity has not yet been definitely correlated with any of the working properties, but it is used in calculations for other properties and serves as a check on other determinations.

TENSILE STRENGTH.

The tensile strength tests on clays are valuable as indicating the amount of cohesion between the clay particles in the dry condition. Upon this property depends the resistance of the dry clay to crumbling, to rubbing off, to breaking when handled and to pressure when set in kilns.

The test is usually made by forming briquettes in the molds used for making cement briquettes. These molds are filled by pressing in the stiff clay with the fingers and striking the surface level with a knife or wire. A second method[1] consists in mixing the clay to a thick slip and pouring on a plaster slab. When it has dried to the consistency of stiff mud it is cut into briquettes by a thin cutter, similar to a biscuit cutter, and pressed into the briquette molds by a plunger. This method does away with much of the variation due to the personal factor in the first method.

After being dried the briquettes are broken in a Fairbanks Tensile Strength Machine, and the tensile strength recorded in pounds per square inch.

No tensile strength tests were made on the Oklahoma clays.

DRYING SHRINKAGE.

The water, which is taken up by a clay when it becomes plastic (water of plasticity), may be regarded as being in two conditions, (1) pore water or the water which fills the pores existing in the dry clay, and (2) shrinkage water or the water that forms films around the grains of the clay separating them from each other. In drying the water is evaporated from the exposed surfaces and the grains move closer together. The water moves outward from the interior of the pieces of ware through the pore system and is evaporated from the surface. The condensation or shrinkage of the clay will continue as long as there is any water between the grains. After all the shrinkage water is removed, the pore water is slowly removed by evaporation from the surface and outward movement from the interior through the capillary pore system.

The amount of shrinkage, which takes place in a clay in drying, is important in several respects. The dies and molds used in forming the ware must be large enough to allow the shrinkage (both in drying and burning) to take place and still have the product of the desired size. The energy and time required to evaporate the water in the process of drying are very important items. Excessive shrinkage is usually accompanied by warping or cracking of the ware. This feature

1. Ill. Geol. Survey, Bull., No. 8. ——, 163.

may be so pronounced as to render a clay altogether useless for manufacturing purposes.

The amount of shrinkage of a clay depends on the amount of water required to make it plastic, which in turn depends largely upon the fineness of grain and the amount of colloidal matter present. The extremely plastic, fine-grained clays may require water equivalent to 30 per cent of the weight of the dry clay to make it sufficiently plastic to work, while coarsely ground shales and very sandy clays may require only 12 to 15 per cent or even less.

Measurement of The Linear Drying Shrinkage.

The linear drying shrinkage may be determined by measuring the length of dry pieces or briquettes in the wet and dry conditions, or by making marks a definite distance apart on the wet pieces and measuring the distance between the marks when the pieces are dried.

The drying shrinkage is then calculated by the following formula:

$$\text{Linear drying shrinkage in per cent of wet length} = \frac{100\ (\text{Wet length} - \text{dry length})}{\text{wet length.}}$$

$$\text{Linear drying shrinkage in per cent of dry length} = \frac{100\ (\text{Wet length} - \text{dry length})}{\text{dry length}}$$

The linear drying shrinkage varies from 12 to 13 per cent of the wet length in very plastic clays to practically zero in very sandy clays.

Measurement of Volume Drying Shrinkage.

The volume drying shrinkage may be calculated from the linear shrinkage.

The following table gives the calculated volume shrinkage when the linear shrinkage is determined:

%L. S.	%V. S.	For. 1% L. S.	% L. S.	%V. S.	For. .1% L. S.
1	2.97	.285	9	24.64	.246
2	5.88	.285	10	27.10	.24
3	8.73	.28	11	29.50	.235
4	11.53	.273	12	31.85	.230
5	14.26	.268	13	34.15	
6	16.94	.262	14	36.36	
7	19.56	.256	15	38.25	
8	22.08	.252			

The third column gives the correction to be added to the volume shrinkage for each .1 per cent of linear shrinkage in excess of the lower number e. g.

8.7 per cent. linear shrinkage=22.08+(7 times .252)=23.84 per cent. volume shrinkage. The table can be used only in calculating the volume shrinkage in per cent. of the *wet* volume when the linear shrinkage is given as per cent. of the wet length.

For the ordinary purposes the method of calculating the volume shrinkage from the linear shrinkage is sufficiently accurate, but, since any mechanical error in determining the linear shrinkage is increased by the calculation, the calculated volume shrinkage may vary somewhat from the true volume shrinkage. Where the true volume is desired it is determined by displacement of some liquid as follows:

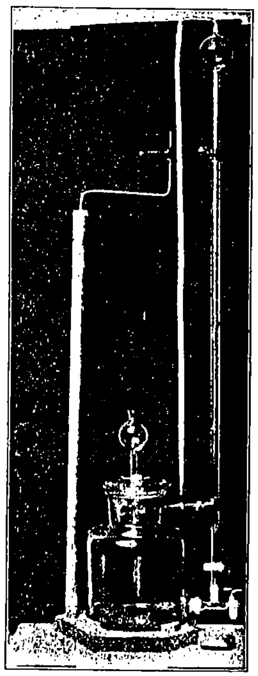


Fig. 2. Seger Volumeter.

The apparatus used for this determination is the Seger Volumeter (fig. 2[1]). "The volumeter consists of a glass jar with a capacity of about four litres, having a broad mouth closed with a ground glass stopper. Through the center of the stopper is a cirular opening into which fits the ground end of a short glass tube. The latter expands into a bulb a few inches above the stopper and is again contracted to small diameter beyond the bulb. The interior of the jar is thus open to the outside through this small tube, into which the liquid will rise when the jar is filled. Near the base of the jar is a glass stop cock, connected above with a long burette graduated to tenths of a cubic centimeter of 125 cubic centimeters capacity. The upper end of the burette expands to a bulb that serves as a reservoir for the liquid when drawn upward through the burette. To the bent portion of the tube above the bulb is connected rubber tubing of convenient length to use in drawing the liquid into the burette. On the glass tube inserted in the stopper of the jar, just beneath the expanded portion, at the level of the zero in the graduations on the burette is a mark. When the stop cock in the lower part of the burette is open and the jar is filled with liquid up to

(1) By permission of Iowa Geol. Survey.

the mark on the small glass tube, the liquid will stand at the zero point in the burette."[2]

To use the volumeter the jar is filled with water (in the case of substances dissolved or disintegrated by water some liquid by which they are not affected must be used) to the zero marks. The liquid is then drawn by suction through the burette into the bulb at the top and the stop cock closed. The stopper is removed, and the piece whose volume is to be determined is placed in the jar, care being taken not to splash out any of the liquid. The stopper is replaced and the stop cock opened allowing the liquid to flow back into the jar until it reaches the zero mark on the tube above the stopper and the stop cock closed. The amount of liquid remaining in the burette represents the volume which has been displaced by the piece introduced into the jar and can be read directly from the graduations on the burettes.

Where the pieces are larger than 125 c. c. some of the liquid must be drawn from the burette through the lower stop cock into a measuring flask or graduated cylinder, so as to bring the top of the liquid column down into the graduated portion of the burette so it can be read. The number of cubic centimeters drawn off is then added to the burette reading to determine the volume.

Water may be used for determining the volume of burned clay, but for the wet or dry pieces some other liquid, usually kerosene, is used. In any case the pieces, whose volume is to be determined, are soaked in the liquid used for a sufficiently long time to fill the pore space so that there will be no absorption of the liquid in the volumeter. After the wet and dry volumes have been obtained the volume shrinkage is determined in the same manner as the linear shrinkage.

$$\text{Vol. Shrinkage in per cent. of wet vol.} = 100\,\frac{(\text{wet vol.} - \text{dry vol.})}{\text{wet vol.}}$$

$$\text{Vol. Shrinkage in per cent. of dry vol.} = 100\,\frac{(\text{wet vol.} - \text{dry vol.})}{\text{dry vol.}}$$

Cracking in drying. The removal of the water from between the grains of the clay and the consequent condensation and shrinkage sets up a stress as the clay trys to adapt itself to the new condition. If the shrinkage water be large in amount and the shrinkage very great the strain may be sufficient to cause warping or cracking of the pieces of ware. The cracks in stiff mud ware show along the lines of lamina-

(2) Beyer and Williams, Iowa Geol. Survey, Vol. XIV, p. 108, 1903.

tion produced by the auger machine, but in some clays a cube-like structure is developed by the ruptures. Naturally the tendency toward cracking in drying is much greater in very plastic clays than in those which are less plastic.

The remedies for cracking fall into two divisions: (1) to allow the clay to adjust itself to the excessive shrinkage by drying it at a very slow rate; (2) to change the nature of the clay by adding non-plastic substances or by heating.

Various methods are used to reduce the rate of drying such as conducting the drying in closed rooms, and keeping the ware covered with wet cloths. The amount of retardation of the rate of drying is necessarily governed by the tendency of the particular clay to crack and the kind of ware being produced.

Sand or other non-plastic material may be added to decrease the shrinkage and consequent cracking. Sand is very often added to the clay in the manufacture of soft mud brick. Saw-dust or coal dust may be added to clays used for terra-cotta lumber—both to reduce the shrinkage and to produce a porous body in the burned ware.

Bleininger and Layman[1] in working with the plastic joint clays of Illinois found that the plasticity, shrinkage and amount of cracking were greatly reduced by subjecting the clay to a temperature of 200° to 300°C. for a few hours. This process could be used for almost any of the extremely plastic clays although further work has shown that all clays do not respond equally to the treatment. By installing rotary dryers clay could be dried at the temperature required at a cost of 10 to 15 cents per ton of bank clay. This increased cost of production will prohibit the use of this preliminary treatment in localities where it is possible to procure clays which may be worked without it.

BONDING POWER.

This is the property of clay which enables it to hold non-plastic material and render the whole mass plastic. The more plastic clays usually have greater bonding power; but there are some exceptions. The bonding power of a clay is very important in some industries, especially the manufacture of fire brick, and of some other refractory wares as the clay must hold large quantities of non-plastic, refractory material. There is no method of testing the bonding power of a clay except simply trying it by mixing it with non-plastic material and de-

1. University of Ill. Bull., Vol. VI, No. 25. 1909.

termining the amount that can be added without reducing the plasticity below the point where the ware can be handled with safety.

POROSITY.

The amount of pore space in the raw clay has been considered by different authorities as giving evidence of the fineness of grain, amount of water required to develop plasticity, rate of drying, etc., but the data collected do not show any constant relation between the porosity and any of the other properties. It seems that the size of the pores as well as the total amount of space occupied by them has an important bearing on the drying properties, but this feature has not been determined experimentally.

For example, if two clays contained an equal percentage of pore space, the space in one may be distributed as a vast number of almost microscopic openings between the grains while in the other clay the pores might be smaller in number but the individual pores relatively larger. The working and drying properties of the two clays would of course be very different.

The porosity may be obtained in three ways.[1] (1) By Volumeter. The briquette of dry clay is thoroughly saturated in oil or some liquid which does not attack the clay and the volume determined. The weight of the briquette is determined before and after saturation. Then per cent of porosity $=100\frac{(W-D)S}{V}$ where W=weight of saturated briquette, D=weight of dry briquette, S=density of saturating liquid, and V=volume of briquette as determined in the volumeter.

(2) By the chemical balance. The dry briquette is weighed, then saturated with a liquid which does not affect it and the weight of the saturated briquette and of the briquette suspended in the same liquid are taken.

Then per cent. of porosity—$100\frac{(W-D)}{(W-S)}$ where W=saturated weight, D=the dry weight, and S=the suspended weight of the briquette.

(3) By calculation from the true specific gravity of the clay and the weight and volume of the dry briquette.

1. Purdy, R. C., Ill. Geol. Survey, Bull. No. 9, pp 141-142.

The true volume of the clay particles $= \frac{\text{Dry weight}}{\text{Sp. Gr. (true)}}$

Volume of pore space (V_p)=Vol. of briquette (V_b)—Vol. of clay particles (V_c).

Per cent of pore space $= 100 \frac{(V_p)}{(V_b)} = 100 \frac{(V_b - V_c)}{(V_b)} =$

$100 \frac{(1 - V_c)}{V_b}$ where $V_c = \frac{\text{Dry weight}}{\text{Sp. Gr.}}$

Since it has been found that the porosity of the raw clay does not give any definite indication as to its working or drying qualities it was not deemed necessary to make the determination upon the clays tested for this report.

SLAKING.

If a lump of surface clay be placed in water it almost immediately crumbles into a shapeless mass. This is called slaking. Shales also slake, but usually require a much longer time. Indurated shales and flint fire clays may not slake appreciably in the time allowed for laboratory experiments. The rate of slaking may be taken as an index of the amount of grinding and working necessary to develop plasticity, the clays that slake faster being more easily prepared.

FINENESS OF GRAIN.

By fineness of grain is meant the size of the mineral particles as they occur in the clay. The different sizes of the particles and the proportion in which they are present is determined by mechanical analysis.

In mechanical analysis the particles of different sizes are separated by one of three methods. In any of these processes the clay is previously disintegrated by prolonged shaking in water.

(1) The length of time required for particles of a goven size to settle after the clay has been thoroughly stirred up with water is determined. A sample of the clay is then stirred up with water and allowed to stand until the coarser particles have settled to the bottom. The supernatant liquid with the finer particles is then poured off and allowed to settle for another period of time and the process repeated until the clay is divided into the number of divisions required.

(2) The sample is placed in a can and a current of water, which will carry out the smallest particles, is passed through the can from the bottom. After the particles of the smallest size are washed out and collected, the current of water is increasel to the rate required to carry out the next larger size of particles and so on.

(3) The sample is mixed with water and placed in a test tube in a centrifugal machine and rotated at a rate sufficient to throw out the largest size of particles. The liquid with the smaller particles in suspension is poured into another tube and rotated at a rate sufficient to throw down the next larger size and so on.

The clay may be divided into any number of divisions with reference to the size of the particles, but the following classification is often followed:

Particles	from	.00	to	.005	m. m.=clay.
"	"	.005	to	.02	m. m.=silt.
"	"	.02	to	.15	m. m.=fine sand.
"	"	.15	to	5.0	m. m.=coarse sand.
	Above			5.0	m. m.=gravel.

While all the particles less than .005 m. m. in diameter are reported as clay substance there is always considerable fine sand in this division and there is also some clay in the coarser divisions.

The fineness of grain of clay is closely related to many of its working and burning qualities such as plasticity, porosity and rate of drying, tensile strength, shrinkage and warping or cracking, temperature of fusion and vitrification range. Other things being equal, the finer grained the clay, the more water is required to make it plastic, and the smaller is the pore space. This causes a greater shrinkage in the fine-grained clays and a slower rate of drying as the water can only move out through the small pores very slowly. The surface dries rapidly and contracts around the wet interior causing considerable strain and tendency to warp and crack. The finer grained clays, however, possess a greater inherent strength than the coarser grained clays and this may be sufficient to overcome the tendency toward cracking.

The finer grained clays heat up more rapidly in the kiln and also melt more rapidly, since the different minerals in the finely divided condition can exert a greater fluxing action upon each other than when they occur in larger pieces. This fact renders the finer grained clays harder to oxidize. The interchange of the gases formed in the interior of the ware (carbon dioxide and water vapor) and the oxygen bearing kiln gas can only proceed slowly through the fine pores and the surface is liable to vitrify and close the pores completely before the process is complete, and thus produce "black coring."

In view of the close relation between the fineness of grain and the working and burning properties, the mechanical analysis very often gives valuable indication of the behavior of the clay. The actual working behavior in commercial processes however, is likely to be considerably different from those indicated by the mechancal analysis, probably due to the fact that the disintegration in preparation for mechanical analysis, is much more complete than is accomplished in the preparation of the clay in pug mills or wet pans. In the latter process aggregates of small particles may remain cemented together and act as large particles, that in the mechanical analysis would be separated and reported as finer material.

Since the tests made upon the clays for this report consisted in a determination of the actual working and properties, it was not considered necessary to make mechanical analyses.

FEEL.

By the feel of the dry clay the approximate amount of coarser sand present may be determined. By testing between the teeth the presence of fine sand also becomes apparent. The working qualities of the wet clay can be told by the feel of the plastic mass between the fingers. This is the only test used by the experienced clay worker to tell when the clay is ready for the machine.

COLOR.

The colors of clays grade from pure white through grays and pinks to blacks and reds. The principal coloring matter of clays is iron in some form. The gray, green and black shales usually contain the ferrous forms of iron, while the reds contain the ferric form. The blacks and even some of the reds, are due to the presence of organic matter which masks the color due to the iron.

While it is occasioally possible to prophesy the burned color from the color in the raw state, it cannot be done accurately; the color after burning usually has no relation to that of the raw clay.

CHAPTER IV.

THE CHEMICAL AND PHYSICAL CHANGES IN THE BURNING OF CLAYS(1)

CHEMICAL CHANGES IN BURNING OF CLAYS.

INTRODUCTION.

The changes, which clays undergo in burning, take place in three stages, dehydration, oxidation and vitrification. It is not to be understood that these three stages are distinct and separate from each other or that these are the only operations that may take place in burning. On the contrary oxidation may begin before dehydration is complete and continue until vitrification has well advanced. There may also be interpolated stages due to variations of conditions in burning, as reduction and reoxidation or "flashing." Some of these minor reactions are necessary to successful burning; some seem to have no influence on the result; while others are harmful and are to be avoided as much as possible. In the following discussion the effects of the different constituents of the clay on the changes in physical structure, chemical composition, porosity, hardness, and color of the clays will be noted as far as possible in the natural order in which they take place in burning.

THE DEHYDRATION PERIOD.

As defined by Orton[1] this stage consists in "the dissociation of those materials which are unstable at high temperatures, and the expulsion of the volatile portions from the mass of the clay."

(1) Much of the material for this chapter has been adopted from two papers.

(a) On the role played by iron in the burning of clays. by Prof. Edward Orton, Jr., Trans. Am. Cer. Coc., Vol. V, 1903.

(b) Pyro-chemical and physical behavior of clays by R. C. Purdy and J. K. Moore, Uni. of Ill. Bull., Vol. 4, No. 13. 1907. Reprinted from Trans. of Am. Cer. Soc., Vol. IX, 1907.

1. Loc. Cit., p. 16-17.

The reactions are chiefly:

(a) Expulsion of hygroscopic water from the clay.
(b) Combustion of carbonaceous matter.
(c) Distillation of S from pyrites, leaving Fe S.
(d) Dehydration of Kaolinite, Ferric hydroxide and other hydrous minerals.
(e) Decarbonization of carbonate minerals.

(a) Expulsion of Hygroscopic Water.

Theoretically, this process should take place at the boiling temperature of water, but, as the water is enclosed in the small pores of the clays, it takes some time for it to escape, hence the clay usually reaches a temperature higher than 100°C. before it is all driven out. This action is not important in itself as it affects practically no change in the properties of the clay, but it may prevent other necessary reactions from taking place. As long as the pores of the clay are filled with the escaping water vapor no oxidation from the gases outside the ware can take place, nor can the combined water be given off.

If a dry piece and a wet piece of clay be placed together in a kiln the dry piece rises in temperature much more rapidly than the wet one due to the absorption of heat by the vaporization of the water in the latter. Consequently, the dry piece is better prepared for the next step when the kiln reaches the proper temperature.

The remedy for all troubles in this stage of burning is to have the ware perfectly dry when set in the kiln or to hold the kiln at a temperature of 100°—150°C. until ample time is given to expel the hygroscopic water.

(b) Combustion of Carbonaceous Matter.

The carbonaceous matter of clays may consist of (a) fresh, unaltered organic matter such as rootlets, leaves and stems of plants in surface clays, or sawdust added to give a porous body or to decrease the shrinkage as in the making of terra cotta, (b) partially decomposed animal and vegetable matter as in the bituminous or lignitic shales, (c) inorganic carbon minerals such as graphite.

The first class, or woody tissue usually does little harm unless it is present in considerable quantity. It catches fire and burns at 200° to 300°C. If it is present to the extent of several per cent., this combustion may take place with sufficient rapidity to supply enough heat to raise the temperature of the kiln so rapidly as to cause swelling and black coring of the ware. Proper care in the firing and regulation of the air supply will usually prevent this trouble.

The second class or bituminous matter is solid at ordinary temperatures, but distills at a moderate heat, giving gaseous products which burn rapidly with intense heat, leaving a residue of coke which must be burned out later. Naturally the combustion of this material, which is evenly disseminated through the clays giving the maximum heating effect, may carry the temperature of the kiln up too rapidly. and as no oxidation can take place while the pores of the ware are filled with the gases from this combustion, it is very likely to cause swelling and black coring. It has been estimated that a clay containing six per cent. of bituminous matter will furnish one-third of the heat required to burn it, if this heat could be utilized at the proper periods of burning. The danger of swelling and black coring from this cause is greater in fine-grained than in coarse-grained clays as the latter allow greater opportunity for the escape of the gases through the pores. In burning this sort of clay it is sometimes necessary to stop the firing and shut off the air supply in order to allow the bituminous matter to burn itself out without raising the temperature of the kiln past the point of safety.

The third class or graphitic matter seldom gives trouble as it burns slowly at rather high temperatures and does not often occur in large quantities in clays or shales. Such material is sometimes mixed with clay to secure a better distribution of heat in the kiln.

(c) Distillation of Pyrites.

The sulphur of pyrites is driven off in two stages, the first at 400° to 600°C. leaving the ordinary black iron sulphide, $FeS_2=FeS+S$.

The second molecule is driven off at about 900°C. by roasting in good oxidizing conditions. If proper oxidation cannot take place, this sulphur is not driven off but the FeS melts to a black slag.

(d) Dehydration of Hydrous Minerals.

The dehydration of kaolinite takes place at 550° to 650° C. It proceeds quietly and has no effect on the burning behavior except that no oxidation can take place until the pores are freed from the water vapor. Ferric hydroxide and zeolites as well as other hydrated minerals may be present, but all lose their water quietly at moderate temperatures.

(e) Decarbonization of Carbonate Minerals.

Four carbonate minerals are of common occurrence in clays. These are calcium carbonate, iron carbonate, magnesium carbonate, and dolomite, the latter is a mixture of calcium or lime and magnesium carbonates. The carbon dioxide is driven off from these compounds at 400° to 600°C. The principal effect of this action is that the pores of the clay are filled with the escaping carbon dioxide allowing no oxidation to take place until said gas is all driven out. The ferrous oxide, which remains from the destruction of iron carbonate, is very active and combines vigorodusly with oxygen to form ferric oxide. This oxide is responsible for the color of red burning clays.

The lime remaining from the calcium carbonate is an active flux. It may combine with the iron, masking the red color and producing the different shades of buff. These changes, however, really are part of the next or oxidation period.

THE OXIDATION PERIOD.

During this period the unstable compounds set free in the dehydration period form more stable compounds by absorption of gases from without the mass.

The formation of the red color of most clays is due to the absorption of oxygen by ferrous oxide forming ferric oxide during this and the succeeding vitrification stage.

In the pure, white burning clays this stage is of short duration and is really not a separate stage, but in the buff and especially in the red burning clays, it is of great importance to have the mass of clay thoroughly oxidized before vitrification takes place.

The difficulties, which arise at this stage, are usually due to not giving sufficient time for the oxidation to take place throughout the mass before vitrification starts in the outer portions. All the gases formed during the dehydration period must have time to escape; then the kiln gases must permeate the clay thoroughly. In dense clays these processes may take many hours and even two or three days.

After having raised the temperature of the kiln to 900°C. it is sometimes necessary to allow the fire to die down in order that the kiln may be filled with hot air, containing a large percentage of oxygen and a small amount of combustion gases, while the temperature falls to 600°C.

Orton[1] gives the following points as effecting the oxidation:

(1) *Mechanical action of the clay itself.* The oxygen bearing gases must circulate through the clay by means of the capillary system of pore space, established by the water of plasticity, in soft or stiff mud ware or in the open spaces of dry pressed ware. This requires some time as the ware is simply lying in the atmosphere containing the oxygen and there is no difference in pressure to hasten the circulation.

(2) *Hindrance caused by the evolution of gases.* This has already been pointed out in the discussion of the dehydration period.

(3) *The effect of the combustion gases.* In the early stages of burning, up to a temperature of 600° to 800°C., there is a large excess of air in the gases in the kiln. Above this temperature however, it is customary to raise the degree of heat rapidly; to do this the air supply is cut off. As long as the air supply is large the kiln gases will contain only the products of combustion, i. e. carbon dioxide, water, and nitrogen, with nitrogen and oxygen from the air. If the supply of air to the fires be deficient the kiln gases may contain in addition carbon monoxide, methane, ethylene, carbon disulphide, sulphur dioxide, ammonia, and hydrogen. All of these are reducing in their action and hence use up or counteract much of the oxygen of the air supply before it can have any oxidizing effect on the ware itself.

(4) *The effect of solid reducing agents in the clay.* The most common solid reducing agents are the carbonaceous materials and the ferrous sulphide which remains from the distillation of pyrites. These take up oxygen from the kiln gases more readily than ferrous oxide consequently there can be no oxidation of the latter to ferric oxide until the carbon and ferrous sulphide are satisfied.

In very carbonaceous clays the oxidation may take several days, while in some cases it is almost impossible to bring about complete oxidation.

(5) *The effect of the structure of the ware.* Since the oxygen bearing gases must work their way through the mass of the clay to bring about oxidation, it is evident that the more open and porous the structure, the faster the oxidation will take place. Sandy clays very seldom, if ever, give trouble in oxidation on account of their open texture; shales oxidize more easily than surface clays because the latter grind down finer; with most clays the dry press body is more open

1. Loc. Cit., p. 27. et seq.

and porous than the plastic bodies, consequently oxidation takes the place more readily; side cut brick oxidize more readily than end cut on account of the direction of the lamination.

THE VITRIFICATION PERIOD.

Strictly speaking, vitrification means the production of a homogeneous, glassy body free from bubbles. This stage is never entirely reached in clay burning so vitrification is taken to mean the stage at which the body of the ware is most dense, i. e. at which the porosity reaches a minimum. The following are the principal changes during this period.[4]

Fire Shrinkage.

During this stage the kaolinite condenses or shrinks; the lime and the alkalies act as fluxes and combine with the other minerals to form aluminates or silicates. As the temperature increases these compounds decompose and the free silica begins to enter into combination. The whole stage may be regarded as one of successive chemical changes tending to the formation of a homogeneous complex silicate mineral. Different minerals have been identified at different stages of vitrification, but little work has been done in regard to isolating and naming them.

Normal Color Changes.

The red burning clays at the beginning of the vitrification period have a yellowish red or pink color usually called salmon. During vitrification this color continually deepens and brightens until the bright dark reds are produced. This red is probably due to a thin film of iron oxide (Fe_2O_3) coating the mineral particles. The oxide increases in density with increase of temperature and so causes the gradual deepening of the color. It appears strange that the iron oxide should remain uncombined at these high temperatures in the presence of active fluxes. but there seems to be no evidence of silicate or aluminate formation; pure iron oxide undergoes similar color changes with the increase in temperature.

In this connection it is interesting to note that the red and pinks of the orthoclase feldspars in many granites are due to the presence of finely divided iron oxide. The conditions are somewhat similar although, of course, the temperature at which the granite crystallized was far higher than that reached in the burning of clay wares and the time required for cooling was immensely longer. The presence of the iron

oxide in the feldspar proves however, that the oxide has the power of retaining its own identity in the presence of molten substances with which it might be supposed it would combine.

Blue Stoning.

Between the stages of complete vitrification and fusion, a decided color change takes place. The reds change to grays or bluish grays. The nature of the ware is unaltered except that it is somewhat more brittle. The cause of this color change which is called "blue stoning," is not precisely known, but it seems to be the first stage of the ferrous silicate formation which takes place on fusion. The iron oxide may enter into compounds which are again decomposed on complete fusion. but these compounds have never been isolated.

The above discussion takes for granted that oxidizing conditions are maintained throughout the burn. If *reducing conditions* maintain for any part of the burn the iron oxide is reduced from the ferric to the ferrous form. This is very active and combines at once to form ferrous silicate, a bluish green to black substance. This bluing or blackening proceeds from the surface inwards, the depth reached depending upon the length of time that reducing conditions maintain and upon the nature of the ware.

If the burn ends with reducing conditions, the silicate color is the permanent color of the ware. This color is well shown in sewer pipe in which it is produced by the reducing action of the salt glaze If a piece of sewer pipe be broken, the silicate color is seen to extend inward from the glazed surfaces, while the middle of the body still possesses the red ferric oxide color.

Black Coring.

If the ware is not oxidized throughout before vitrification starts on the surface, a condition results which is known as "black coring." This is caused by the evolution of gases in the unoxidized inner portion of the ware while the porosity in the outer vitrified portion is so low as to render the escape of the gases impossible. In bituminous or carbonaceous shales the gases may be sufficient in quantity to cause a pronounced swelling and puffing of the ware, and separation of the vitrified portion from the "black core" leaving a space between them. In other cases no deformation is observed and the black coring is shown only by the color of the broken piece of ware. Even in this case, however, there is a decided weakening of the material. The only remedy for black coring is to allow the kilns to remain at oxidizing conditions for a sufficently long time to oxidize the pieces completely before any vitrification takes place. This is, however, commercially impossible with the more carbonaceous shales.

Puffing or Swelling.

Some clays exhibit *puffing and swelling* with the development of a pronounced vesicular structure when they show no evidence of black coring. This usually occurs in clays of fine texture that contain sulphates or other minerals which decompose at moderate temperatures with the evolution of gas. Calcium sulphate is probably the most common cause of this phenomenon. Two of the clays tested by the writer developed this condition at as low temperatures as cone 04, when made by the stiff or soft mud process. Pieces made by dry press did not puff or become vesicular at cone 02, or cone 1, as the open structure of the dry press body permitted the escape of the gases as they were formed.

Reoxidation or "Flashing."

If reducing conditions exist for a part of the burn, but oxidation again takes place before the end, the process is known as "flashing." The red color varies considerably from the red produced when no reduction takes place, being usually more nearly a chocolate. With some clays the color produced by flashing is not so pleasing as the original color and, consequently, reducing conditions are avoided throughout the burn. In other clays the "flash" color is more pleasing than the normal color or is better fitted for some especial use and flashing is brought about purposely by producing reducing conditions, usually by shutting off the draft, through part of the burn and restoring the oxidizing conditions at the end of the burn. The flash color is rendered brighter and more pronounced by alternate reducing and oxidizing conditions and sometimes the conditions are changed from oxidizing to reducing and vice versa several times in a single burn.

THE FUSION PERIOD.

This stage is never reached in clay burning except by accident. Vitrification grades insensibly into fusion and there is no line of demarkation between the two stages. In practice fusion is considered to commence when the ware becomes so viscous as to be pressed out of shape by the weight of the ware above it. The temperature at which this state of "viscous vitrification" is reached will depend upon the weight which the ware must carry in the kiln. The bricks at the bottom of a kiln bear considerable weight and are pressed out of shape at a lower temperature than the ones higher up in the kiln.

Complete fusion is the formation of the homogeneous complex silicate. It is probably a complex reaction during which considerable gas is liberated. This gas forms bubbles in the body and the structure is known as vesicular. After the gas passes off the fused mass is a glassy substance of dark green color.

THE VITRIFICATION RANGE.

The vitrification range is the difference in temperature between the points of "complete" and "viscous" vitrification. Clays containing a large amount of active fluxes, such as lime, melt very rapidly and deformation takes place almost as soon as vitrification commences. Such clays are called "unsafe" because it is impossible to bring the coolor portions of the kiln to vitrification without melting the ware in the hotter portions. Other clays, containing less fluxing material, melt very slowly, and have a long vitrification range. These are known as "safe" clays on account of there being no danger of melting in the hotter parts of the kiln before all the ware is vitrified.

PHYSICAL CHANGES IN THE BURNING OF CLAYS.

DEHYDRATION PERIOD.

During *dehydration* the plasticity of the clay is usually destroyed although in certain instances some plasticity may develop in dehydrated clays. This loss of plasticity is probably due to the permanent setting of the colloids in the clay. The apparent specific gravity of the ware becomes less, due to the escape of the volatile matter, while the true specific gravity of the clay substance shows a slight increase from the same cause. The color in red burning clays usually becomes pink or salmon. The porosity is slightly greater than that of the raw clay while the tensile strength is less than at any other stage of working and the material is soft and easily powdered.

OXIDATION PERIOD.

During *oxidation* there is a very gradual increase in the apparent specific gravity, in tensile strength, and hardness, and a corresponding decrease in pore space. The color darkens to the normal oxidized color.

As has been said previously, there is no sharply defined limit between oxidation and vitrification and it is possible that part of these changes are due to the beginning of vitrification which takes place before oxidation is complete.

VITRIFICATION PERIOD.

During *vitrification* there is a gradual condensation with increase of apparent specific gravity and decrease of porosity. These changes are due to the gradual melting of the clay substance and consequent filling up of the open pore space. This shrinkage continues until the pore space is practically zero or until complete vitrification. Beyond this point blebs or bubbles begin to form in the glassy substance and the processes are reversed, i. e. the specific gravity becomes less, the pieces increase in size, and the porosity increases.

These changes are well shown by the following report[1] of the microscopical examination of sections of a paving brick shale of which draw trials were made at several different temperatures:

"Thin sections of briquettes burned at a low temperature exhibit under the microscope a very fine-grained, fragmental ground mass, or matrix, in which are imbedded crystalline and other fragments, which were present in the original clay. From these materials are developed at high temperatures amorphous glass and crystals.

"The cavities beween the particles of a brick may be divided into two classes:

"(1) Pores, which are present in pieces fired at low temperatures, due to the incomplete consolidation of the clay. These are the original interstitial spaces of the unburnt clay.

"(2) Blebs or bubbles, which are formed in the glass at higher temperatures by the liberation and expansion of gases.

"Pores of the first sort are of small size and irregular outline. As the temperature increases, and the material of the matrix gradually fuses into glass, these interstitial spaces tend to disappear.

"Cavities of the second sort, which we may for convenience designate as blebs, are simply gas bubbles in glass. They are circular in outline and vary greatly in size. They are not present in the bricks

1. C. H. Wegemann, pp. 30 et seq., Uni. of Ill. Bull., Vol. IV, No. 13, by R. C. Purdy and J. K. Moore

burned at lower temperatures, but appear only after the formation of considerable glass.

DESCRIPTION OF SLIDES

"*The R 3 Series. R* 3—14. This briquette was drawn at cone 3, or about 1190°C. The color is red. Under the microscope, the earthy matrix or ground mass is dark brown, the color being due to the presence of iron oxides.

"The mineral fragments are quartz, feldspar and mica, named in the order of their abundance. They are angular in outline; the thin edges being sharply defined.

"Glass has formed to some extent throughout the ground mass, and in a few instances it has separated out into clear transparent masses, in several of which blebs appear. The blebs, however, are so few and so small that the cavities may be considered as made up almost entirely of pores of the first class. As estimated under the microscope, the porosity is 1.9 per cent.

R 3—16. Drawn at cone 5, or approximately 1230°C.; color dark brown. Under the miscroscope the ground mass appears somewhat denser and darker than in R 3—14. The quartz fragments are apparently unchanged. The feldspar fragments, however, have disappeared. Mica is present, but in very small quantity.

"Glass has been formed in considerable amount. It appears in clear transparent areas, often 0.1 m. m. in diameter. In some of the glass, needle-like crystals have begun to form, but where free from these the glass is colorless. This fact would seem to indicate that but little iron has entered into its composition.

"As above stated, fine needle-like crystals are often present, imbedded in the glass. They do not appear to have any definite arrangement with respect to each other, but occur singly or in dense masses. When viewed singly they are colorless, but when seen in masses, they possess a greenish yellow tint, which they impart to the glass in which they are imbedded. What the crystals are was not determined.

"The iron oxides present in the matrix have become segregated into dense masses, which, where they transmit light at all, show the red of hematite, but no definite crystals are to be seen. Pores of the first class have disappeared, and blebs in the glass have become numerous and large, their average diameter being 0.066 m. m. The estimated pore space has increased to 4.2 per cent.

"*R* 3—18. Drawn at cone 7, or 1270°C. The fragments of quartz appear unchanged. The earthy ground mass is rapidly fusing into glass, which has increased greatly in amount over that in the preceding slide. The fine needle-like crystals are also present in greater number.

"Minute crystals of iron oxide are seen, apparently in the form of rhombohedrons, having slightly concave faces. They do not exceed 0.0014 m. m. in diameter. The blebs have an average diameter of 0.1 m. m. and the pore space has increased to 12.0 per cent.

"*R* 3—20. Drawn at cone 9, or approximately 1310°C. Quartz fragments are present as before, but occasionally one is observed the edges of which have fused into a glass. The needle-like crystals are everywhere present in the glass, giving to it the yellowish-green tint mentioned before. The iron oxides appear much the same as in the last specimen. The blebs are but little changed.

"*R* 3—22. Drawn at cone 11, or approximately 1350°C. The earthy matrix has given place entirely to glass.

"Quartz fragments are still present, but thin; their edges have been rounded by fusion.

"The fine needle-like crystals in the glass have increased greatly in length, being in some cases 0.03 m. m. long. They exhibit for the first time a marked tendency to collect in radiatina clusters. Often they appear to be attached to the corners of the crystals of iron oxide. These latter have increased in number and size, being 0.005 m. m. in diameter. In some cases the individuals unite, forming long serrated columns.

"Blebs have increased greatly in size, their average diameter being 0.128 m. m. The pore space as estimated from them is 19 per cent.

"Generalized Summary of Changes Observed at Different Heat Treatments.

Cone 02.—Quartz and feldspar fragments are unchanged.
No blebs are yet formed.
But little glass is developed.

Cone 1.—No marked change has taken place over cone 02.

Cone 3.—A small amount of glass is developed from the ground mass.
A few blebs appear.
Needle-like crystals are developed in the glass.

Cone 5.—Feldspar fragments are fused into glass.
Quartz fragments are unchanged.
Blebs increase in number and size.
Minute crystals of iron oxide develop.

Cone 7.—Glass increases in amount.
Blebs increase in number and size.
Quartz fragments are unchanged.

Cone 9.—Quartz fragments begin to fuse in the glass along their edges.

Cone 11.—Ground mass is completely fused into glass.
Some rounded quartz fragments still remain.
Blebs have increased remarkably in size and number.
Microlites are more numerous.

It should be borne in mind that this is but a preliminary study. The number of slides examined is too limited to warrant broad generalizations."

SPECIFIC GRAVITY AND POROSITY CURVES.

The change in volume is also well shown by curves made by plotting the burning temperature in cones on the horizontal axis and the volume fire shrinkage in per cent. of the dry volume upon the vertical axis. Fig 3 shows the volume fire shrinkage curve for four Oklahoma clays of different types.

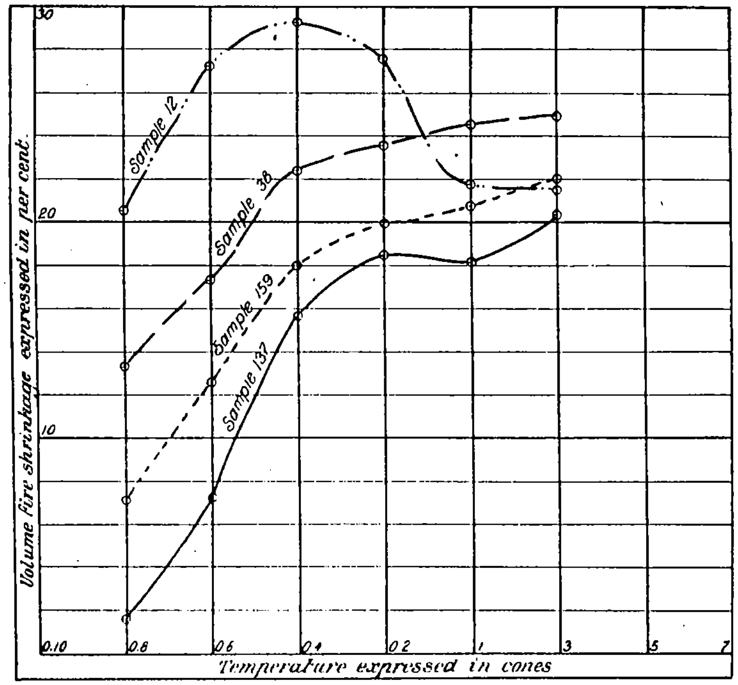


Fig. 3. Volume fire shrinkage curves for clays Nos. 12, 38, 137, and 159.

Similar curves may be drawn showing the changes in specific gravity and in porosity. Fig. 4[1] shows the specific gravity curves of four typical Illinois clays, a No. 1 fire clay, a No. III fire clay, a paving brick shale and a building brick shale.

1. Figs. 3, 4 and 5 are compiled from Purdy and Moore., Op. Cit.

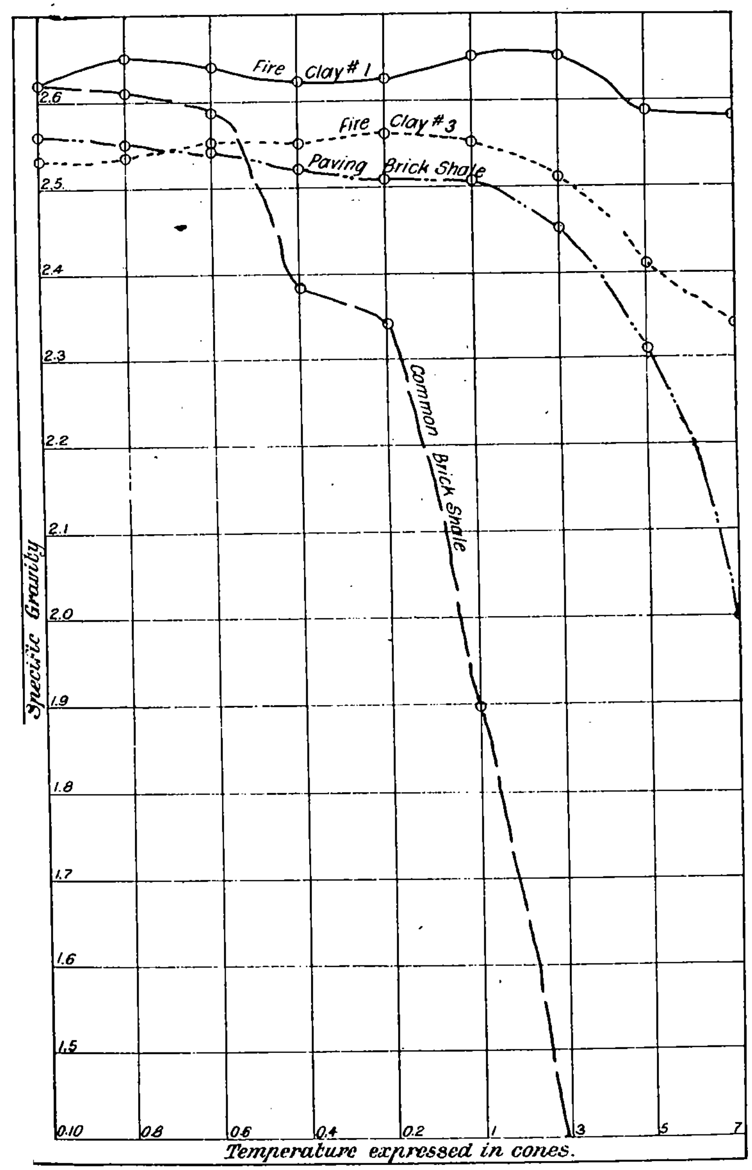


Fig. 4. Specific gravity curves for clays of four types

The porosity curves for the same clays are shown in fig. 5.

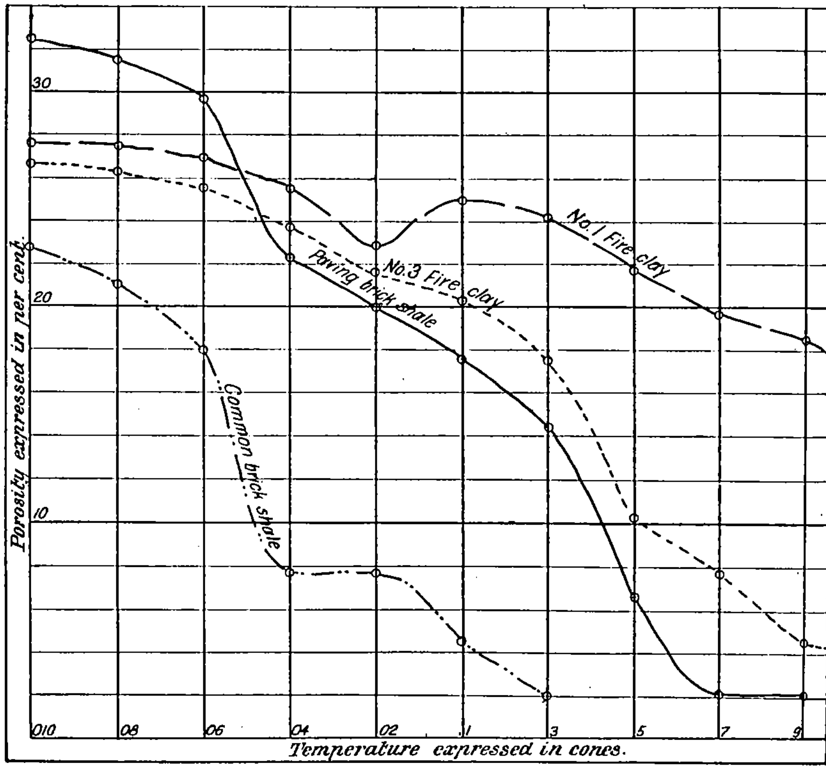


Fig. 5. Porosity curves for clays of four types.

All these curves show similar phenomena, i. e. a gradual condensation with increasing shrinkage, and decreasing specific gravity and porosity throughout the early stages; a rather sudden change with increased rate when vitrification starts, this rate continuing about the same until fusion sets in, when the curve takes a change in direction due to the increased volume and porosity due to fusion. The curve of course has a greater slope in building brick shales than in paving brick shales and a less slope in the fire clays, indicating the rate at which vitrification takes place.

USE OF SPECIFIC GRAVITY AND POROSITY CURVES.

Purdy[1] regards these curves showing the changes in specific gravity and porosity with increasing heat treatment as giving the best insight to the properties of a clay.

On the basis of use he divides clays into classes as follows:

1. No. 1 fire clays.
2. No. 2 fire clays.
3. No. 3 fire clays.
4. Paving brick clays.
5. Sewer brick clays.
6. Building brick clays.

In testing a large number of clays the porosity and the specific gravity curves of the clays in each group fall in well defined limits, which are shown in the following figures.

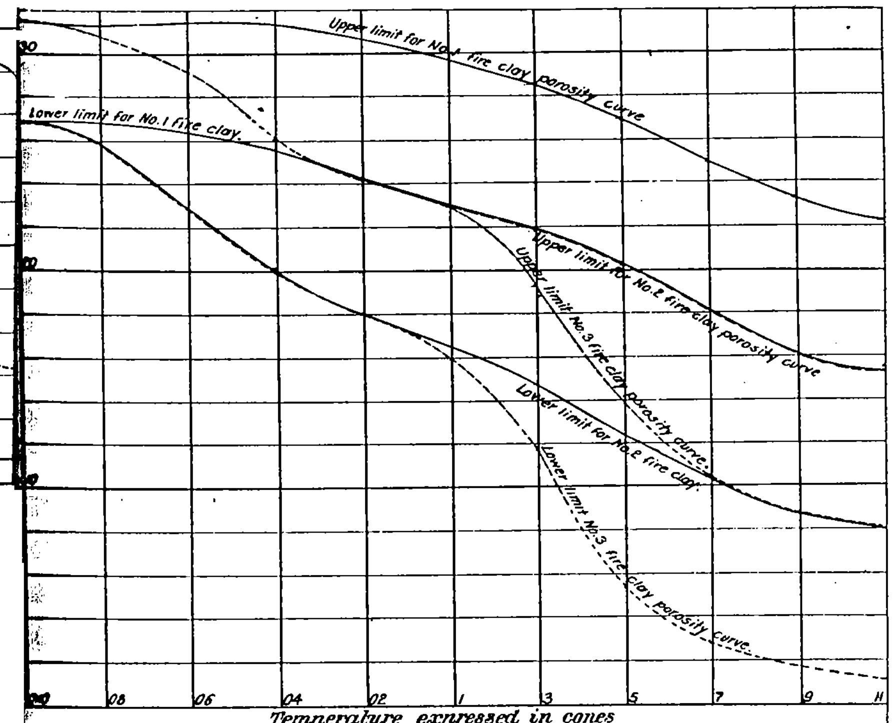


Fig. 6. Porosity curves showing limits of areas for fire clays.

1. See Uni. of Ill. Bull., Vol. IV, No. 8, and Ill. Geol. Survey Bull., No. 9.

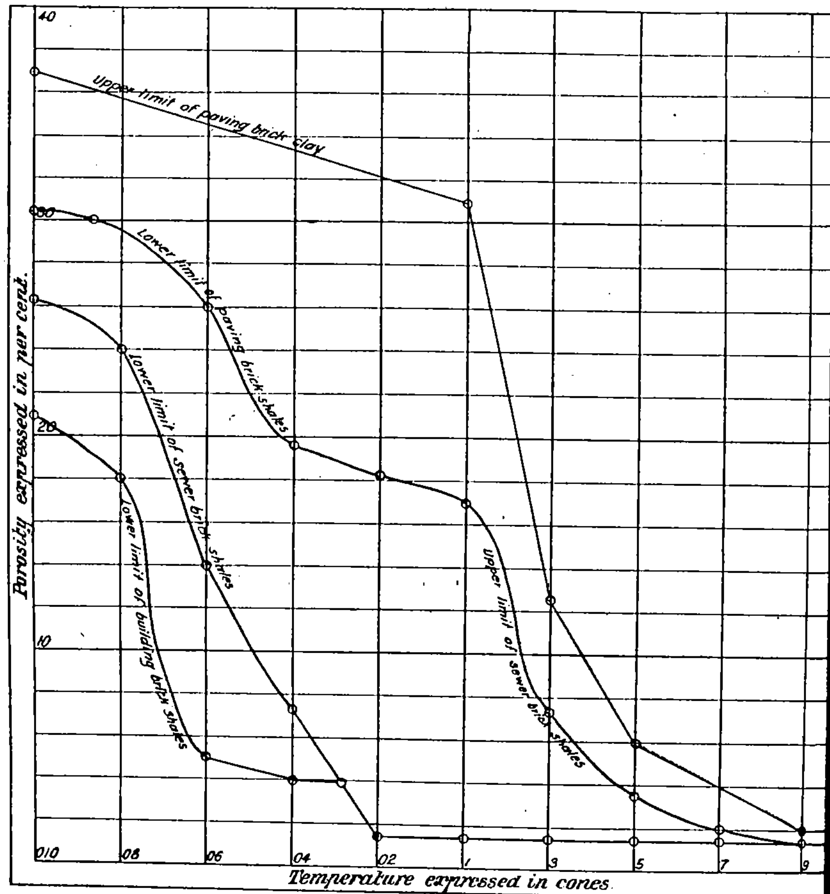


Fig. 7. Porosity curves showing limits of areas for paving brick

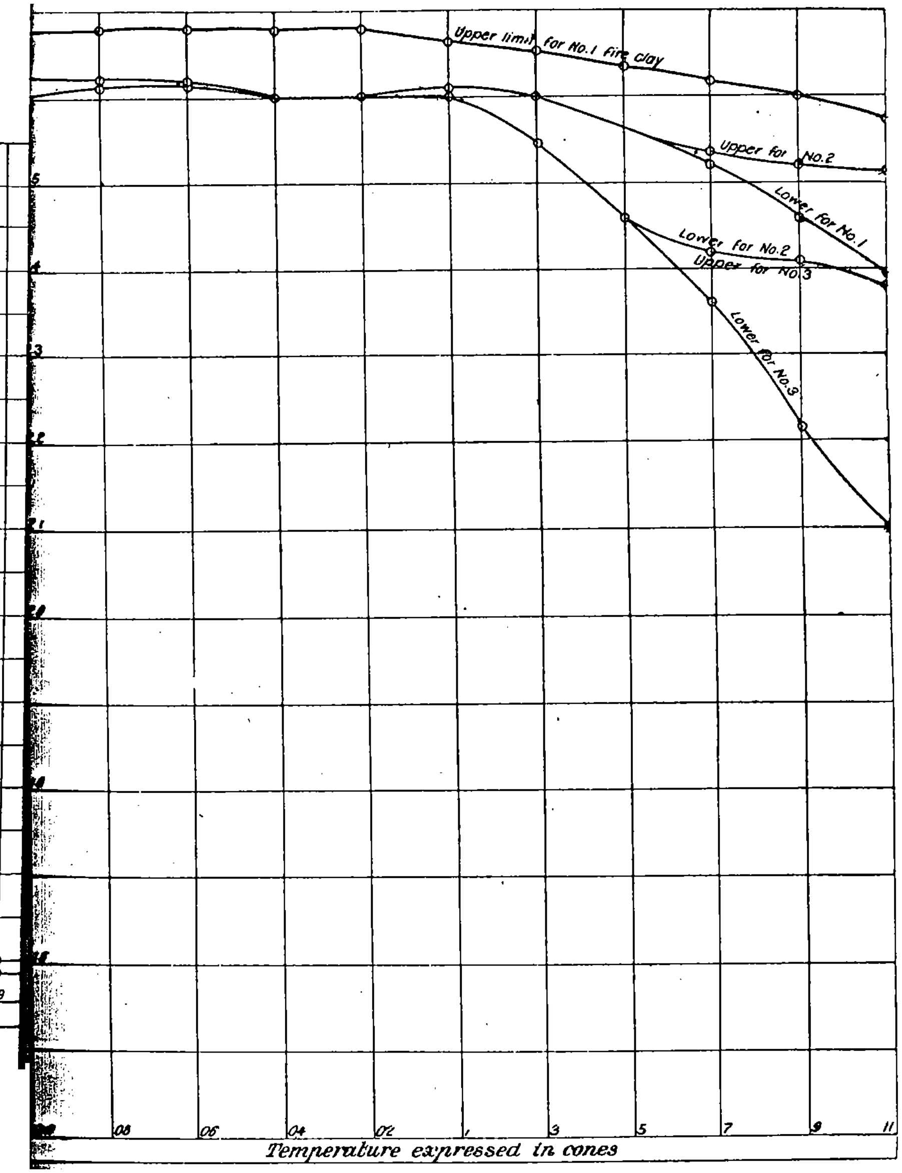


Fig. 8. Specific gravity curves showing limits of areas for fire clays.

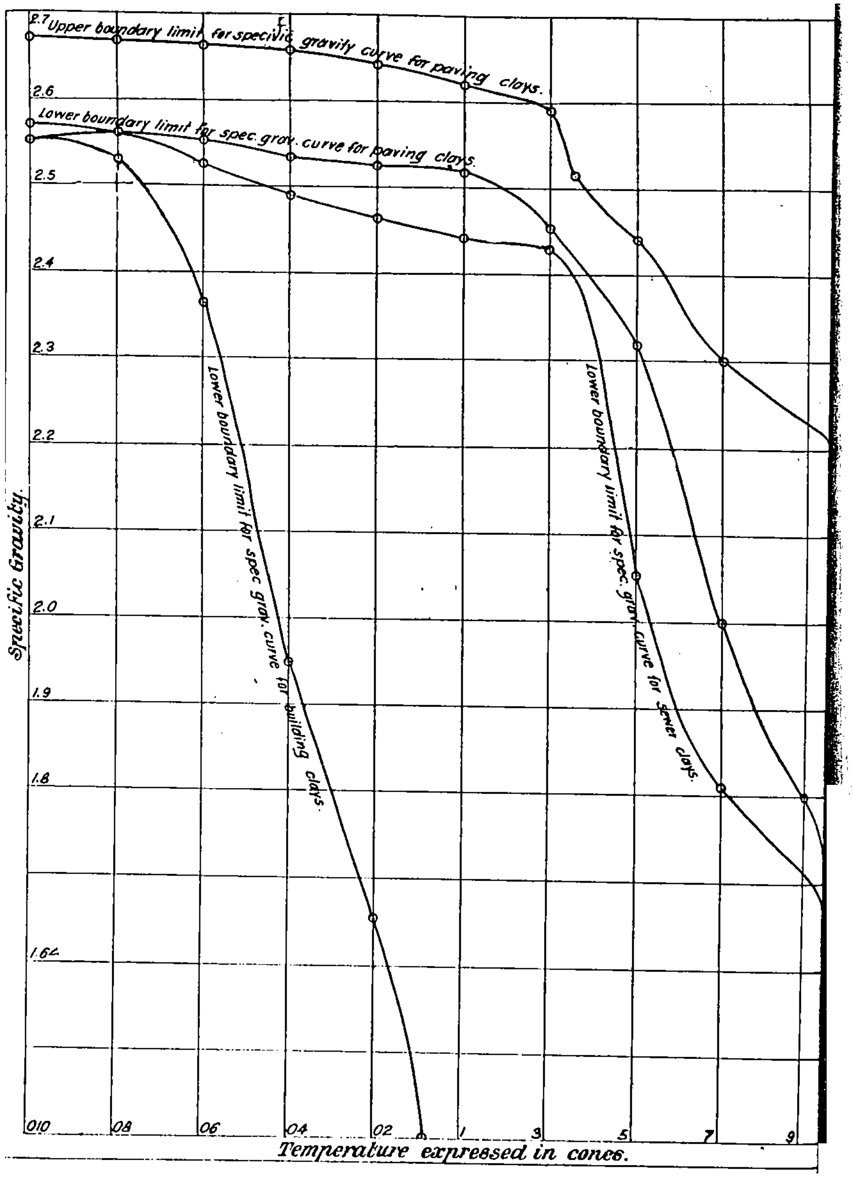


Fig. 9. Specific gravity curves showing limits of areas for paving brick, sewer brick and building brick clays.

It is to be understood that the clay in any of the higher divisions can usually be used for products in the lower divisions, but it would seldom be economical to do so on account of the expense in burning. The clay in the lower classes cannot be used for the products in the higher divisions, e. g. a paving brick clay can be used to make building brick, but a building brick clay cannot be used for paving brick.

The curves do not show the relative values of different clays of the same class, for instance, the rattler loss of paving brick cannot be prophesied from the curve, nor can the clays which preserve their maximum strength through a wide heat range be distinguished from those that preserve their maximum strength through a narrow heat range.

The working and drying qualities must also be taken into consideration in testing a clay by this method. The burned color and freedom from discoloration are also important items of the suitability of a clay for some products. Sandy clays give curves which approximate the No. 1 fire clay curves although they could not be used as fire clays. Clays of this sort can of course be easily distinguished by their physical characteristics.

In spite of these limitations to the use of the specific gravity and porosity curves as a practical laboratory test for clays, the fact remains that they give a better idea of the properties of a clay than any other test yet devised.

CHAPTER V.

TECHNOLOGY OF CLAYS

PROSPECTING FOR CLAYS.

The presence of a body of clay or shale may often be shown by its outcrop. However, owing to the relatively soft nature of the material and the rapidity with which it weathers, natural outcrops of clay or shale are much rarer than those of the harder rocks, such as limestone or sandstone. It is only in very steep bluffs, along streams or in freshly cut gullies, that natural exposures of shale are likely to be found.

Large bodies of shale have a pronounced effect on the topography of a region. The shale usually occupies valleys or trough-like depressions between the ridges formed by the more resistant rocks. So, even if no outcrop occurs, clay or shale may be expected to be found below the soil in such localities.

The presence of clay may also be indicated by a line of springs, the clay being almost impervious to water causes it to come to the surface . Ponds also sometimes indicate layers of shale or clay, which furnish the impervious bottom. Fresh cuts for railroads, sewers or public highways often reveal clay beds. Wells, cellars and cisterns are also excellent means of determining the presence or absence of clay.

After the location of a clay bed is known, the clay should be tested thoroughly before any attempt is made to develop it. If the tests prove the material to be valuable, the quantity available should be determined, either by stripping along the outcrop or by test holes or core drilling. The latter method also determines the amount of stripping or over burden which must be removed in developing the deposit.

The question of transportation facilities, of fuel and of market are of prime importance in the clay industries and should be fully investigated before attempts at development are made.

WINNING THE RAW MATERIAL.

The method of obtaining the raw material differs with the mode of occurrence of the clay.

Shovels and wheel barrows. Surface clays are sometimes handled by shovels and wheel barrows, but this method is very expensive where labor is as scarce and commands as high a price as it does in Oklahoma.

Plows and scrapers. A more economical method is to plow the clay loose and to haul it to the plant in wheeled scrapers. This method is probably as advantageous as any where the distance from the clay bed to the plant is very short. It requires only one man to drive the teams at the loading place and another to load the scrapers for five or six teams and a third to dump the scrapers. The teams soon learn to follow beaten paths and require no drivers between the loading and unloading. The unloading is often done on an elevated platform from which the clay can be shoveled directly into the pans or disintegrators.

Shovels and dump cars. When the haul is too long or on too steep a grade for the use of wheeled scrapers to be economical, the clay may be hauled in side or end dump cars either by horses or by a wire rope attached to a hoisting drum. These may be loaded by hand shovels or by a steam shovel, if the thickness of the bed and the output of the plant warrant the outlay for the machine.

Pits. Where there are several types of clay in one deposit the usual method of working is to dig rather small square pits through the deposits. Spades resembling ditching spades are used and the material is thrown out at the mouth of the pit or, if the pit become too deep, is hoisted by a bucket and windlass. This method makes it easy to separate different kinds of clay in the same bed. There are probably no deposits in Oklahoma where this method will be necessary, but is used extensively in the winning of the high grade clays of New Jersey[1] where several kinds of clay occur in one bed.

Quarrying. Shale deposits are usually worked by quarrying in long banks or benches. The stripping is removed and then the material is loosened either by blasting or by a steam shovel. If there is little or no variation of the clay in the depth of the deposit a face of 40 or 50 feet may be worked, but it is usually more advantageous to work in benches of 10 to 20 feet.

The loosened shale is loaded by hand labor or by a steam shovel on to dump cars and hauled to the plant. If the plant is situated below the level of the floor of the pit opening the hauling may be done by gravity. Double tracks are often used so that the weight of the

1. H. Ries. Geol. Survey of New Jersey, vol. VI. pp. 33-35.

loaded cars may be utilized to pull the empty ones back to the pit. If the plant is above the quarry the cars are usually hauled up by a hoist consisting of a drum operated by a clutch. In some plants an electric trolley (see fig. 49) or third-rail line with a motor car is used for this purpose.

Mining. Underground mining is much more expensive than open pit or quarry working and is practiced only in the case of the more valuable clays. The methods of mining clay do not differ from those employed in mining coal. If the clay outcrops along the side of a hill drift mines may be opened from the outcrop, but if there is no outcrop available the shaft and tunnel method must be used. The roof of the tunnel may be supported by timbering or by leaving pillars of the clay at intervals as is done in coal mining.

High grade clays often occur under or over coal veins and are mined in connection with the coal. In some instances the clay is the more important and only enough coal is mined to furnish fuel for the burning of the clay, or the coal may be disregarded altogether.

PREPARATION OF THE CLAYS.

WASHING.

The higher grade clays such as kaolins and ball clays are often washed to separate the kaolinite from the sand with which it occurs. The washing process consists in disintegrating the clay and stirring it up with water. The sand settles quickly, while the clay remains in suspension for some time and may be drawn off and allowed to settle. The washing is often done by carrying the clay by means of a stream of water through a long series of troughs with continually increasing area in the direction of flow. The increasing area of the troughs causes the current of water to become slower so that the sand is dropped and removed by automatic scoops or by shoveling. The clay suspended in the water is carried into settling tanks, allowed to settle and the clear water drawn off. The wet clay (slip) is placed in gunny sacks, and pressed to remove the remaining water. The pressed cakes are dried and are ready for market. The yield of washed material is usually from 20 per cent. to 50 per cent. of the material as it comes from the mine.

CRUSHING AND DISINTEGRATING.

The preparation of ordinary clays consists in breaking it down until it will readily take up water and be molded into the desired shape.

Clays of ordinary hardness can be prepared by grinding in dry or wet pans, but the more resistant ones require breaking up before they can be ground in the pans. Ordinary rock crushers of the jaw or gyratory types are sometimes used, but owing to the tendency of the clay to pack and clog the crusher they are successful only in the preparation of flint fire clays and stony shales. For the somewhat softer clays roll disintegrators are used. The *rolls* (fig. 10.) may be two or more in number and may be of the same size and smooth surfaced or may be of different sizes and one or both may have projections or raised spirals on the surface. One roll often has a conical shape. When the rolls are smooth, of the same size and revolve at the same rate the action is simply a crushing one, but when the rolls revolve at different rates or

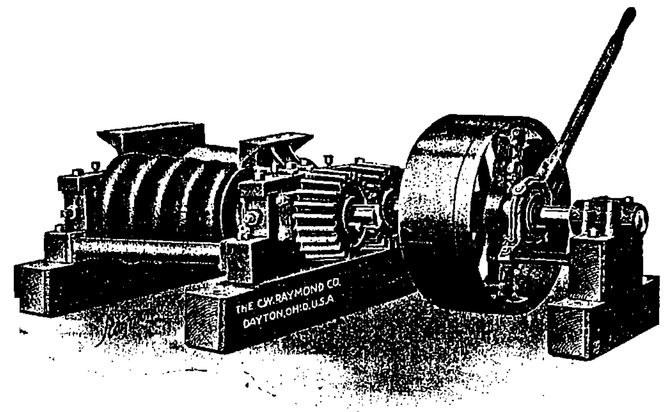


Fig. 10. Raymond Conical-Roll Disintegrator.

have projections on the surface or when one has a conical shape there is a grinding action as well and, especially with the conical roll, a tendency to force pebbles or hard lumps, which are not easily taken between the rolls, to the end of the machine where they fall out through a spout.

Disintegrators or pulverizers are two general types, one of which consists of a series of concentric, cylindrical cages, the alternate ones revolving in opposite directions. The clay is fed into the inner cage and is disintegrated by impact and friction with the bars of the cages. The second type consists of series of hammers fastened to axles revolving in different directions. The clay is disintegrated by the blows of the hammers which are flung out by centrifugal force.

The majority of residual clays and shales do not require treatment with rolls or disintegrators, but can be sufficiently reduced by treatment in the grinding pans. These are of two types, the wet and the dry.

The *dry pan* (pl. 1) consists of a heavy revolving pan supported on a vertical shaft and driven by a heavy gear at the top of the frame. The pan supports two large wheels or mullers which are mounted on horizontal shaft. The ends of the shaft work in grooves in the frame of the machine to permit the mullers riding over the pebbles or hard lumps of the clay. Usually the mullers are on independent shafts although they may be on a continuous axle. The mullers are rotated by their contact with the revolving pan. The bottom of the pan is solid under the mullers, but perforated near the circumference.

Clay is thrown into the pan, crushed under the mullers, and thrown out toward the circumference by the centrifugal force. That which is sufficiently reduced falls through the screen of the pan into a second bottom from which it is pushed by sweeps into the collector which leads to the bin, or to an elevator to the bins. The material, which is too coarse to fall through the perforations, is returned under the mullers by scrapers set at the proper angle and supported by arms from the frame work.

Dry pans are made in sizes of from 5 to 9 feet in diameter with mullers with from 8 to 14 inch face. The perforated bottom is made in sections so that they can be easily removed and other sized perforations substituted. The dry pan requires considerable power to operate, but all things considered is probably the most satisfactory and most widely used of any of the clay grinding machines. A recent form of dry pan has the mullers and grinding floor separate from, and mounted higher than the screening floor. This arrangement permits more rapid rotation of the grinding floor. The screening floors of these pans are 12 feet in diameter.

Ball mills are used where extreme fine grinding is required, as in the preparation of glazes for pottery. They consist of jars mounted on a revolving frame, or set between small revolving wheels. The jars are partially filled with steel shot or smooth pebbles and the material to be ground is added. The material can be ground to an impalpable powder by the attrition of the shot or pebbles. When it is desired to keep the material free from iron, porcelain jars and water worn pebbles are used but otherwise the jars may be of iron and the charge of steel or cast shot.

SCREENING.

For many of the clay products it is necessary to have the material of a more uniform fineness than is produced by any of the disintegrating or grinding machines. For this purpose screens are used. The screens are of two general types, the rotary and the inclined. The *rotary screens* are cylinders or octagonal prisms, the walls of which have perforations of the desired size. One end is mounted somewhat higher than the other. The clay is fed into the higher end and as the screen revolves the fine material falls through the perforations into a bin or hopper and the coarser moves to the lower end and falls into a chute, which takes it back to the grinding machines to be ground again.

The *inclined screens* are rectangular troughs, the bottoms of which are wire, or of perforated metal sheets, the distances between the wires or the size of the perforations regulating the size of the clay particles. The inclined screens may be either stationary or oscillatory. The stationary screen must be longer than the vibratory and hence require a higher building and the elevation of the clay to a greater height than is the case with the vibratory. However, they require no power to operate them and are much longer lived than the vibratory type.

The vibratory screens may rock back and forth on an axle at the middle of the length of the screen or the whole screen may move from side to side. The clay moves down the screen, the fine material falling through while the coarse falls from the end of the screen into a chute which carries it back to the grinding machine. These screens have a greater capacity than the stationary screens, but, as previously remarked, require considerable power to operate and the jar of the vibratory movement tends to shorten their existence.

The tendency of clay to pack and clog the openings of the screens sometimes makes it necessary to provide means of cleaning the screens of either type. This is done by the use of brushes or pounding apparatus. Either method tends to wear out the screens, but are sometimes necessary to keep the screens open.

TEMPERING.

By tempering is meant the thorough mixing of the clay with water until a homogeneous plastic mass results. Tempering is accomplished by one of four methods, the soak pit, ring pit, pug mill, or wet pan.

The *soak pit* consists simply of a rectangular or circular pit dug in the ground. The clay and sand are thrown into the pit and mixed, wet with water and allowed to stand until the clay is thoroughly softened. This method does not mix the clay and is applicable only to the soft mud process of making brick.

The *ring pit* is like the soak pit except that it is always circular and has walls of board or brick. A post is set in the center to which a long rod or sweep is attached by a pivot. The sweep carries a wheel which is so geared that as the sweep travels around the circle the wheel travels back and forth between the centre and the circumference. This thoroughly kneads and mixes the clay. The capacity of ring pits varies from 3,000 to 8,000 bricks. The wheel is usually of iron and six feet in diameter. The pit is three feet in depth. The sweep is driven by steam power or by horses attached to its outer end. Like the soak pit, the ring pit is used only in the preparation of soft mud for bricks.

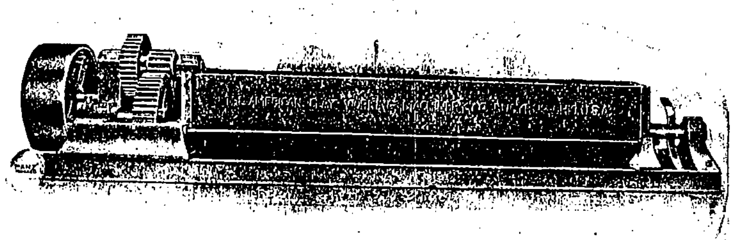


Fig. 11. Open-top Pug mill.

The *pug mill* (fig. 11) consists of a cylindrical shell within which revolves a shaft, bearing knives that are set an angle so that the clay while being cut and kneaded is forced from one end of the cylinder to the other. Some form of pug mill is used with almost all molding machines. In the stiff mud auger machines the pug mill may be combined with the machine while in machines of the piston type the pug mill is usually separate. In some pug mills the upper portion of the cylinder is left open, while in others the cylinder is closed. The latter type permits more power to be applied to the knives and gives more thorough pugging than the open form.

The *wet pan* is similar to the dry pan previously described, the only difference being that the bottom of the wet pan is solid instead of being perforated.

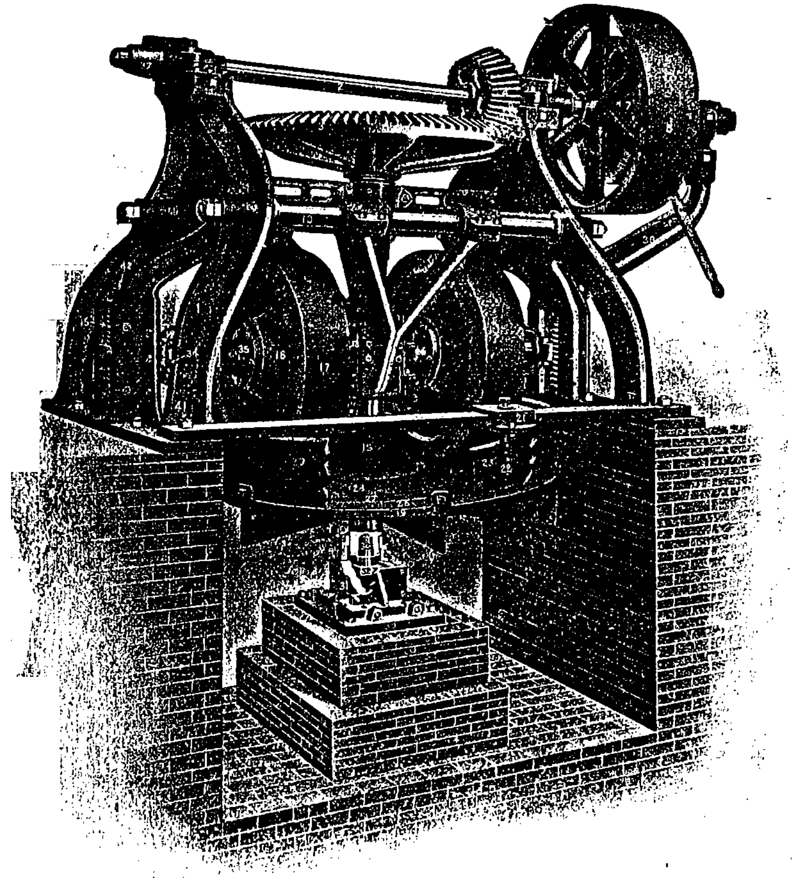


Plate 1. . Stevenson 9-foot dry pan.

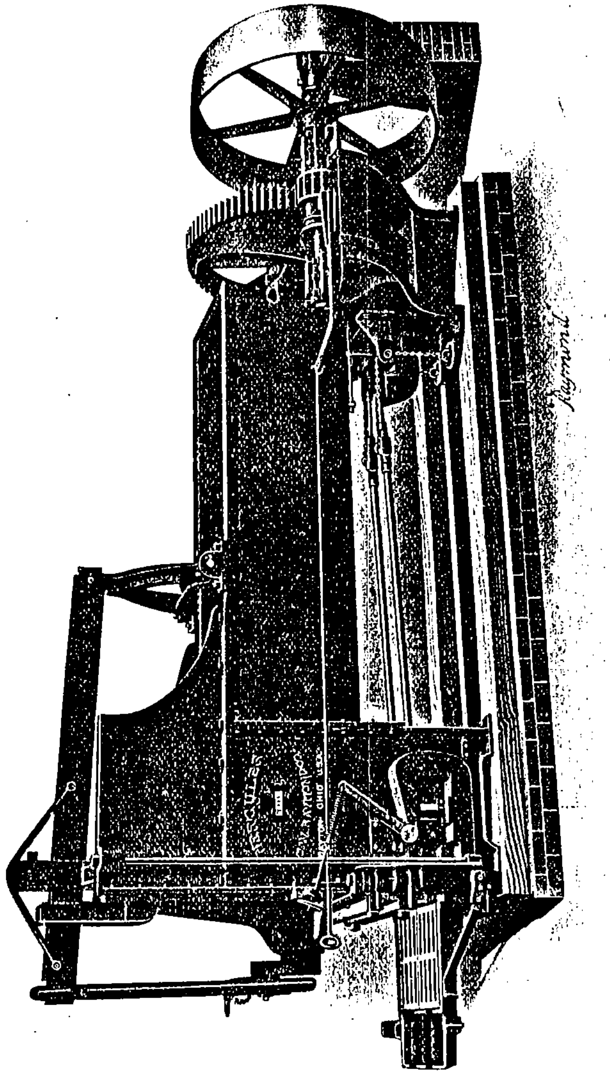


Plate 2. Raymond horizontal soft-mud brick machine.

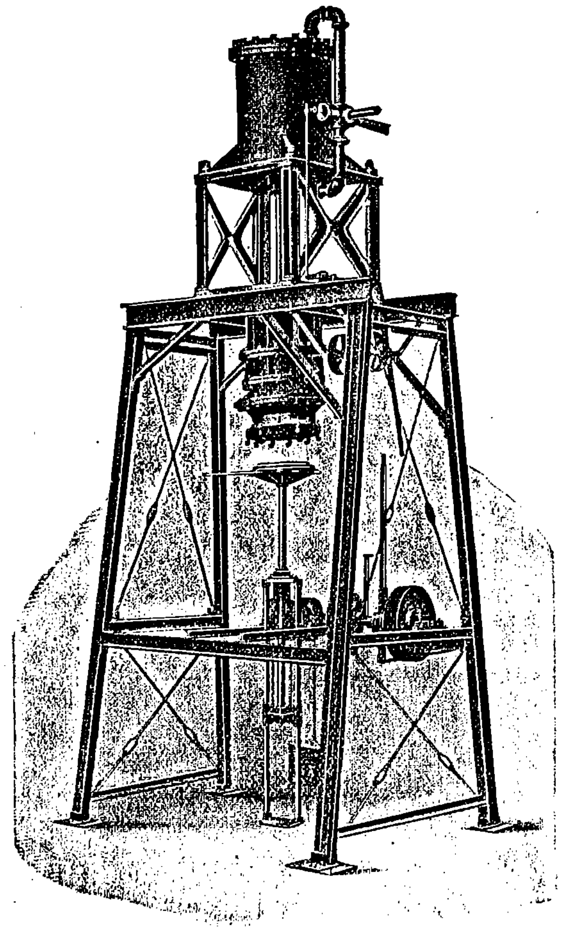


Plate 3. Stevenson sewer-pipe press.

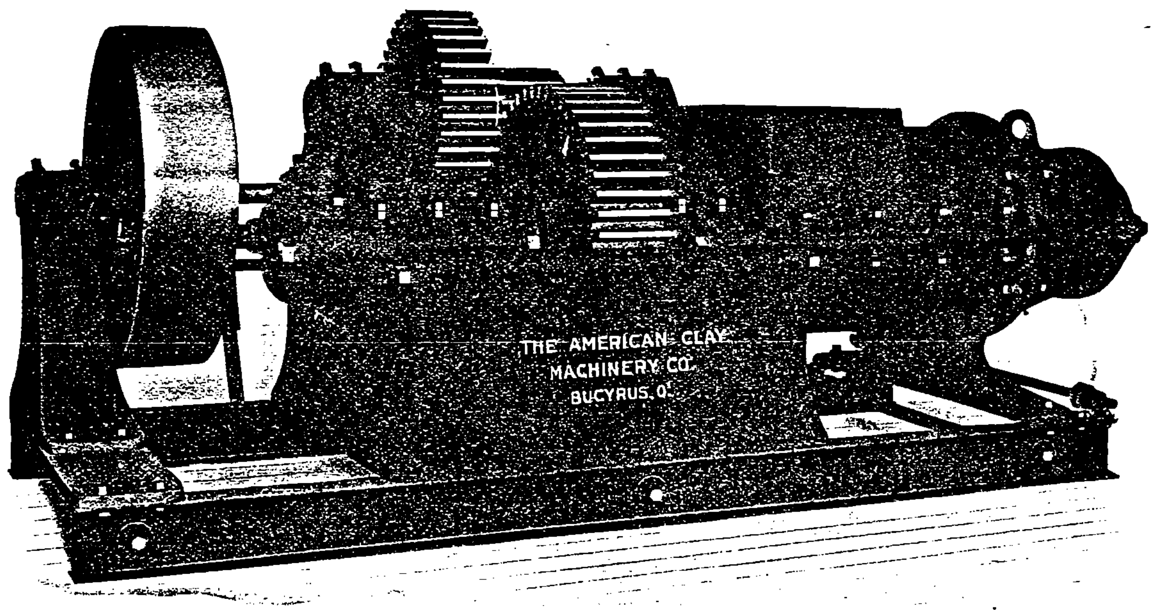


Plate 4. American No. 65 auger machine.

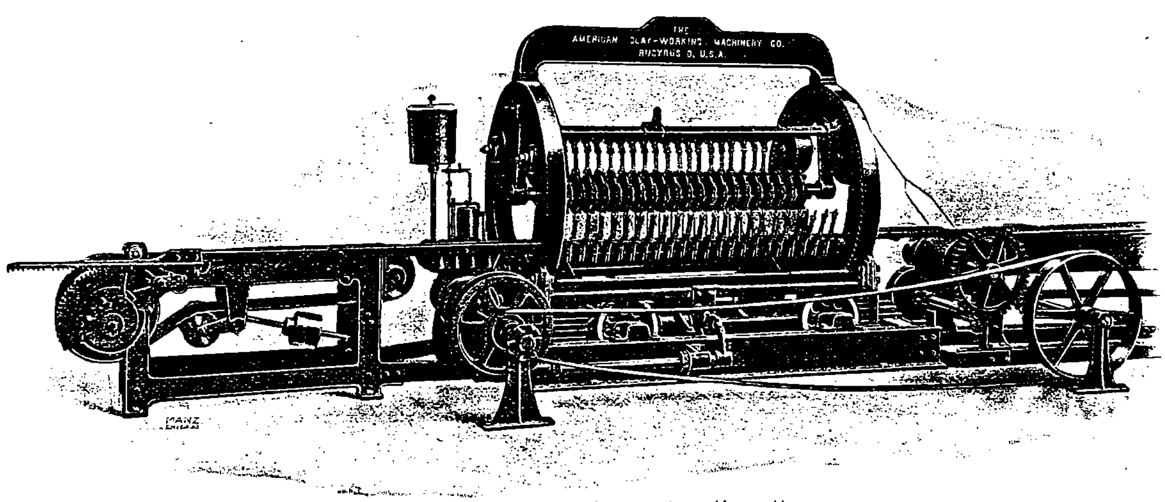


Plate 5. American rotary automatic cutter.

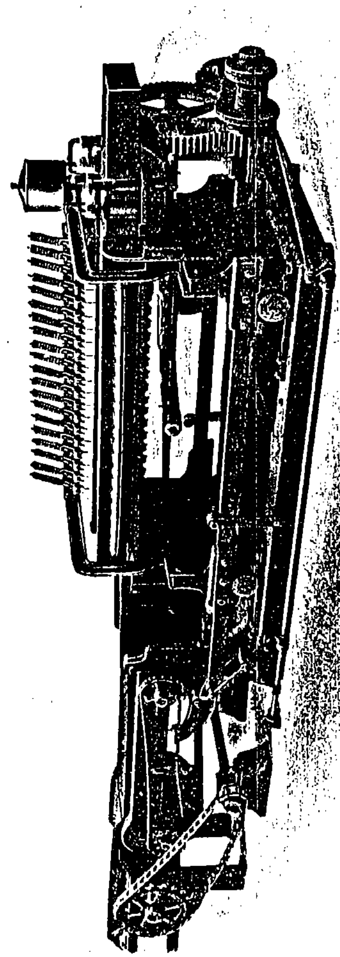


Plate 6. Bonnott & Co. oscillatory automatic cutter.

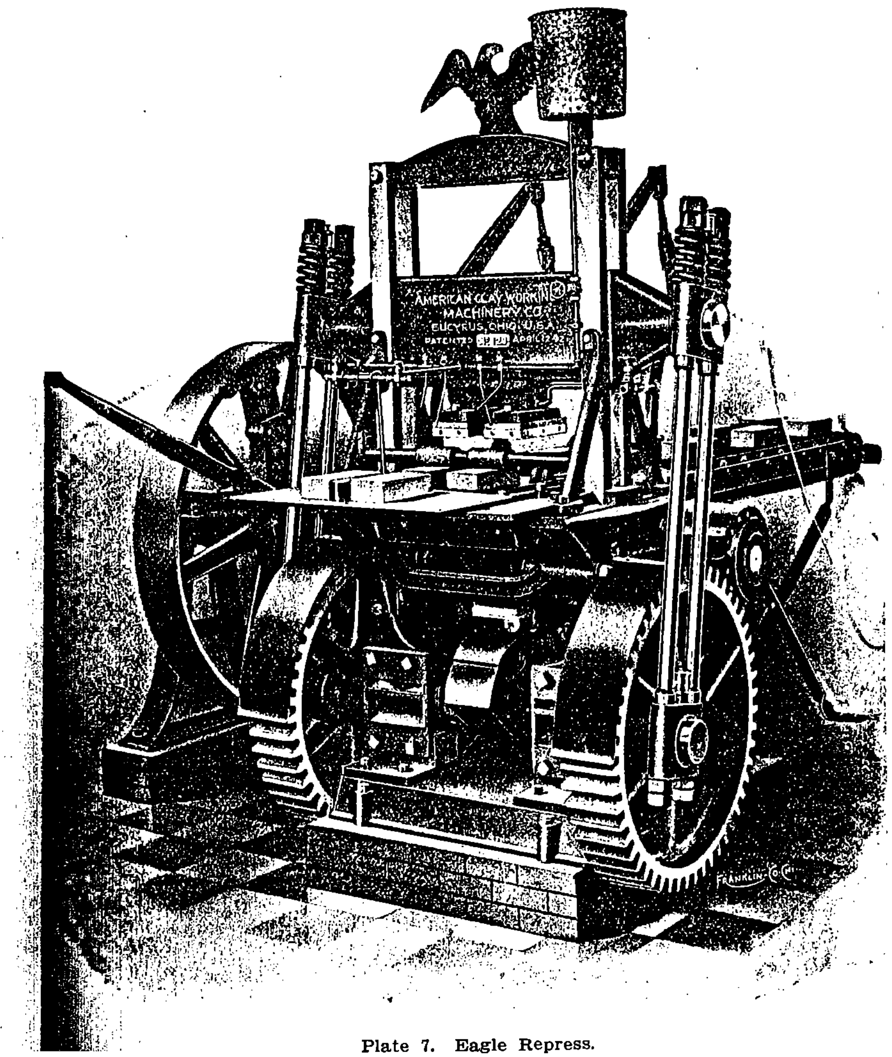


Plate 7. Eagle Repress.

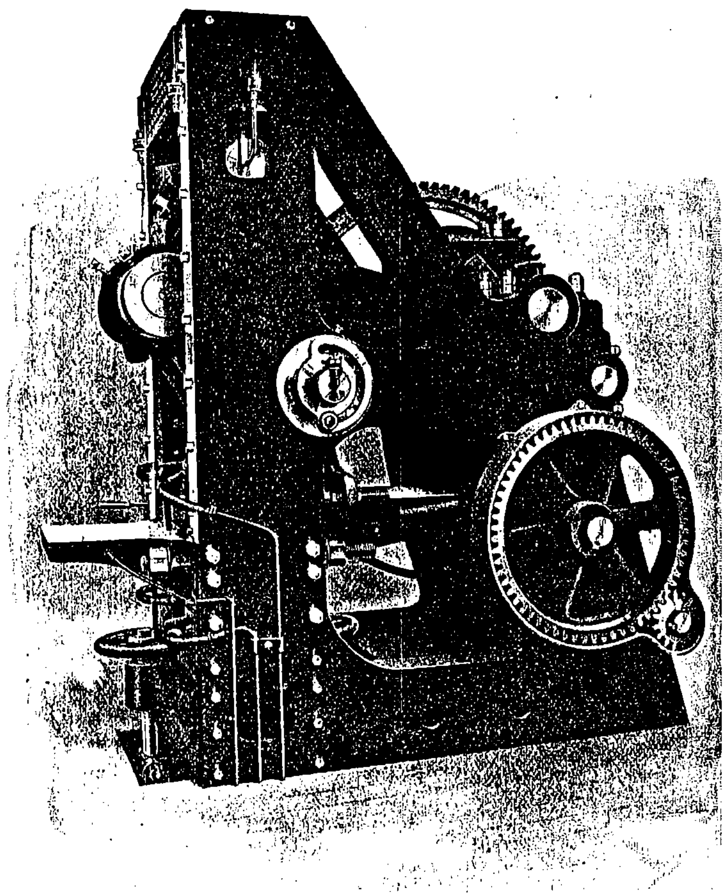


Plate 8. Berg 4-mold dry press.

The clay to be prepared is thrown into the pan, is ground to the required fineness and water is added, the action of the mullers and scrapers thoroughly mixing and kneading the clay. The wet pan is an intermittent machine for it must be stopped to be emptied. The amount of time lost in this way, however, is not great and a wet pan will supply a large amount of tempered clay per day.

Where it is important to have the material very fine and uniform the wet pan cannot be used as some pieces of the clay will almost invariably escape the mullers, but where the presence of some lumps is not a draw back, as in making common, fire or paving brick, the wet pan is very valuable as it does duty both as a grinding and a tempering machine.

MOLDING.

Clays are molded in three different conditions; (1) soft mud; (2) stiff mud; (3) dry press. The soft mud and stiff mud may be molded either by hand or machine, but the dry press requires more power than can be given by hand.

THE SOFT MUD PROCESS.

Hand Molding.

In the method of molding by hand, the clay is taken from the soak pit or ring pit in wheelbarrows tc the molding table. The molding table is usually near the drying floor which is a level piece of ground covered with sand. The molder takes a frame, which contain six molds, dips it in water and then in sand. He then takes a mass of clay somewhat larger than the mold, kneads it and throws it into a mold with a sharp blow so as to completely fill the mold. This is repeated until all the molds are filled. The tops are struck off level with the frame by a wire stretched on a bow and the excess thrown back into the heap to be used again. The off-bearer takes the frame to the drying floor and turns the brick out on the sand. When they are sufficiently dry to be handled they are turned on edge to hasten the drying. A good molder can make 5,000 to 8,000 bricks per day.

Machine Molding.

The soft mud brick machine (pl. 2) is of the plunger type. It consists of a pug mill which runs the clay into a sort of bin or hopper. When sufficient clay is in the bin to fill the molds the plunger pushes it down into the molds which are on a table beneath the bins. The plunger is then withdrawn and the bin filled from the pug mill. While the bin is filling a mechanism operated by a lever removes the filled molds and places an empty frame in its place. The molds are sanded as in hand molding or by machines driven by horse or steam power which perform the work more rapidly. The horse power machines have a capacity of from 8,000 to 15,000 and the steam power of from 20,000 to 35,000 bricks per day. The soft mud process is suited to clays of low plasticity. Plastic clays stick to the molds and cannot be removed easily. The hand molding process is used in some of the largest fire brick factories in the country.

THE STIFF MUD PROCESS.

In the stiff mud process, as the name indicates, the clay is mixed to a plastic mass sufficiently stiff to resist ordinary deforming forces. The wet ware can be handled without harming it. Almost all stiff mud molding is done by machinery.

Hand Molding.

Hand molding is resorted to in forming special pieces of terra cotta, curved sewer and sanitary piping and in making pottery and glass pots. In making terra cotta and sewer pipe and some forms of pottery, plaster molds are made of the desired shape and the clay packed into these molds by hand to the desired thickness and then the molds are removed.

Machine Molding.

Stiff mud clay machines are of two types, the plunger and the auger machines. The plunger machines have already been noticed in connection with the soft mud process. They were formerly used very largely for all the stiff mud products, but are almost altogether replaced by the auger machines except for the manufacture of sewer pipe.

The sewer-pipe press (pl. 3) consists of two vertical cylinders. A rod connects two pistons, one in each cylinder. The upper cylinder is the steam cylinder and the lower the clay cylinder. When the piston is withdrawn from the clay cylinder it is filled with the clay in the stiff mud condition from a moving belt. The cylinder is closed and steam admitted above the piston in the upper cylinder which forces the piston rod down. In its downward movement the piston in the

clay cylinder forces the clay out through the die at the lower end of the cylinder. This die consists of a cone-shaped middle piece surrounded by a cylinder or bell. The diameter of the cone regulates the diameter of the pipe, which can be made from six to thirty-six inches. As the pipe issues from the die it encounters a table which rests on a vertical rod beneath the center of the cylinder. This table is counterpoised so that when it has no weight upon it, it rises to a position immediately beneath the cylinder, but the weight of the pipe is sufficient to cause it to descend as the pipe issues from the cylinder. When the pipe has reached the desired length it is cut off by a wire or by a knife controlled by a mechanism inside the cylinder. The steam is then exhautsed from the above the piston in the upper cylinder, and forced in below it. This raises the piston in the clay cylinder so that the cylinder can be filled with clay and the operation repeated.

The *auger machine* (pl. 4) consists of a closed cylinder pug mill with an auger at the end of the shaft. The clay is mixed by the blades on the shaft and pushed forward to the auger which forces it out of a die as a column of the desired shape. By changing the die, brick, drain tile, roofing tile, fire proofing or the simpler forms of terra cotta can be made on the same machine. The die may be shaped so that its length is either the width or the length of the brick. In the former case the product is end cut brick and in the latter, side cut brick.

Cutting.

When the column leaves the machine it is carried on a belt to the cutter. Cutters may be of different types, but the automatic style are being so generally used that only the two principal kinds of the latter will be described here.

The rotary automatic cutter (pl. 5) consists of two circles connected by arms. Wire placed the width of a brick apart connect two opposite arms. The column of clay moves through the circles across the cutting table, which consists of plattens with slits between to allow the wires to pass through. The cutter is so mounted and geared that as the column moves the entire cutting frame moves forward at the same rate and the circle revolves and brings one set of wires down through the column and cuts it into brick with straight faces. As soon as the wires pass through the column the frame moves back rapidly to its original position and is ready to repeat the operation by the time the solid column has advanced the length of the table. The wires of these cutters are suspended from hooks on the arms so that they may be easily replaced when broken.

There are many variations of these cutters; some have two sets of wires at right angles to each other and make a cut with each quarter revolution. In these the circle stops while the carrier makes the return trip. Others are semi-automatic and require to be returned to their first position by a lever. Others have to be rotated by hand. On the oscillatory cutter (pl. 6) the large circular frame is dispensed with and the wires move down through the clay column and back while the cutter is traveling forward with the clay column.

The wheel cutter. The other type of cutter (fig. 12) is used principally for end-cut brick and for hollow ware, althought it is sometimes used for side-cut brick. It consists of an endless apron or belt, somewhat wider than the clay column, which rotates in the direction and at the rate of the movement of the column. Upright arms are attached in pairs to this apron, the distance between the pairs being the lengths into which the column is to be cut. A wheel with bifurcated spokes with wires stretched between the ends of the branches is mounted above the table. As the column moves forward the uprights catch upon projections of the spokes and cause the wheel to rotate. The wheel is adjusted so that on its rotation the wires pass down through the clay column and up again, thus cutting the column into the desired lengths

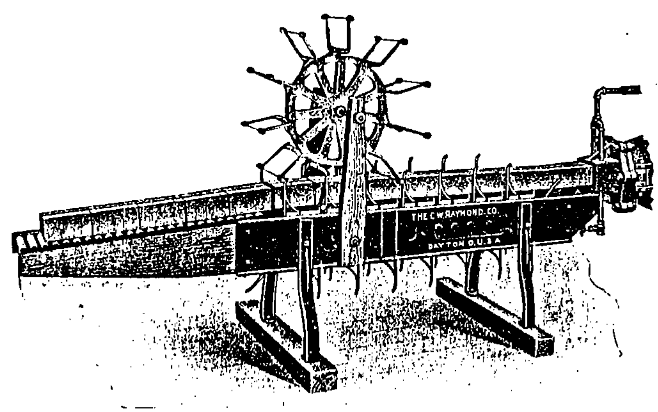


Fig. 12. Raymond "Ferris Wheel" Automatic Cutter.

Repressing.

Where it is desired to have slightly different shape to brick, to round the corners, to make a smoother surface, to impress any design on them, or to break up the laminated structure which they have from the auger machine, they are repressed.

The repressing machine (fig. 13 and pl. 7) consists of a heavy frame with plungers working into molds. The plungers have a vertical motion, and usually the pressure is applied from above and below at the same time. The brick are taken directly from the off bearing belt of the stiff mud machine or from the drying floor in case of soft mud brick. They are automatically placed in the molds by a belt carrier and the pressure applied by the plungers. When the plungers withdraw the brick are pushed onto the delivery table as the next set are pushed into the molds.

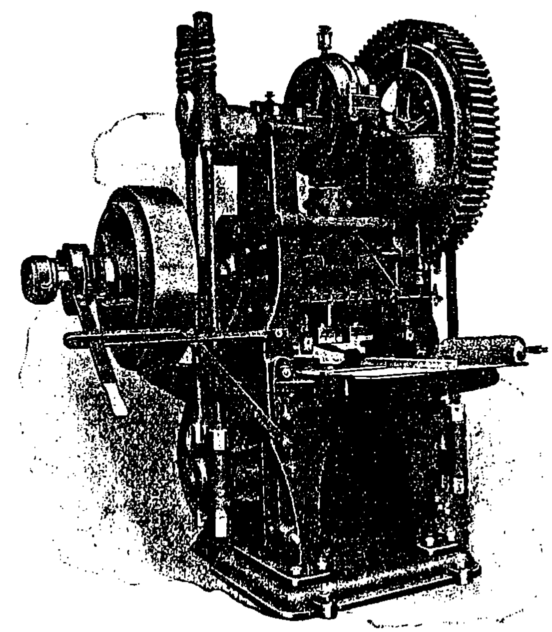


Fig. 13. Canton Repress.

By use of different shaped molds any form can be given to the brick or any design impressed or expressed upon it. The rubbing of the brick over the smooth surface of the molds gives a smoother finish than can be obtained from the die of the auger machine. There is always a change of structure of the brick as the brick cannot fit the molds exactly when first placed in them. Allowance is made for brick larger than ordinary by providing vent holes in the plungers or by having the plungers on heavy springs. The first method gives brick of uniform size, but the surface is slightly marred where the clay escapes from the vents while the second method always gives a smooth surface, but the brick may vary in size.

THE DRY PRESS PROCESS.

In the dry process the clay is not mixed with water, but is taken when damp enough to retain its shape when pressed firmly in the hand. In usually contains 5 to 10 per cent. of water. The material is ground in the dry pan, and screened to about one-sixteenth inch.

The machine (pl. 8) consists of a very heavy iron frame containing a press box and delivery table and two sets of plungers working vertically in opposite directions. The clay is fed from the bin into the charger which, when filled, is pushed forward over the molds filling them with clay and is then withdrawn. The upper plungers then move down against the clay and the lower ones, the bottoms of the molds, are forced upward, and subject the brick to pressure from both sides.

When the upper plungers withdrawn the lower ones follow them up, pushing the brick to the level of the delivery table. The charger in its next move forward over the molds pushes the brick out upon the delivery table. The brick are taken from the delivery table and stacked on wheelbarrows and wheeled directly to the kiln. This method eliminates the drying necessary in the soft mud and stiff mud processes, but the ware usually requires a longer period of water smoking than that made by the other processes.

DRYING.

THEORY OF DRYING.

By the drying of clay products is meant the removal of the water which was taken up by the clay in becoming plastic,. i. e. the water of plasticity.

Drying is carried on by means of air currents, either the natural wind currents or those produced artificially. Air at a certain tempera-

ture can contain a certain amount of water vapor per unit volume, but by raising the temperature the amount which it can contain is greatly increased. If air, which contains only a small percentage of the water that it is capable of holding, is brought into contact with wet substances, the water on the surface of the latter is rapidly evaporated and passes off as vapor. In the case of clay products this evaporation is supplied by the movement of the water within the ware outward to the surface through the system of capillary pores in the body of the ware

To obtain the most rapid drying the air should be very warm when it is brought into contact with the wet ware, since the warmer the air the greater the amount of moisture it will hold. As much of the surface of the ware as possible should be exposed and the air should be drawn through the ware at such a rate as to be very nearly saturated when it leaves the dryer. This ideal condition is seldom realized in practice as there are several conditioning factors, the principal one probably, being the danger of cracking and warping of the ware when the drying takes place too rapidly. This has already been discussed in the consideration of "drying shrinkage" in chapter III.

METHODS OF DRYING.

Natural or Open Air Drying.

In this method of drying the heat is supplied by the sun and the circulation of the air depends on the wind currents. In many soft mud plants the brick are simply "hacked" or set cris-crossed so as to leave as much space as possible between the bricks and left in the open yard to dry. In other yards a roof is built over the drying floor. In either case the drying depends entirely on the weather, the drying proceeding rapidly and being completed in a few days of warm weather when there is considerable circulation of the air, but possibly requiring weeks in cool, damp weahter. The brick are also subject to considerable damage from heavy rains and require handling several times.

Rack and pallett drying. In drying by this method the stiff mud brick from the machine or the soft mud brick from the drying floor are placed on palletts and taken to the drying shed where the palletts are placed on racks. The hauling is usually done on cars and the tracks are laid between the racks. By this method the brick are removed from the storms and there is also the possibility of controlling, in some measure, the air circulation through the sheds by means of removable or hinged side walls.

Artificial Drying.

In artificial drying, heat from the consumption of fuel is utilized. In drying sewer pipe, terra cotta, etc., large rooms are used with floor of wooden strips. Steam pipes, are laid under the floor and the air supply is from below so that the air passes around the pipes and is heated. It then passes up through the cracks in the floor to the ware.

For bricks the dryer is usually in the form of a tunnel built of bricks or of concrete. Tracks are laid through the tunnel and the bricks are hacked on cars and pushed into the tunnel. The heat is supplied by steam pipes or gas in pipes laid under the tracks or by hot air driven into the tunnel. In the latter case the air is heated in a furnace and drawn through the tunnel by a fan. Waste heat from the kilns is sometimes used. When steam is used for the heating it is usually the exhaust steam from the engines. The air supply is regulated by drafts, the moist air being drawn off by chimneys. In several plants in Oklahoma the heat is supplied by burning gas under the ware. Trenches are dug under the tracks and gas pipe, perforated so as to form a burner is laid in the trench. Any dryer which is filled with the wet ware and then the heat applied equally throughout the dryer until the ware is completely dried is an intermittent dryer.

In *continuous tunnel dryer* the heat is increased as the distance from the entrance is increased and the cars are gradually moved through the tunnel. The increase in heat is produced by increasing the number of sections of steam pipe, or number of gas burners, or by introducing the hot air at the end of the tunnel opposite the entrance.

BURNING.

The different stages of the burning of clay wares and the changes which take place in the clay during the process have been noted in a previous chapter. In this connection only a brief mention will be made of the different types of kilns used in the burning, and of the different fuels and methods of heat regulation.

TYPES OF KILNS.

The following classification [1] gives the different types of kilns used in burning the various clay products.

1. Beyer and Williams, Geol. Survey of Iowa, Vol. XIV, p. 288.

- Intermittent kilns.
  - UpDraft
    - Temporary
      - English clamp
      - American scove
    - Permanent
      - Direct
        - Rectangular
        - Round
      - Semi-Muffle
      - Muffle
        - Pottery kilns
  - Down Draft
    - Direct
      - Round
        - Single Stack
        - Multiple Stack
      - Rectangular
        - Single Stack
        - Multiple Stack
    - Muffle
- Continuous kilns

Up-Draft Kilns.

Up-draft kilns are of two shapes, rectangular and round. In the *temporary rectangular up-draft kilns* the brick are set into a rectangular pile and surrounded by a double wall of green or soft burned brick. This wall is covered with mud to prevent the escape of heat and the entrance of cold air. The top is covered by a layer of brick called the platting. Fire boxes are provided by setting the lower courses of brick in the form of arches. The fires are started in these arches and the heat, passing upward through the brick, burns the ware. The kiln is usually covered by an Λ board roof. This method of burning is applicable only to common brick as there is little regularity in the degree of burning. The brick in the arches are usually over burned and often slaggy while the top courses are often too soft to be salable. Seventy per cent. of salable brick is considered a good yield from a burn in a scove kiln. The *permanent rectangular up-draft kilns* have permanent walls, otherwise they work on the same principle.

The round up draft kilns have a lower combustion chamber whose bottom is solid except for the fire grates. This chamber is separated from the upper chamber in which the ware is placed by a layer of fire brick with interstices to permit the heated gases to pass upward through the ware. The gases escape through several small chimneys in the roof of the kiln. This type of kiln is used principally in burning pottery and stoneware. As these materials are injured by direct contact with the combustion gases most of these kilns are of the muffle type, the ware being placed in chambers closed from the direct flames and receiving the heat by radiation and conduction through the walls.

Down-Draft Kilns.

The down-draft kilns are constructed with permanent fire boxes on the outside of the walls. They may be either round or rectangular in shape and in either case are roofed in. The combustion gases pass to the top of the kilns through flues, or through openings left in the setting of the ware, down through the open spaces between the pieces of ware, and find an outlet to the flue or stack through the grated floor and the tunnels leading to the stack. There are many variations in the number of fire boxes, and stacks, and in the method of construction and spacing of the tunnels under the floor which lead the gases to the stacks; the object being to obtain an equal temperature throughout the kiln and the greatest possible heat value from the fuel consumed.

Continuous Kilns.

The continuous kiln consists of a number of chambers arranged in a circle, oval, or rectangle. These chambers are connected with each other and with a central stack by flues so that the combustion gases may be led from any chamber into any of the others or to the stack.

In practice the waste heat from a chamber which is being burned is conducted through a chamber which has been newly set thus raising its temperature and performing the water smoking. By the time the first chamber is burned it requires only a short period of active firing to finish the second chamber and the waste heat from it is utilized in warming up and water smoking the third chamber. The process is considerably varied to suit different clays and products, but is essentially as outlined above. In the continuous kiln all the processes of setting, water smoking, finishing, cooling and drawing may be going on at once in the different chambers of the kiln. The continuous kiln is widely used in Europe and its use in this country is increasing, especially in the manufacture of paving brick.

All of the permanent kilns are constructed of one or more thicknesses of brick, the inner layer being of fire brick. The amount of heat lost through the walls is very great, usually representing a large percentage of the fuel value of the coal. This is in some measure overcome by building the kiln wall in three layers—an inner and an outer one of brick and a middle one of hollow brick or fire proofing. This makes a dead air space which checks the movement of heat through the wall. The spaces in the hollow ware may be filled with some loose material

FUELS.

Among the different substances, which may be used for fuel in the burning of clay products, four need to be considered in connection with the industry in Oklahoma. These are wood, bituminous coal, oil and natural gas.

Wood can be used profitably only in the southeastern part of the State and only for products which do not require exceptionally high temperatures, such as common brick and drain tile. It may be used to advantage during the water smoking period, the remainder of the firing being done with coal. Wood should be perfectly dry, since when wet the greater part of the heat value is expended in evaporating the water it contains.

Bituminous coal will be the principal fuel in the coal belt and in the western part of the state as it is the fuel which is most economical to transport. It can be used to produce any temperature desired in clay working. Firing with coal requires considerable attention, but not so much as with wood. The combustion gases from coal contain some sulphur and may discolor the ware if they come into direct contact with it. There is also considerable soot and smoke which may have a similar effect.

Crude oil is used as fuel in some localities. It is especially adapted for use under the boilers on account of its great heat value, the lack of ashes and soot, and the small amount of draft required which permits of much lower temperature of the flue gases. The oil is fed into the fire through injector nozzles and the firing requires little attention. Oil may be used economically in the northeastern part of the State and along the pipe lines leading from the oil fields. It may be transported in tank cars, but where this is necessary coal will probably be the cheaper fuel.

Natural gas is the ideal fuel for burning clay products. It possesses a great heat value, is without ashes, soot or combustion products which discolor the ware, is easily regulated and requires very little attention in firing, and can be used with a light draft and consequently with a relatively small amount of waste heat in the flue gases. Gas is used as fuel in several plants in northeastern Oklahoma, but only a fraction of the available supply is being utilized. In many localities gas may be had at as low as two cents per 1,000 cubic feet.

CONTROL OF TEMPERATURE.

In most of the brick plants of the state the temperature to whicl the product is burned is judged by the eye, i. e. the ware is burned to a "dull red" heat, "cherry red" or "white heat." This is an extremel crude way of judging temperature and results in much variation i the burned products. The appearance of the kiln at th same temperature differs greatly to different persons and to th same person at different times, e. g. a kiln appears much hotter at nigl than in the day time, on cloudy days than on bright days, etc. Th conditions of the kiln gases and of the fires also have a pronounce effect on the appearance. There may be a wide difference in temperatu in different parts of the kiln which will not be apparent to the eye.

The matter of controlling the temperature and of obtaining a un formly burned product is comparatively simple. One of the metho best adapted to the commercial plants in the State is the use of t *Seger pyrometric cones.*

These "cones" are small triangular pyramids, about one-half in in dimension at the base and one-eighth inch at the top. They are abo three inches long. The original series of Seger cones was number from 36 down to 1. Cone 36 contains alumina and silica in the pr portion of the molecular weight of alumina and one and one-half tim the molecular weight of silica, this being the most refractory mixture the two subtsances. The cones down to cone 28 contain different pr portion of alumina and silica so that successively lower numbers me at 20°C. lower temperature. From cone 28 down to cone 4 they co tain varying proportions of alumina, silica, lime and potash, from co 4 to cone 1 they contain alumina, silica, lime and ferric oxide. This com pleted the series as first made by Seger. Later Cranier added a mo fusible series, beginning with cone 01 which melts 20°C. lower th cone 1 and going down to cone 022. He formed those of lower melt points by using soda, lead oxide and baric oxide as constituents wi alumina, silica, ferric oxide, lime or potash.

We have then, a seres of cones numbered from 022 to 1 and fro 1 to 36. The difference in the melting points of any two success members of the series from cone 022 to cone 010 is 30°C. and fro cone 010 to cone 36 is 20°C. Cone 022 melts at 590°C. which is a a visible red heat while cone 36 melts at 1850°C. a dazzling white he

In practice the cones are set in a small clay pat (fig. 14) and fa ened to a brick and so pla ed that it can be observed through a peep ho

The peep hole should be closed by a glass plate to prevent any cold air from striking the cones as this causes a scum to form over them which prevents their falling when the proper temperature is reached. When the temperature at which the cone melts is approached the cone begins to bend over and when that temperature is reached the tip touches the base.

Three or more cones are placed in one pat, e. g. if it is desired to burn at cone 5, the pat may contain cones 2, 3, 4, 5, and 6, numbering from left to right. As the temperature rises the melting and falling of cones 2, 3, 4, successively give notice of the approach to the desired temperature and the condition of cone 6 will indicate the amount of

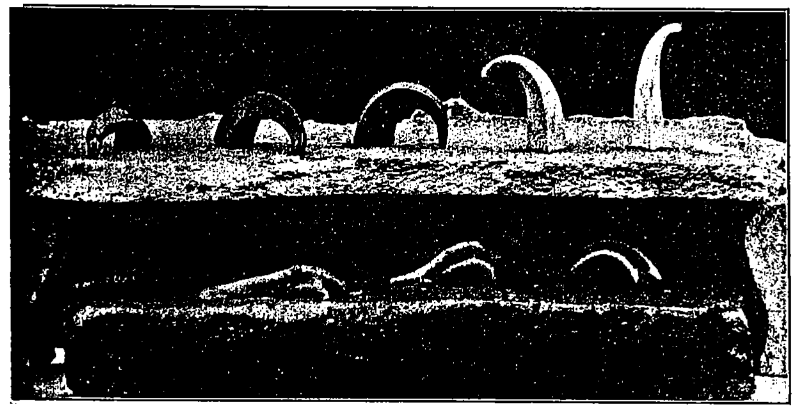


Fig. 14. Seger Cones showing effect of high temperatures.

over burning if any. The pats of cones are set in different parts of the kiln in front of peep holes through which they may be observed. If the cones in one part of a kiln begin to melt before those in another, the firing may be checked in the fire boxes controlling the hotter portion and the draft regulated so as to secure approximately equal temperatures throughout the kiln at the completion of the burn.

The use of the cones is easily learned by the burners and as the only expense is the initial cost of the cones (about one cent each) and the time consumed in setting of the ware to permit the view of the cones through the peep holes, the improvement in the quality of the ware represents much more than the extra expense.

Another instrument which is coming into wide use as a means of recording temperatures is the *thermo-electric pyrometer*. This consists of two wires enclosed in a porcelain tube, and separated from each other by a smaller tube through which one of the wires extends. One wire is usually of platinum and the other of an alloy of platinum and rhodium. The two wires are coupled at the closed end of the outer tube. The heat acting on this couple sets up a small electric current whose strength increases with the temperature. The outer ends of the wires are connected with a galvanometer which is graduated so as to read the degrees of temperature. The galvanometer may be set at some distance from the kiln so that the temperature may be read in the office is desired. Recording devices may be used in connection with this pyrometer. A full outfit of thermo-electric couple and galvanometer costs from $150.00 to $200.00. In practice the porcelain tube containing the couple is inserted through an opening in the kiln wall before the fires are started and allowed to remain throughout the burn. It may be inserted into the kiln only at the time when it is desired to observe the temperature, but this must be done very slowly and with extreme care to prevent the porcelain tube from being cracked by the heat. The thermo-electric pyrometer and the Seger cones are often used as checks and to supplement each other.

CHAPTER VI.

CLAY PRODUCTS, THEIR MANUFACTURE AND USES

INTRODUCTION.

The use of clay products has become so common and so important in so many lines of activity in modern life that few people realize the importance of these products or the variety of forms in which they occur. The following list of Ries[1] is complete and is used to show the myriads of uses to which raw and burned clays can be put.

"*Domestic.* Porcelain, white earthenware, stoneware, yellow ware and Rockingham ware for table service and for cooking, majolica stoves: polishing brick, bath brick, fire kindlers.

"*Structural.* Brick: common, front, pressed, ornamental, hollow. glazed, adobe; terra cotta; roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney pots; doorknobs; fireproofing; terra-cotta lumber; copings; fence posts.

"*Hygenic.* Urinals, closet bowls, sinks, washtubs, bath tubs, pitchers, sewer pipe, ventilating flues, foundation blocks, vitrified bricks.

"*Decorative.* Ornamental pottery, terra cotta, majolica, garden furniture, tombstones.

"*Minor uses.* Food adulterant; paint fillers; paper filling; electric insulators; pumps; fulling cloth; scouring soap; packing for horses' feet; chemical apparatus; condensing works; ink bottes; ultamarine manufacture; emery wheels; playing marbles; battery cups; pins, stilts and spurs for potters' use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pump wheels; electrical porcelain; foot rules; plaster; alum.

"*Refractory wares.* Crucibles and other assaying apparatus; gas retorts; fire bricks; glass pots; blocks for tank furnaces; saggers; stove

1. Ries, Heinrich, Geol. Survey of N. J., Vol. VI, p. 213-214, 1904.

and furnace bricks; blocks for fire boxes; tuyeres; cupola bricks; mold linings for steel castings.

"*Engineering works.* Puddle; Portland cement; railroad ballast, water conduits; turbine wheels; electrical conduits; road metal."

In this chapter the principal products will be noticed, with the variations of the general processes of manufacture used in their production, the clays fitted for use in the manufacture, and a short discussion of the tests upon the finished products where these are important. The arrangement of the list previously given is not strictly adhered to, but the products are grouped more nearly in order of their importance and with regard to the processes used in their manufacture.

STRUCTURAL AND ENGINEERING WARES.

Under structural wares the following products will be noted: common, front and ornamental building brick, glazed and enameled brick; sidewalk and sewer brick; paving brick; tile (drain, roofing, wall and floor); fire proofing, hollow block and hollow brick; terra cotta.

BUILDING BRICK.

Common brick are probably the most used of any clay products. They are manufactured extensively in every state in the Union. Almost any clay can be utilized for common brick by one or more of the three processes as discussed in the preceding chapter, but those clays are usually selected which have good working qualities and which will burn to a satisfactory hardness at low temperature. Most common brick are burned at a temperature below cone 05 and very few above cone 1. The soft mud, stiff mud and dry press processes are used for common brick. Sandy clays work better by soft mud process, shales by the stiff mud process, while extremely plastic clays give better results with the dry press.

Common brick are used in all structural work where appearance, i. e. color and regularity of form, are not essential, such as in side walls, back walls and partitions, foundations and, from motives of economy, in front walls.

There are no standard tests for common brick. In some cities a crushing strength test and absorption test is required, but the lines are seldom drawn very closely. There is little need for such a test because the crushing strength of practically any well burned common brick is far greater than that to which it will be subjcted in any structure in which it is likely to be used. Brick so soft as to fail under a reasonable crushing load can be easily detected by a casual inspection and the cracked or broken brick should, of course, be discarded. The absorption of common brick runs as high as 20 per cent., the average being 12 to 15 per cent. Bricks with high porosity may show a tendency to weather down rapidly especially in regions where they are subjected to much freezing.

The common brick produced in the United States during 1908 represented over one-third of the total value of all clay products. The production was 7,811,046 thousand, valued at $44,765,614.00. Oklahoma's production was 74,836 thousand valued at $457,588.00.

Front or face brick are manufactured by the same general process as common brick, but strict attention is paid to the matters of color, regularity of form and sharpness of edge. Dry press brick when properly made are regular in outline and have sharp well defined edges. For these reasons dry press brick are very popular for front work. Stiff mud and soft mud brick are usually repressed to produce these results.

The price of face brick is usually much higher than that of common brick and they may therefore be made of clays which must be burned at a rather high temperature. No. 2 fire clays, which must be burned as high as cone 10, are often used for front brick on account of their peculiar color. Especially bright and sometimes odd colors are produced by "flashing" or reduction and reoxidation during burning. Mottled brick are usually made by the addition of a small percentage of iron or manganese ore to the clay in grinding. In burning the small pieces of iron or manganese in the brick melt and produce black spots or the mottled effect on the surface. Face brick are as a rule much less porous and have a higher crushing strength than common brick.

In 1908, Oklahoma produced 1231 thousand front brick valued at $16,010.00.

Glazed and enameled brick are made by dipping one, or in some cases, two surfaces of the dried or burned brick in a slip of low melting point. After drying, the bricks are burned and the thin layer of slip clay on the surface is melted and forms a glaze or enamel. A glaze is transparent so that the original color of the brick shows through, while an enamel is colored and opaque so that the original color of the brick is hidden and the finished product has the color of the enamel.

Bricks to be enameled or glazed must, of course, be made of clay which will not be affected by the temperature required to melt the slip clay or glaze used. Glazed and enameled brick are sometimes used for front brick, and for walls of hallways, stairways, bathrooms, etc.

SIDEWALK AND SEWER BRICK.

Sidewalk and sewer brick may be made of better grade clays than are used for common brick. They are made by the stiff mud process, are usually repressed, and are then burned nearly or quite to vitrification. Their use is expressed in the name.

PAVING BRICK.

Paving brick and paving block differ only in size, the former being 2 x 4 x 8″ and the latter 3 x 4 x 9″. In the following paragraphs the word brick will be used to refer to both sizes. They are usually made from shales, although low grade fire clays may be used. Clays for paving brick must have a slow rate of vitrification and a long fusion range. (See description of porosity curve, page —). After the shale or clay has been ground rather coarsely it is then made up to a stiff mud in a pug mill or wet pan and molded by auger machines. The brick, after cutting, are repressed to give smoother surfaces and more regular outlines. Some design is usually impressed or expressed on one or more surfaces in repressing and sometimes one edge is beveled so as to afford a foothold for horses in the pavement. The brick are dried by any of the methods previously described and burned in down draft kilns. They are burned to complete vitrification usually at temperatures ranging from cone 3 to cone 7.

Use of Paving Brick.

The use of brick for paving is of comparatively recent introduction. The first brick pavements were laid in Charlestown, West Virginia in 1872. Since that time their use has increased very rapidly until at present there is probably as much pavement being constructed of brick as of asphalt, stone block and wood block combined. The brick streets have been universally successful for residence streets and for moderately heavy business traffic, where proper care was used in the selection of material and the construction of the streets.

Advantages. The advantages of brick pavements are given as follows[1]:

1. Byrne, A. T., Treatise on Highway Construction, p. 258.

1. Ease of traction.
2. Good foothold for horses.
3. Not disagreeably noisy.
4. Yields but little dust and mud.
5. Adapted to all grades.
6. Easily repaired.
7. Easily cleaned.
8. But slightly absorbent.
9. Pleasing to the eye.
10. Expeditiously laid.
11. Durable under moderate traffic.

Defects. The failure of brick pavement usually result from the use of poor brick, i. e. those which are not uniformly burned, or those which are made from clay not adapted to their manufacture, or to improper construction in the foundation or cushion coat.

The Properties of Paving Brick.

Paving brick should be regular and uniform in size and shape, so that they will fit closely together in the pavement. They should be uniform in hardness, (i. e. must not be over nor under burned), and this hardness must be sufficient to resist the action of traffic. Each brick should be homogeneous in texture and should be free from laminations and seams.

The general appearance gives an idea of the relative quality of the different brick from the same plant, but does not give a basis for comparison of brick from different plants or clays. The edges of the brick should be reasonably straight and smooth and should not be easily chipped by light blows of a hammer. The *sides* should be flat and the *corners* round. Brick from the same plant should be uniform in size as large brick may indicate under burning and small brick, over burning. They should also be uniform in color as lighter colored brick are usually under burned and softer, while darker colored are over burned and harder than the average. Color cannot be used in comparing bricks made by different processes or from different clays, but only in comparison of bricks in the same lot. The *surface* color is often misleading on account of the sand which has been used in setting the brick in the kiln or from the effect of sulphur in the coal or other causes. Color comparisons should be made on freshly chipped surfaces. The *interior* of the brick should be uniform in texture and color. It should not show either unfused or glassy spots as these indicate poor mixing of the materials. There should be no lumps unless the boundaries are well fused in the rest of the brick. Lumps of lime are very detrimental as they slake when they become wet and are apt to disrupt the brick. The fresh surfaces should have a vitreous or glassy lustre.

Physical Tests.

The physical tests which have been used for paving brick are crushing strength test, absorption test, transverse strength test, and rattler test.

If made under uniform conditions the crushing strength test would be useful to compare the qualities of different brick, but otherwise it is of little value and has been generally abandoned. Brick are very unlikely to fail from lack of crushing strength as very ordinary brick will show a strength of 6000 to 8000 pounds per square inch and they are very seldom subjected to a load of over 2000 pounds per square inch.

The transverse strength test is made by resting the ends of the brick upon knife edges and applying pressure upon a third knife edge in the middle of the brick until failure takes place. As in the case of the crushing strength test this furnishes a means of comparing different brick but is of little value in determining the properties of a given brick, as bricks in pavements are seldom known to fail in this way until they are worn almost through.

The absorption test. This test is of value in showing the measure of the vitrification which has taken place. Under burned brick are very porous, while over burned brick may be somewhat porous due to the formation of bubbles in melting. Brick properly vitrified have no pore space and consequently will not absorb any water.

To make the absorption test, five brick are dried carefully and weighed, then placed in water with the upper surface of the brick level with or slightly above the surface of the water, and left for forty-eight hours. The surface is then dried by wiping with a cloth and the brick re-weighed. The per cent. of absorption is obtained by calculating the gain in weight as per cent. of the weight of the dry bricks. Good paving brick may show absorption of from five-tenths to two per cent.

The rattler test. This test is supposed to give a measure of the resisting power of the brick to wear by impact and abrasion. As usually performed the test is as follows:

A charge of given number of brick (usually 10) is placed in a drum, twenty-eight inches in diameter and twenty inches in length. which has cast iron heads and is enclosed by fourteen cast iron staves. Small spaces between the staves permit the escape of the fine material worn from the brick. There is introduced with the brick a charge of 300 pounds of cast-iron shot of two sizes, one-fourth or seventy-five pounds of which is of the larger size, each shot being two and a half by two and a half, by four inches in dimensions with rounded corners and weighing about seven and a half pounds. The remaining 225 pounds is of one and a half inch cubes with square corners and edges weighing about seven-eighths pounds each.

After being securely closed the drum is rotated 1800 times at the rate of thirty revolutions per minute. At the end of the test, the brick are removed from the drum and weighed. The rattler loss is calculated by obtaining the loss in weight as per cent. of the original weight. The loss of standard paving brick runs from fifteen to twenty per cent. as a general rule, although different brick may vary somewhat widely and still give satisfactory results in paving.

Construction of The Brick Pavement.

The *foundation* of the brick pavement is usually a six inch layer of Portland cement concrete. Upon this is spread the "Cushion coat" consisting of one inch of fine, clean sand. This is rounded into the exact form of the crown desired in the finished pavement by a template. The bed is now ready for the brick. These are usually delivered by wagons and laid in piles along the curbs ready to be transported to the layers in wheel-barrows. The brick are laid in courses with the long direction perpendicular to the curb, except at street crossings, where they are set diagonally. In order to alternate the joints in the courses, every other course is started at the curb with half a brick. After the brick are laid, the pavement is rolled with a steam roller of from four to six tons in weight. Brick around manholes, and other like places. that cannot be reached with the roller, are thoroughly rammed in a well constructed pavement.

Filling the joints. After the rolling, the joints between the bricks should be filled to keep the brick in the proper position and to render the pavement impervious to water. The three materials commonly used for filling are sand, tar, and cement. *Sand* is most commonly employed as a filler. It should be shoveled on the street and thoroughly swept into the joints. When this is done the street is covered with a second layer of sand one-fourth to one-half inch in thickness and opened to traffic. The advantages of a sand filler are[1]: (1) It is cheap, usually costing about two cents per square yard. (2) The pavement may be open to traffic as soon as the brick are laid. (3) The pavement may be taken up easily and without breaking of the brick. (4) It is practically water-tight, particularly after being in service a short time. The disadvantages of a sand filler are: (1) It does not protect the edges from chipping. (2) It may be washed out on steep slopes. (3) It is removed from the top of the joints by street sweepers. *Tar or asphalt* or a mixture of the two is sometimes used as a filler. It is heated and poured into the joints. It is somewhat more expensive than sand. It makes a perfectly water-tight joint; and tends to make the pavement less noisy. However, it is likely to melt and run out of the joints in hot weather and to become brittle and chip out of the joints in cold weather. *Portland cement-grouting* is made by mixing one part of cement with one part of fine sand and making up to the consistency of thin cream with water. It is poured on to the surface of the street and swept into the joints. The street should then be covered with a thin layer of fine sand and closed to traffic until the cement sets. The cement joint protects the edge of the bricks from chipping but does not take up the expansion of the pavement in hot weather as the sand or tar joints will do. It also make it difficult to take up the pavement without breaking the brick.

Rumbling. The rumbling noise often produced by a brick pavement, especially in hot weather is due to the expansion of the pavement by heat, which causes the crown to arch up away from the cushion coat. It can be prevented by placing an inch board along the curb when the brick are laid, removing this after the pavement has been completed and filling the space with pitch. For the expansion in the direction of the length of the street, it is well to have rather wide (one-half to one inch) joints at intervals filled with pitch.

Maintenance. The maintenance of the brick pavement consists in keeping the surface absolutely even. If any holes or depressions arise from the rapid wearing of a soft brick or the settling of one into the cushion coat, the continual hammering from the wheels dropping into the depression rapidly wears away the surrounding brick and increases the hole. In such cases the brick should be removed and replaced by

1. Baker, I. O., Roads and Pavements, p. 507.

a good one, or sand should be added to the cushion coat and rammed and the brick replaced on a level with the others.

Life of the brick pavement. Where they have been properly laid and are composed of good brick of uniform quality, brick pavements have proved very durable. Many pavements are still in good condition after fifteen to twenty years' use under moderate traffic.

Cost. The cost of brick pavements varies with the locality, with distance which brick must be hauled from factory to town where used, and from cars on switch to street, with labor conditions, etc. Where pavers are made within a reasonable distance the cost of the pavement usually ranges from $1.50 to $2.00 per square yard. If the concrete foundation can be dispensed with, the cost is reduced one-fourth to one-third.

Use of Brick for Country Highways.

So far, the initial cost of brick roads has prevented their general use but during the last few years several miles of brick roads have been built especially in Ohio and Pennsylvania. They are proving very satisfactory and it is generally conceded that the difference in initial cost between the brick and other roads is more than made up by the excellence of the roads, the ease of maintenance and the difference in the costs of repairs. At present, there are not enough paving brick made in Oklahoma for them to be considered as an available country road material. This condition, however, cannot endure as the immense beds of shale in the eastern part of the State combined with the advantage of the same section in the way of fuel and transportation, will make this region a great center for the manufacture of clay products, paving brick among others. The increase of population and of land values in the same region, will soon bring about a demand for permanent highways and brick will become not only an available, but an advisable road material.

Statistics for Paving Brick.

The rapidly increasing popularity of vitrified brick as paving material is shown by the fact that between 1905 and 1908 the value of the output for the United States increased 58.98 per cent. and the number increased 46.89 per cent. In 1907 the value of the output increased 22.89 per cent. over that of 1906 and in 1908 it increased 10.39 per cent. over that of 1907. This is more noticeable in view of the fact that all other clay products (except drain tile) showed marked decrease in value and number in both 1907 and 1908.

The value of the paving brick produced in the United States in 1907 was $9,654,000 and in 1908 $10,657,475. Oklahoma produced 3528 thousand paving brick valued at $39,676 in 1907 and 7681 thousand valued at $71,545 in 1908[1].

DRAIN TILE.

Manufacture.

Drain tile may be made of almost any clay which does not crack too badly in drying or burning. A further requirement for the clay is that it shall not contain chunks of lime or magnesium carbonates as these are reduced to the oxides when burned and when wet, slake and swell, thus causing the ware to crumble. Tile are made from stiff mud, usually by an auger machine having a circular die, although different styles of plunger machines and also hand presses are used in their manufacture. They are made in sizes varying in diameter from two inches to three feet or even larger. Any means of drying and burning may be used with the smaller sizes, but the larger sizes require considerable care to prevent cracking. Contrary to the popular notion it is not necessary for drain tile to be porous so they may be burned to vitrification if desired. They are usually burned sufficiently hard to resist breaking when handled and to support the required weight when they are stacked up or are buried in the drains. Besides sufficient hardness, the important requirements for drain tile are straightness, uniformity of diameter and smoothness of ends.

Advantages of Under-Drainage for Soils.

Whenever the ground water level is less than three or four feet below the surface of a soil for any length of time during a season the soil will be improved by under draining.

This under draining will lower the water level and thus permit (1) the earlier working of the soil after the wet seasons, (2) the growth of the roots of the plants deeper into the soil with corresponding increase in the portions of the plant above the ground, (3) the circulation of air through the soil producing chemical changes necessary to plant growth, (4) the permanent loosening of the surface soil with consequent attraction (by capillary forces) of the deeper seated ground water, which is thus drawn into the surface soil as needed. It is this last item which makes drainage valuable in dry weather as well as wet. It is a fact that well drained soil is looser and thus holds moisture

1. Statistics from Mineral Resources of the U. S. 1908., U. S. Geol. Sur.

much longer than a heavy soil in which the ground water may stand at a higher level, but in which the surface "bakes" to a hard crust as soon as it dries.

Method of draining. Draining may be accomplished by open or closed ditches.

The open ditch is often used in new countries, but is soon replaced by closed ditches for one or more of the following reasons:

(1) The open ditch is only temporary, as it requires opening every season or even several times in a season.

(2) It breaks up a field into little patches that cannot be plowed across without being filled.

(3) It is not possible to plant nor cultivate very near an open ditch; therefore a lot of waste land results, which is allowed to grow up in brush and weeds or which requires as much care as an equal amount of productive land.

(4) On sloping land open ditches may give rise to destructive washes or gullies.

On the other hand the closed drain is permanent, allows large tracts to be tended, and produces no waste land.

Various materials have been used in the construction of closed drains, such as brick, boards, stone, brush and drain tile, but the advantges of the cylindrical drain tile are so important and so evident that no other material is used where this can be obtained.

Construction of tile drains. Since little or no drain tiling has been done in Oklahoma and as such drainage would permanently improve large areas of land, the following article[1] is given as it discusses the fundamental principles of tile drainage briefly and clearly.

"*What Soils Need Tile Draining?*. A brief answer to this question would be, that all soils suited to cultivation and crop growing, not readily freed from an excess of water, should be tile drained.

"The above answer is not sufficiently definite, perhaps, for many who would like to know how far they may profitably extend the work of tile draining their land. We further answer, therefore that the work may be extended on land adapted to profitable farming until water from an ordinary rainfall is passed down into the soil and the excess of water is carried away through the under-drains with-

1. J. J. W. Billingsley in Clay Worker for Oct. 1908.

out injury to the growing crops, or surface washing of the land. To carry out this view of under-drainage practically involves a very considerable enlargement of the work, much more than has been contemplated by many farmers.

"The opinion was entertained by some in the beginning of the work of tile drainage that only the low, wet places, sloughs, or ponds, needed this improvement of soil conditions, and a few may be of the same opinion now, but there has been a radical change as to the extent of the need of drainage among intelligent farmers and other land owners.

"It is very common now for a good farmer to say: 'The more I tile drain, the more I see the need of it.' Another says: 'When I commenced tile draining my land, I thought that one hundred rods of drain tile, or a very little more, would be all that I needed, but it looks now as though I shall not get through tile draining my land until all that is in cultivation is underdrained.' So it is with those who have learned something of the benefits of underdrainage.

"It is believed by many that ordinary farm lands, which have a surface drainage sufficient to carry off the water of heavy rainfalls in a few hours, do not need tile draining; but such lands may need it very much, not only to prevent the waste of fertility from surface washing, but rolling lands are often injuriously affected by an excess of water in the under soil, which, coming out slowly to the surface evaporates making the top soil cold and sodden. Water falling on higher land enters into the soil, and passing into the subsoil, may come in contact with a strata of almost impervious clay, then passes slowly through the soil over the close retentive clay, keeping near the surface soil until a lower level is reached, or it may come out in what are called seeps of considrable extent. This underflow water is quite general and it may be so near the surface that the water coming out to the surface may have a chilling effect and greatly retard and injure the growing crop. If we have not familiarized ourselves with these facts, we will often be at a loss to account for the spotted conditions of crops on rolling lands, they grow slowly and get yellow and spindling on lands that have a sunny exposure.

"The wonderful change wrought by underdraining such land will prove a most gratifying surprise to many land owners. The soil will become open, warm and mellow in its nature, and the crop yield will be quite doubled.

"Clay soils having no underlying strata of sand or gravel near

enough to the surface to afford an outlet for the excess of water, need tile drainage.

"Thorough work in drainage involves the construction of underdrains in parallel lines, near enough to each other so that the soil and subsoil will be affected nearly alike, and the water level in the soil be lowered to a point where it will not injuriously affect the growing crops, and give a circulation of air through the soil and subsoil above the water level.

"The drainage is expensive when well done, and more expensive when poorly done. But it is most costly of all when not done at all. when it is badly needed, and it is often needed more than we think.

"*The Work of Drainage.* A broad, correct view of the extent of the work needed to be done is very essential for a right beginning, otherwise much of the work done at first may prove a hindrance to its progress afterwards; in the failure of not having well-planned the work, in the using of sizes of tile too small, and in digging the drains too shallow.

"*A general Plan.* In planning to drain a field or any given area of land, the general surface configuration of the land should be carefully studied and levels taken, if the use of an engineering level can be had at a reasonable cost. It is important to know definitely where the best outlet should be located to afford a free flow of the water—where the main and submain drains should be placed to secure the most efficient drainage. It is also important to know what fall can be had in the several drains, including the main and lateral drains, for the reason that drains, including the main and lateral drains, having considerable fall require a less size of tile than those having much less fall.

"Again it is important to know the character of the soil and subsoil. If open, the lateral drains may be laid further apart (from 60 to 100 feet); if the soil, or, more particularly the subsoil, is retentive or close, allowing the water to percolate slowly through it, the drains need to be closer together (from 30 to 50 feet apart), to secure the most efficient drainage.

"Another important factor to be considered in the general plan is the amount of water that flows on to the land to be drained from land adjoining. This, if considerable, must be provided for by using larger tile for the drains that will necessarily carry this extra or water shed.

"After determining all these factors that have to do with the efficiency of the work when completed, the entire system should be outlined on paper, including the levels, each drain, mains, submains, and lateral drains, and the sizes of tile to be used, including, also the depth of the drains.

"*The Outlet.* The work of construction properly begins at the outlet, which, if selected carefully, should give the most fall and direct outflow of water to drain the area in the system mapped out, in the mind of the owner or on paper. Beginning at the outlet, the main drain should be as deep as the conditions will allow, or the perfect working of the system requires, not exceeding ordinarily 4 or 5 feet. The tile for the main drain should be large enough to carry all the water that will fall on or run onto the area intended to be drained by the outlet.

"*Size of Tile.* The size of tile to be used depends first upon the extent of the area to be drained; second, upon the inclination or fall, and third, upon the depth of the drains and the character of the soil and subsoil.

"First, as to the area to be drained. To illustrate more fully: A proposes to drain twenty acres of land through one outlet, and wishes to determine the size of the tile for the main drain. He finds that here is an area of as much as twenty acres of land adjoining that sheds its surface water from rainfalls and water percolating through the soil upon and into the land of the twenty acres which he wishes to drain. The natural outlet is over or through A's twenty acres under consideration. Therefore, the tile for the main drain and subdrains should be large enough to receive and carry the water shed onto the land.

"For a simple rule for those who wish to construct drains through the low places of the farm, a practical drainage contractor gives the following as the result of his experience: 'On the average the fall usually secured is about 6 inches in 100 feet. With ordinary accurate work in securing a regular fall, a 3-inch tile drain will carry the water of six acres; a 4-inch tile will drain eight acres, a 6-inch twenty acres, and an 8-inch eighty acres.' The above rule is for casual, not thorough drainage.

"In thorough work, the following brief estimate of the number of acres drained by different sizes of drain tile to be used in the construction of drains is taken from a table prepared by Prof. R. C. Carpenter:

"SIZE OF TILE—ACRES DRAINED.

Rate of Inclination.	3-In. Tile.	4-In. Tile.	6-In. Tile.	8-In. Tile.	10-In. Tile.	12-In. Tile.
1 ft. in 50	8.4	17.0	47.7	98.0	170.4	296.0
1 ft. in 100	5.7	11.9	33.1	69.2	120.6	190.5
1 ft. in 150	4.5	9.5	26.6	56.0	97.3	154.4
1 ft. in 200	3.9	8.2	22.8	48.0	83.9	132.5
1 ft. in 250	3.5	7.5	20.4	42.4	74.4	117.0
1 ft. in 300		6.9	18.4	38.2	65.5	107.0
1 ft. in 400		5.9	16.5	34.6	60.3	90.7
1 ft. in 500		5.2	14.8	30.1	54.0	81.6
1 ft. in 600		4.8	13.3	28.0	48.6	74.0
1 ft. in 800		4.1	11.4	24.0	41.9	65.0
1 ft. in 1000		......	10.2	21.2	37.2	56.0

"The above table is intended for accurate, thorough drainage, but it is better practice, in our judgment, in ordinary or casual work, to use larger sizes of tile in proportion to the number of acres to be drained. To make sure of sufficient capacity in the drain to carry the water of ten acres, we advise the use of 4-inch tile, instead of 3-inch tile.

"Second, the inclination or fall is an important factor in determining the size of tile to be used. The greater the fall the greater will be the rapidity of the water flow, increasing correspondingly the amount of water discharged through the drain. A 4-inch drain may have a fall enough to carry as much water as would flow through a 5-inch drain laid with much less fall. A main drain may be laid at almost a level grade and do good work, but the size of the tile should be larger in proportion to the less fall for the reason that the water will flow with less rapidity than would the water in a drain with much more fall.

"Third, the depth of the drain is also a factor in determining the size of the tile needed to secure the most efficient drainage. The greater depth requiring a less size, when the fall is the same as that of a drain laid at a less depth, other conditions being equal.

"The increased depth gives an increased water pressure in the soil, which increases the water flow in the drain. Another reason why the size of the tile may be less in deep drainage is that the greater the depth of the drained soil and subsoil, the more water there will be required to bring the deeper subsoil to the point of saturation, when the water will fall away and enter the drain. A soil drained to the depth of 4 feet would receive and hold the water of a heavy rainfall almost to the point of saturation before the water would pass into the drain. The deeper drainage will aid in conserving needed moisture for the growing crops.

"Drainage in England is usually at a depth of from 4 to 5 feet. In their retentive clay soils, the drains are laid from 20 to 30 feet apart, the tile used are small, 1 1-2 inch and 2 inches being in common used for the lateral drains: with almost perfect construction their drains do good work, but in the experience of some of our most extensive land drainers in this country, a 4-inch tile is as small as they will use for the side drains to carry off the water of heavy rainfalls. besides, it is claimed that by using larger tile, a better aeration of the soil is secured.

"Another factor in determining the size of tile to use is the method of constructing the drain, the regularity of the fall, the directness of the flow of water in the drain, and the laying of the tile.

"A drain may be dug and leveled correctly, but the laying of the tile may be so imperfect as to greatly diminish the working capacity of the drain. By placing the tile in the drain unevenly jointed, or shouldered, more or less, the water in flowing through the drain strikes against the shoulders and deflects across the current, hindering the flow, reducing the capacity of the drain at every uneven joint.

"*Connecting Drains.* Lateral or side drains should be made to enter the main drain at an acute angle. Otherwise, the water flowing in from the side drain will interfere with the current of the main drain. If entered into the main at an acute angle, the currents will flow as nearly in the same direction as possible, giving the best results.

"*Depth of Drains.* If our knowledge of the benefits of drainage is broad, embracing not only the removal of the excess of water on or in the soil, but also the greater depth of food supply secured for the growth of crops and the circulation of air through the soil and subsoil, we will, if true to our best thought upon the subject, practice deep drainage if the conditions will admit of 3 to 4 1-2 feet and deeper. if necessary to perfect the work.

"There are cases, however where it is hardly possible at any reasonable cost to secure an outlet for deep drainage. Then we advise those interested to do the best that can be done, and drain shallow, rather than not to drain at all where the lands need it.

"*Width apart of drains.* The width between drains to secure the most efficient drainage at a reasonable cost, depends upon the depth of the drains and the character of the soil and subsoil. Deep drains drain a much wider space on each side of the drain than shallow drains would in the same soil. In any case, the width drained depends on the character of the soil and the subsoil. But we should not conclude that because the surface soil midway between the drains is made dry enough for the plow, that the drains may be 80 feet apart if it is intended to drain deeper than we plow midway between the drains. For the reason that the water in passing through the soil and subsoil to the drain must have some fall toward the drain. Drains laid at the depth of 3 feet and 80 feet apart in a close retentive clay soil would afford very little drainage to the soil midway between the drains, but would probably be satisfactory in an open soil. In an open soil and subsoil the water, in passing through the earth to the drain, meets with less resistance.

"If it is intended to do anything like thorough work in drainage, we must take these conditions under consideration to determine how deep and wide apart the drains should be laid to secure the best results.

"*Digging the ditch.* It may be thought that to dig a ditch is a very simple undertaking, but there is much importance in doing the work well. In digging, make the ditch only wide enough to work in conveniently, make the side sloping to the bottom, which should be only wide enough to lay the tile, whatever the size of tile may be. In leveling the bottom, use a push scoop the size of the tile to be laid. and grade the bottom so as to give a regular flow of water from head to mouth, if at all practical, or if any change in grade is made it should be gradual.

"*Laying the Tile.* Begin at the outlet and lay up grade. Lay the tile end to end in a straight line, and avoid shouldering or unevenness at the joints; fit the joints close together, and secure, as far as possible, a regular flow of water on the inside with the least resistance. Settle the tile firmly at both ends, so as to secure a regular fall After laying a few tile, shovel in clay from the top of the bank and cover the tile so as to secure them in position, then proceed to lay more and so on continue the work. If water is running in the ditch. be careful not to let the loose earth wash into the tile. To prevent this a short board of right width may be used to set at the end of the last tile laid. After laying the tile as directed, the filling of the ditch may be done in the most convenient and speedy way."

Statistics for Drain Tile.

The great majority of the drain tile used in the United States are made and used in the north-central states. In much of this region draining was absolutely essential before the land could be successfully farmed. Many of the southern states are beginning to use tile, and although none are being made or used in Oklahoma at present it is certainly only a question of time until their use will be quite common especially in the eastern and southern part of the State.

In 1907 the value of the drain tile produced in the United States was $6,864,162, while in 1908 it was $8,661,476, a gain of $1,797,314 or 16.18 per cent. When it is considered that all other clay products (except vitrified paving brick) showed marked decrease in production, the increased use of drain tile is excellent proof of its value and increasing popularity. It is also interesting to note that in 1908 the five states, Iowa, Indiana, Ohio, Illinois and Michigan—the states where drain tile has been used most extensively and where its value is most appreciated—produced 89.84 per cent. of the total for the country.

ROOFING TILE.

Roofing tile is usually made of shales by the stiff mud process. Auger machines with special dies may be used for the more simple forms, but hand or power presses are used to give the more complicated designs. The most important quality of clay for roofing tile is slight and uniform shrinkage, i. e. they must not warp in drying or burning. The burned color is also a very important item if the tile are not to be glazed.

Clays of long vitrification range are usually selected for roofing tile as these are less likely to suffer deformation in burning. If the natural burned color is desired they must be burned nearly to vitrification to render them impervious. If entirely vitrified they are more liable to warp and "sweat" on the under surface after being laid. Where the natural burned color is not satisfactory or where too high temperatures are required to produce partial vitrification, the tile may be glazed or enameled by dipping in slip or spraying slip on the tile and reburning. By choosing a slip of the proper composition, the product may be given any desired color and at the same time the porous body may be rendered impervious. Care is required in drying and in setting in the kilns to prevent warping. Roofing tile are often burned in semi-muffle kilns and sometimes are set in saggers. No roofing tile is at present made in Oklahoma, but several deposits of shale are

well adapted to their manufacture and one or two companies are contemplating installing the necessary machinery to produce them.

WALL AND FLOOR TILE.

Wall tile are usually made of high grade, white burning clays. The body of the tile is formed on hand power dry press machines and is burned steel hard in saggers. The body is thus quite porous, showing absorptions as high as 15 to 20 per cent. They are then glazed or enameled by dipping or spraying and using different glazes or enamels. Hand painting and printing are also used for decorating ornamental tile. The defects which wall tile may show are warping, crazing, (cracking of the glaze due to its having a greater rate of contraction than the body), peeling of the glaze (due to the body having the greater contraction than the glaze), and bubbles, spots or pin holes in the glaze. Imperfect tile are always sorted out at the factory. Crazing, however, may not appear until sometime after the tile are set in the wall.

Floor tile is also made by hand power dry press machines. Care is required in the selection of clays for floor tile as they must be free from warping and cracking in burning and must have good clean burned colors. They are burned in saggers in down draft kilns. Floor tile must be burned to vitrification so that they will not absorb moisture. Floor tile are of two varieties, one in which the whole tile is of one color throughout, and the other—encaustic tile—in which the colors of the surface extend in about one-eighth inch. White tile are made from mixtures of white burning clays, flint and feldspars; buff and artifically colored tile from fire clays, and red tile from shales. Artificial colors are produced by mixing various substances with the clay e. g. manganese and umber for the browns and blacks; chromium for green, etc. Encaustic tile is made by making the pattern of the design with brass strips. This is placed in the mold and the clays or mixtures which will produce the desired colors sifted into the proper compartments to a depth of one-fourth inch. The pattern is then removed and the buff clay is added to the required thickness for the body and the tile pressed.

No floor or wall tile is being manufactured in Oklahoma at present.

TERRA COTTA.

The use of terra cotta as a structural material has increased very rapidly in the last few years and the rate of increase bids fair to continue for some time to come. This popularity of terra cotta is due to its many advantages, some of which are (1) its durability, which is greater than that of many building stones in use; (2) its strength, which is more than ample for any use to which it is likely to be put; (3) its lightness and the ease with which it can be handled; (4) the endless variety of design and color which can be had; (5) the sharpness of line and regularity; (6) outline of the designs which is greater than can usually be had in stone; (7) the impervious surface which prevents the absorption of moisture and which is not discolored by atmospheric agencies; (8) the cheapness of the material when its advantages are taken into consideration.

Terra cotta is now made almost altogether of fire clays, usually No. II or mixtures of No. II with No. I or No. III or both. Very seldom is a single clay found which is satisfactory in every respect. The important factors are (1) small and regular shrinkage with freedom from warping and (2) long vitrification range. Where the terra cotta is not glazed the burning color and freedom from soluble salts liable to cause scum or whitewash is also important. Lower grade clays are sometimes used for terra cotta, but poorer material necessarily results. Such clays are not used so much as formerly and the practice should be discouraged.

Manufacture. Terra cotta is molded by hand either in plaster molds or by hand modeling. When molds are used, the patterns are first made and the molds cast from the patterns, so that the inner surface of the mold forms the outer surface of the piece of ware. The clay is usually weathered to leach out the soluble salts and to oxidize any iron carbonate concretions. It is ground in a dry pan, screened and is then tempered in a wet pan and also in horizontal or vertical pug mills. The clay issues from the pug mills as a continuous bar about 8 inches square, which is cut into pieces about one foot in length and stored in bins, where it is allowed to remain for sometime before being used.

When molds are used the clay is spread over the inner surface by hand, care being taken to work it carefully and smoothly into all the depressions and corners of the molds to a thickness of about one and one-half inches. The molds are then set away for a few hours until the ware is dry enough to remove. The rough edges are trimmed smooth and any irregularities remedied. Large designs are molded in sections and the sections placed together in the building. Intricate or undercut designs must be modeled by skilled workmen. The drying

must be conducted very slowly and carefully. The slatted floor system is usually used. After the ware is dried the slip for the glaze is sprayed on to the outer surface. The slip usually contains kaolin, ground quartz, and feldspar with the proper coloring materials. Terra cotta is burned in circular down draft kilns. Each piece of ware is surrounded by a frame work of slabs or fire brick so that it supports only its own weight. The usual burning temperature is cone 6 to cone 8.

Terra-cotta lumber is made on stiff mud auger machines. A large amount of saw dust or other combustible material is added to the clay. During the burning this combustible matter is burned out making the ware extremely porous—so much so that nails can be driven through it without breaking. The presence of so much combustible matter necessitates very slow and careful burning. There is at present no terra cotta made in Oklahoma although some of the clay veins under the coal in the eastern part of the State would probably be suited to its manufacture.

FIREPROOFING, HOLLOW BLOCK AND HOLLOW BRICK.

All types of hollow ware are made on stiff mud machines and cut by end-cut cutters. They are usually burned in down draft kilns. Clays of moderately high fusion point and long vitrification range are usually selected for these products. The shrinkage is an important factor while the color is immaterial since this ware is covered in the building.

ELECTRIC CONDUITS.

Electric conduits which are used to enclose underground wires and cables, are made of clays by the same methods of manufacture as the other kinds of hollow ware, but, as they must be entirely waterproof, they are burned to vitrification and are salt glazed. This makes it necessary for them to be made of tolerably refractory clays, usually No. II fire clays.

SEWER PIPE.

Sewer pipe is made from stiff mud by a machine of the plunger type as previously described in connection with manufacturing processes (p. —). Elbows, turns and all odd shapes of pipe are molded in plaster molds as previously described under the molding of terra cotta. The halves of the pipe are molded in separate molds and then the parts placed together and the halves cemented by a slip. After the pipe has partially dried the molds may be removed.

No. II or No. III fire clays or mixtures having properties similar to these clays are used in manufacture of sewer pipe. The clay is ground in dry pans, and then screened and well tempered in wet pans or pug mills. After having been molded the pipe are dried on slatted floors by steam heat. The drying, especially of the larger sizes of pipe must be conducted very slowly and with extreme care to prevent any warping or cracking. The pipe are burned in round down draft kilns at temperatures approximating cones 6 to 9. The pipes are usually nested, i. e. the smaller sizes set in the larger ones, in the kilns to economize space and fuel. All sewer pipe are burned to vitrification and are salt glazed to render them impervious.

Although large quantities of sewer pipe are used in Oklahoma none is made in the State. Some of the clays from the coal mines are well adapted to its manufacture, e. g. sample Nos. 47, 287, 70. (See Chap. VII.)

DOMESTIC AND SANITARY WARE.

Domestic and sanitary ware includes a great variety of ware which is generally included in the general term "pottery." There are so many different grades of pottery and so many terms used in describing these grades that anything resembling a complete discussion would be out of place in this connection. The principal classes of pottery are earthenware, stoneware, and china or porcelain. Earthenware, such as flower pots, can be made of low grade red porous burning clays. It is usually not glazed, but may be. Stoneware such as jugs and jars are made from buff burning clays of dense body. China and porcelain are made from mixtures of ball clay and kaolin with ground quartz (flint) and feldspar (spar.)

Manufacture of Pottery.

Clays for pottery must be well tempered in order to develop the best plasticity. They are usually ground, worked through vertical pug mills and stored in wet closets or bins. They are also well worked by hand or by rollers previous to molding. Molding is done in four different ways, turning, jollying or jigging, pressing and casting.

Turning is performed by placing a lump of plastic clay on a set horizontal wheel which can be rotated rapidly. While the wheel is rotating the potter wets the surface of the lump with a thin slip of clay and water to prevent the clay from sticking or tearing, and then gradually draws the lump into the desired shape with his hand. After

the object is completed it is cut loose from the wheel by a wire or thin blade and set away to dry. Many articles of stoneware as jugs, jars, and similar articles are made by turning. In recent years, however, presses similar to the sewer pipe press have been devised to make many of these articles and turning is not so extensively practiced as formerly.

Jollying and jigging are more rapid than turning. The clay is made up much softer and a lump is placed into a plaster mold which sets upon a rapidly revolving plate. The interior of the mold corresponds to the exterior of the vessel to be made. While the mold is revolving rapidly the clay is pressed up around the sides and the shape is produced by a template which is forced in from above. Articles of a jug shape are made in two pieces which are later cemented together. Plates, saucers, bowls, etc., are made in a similar manner, the mold having the shape of the top or hollowed surface, while the template forms the bottom surface.

Pressing has been described under the manufacture of sewer pipe and terra cotta. This process consists in pressing the clay into plaster molds. Large objects are molded in sections, and the molds placed together and the different parts cemented by clay slip. After partial drying the molds may be lifted from the object.

Casting consists in pouring a slip of clay and water into a plaster mold having the shape of the exterior of the object. The mold being porous absorbs some of the water which causes a layer of clay to stick to the mold. When this layer is thick enough the remaining slip is poured out. After a few hours the object can be removed from the mold.

Drying. All kinds of pottery are usually dried on shelves in steam heated rooms.

Glazing. Common earthenware is not often glazed. When it is, easily melted glazes in which lead oxide and boracic acid form the important constituents are used. Stoneware is either slip or salt glazed. White earthenware, china, and porcelain are glazed with mixtures whose composition depend upon the nature of the ware and the kind or color of glaze wished. The ware is first burned to steel hardness. After cooling it is dipped in a slip of the glazing material, dried and re-burned in saggers in round up draft kilns. Enough of the glaze adheres to the ware to form a coating which in the second burning melts into a glass. In high grade china and porcelain the second burning conducted at a higher temperature than the first.

Decorating. Stoneware may be decorated by etching designs i the green ware and filling the etching with coloring matter. Whi earthern ware or china is usually decorated with print work. Color designs are printed on special paper. The paper is moistened and pa ted face of design down, on the ware before glazing. After the pap has dried on the ware it is rubbed off with a wet sponge, the desig remaining on the ware. The ware is then glazed as previously d scribed. The designs may be retouched by hand or in fine china an porcelain the whole design may be hand painted. Gold and oth delicate colors must be applied over the glaze as these colors are d stroyed by hard firing.

Sanitary ware such as bath tubs, wash basins, etc., are usual made of buff burning clays. They are molded in large plaster mol Extreme care must be taken in drying and burning the larger pie of ware. This sort of ware is heavily glazed. The burning temper ture is high—usually cone 8 to cone 10.

At present no pottery is made in Oklahoma, and so far no cl has been found which is suitable for the manufacture of the high grades of clay products. However, since the fuel is about as an im portant an item as the clay, there is no reason why the vast amoun of fuel in this state should not make the manufacture of this wa possible here even if all the raw material should not be found cl at hand.

REFRACTORY WARE.

Refractory wares are those which will withstand high temperatur there are many products of this type, but the principal ones are fi brick, glass pots and saggers. Only the three named will be mention here.

FIRE BRICK.

Fire brick are used for setting boilers, lining furnaces, cupo and kilns; walls of fire places, etc. No. I fire bricks should not so below cone 32 and should carry a load of 50 pounds per square in at a temperature of 1350°C. Fire bricks are made out of mixtures plastic and flint fire clays. The flint fire clay has a very high burn shrinkage. Crushed old fire brick or "grog" is often added to mixture to reduce this factor.

The materials are ordinarily ground in dry pans, molded by hand and dried on steam heated floors. They are usually repressed in hand power represses when partially dried. For special purposes brick of an acid nature are required, and silica fire brick consisting principally of quartz are made. At present no fire brick are made in Oklahoma and there seems to be no No. I fire clay known to occur in the State. It is entirely possible that such clays may be found and if they should be the vast amount of cheap fuel available should make this a leading center for this manufacture.

GLASS POTS.

Glass pots are used for melting the charges in the manufacture of window or plate glass. The pots must be very refractory and strong to resist the strains incident to being taken from a furnace at white heat into the ordinary room temperature, and to being lifted while containing a charge of several hundred pounds of molten glass. Mixtures of high grade light burning clays are used. They are tempered very carefully and seasoned to develop their maximum plasticity. The pots are usually 42 by 31 inches in size and hold 170 square feet of glass. The pots are built by hand, about 30 are started at once and 3 or 4 inches are built on to each one every day until the group is finished. Several weeks are required for drying. When in use the pots are fired once each day. The average life of a pot is 20 days or 20 casts.

SAGGERS.

Saggers are large containers in which ware that would be injured by direct contact with the flames, are set to be burned. They are used extensively in the burning of all sorts of china and porcelain and sometimes for encaustic tile. Saggers are of elliptical cross-section with flat bottoms so that when set in the kiln, the bottom of one serves as the cover of the one below it. They are made of a plastic, refractory clay with high bonding power. Large amounts of grog are used. They are molded in the stiff mud condition either by hand or by especially designed presses.

OTHER PRODUCTS.

Electrical porcelain is made of high grade white burning clays. In this ware it is especially important that the shrinkage can be controlled accurately since the pieces must be of exact sizes in order to fit each other or the metal parts in which they are introduced. The ware is molded by the dry press process, is glazed and burned in saggers at high temperatures. It is carefully tested for flaws, for accuracy in size and as to its insulation powers.

Chemical porcelain, evaporating dishes, crucibles, etc., are made of high grade, white burning clays and is glazed. Practically all of this ware is made in Germany.

Battery cups are porous cups used in electric batteries to permit of a slow transfer and mixture of different solution.

Portland cement contains some form of clay as an essential constituent. This is a very important product but can not be considered in this connection.

Clay is often burned sufficiently to destroy the plastic properties and then used for *railroad ballast.* Unless burned almost to vitrification it wears down rapidly and is not much used except in regions where crushed stone or gravel is difficult to obtain. Burned clay roads are built by digging trenches across the road at short intervals and filling these with wood which is then burned. This treatment destroys the plasticity of the clay and renders the road less muddy. Such roads are being constructed in parts of the southern states where stone cannot be obtained.

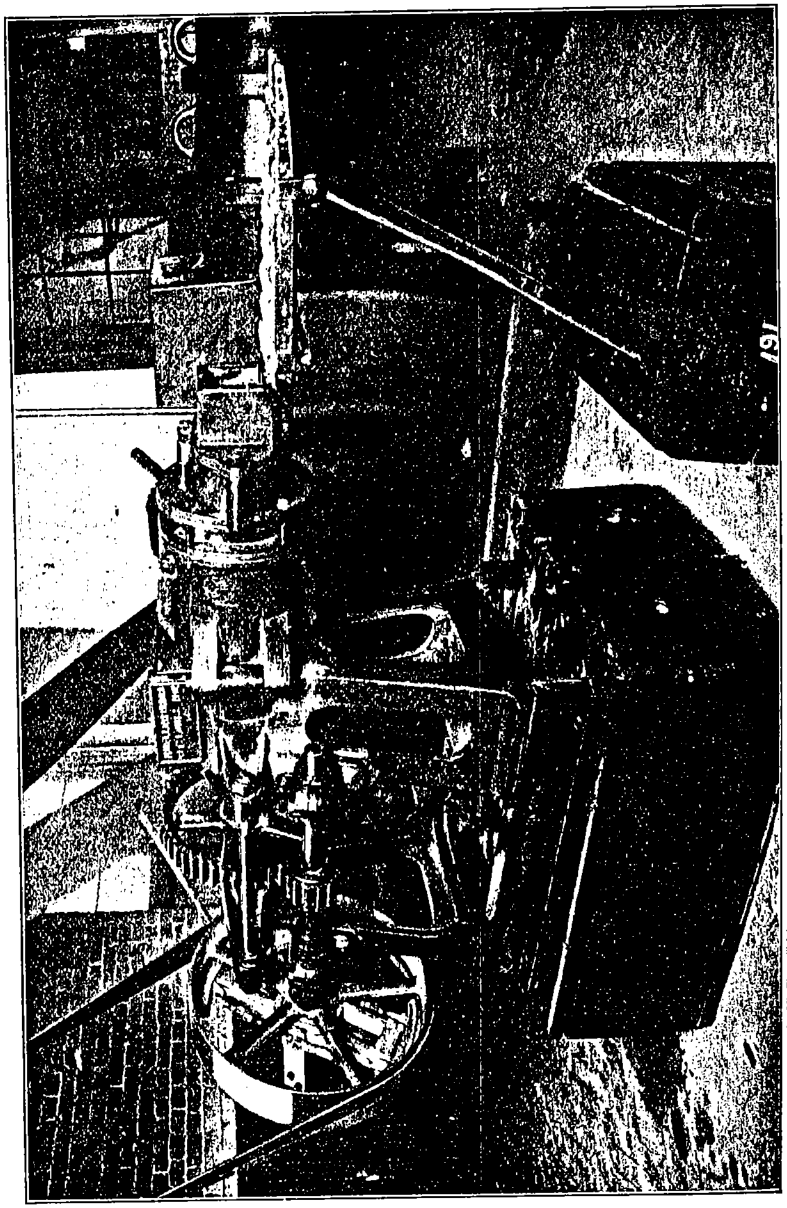


Plate [illegible].—View of small auger machine used in [illegible] Clays [illegible]

CHAPTER VII.

THE TESTS ON THE OKLAHOMA CLAYS

INTRODUCTION.

The tests on the Oklahoma clays were performed in co-operation with the clay products division of the Technologic branch of the United States Geological Survey, now a part of the Bureau of Standards. The samples were collected in Oklahoma and shipped to the testing plant at Pittsburg, Pennsylvania, where they were tested by the writer. The work was performed under the direction of A. V. Bleininger, now of the University of Illinois. The writer desires to express his thanks to Mr. Bleininger and to his assistants Mr. G. H. Brown and Mr. R. K. Hursh for their uniform kindness and assistance while the work was in progress.

COLLECTING THE SAMPLES.

Owing to the lack of appropriation for such work it was found impossible to visit each locality and collect the samples so some of the samples were collected by the owners of the deposits. The writer visited as many localities and collected as many samples as was possible with the time and means at his disposal.

In collecting the samples the following points were noted:

(1) Location of clay; (2) thickness of deposit; (3) area of deposit; (4) amount of stripping; (5) distance to railroad and shipping facilities; (6) kind of fuel available and approximate price.

The following directions were followed in the collection of the samples.

"Dig back into the clay or shale bank so as to get into the fresh, unweathered material. Get a straight face of the whole thickness of the bank if possible.

From the straight face, dig down and throw into a heap 400 or 500 pounds, taking care that all the bed from tip to bottom is represented equally. Mix this pile thoroughly and take one-fourth of it as a sample."

These samples were placed in boxes or sacks and shipped to Pittsburg.

WORK AT PITTSBURG IN 1909.

The work at Pittsburg occupied the months of July, August and September in 1909, and May, June and July in 1910.

In 1909 the following procedure was followed:

The clay was ground dry in a wet pan but was not made up to the stiff mud in the pan. It was taken from the pan and screened through a piano wire screen (about 8 mesh). Some of the clay was then taken and made up to a stiff mud by hand and carefully kneaded. Discs were then made of each clay in a hand press with a die three inches in diameter.

Twenty discs of each clay were made, taking pains to obtain as uniform a thickness as possible (1½ inches.) Kerosene was used to lubricate the die to prevent the clay sticking. The number of the clay sample and the number of the disc (1 to 20) was stamped on each disc.

Thirteen of these discs were weighed as soon as made and the volume of three of them determined. For this purpose the wet discs were immersed in kerosene for at least two hours and the volume measured by displacement of kerosene in the Seger volumeter.

While these discs were in the kerosene, the diameter and thickness of the remaining ten discs, that had been weighed were measured with vernier calipers and the discs were then placed on pallets in the drying room and allowed to dry.

After the discs were dried perfectly; those that were weighed before were reweighed. The volume of the three discs whose volume had been found before was taken by the same method except that they were immersed in kerosene for six to twelve hours.

After all the measurements of the dry discs had been made, three discs of each clay were burned at each of the following temperatures: cone 08, 06, 04, 02, 1 and 3. One disc of each set of three was taken to determine the porosity. A piece weighing about thirty to forty grams and representing the average composition of the disc, was broken from it and weighed dry. It was then immersed in distilled water and soaked

for twelve hours and then boiled in water under reduced pressure for five or six hours. The manometer registered from twenty-eight to twenty-nine inches vacuum during the boiling. The wet weight was then taken and also the weight of the pieces suspended in water.

Per cent. of pore space=

$$\frac{\text{Wet weight—dry weight}}{\text{Wet weight—suspended weight}} \times 100.$$

The two remaining discs were measured by the vernier calipers, dried at 100°C, and were weighed. They were then immersed in water for forty-eight hours and weighed again, and the volumes taken in the Seger volumeter by displacement of water.

CALCULATIONS OF RESULTS.

From the data obtained the following properties were calculated:

1. Water of plasticity=

$$\frac{\text{Weight of wet disc—weight of dry disc}}{\text{Weight of dry disc}} \times 100.$$

2. Linear drying shrinkage

(a) in per cent. of wet length=

$$\frac{\text{Wet length—dry length}}{\text{wet length}} \times 100.$$

(b) in per cent. dry length=

$$\frac{\text{Wet length—dry length}}{\text{dry length}} \times 100.$$

3. Volume drying shrinkage

(a) in per cent. of wet vol.=

$$\frac{\text{wet vol.—dry vol.}}{\text{wet vol.}} \times 100.$$

(b) in per cent. of dry vol.=

$$\frac{\text{wet vol.—dry vol.}}{\text{dry vol.}} \times 100.$$

4. Linear fire shrinkage at each of the six temperatures in per cent. of the dry length=

$$\frac{\text{dry length—burned length}}{\text{dry length}} \times 100.$$

5. Total linear shrinkage in per cent. of wet length=

$$\frac{\text{wet length—burned length}}{\text{wet length}} \times 100.$$

6. Volume fire shrinkage at each of the six temperatures in per cent. of the dry volume=

$$\frac{\text{dry vol.—burned vol.}}{\text{dry vol.}} \times 100.$$

7. Total volume shrinkage in per cent. of wet volume=

$$\frac{\text{wet vol.—burned vol.}}{\text{wet vol.}} \times 100.$$

8. Absorption of the discs burned at the six temperatures in per cent. of the weight of the dry burned disc=

$$\frac{\text{wet weight of burned disc—dry weight of burned disc}}{\text{dry weight of burned disc}} \times 100.$$

9. Porosity of the discs burned at each of the six temperatures in per cent. of the volume of the burned discs=

$$\frac{\text{Wet weight—dry weight}}{\text{Wet weight—suspended weight}} \times 100.$$

From the per cents of porosity at the different temperatures the porosity curve for each clay was plotted.

PROGRAM OF TESTS MADE IN 1910.

For the work of the summer of 1910 a slightly different plan was followed on account of a small auger machine (pl. 9) having been installed which made it possible to make up the discs in a manner more nearly resembling the conditions in commercial practice.

The clay was ground (screened if necessary) and made up into stiff mud in the wet pan. It was then run through the small auger machine, using a three inch square die. The column was cut into pieces about a foot long, placed in a mitre box, and cut into briquettes one and

one-half inch thick with a wire cutter. Twelve of these discs were weighed, and marks eight c. m. apart made on the large surface with the vernier calipers. The volumes were taken on three pieces as in the previous season. The distance between the marks previously mentioned was measured in the dry and burned condition by means of the vernier calipers and the linear drying and fire shrinkage calculated as before.

Two of the stiff mud briquettes were cut into small pieces of approximately the same size, (each block being cut into eight pieces). The number of the clay was stamped on each of the pieces. After drying, these small pieces were used for determining the temperature range and porosity as follows:

About twenty clays were burned at one time. Ten sets consisting of one piece of each the twenty clays were prepared and set in a down draft test kiln (fig. 15 and pl. 10) in long trough shaped setters.

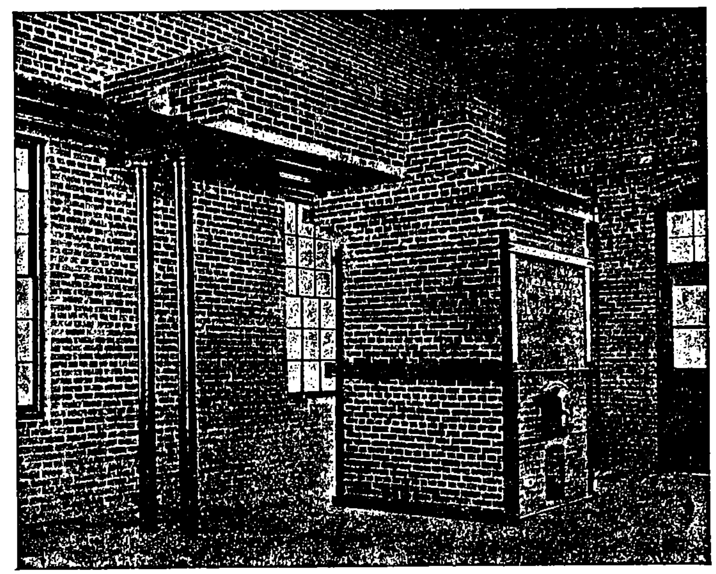


Fig. 15. Downdraft Test Kiln in Clay Testing Laboratory of the United States Bureau of Standards at Pittsburg, Pa.

Six setters were used, each of the two upper ones containing one set of trial pieces, and the two middle and lower ones containing two sets each, one in the front end of the setter and one in the back portion.

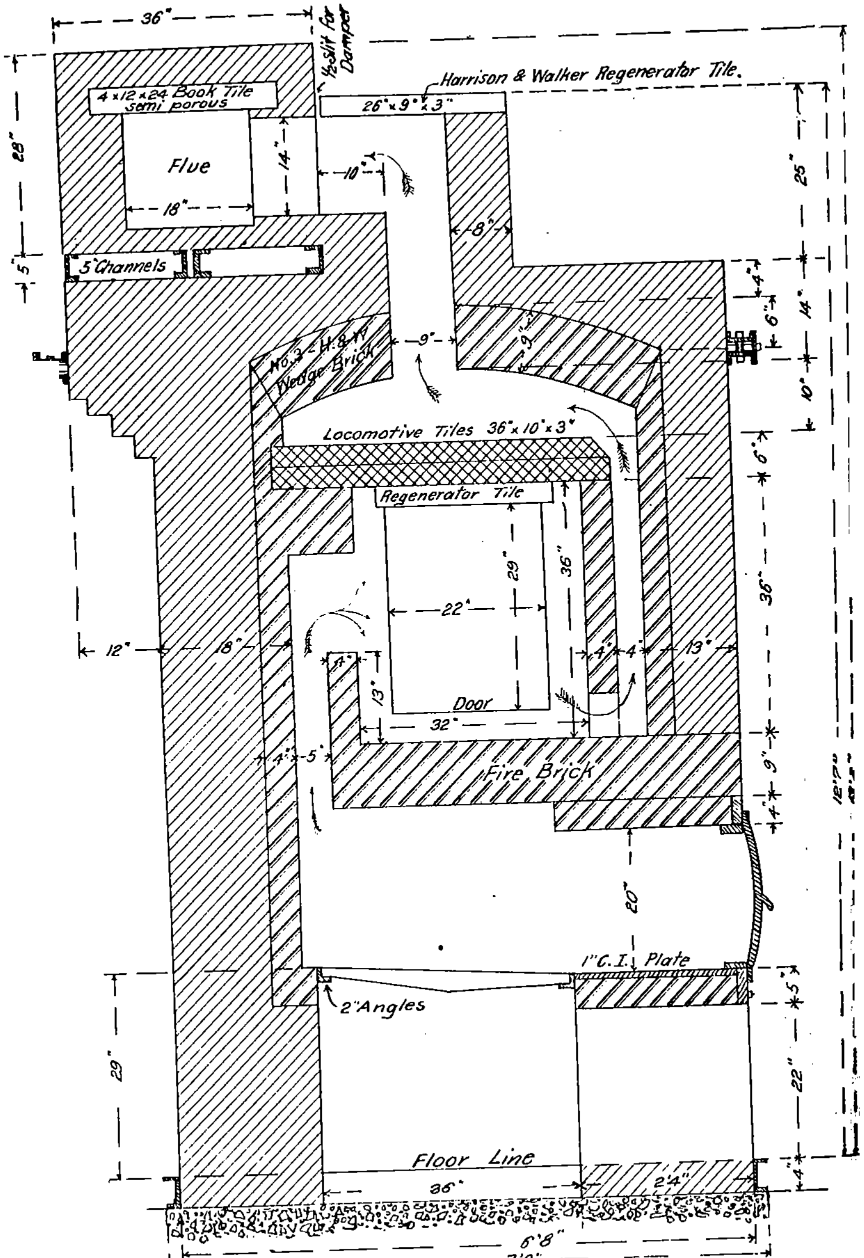


Plate 10. Cross section of test kiln in clay testing laboratory of the United States Bureau of standards at Pittsburg.

Cone pats were placed in front of each set of trial pieces. The pats each held three cones, the middle one representing the temperature to which the set of trials was to be burned and the ones to the left and right being respectively the next lower and next higher cone. The setters were supported by checker work of fire brick which permitted the free passage of the kiln gases but prevented them from striking directly upon the cone pats.

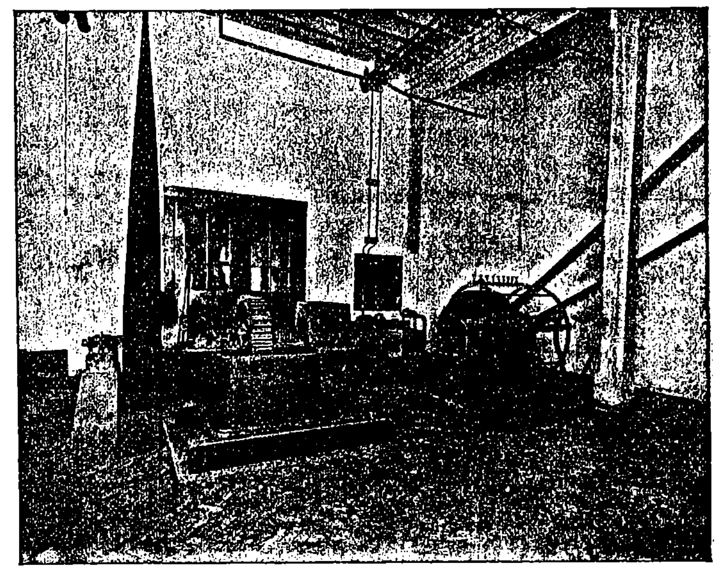


Fig. 16. View of portion of machine room in Clay Testing Laboratory of the United States Bureau of Standards at Pittsburg, Pa.

The sets and cone pats were arranged as follows: The two upper setters contained sets to be burned at cone 010 and at cone 08. The right middle setter contained the set to be burned at cone 06 in the front and at cone 04 in the rear, the left middle setter contained the sets to be burned at cones 02 and 1 in the front and rear respectively; the lower setters contained the sets to be burned at cones 3 and 5 in the right hand setter, and the sets for cones 7 and 9 on the left.

The wicket was built with a brick with a peep hole set loosely in front of each setter, so that it could be removed. The peep hole was closed by a glass disc fastened to the brick with clay.

After the wicket was closed the kiln was heated up until cone 010 in the upper right hand setter was down; the brick in front of the setter removed and the trial pieces drawn, by means of an iron hook, from the setter into a small square setter and immediately covered with sand to prevent too rapid cooling. The brick was replaced in the wicket and the temperature increased until cone 08 was down and the set of trials in the left hand upper setter drawn in a similar manner, and so on until all the sets were drawn from the kiln. About two hours were required, on the average, to raise the temperature two cones, e. g., from 06 to 04, the time being shorter between the lower cones and longer between the higher ones.

As soon as the trial pieces were cool enough to handle they were placed in a desiccator and, later, the porosity was determined by the same method as was used the previous year.

Five of the large discs of each clay were burned at the best burning temperature as determined by the trial pieces. All the more refractory clays were burned at cone 5. The burned length was determined on these, as well as the absorption. The burned volumes were taken on three of them by displacement of water in the Seger volumeter.

NOTES AND DATA OF THE CLAYS TESTED.

On the following pages will be found a description of the occurrence of each clay tested, together with the results of the tests and remarks on the working, drying and burning properties, and the products for which the clay is adapted.

The clays are taken up in the order of the number assigned to the samples, without respect to their distribution or geological horizon.

The porosity curve for each clay is given in a figure placed near the description. The meaning and use of the curve in determining the properties of the clay as well as the importance of the various tests usually applied to clays have been discussed in Chapter V.

The results of the tests are also brought together in a table at the end of the chapter.

Clay No. 4, Boynton, Oklahoma.

Location, NE. ¼ sec. 30, T. 14 N., R. 16 E. Thickness of deposit, 30 ft.; area of deposit, 160 acres; amount of stripping, 4 to 5 ft.; situated ½ mile from Frisco Railroad. Fuel, gas at hand at low price.

DATA.

Water of plasticity	15.2%					
L. D. S.[1]	2.2%w.l. 2.3%d.l.					
V. D. S.	7.8%w.v. 8.4%d.v.					
At cone	08	06	04	02	1	3
L. F. S.	1.3	2.3	4.4	4.7	6.0	6.0
V. F. S.	.8	5.0	10.6	11.9	16.8	16.5
Tot. L. S.	3.4	4.4	6.5	6.8	8.1	8.1
Tot. V. S.	8.4	12.3	17.5	18.7	23.2	22.9
Absorp.	14.8	12.9	8.6	8.0	5.1	4.3
Porosity	30.9	29.1	21.6	21.8	16.1	14.4

Remarks:—Hard shale. Shows considerable mica. Works well and dries nicely with moderate shrinkage. Burns to rich dark red color free from discoloration. Suitable for building and common brick. Is still quite porous at cone 3 and would probably be available for sewer pipe.

Porosity curve on fig. 17.

Clay No. 10, Coalgate, Oklahoma.

Location, SE. ¼ sec. 14, T. 1 N., R. 10 E. Thickness, 3 ft.; area, underlies all the coal in the Coalgate region; must be mined; distance to railroad, 100 yards; M., K. & T. and Rock Island, Ardmore branch; kind of fuel, coal; price, $1.25.

DATA.

Water of plasticity	14.6%					
L. D. S.	5.3%w.l. 5.6%d.l.					
V. D. S.	13.7%w.v. 16.04%d.v.					
At cone	08	06	04	02	1	3
L. F. S.	3.4	4.0	5.6	5.6	5.9	
V. F. S.	9.1	12.7	16.4	17.3	18.5	
Tot. L. S.	8.4	8.9	10.4	10.4	10.8	
Tot. V. S.	22.1	24.7	28.8	28.0	29.8	
Absorp.	9.0	6.7	4.1	3.8	2.7	
Porosity	21.4	20.6	13.4	9.7	9.7	9.3

Remarks:—Fire clay of dark gray color; very fine grained. Some surfaces appear "slicksided." Works very nicely in pan and machine. Dries evenly and without cracking. Burns to rather dirty red color,

1. The abbreviations L-linear, V-volume, D-drying, d-dry, w-wet, F-fire, S-shrinkage are used throughout these tables.

slightly discolored. Suitable for paving brick, fire proofing and sewer pipe. For vitrified ware it should be burned at cones 5 to 9.

Porosity curve on fig. 17.

Clay No. 11, Coalgate, Oklahoma.

Location, SE. ¼ sec. 14, T. 1 N., R. 10 E. Thickness of deposit, 25 ft.; area, overlies all the coal in Coalgate region; stripping, 10 ft. along outcrop; distance to railroad, 100 yards; M., K. & T. and Rock Island; nearest fuel ½ mile; coal, price $1.25.

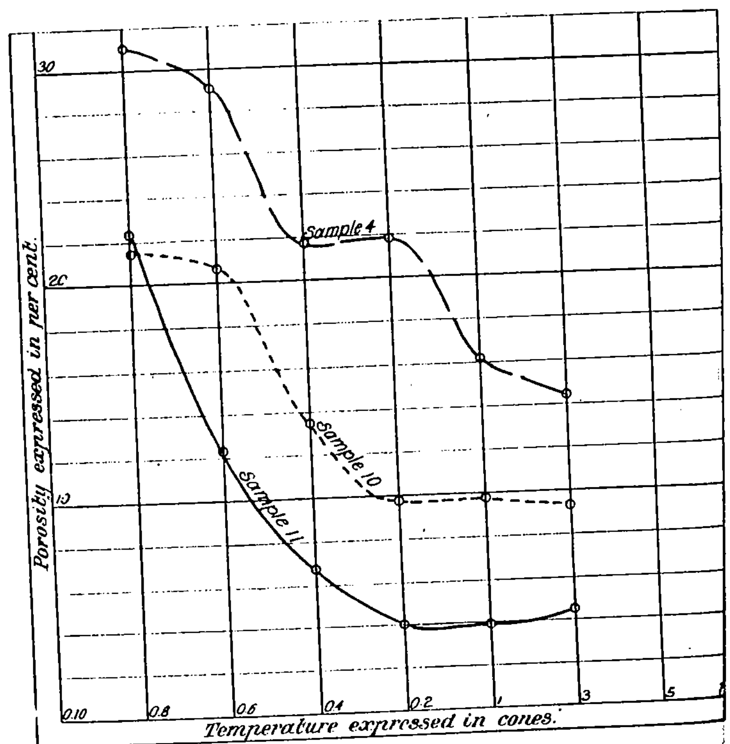


Fig. 17. Porosity Curves for Clays No. 4, 10 and 11.

DATA.

Water of plasticity			18.1%			
L. D. S.			6.5%w.l.	7.0%d.l.		
V. D. S.			18.2%w.v.	22.3%d.v.		
At cone	08	06	04	02	1	3
L. F. S.	4.9	7.4	8.2	8.5	9.5	8.5
V. F. S.	13.4	22.3	25.3	26.4	26.7	25.1
Tot. L. S.	14.0	13.2	13.9	14.2	15.1	14.0
Tot. V. S.	29.2	36.5	38.8	39.8	40.1	38.7
Absorp.	7.1	4.2	1.7	.8	.5	.4
Porosity	22.4	12.3	6.8	4.0	3.9	4.5

Remarks:—Black, fissile shale, with organic matter. Being inclined at a considerable angle this shale would have to be mined if it should be used largely. Enough can be obtained along the outcrop to last for considerable time without mining. Works nicely in pan and machine and dries evenly and without cracking Burns to a peculiar speckled red which is very pleasing. Matures at too low a temperature and is too brittle for paving brick or sewer pipe. Vitrifies at cones 04 to 1. Begins to lose shape at cone 3. Suitable for building and front brick.

Porosity curve on fig. 17.

Clay No. 12, Coalgate, Oklahoma.

Location, SE. ¼ sec. 14, T. 1 N., R. 10 E. Thickness of deposit, 20 ft.; area, extends several miles southwest and northeast; stripping, 2 to 6 ft.; distance to railroad, 50 yards; M., K. & T. and Ardmore branch of Rock Island; nearest fuel, ½ mile; coal, price, $1.25.

DATA.

Water of plasticity			26.9%			
L. D. S.			8.2%w.l.	8.9%d.l.		
V. D. S.			23.4%w.v.	30.1%d.v.		
At cone	08	06	04	02	1	3
L. F. S.	7.6	8.7	10.1	10.3	8.9	7.8
V. F. S.	20.5	27.2	29.3	27.6	21.8	21.5
Tot. L. S.	15.3	17.6	17.7	17.8	16.5	15.5
Tot. V. S.	47.3	44.3	48.6	47.8	40.2	41.1
Absorp.	5.6	1.1	.8	.6	.6	.4
Porosity	13.4	3.9	2.4	3.1	2.8	1.7

Remarks:—Clay shale with concretionary structure. Concretion tested show much ferrous carbonate and a little lime; concretions plenti ful and hard to separate. Works well in pan and machine. Dries evenl and without cracking but has very high drying and burning shrinkag Burns to a brick-red color. Vitrifies between cones 08 and 06 and th shows little change up to cone 3. The great shrinkage is the princip objection to its use. Suitable for building brick. Has a fine color f roofing tile, but the high shrinkage will probably prevent its use f this product.

Porosity curve on fig. 18.

Clay No. 16, Claremore, Oklahoma.

Location, sec. 17, T. 21 N., R. 16 E. Thickness of deposit, 5 to 1 ft.; area, unknown; strippng, 5 to 10 ft.; distance to nearest railro ½ mile; Frisco and Iron Mountain; nearest fuel, ½ mile; gas, pri 5 to 10 cents per 1,000 ft.

DATA.

Water of plasticity	32.2%
L. D. S.	13.1%w.l. 15.1%d.l.
L. F. S.	%
Tot. L. S.	%
Vol. D. S.	30.5%w.v. 43.8%d.v.
Vol. F. S.	%
Tot. Vol. S.	%
Absorp.	%

Cone	010	08	06	04	02	1	3	5	7
Por.	21.2	18.2	10.4	2.4	16.7	15.0	9.3		

Remarks:—Surface clay, light colored. It is very plastic and la nates very badly. Makes up to light yellow color. Has a few limest concretions. Shrinks very greatly and irregular in drying. All pieces cracked badly; steel hard at cone 04, and swollen badly at 1. Puffs very badly and cracks at all temperatures above cone 03. not be used in the manufacture of clay products. No porosity shown.

Clay No. 17, Claremore, Oklahoma.

Location, sec. 17, T. 21 N., R. 16 E. Thickness of deposit, 5 ft.; area, unknown; stripping, 5 to 10 ft.; distance to railroaod, ½ Frisco and Iron Mountain; nearest fuel, ¼ mile; gas, price 5 to 10

DATA.

Water of plasticity	21.8%
L. D. S.	6.7%w.l. 7.2%d.l.
L. F. S. (cone 5)	1.9%
Tot. L. S.	8.5%
Vol. D. S.	20.2%w.v. 25.3%d.v.
Vol. F. S.	4.8%
Tot. Vol. S.	24.0%
Absorp.	5.6%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.5	24.6	23.8	23.7	20.9	22.0	16.3	18.6	17.6	

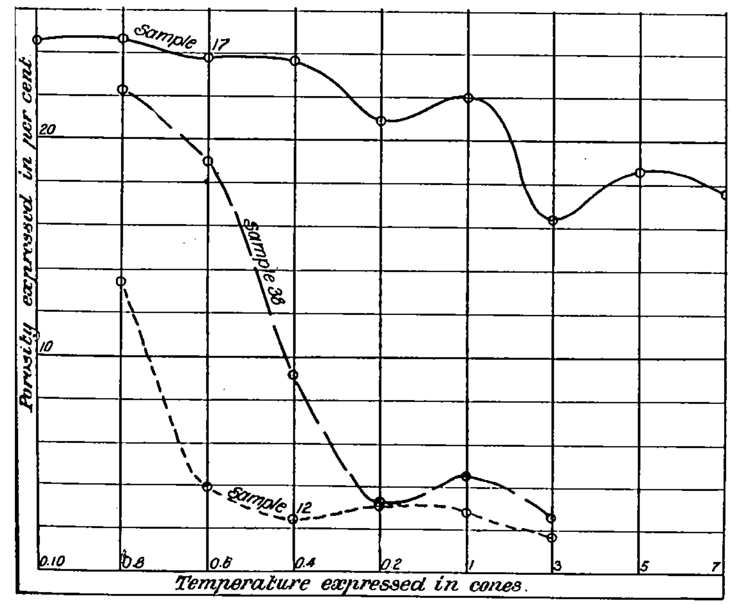


Fig. 18. Porosity Curves for Clays No. 12, 17 and 38.

Remarks:—Light gray surface clay with considerable sand, is fine-grained and works nicely in pan and machine. Little lamination. Dries nicely. Is a brownish pink at 010 and 06, turning to buff at cone 04 and 7, steel hard at 04; no melting at 7. Some spalling due to lime particles when soaked. Would have to be ground very fine to get rid of the pieces of lime. Large pieces burned at cone 5 show firm but not dense structure and rich buff color. Suitable for building and front brick, if the pieces of lime can be eradicated.

Porosity curve on fig. 18.

Perry, Oklahoma.

Clay No. 30,

Location, NW. ¼ sec. 15, T. 22 N., R. 1 W. Thickness, 3 ft.; area, 200 acres; stripping, 7 ft.; nearest railroad, 7½ miles; Santa Fe and Frisco; nearest fuel, coal, 85 miles, gas, 45 miles.

DATA.

Water of plasticity	%
L. D. S.	%
L. F. S.	12.5%
Tot. L. S.	12.5%
Vol. D. S.	%
Vol. F. S.	%
Tot. Vol. S.	%
Absorp.	10.8%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	42.8	32.8	37.4	30.6	31.6	25.3	27.8	19.6	4.2	

Remarks:—Soft light colored. Grinds and works well but is somewhat punky. Crumbles and rubs off and must be handled carefully. Burns to red color with open structure to cone 7, soft at cone 3, vitrified and dark gray color at cone 9. Large pieces were burned at cone 1, but would stand at much higher temperature. Good for common brick.

Porosity curve on fig. 21.

Perry, Oklahoma.

Clay No. 31,

Location, NW. ¼ sec. 15, T. 22 N., R. 1 W. Thickness of deposit, 11 ft.; area, 200 acres; stripping, 10 ft.; nearest railroad 7½ miles Santa Fe and Frisco; nearest fuel, coal, 85 miles, gas 45 miles.

Remarks:—Too sandy to work on machine. Contains very little clay matter.

Stigler, Oklahoma.

Clay No. 33,

Location, NE.¼ sec. 13, T. 9 N., R. 20 E. Thickness of deposit, 9 ft.; area of deposit, 3 acres; stripping, 5 ft.; nearest railroad, ½ mile; nearest fuel, 1 mile; coal, $2.75 per ton.

DATA.

Water of plasticity	24.4%	
L. D. S.	2.4%w.l.	2.4%d.l.
L. F. S. (cone 5)	9.8%	
Tot. L. S.	12.0%	
Vol. D. S.	7.0%w.v.	7.6%d.v.
Vol. F. S.	32.1%	
Tot. Vol. S.	36.9%	
Absorp.	.9%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	34.6	34.4	25.8	27.2	17.0	22.9	3.7	3.3	Swollen.	

Remarks:—A light colored shale which grinds easily. Its working properties are peculiar. It does not seem particularly sandy but has very little plasticity and is very "punky." It also has a peculiar behavior in burning, showing little condensation or change between cones 010 and 1, and then vitrifying completely at cones 3 and 5, and swelling badly at cones 7 and 9. This property would cause a great variation in the size of the burned ware unless the kilns were of remarkably uniform temperature throughout. The burned color is rather an unsatisfactory red. The material could be used to make common brick, but owing to its working and burning properties is not recommended for any other product.

Porosity curve on fig. 19.

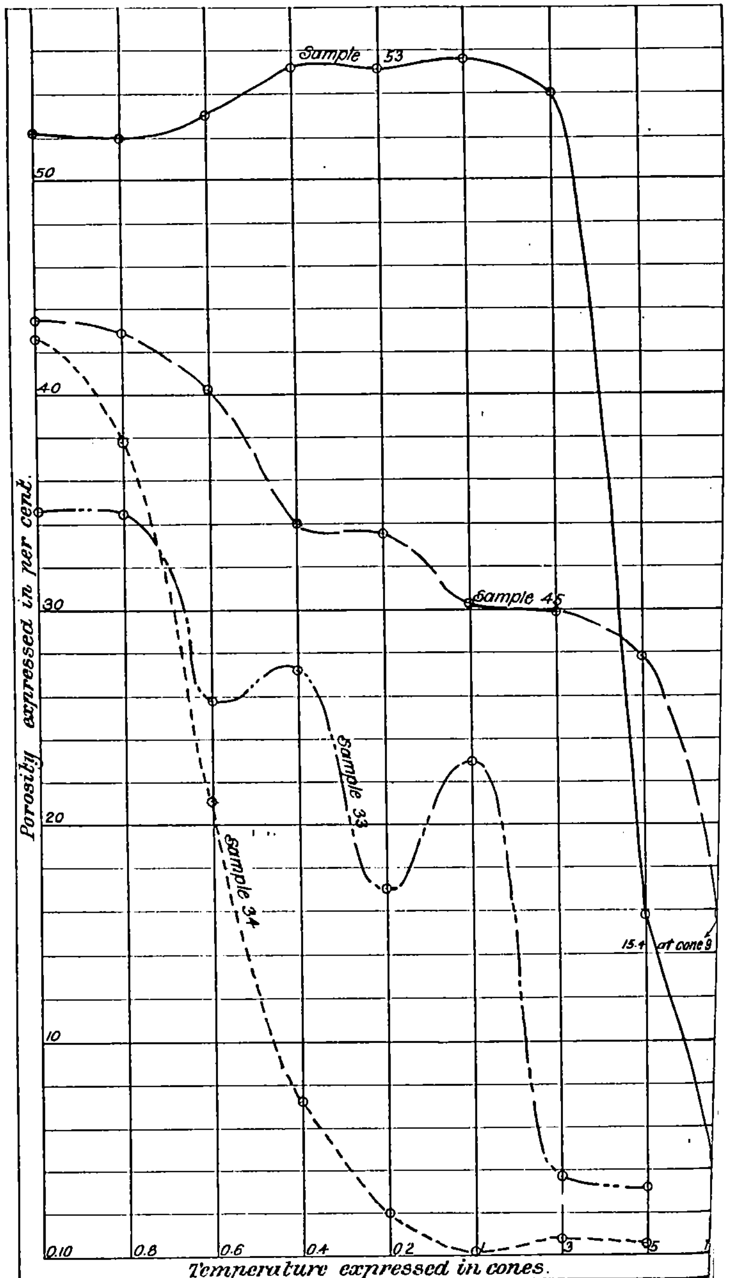


Fig. 19. Porosity Curves for Clays No. 33, 34, 45 and 53.

Clay No. 34, Stigler, Oklahoma.

Location, SW.¼ sec. 7, T. 9 N., R. 21 E. Thickness of deposit, 13 ft.; area, 20 acres; stripping, 4 to 6 ft.; nearest railroad, 1 mile; nearest fuel, 2 miles; coal, price $2.75.

DATA.

Water of plasticity	31.6%
L. D. S.	2.3%w.l 2.3%d.l.
L. F. S.	14.7%
Tot. L. S.	16.6%
Vol. D. S.	4.7%w.v. 4.9%d.v.
Vol. F. S.	39.1%
Tot. Vol. S.	41.8%
Absorp.	.3%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	42.6	37.8	21.1	7.2	2.0	.2	.8	.5		

Remarks:—Is a soft sandy clay of light gray color. Working, drying and burning qualities very similar to those of sample 33. Swells badly on leaving die of machine. Is not desirable on account of working qualities and rapid change in color and texture at cone 1.

Porosity curve on fig. 19.

Clay No. 38, Muskogee, Oklahoma.

Location, NW. sec. 34, T. 15 N., R. 18 E; amount of deposit is not known, but it is very large. Stripping, 3 to 5 ft.; railroads, 1¼ miles to M., K. & T. and ¾ mile to Midland Valley; nearest fuel, gas, ½ mile.

DATA.

Water of plasticity	21.8%
L. D. S.	6.4%w.l. 6.85%d.l.
Vol. D. S.	19.2%w.v. 23.8%d.v.

At cone	08	06	04	02	1	3
L. F. S.	4.7	6.0	7.4	8.3	8.7	8.9
Vol. F. S.	13.3	17.3	22.3	23.5	25.5	24.8
Tot. L. S.	9.6	10.6	13.3	14.1	14.5	14.7
Tot. V. S.	29.9	33.2	37.2	38.2	39.1	39.2
Absorp	9.2	7.1	3.1	1.8	1.1	.4
Porosity	22.3	19.0	9.2	3.3	4.5	2.6

Remarks:—A brown clay shale of good working and drying properties. Burns to a good brick red color and a good but not dense structure. Can be burned between cones 04 and 3 to common building brick or drain tile.

Porosity curve on fig. 18.

Clay No. 39, Muskogee, Oklahoma.

Location, S.½ of NE.¼ sec. 19, T. 15 N., R. 19 E. Stripping, 3 ft.; amount of deposit, very large; nearest railroad, ½ mile; M., K. & T. and Midland Valley; nearest fuel, 1 mile, gas.

DATA.

Water of plasticity	25.6%					
L. D. S.	6.4%w.l. 6.9%d.l.					
V. D. S.	16.9%w.v. 20.3%d.v.					
At cone	08	06	04	02	1	3
L. F. S.	1.0	2.3	2.9	3.6	3.6	3.8
V. F. S.	.3	6.3	9.9	9.9	12.4	13.0
Tot. L. S.	7.1	8.3	8.9	9.5	9.5	9.8
Tot. V. S.	17.1	22.2	25.1	25.1	27.1	27.5
Absorp.	18.3	17.5	14.5	12.5	12.7	12.3
Porosity	36.1	34.1	32.0	32.1	27.3	29.5

Remarks:—A red, sandy shale. Works and dries well. Burns to brick red color and has a somewhat open structure. Would be a good soft mud clay. Suitable for drainage tile and common brick.

Porosity curve on fig. 20.

Clay No. 40, McAlester, Oklahoma.

Location, NW.¼ sec. 32, T. 6 N., R. 15 E. Thickness of deposit 100 ft.; area, 100 acres; stripping, 4 ft. of building brick shale. On M., K. & T. Railroad, switching rate of $3.00 to Rock Island; nearest fuel, 1 mile; bituminous coal, price, $1.50. Clay is used for building and paving brick by McAlester Brick Co.

DATA.

Water of plasticity	23.1%
L. D. S.	7.1%w.l. 7.7%d.l.
L. F. S. (cone 3)	9.7%
Tot. L. S.	16.1%

Vol. D. S.	18.4%w.v. 22.5%d.v.
Vol. F. S.	25.2%
Tot. V. S.	38.9%
Absorp.	.3%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	29.6	26.8	15.2	11.9	4.2	2.7	1.5	1.0	4.6	

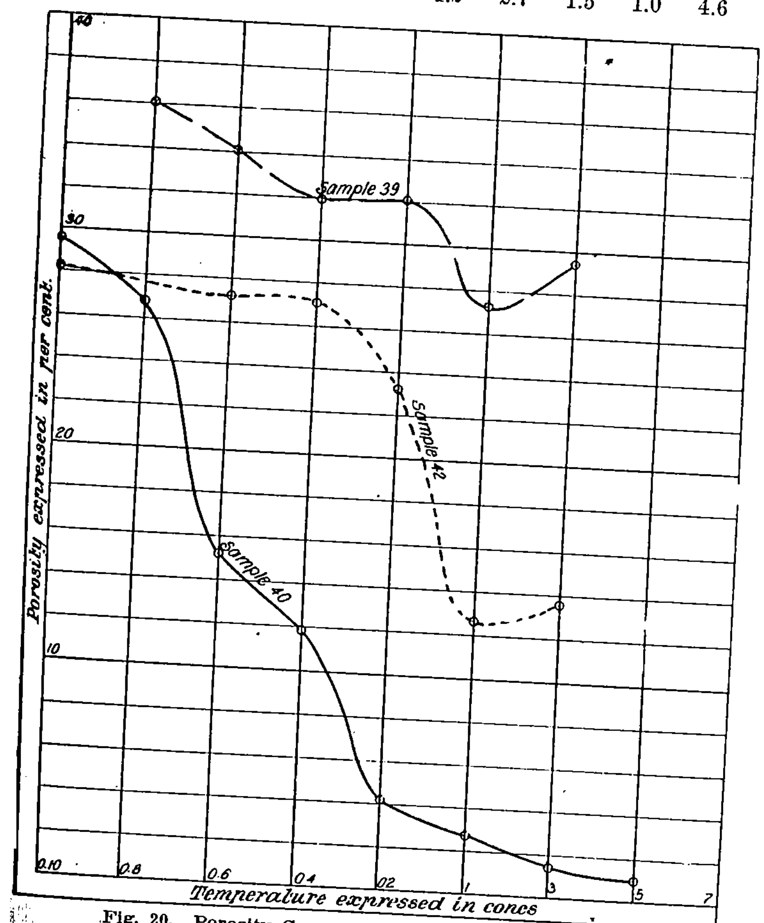


Fig. 20. Porosity Curves for Clays No. 39, 40 and 42.

Remarks: A dark gray, fine-grained clay shale. Works very nicely and dries evenly and without warping or cracking. The total shrinkage is rather high. Burns to a dark red. Shows some discoloration from whitewash. Becomes steel-hard at cones 04 and 02, vitrifies at cones 3 and 5 and is slightly blue-stoned at cone 7. Gives a very fine bright red color and unusually dense, firm structure on the dry press.

Suitable for common, building, sidewalk and sewer brick. Is rather brittle at cone 5 for good pavers. Is also adapted for drain tile.

Clay No. 42, Oklahoma City, Oklahoma.

Location, sec. 31, T. 12 N., R. 3 E. Thickness of deposit, 80 ft.; area, 10 acres; stripping, about 2 ft. Railroads, on Rock Island; Santa Fe, Frisco, and M., K. & T. available with switching charge. Fuel, gas piped from Sapulpa at 10 cents per 1000 ft. Clay is used for dry press brick by American Brick & Tile Co.

DATA.

Water of plasticity	20.4%
L. D. S.	5.9%w.l. 6.2%d.l.
L. F. S.	3.8%
Tot. L. S.	9.5%
Vol. D. S.	18.0%w.v. 21.9%d.v.
Vol. F. S.	14.0%
Tot. Vol. S.	29.5%
Absorp.	.5%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	28.2	.	27.2	27.1	23.2	12.7	13.6			

Remarks:—A red clay shale of excellent working, drying and burning qualities.

It burns to a fine dark red color below cone 5. It begins to vitrify at cone 02 and can be burned safely to cone 4. By careful burning it could be carried to cone 5 where it gives a fine light chocolate color.

It is well suited for use as common, front or sidewalk brick, hollow brick or drain tile. It vitrifies too rapidly and is too brittle for drain tile or sewer pipe. Porosity curve on fig. 20.

Clay No. 44, Hartshorne, Oklahoma.

Location, roof in mine No. 8 of Rock Island Coal Mining Co.; thickness of deposit, 20 ft.; area, 600 acres; on Rock Island Railroad; nearest fuel, coal under clay, bituminous; price, $2.00. Has been used for ballast after burning.

DATA.

Water of plasticity	16.0%
L. D. S.	3.1%w.l. 3.2%d.l.

Cone	010	08	06	04	02	1	3	5	7	9
Por.	38.4	35.8	31.5	28.2	23.2	21.1	19.7	16.8	14.0	13.7

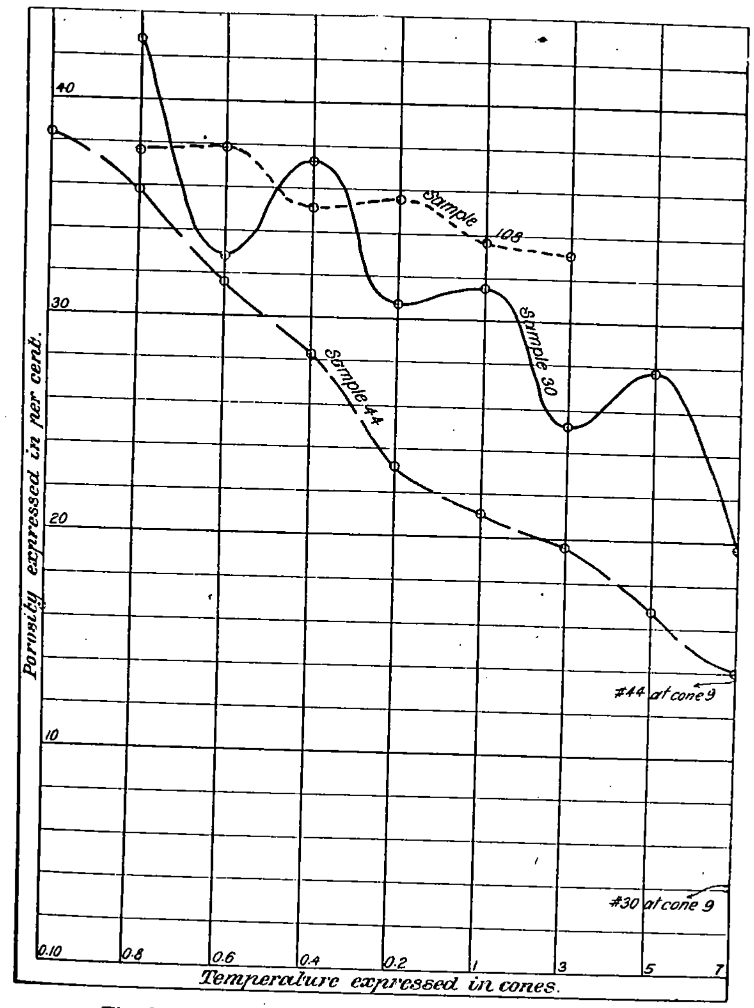


Fig. 21. Porosity Curves for Clays No. 30, 44 and 108.

Remarks:—Black carbonaceous shale. Grinds down and works well. Very tough and gummy. Small pieces were steel-hard at cone 02 and completely vitrified at cone 9.

The large pieces could not be oxidized owing to the large amount of carbonaceous matter. This would prevent the use of the clay in commercial processes.

Porosity curve on fig. 21.

Clay No. 45, Hartshorne, Oklahoma.

Location, floor of mine No. 8 of Rock Island Coal Mining Co.; thickness, 6 ft.; deposit inexhaustible; mine workings cover 600 acres; on the Rock Island Railroad; fuel on ground, bituminous coal, price $2.00. Clay has been used for ballast after burning.

DATA.

Water of plasticity	14.6%	
L. D. S.	3.4%w.l.	3.3%d.l.

Cone	010	08	06	04	02	1	3	5	7	9
Por.	43.5	42.9	40.2	34.0	33.5	30.3	29.9	27.8	15.8	15.4

Remarks:—Black plant impressions. Stiff and gummy. Thin veins of coal. Works and stands up well. Burning behavior similar to that of No. 44. Almost white at cone 010, slightly yellow at 08-1 and light gray 7, and 9. Steel-hard at cone 1. All large pieces black colored at 5 and not fully oxidized at cone 1 when fired for 60 hours at oxidizing conditions. Could not be oxidized in commercial burning.

Porosity curve on fig. 19.

Clay No. 46, Alderson, Oklahoma.

Location, roof of mine No. 5 of Rock Island Coal Mining Co. Thickness of deposit, 10 ft.; amount of deposit, inexhaustible; mine workings cover 500 acres; fuel on ground, bituminous coal; price, $2.00. Clay has been used for railroad ballast.

DATA.

Water of plasticity	17.1%	
L. D. S.	3.9%w.l	4.0%d.l.
L. F. S. (cone 5)	8.8%	
Tot. L. S.	12.3%	
Vol. D. S.	14.1%w.v.	16.4%d.v.
Vol. F. S.	19.4%	
Tot. Vol. S.	30.8%	
Absorp.	3.5%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	29.7	25.8	19.8	18.3	8.1	7.2	7.4	5.7		

Remarks:—Very dark gray to black; hard shale. Works and dries nicely. Burns to red color; is steel-hard at cone 08 and stands up well at cone 7. At cone 5 the large pieces burn to a magnificent red, free from all discoloration. They possess an exceedingly sound and perfect structure. Owing to its excellent working and drying qualities and long vitrification range the material is too valuable to be used in the manufacture of common bricks. It could be used in the manufacture of paving and face brick, sewer pipe, conduits, and for all structural purposes. It is an excellent material.

Porosity curve on fig. 22.

Clay No. 47, Alderson, Oklahoma.

Slate under coal in mine No. 5 of Rock Island Coal Mining Co. Thickness of deposit, 6 ft.; amount of deposit, inexhaustible; mine workings cover 500 acres; fuel on ground, bituminous coal, price, $2.00. Clay has been used for railroad ballast.

DATA.

Water of plasticity	18.9%	
L. D. S.	6.3%w.l.	6.7%d.l.
L. F. S. (cone 5)	7.1%	
Tot. L. S.	12.8%	
Vol. D. S.	17.2%w.v.	20.8%d.v.
Vol. F. S.	18.3%	
Tot. Vol. S.	32.3%	
Absorp.	.4%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	26.9	22.1	17.6	14.6	9.1	6.2	1.4		5.6	8.9

Remarks:—A black clay shale with plant impressions. Works and dries nicely. Burns steel-hard at cone 02 and stands up well at cone 9.

It has a rather poor, very dark buff color and shows a sound flawless structure. It is very similar to the No. 3 fire clay of Ohio and Illinois. It is very useful for the manufacture of fire proofing, conduits, paving brick, and probably for sewer pipe. It can be used for building brick, although its color would limit the demand for it as front brick.

Porosity curve on fig. 22.

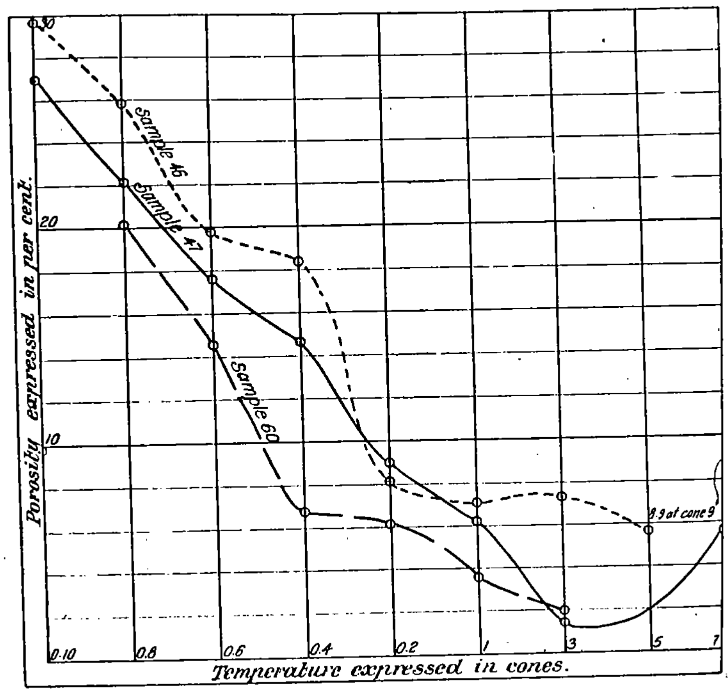


Fig. 22. Porosity Curves for Clays No. 46, 47 and 60.

Clay No. 53, Blackwell, Oklahoma.

Location, NW.¼ sec. 26, T. 27 N., R. 1 W. Thickness of deposit, 625 ft.; known area, 120 acres; stripping, 8 to 16 ft. of ground which may be used as ballast. Railroads, side track from Santa Fe; Frisco, 1 mile distant available with switching charges; fuel, gas is piped to lease at 6 cents per 1000 ft.; coal, $2.25 per ton. Has been used for common building brick.

DATA.

Water of plasticity	20.6%
L. D. S.	3.0%w.l. 3.2%d.l.
L. F. S.	1.8%
Tot. L. S.	4.6%
Vol. D. S.	12.7%w.v. 14.5%d.v.
Vol. F. S.	.8%
Tot. Vol. S.	13.4%
Absorp.	34.8%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	52.2	52.0	53.0	55.3	55.1	55.6	54.0	15.8	4.5	

Remarks:—Is a siliceous clay with large grains of quartz. Works and dries nicely.

Burns to light buff color with open porous structure up to cone 9. It shows little change from cone 010 to cone 3 and then shows a rapid condensation at cones 5, 7 and 9. Is completely melted at cone 15.

Is especially adapted to use as fire proofing on account of its open porous structure. Is also suitable for conduits and for common brick and drain tile.

Porosity curve on fig. 19.

Clay No. 54, Blackwell, Oklahoma.

Location, NE. ¼ sec. 5, T. 27 N., R. 1 W. Thickness of deposit, very deep but unknown; area, 160 acres; stripping, 10 ft.; distance to railroad, 1½ miles; Frisco and Santa Fe; nearest fuel, 1 mile; gas, 6 cents per 1000 ft.; coal, $2.25 per ton.

DATA.

Cone	010	08	06	04
Por.	16.4	9.8	1.9	1.2

Remarks: Is an extremely plastic red shale. Works with great difficulty on the machine, the edges tearing badly even when lubricated with water or steam. All the large pieces cracked very badly in drying. The small pieces puffed above cone 04. Owing to these qualities it could not be used by the stiff mud process. It can be used by the dry process, giving a good red color; but its short temperature range makes its use in any way questionable. No porosity curve shown.

Clay Nos. 60, 61, 62, 63, Cleveland, Oklahoma.

Thickness of deposit, 65 ft.; area, 100 acres; stripping, 18 ft.; nearest fuel, 1 mile; gas, price 2 cents per 1000 ft. Nearest limestone, 1 mile. Clay has been used for brick.

DATA FOR NO. 60.

Water of plasticity 20.4%
L. D. S. 6.0%w.l. 7.6%d.l.
V. D. S. 17.1%w.v. 20.6%d.v.

At cone	08	06	04	02	1	3
L. F. S.	4.0	5.1	7.2	7.8	7.9	7.9
V. F. S.	11.9	14.6	22.8	22.6	21.7	21.0
Tot. L. S.	8.7	10.7	13.8	13.4	13.2	13.2
Tot. V. S.	26.9	29.2	35.9	35.8	35.0	35.1
Absorp.	7.5	6.5	1.2	.7	.4	.3
Por.	20.1	14.5	6.8	6.2	3.6	2.0

Porosity curve on fig. 22.

DATA FOR NO. 61.

Water of plasticity 20.5%
L. D. S. 6.0%w.l. 6.3%d.l.
V. D. S. 15.6%w.v. 18.5%d.v.

At cone	08	06	04	02	1	3
L. F. S.	2.1	3.8	5.4	6.0	6.7	6.6
V. F. S.	7.6	11.1	15.9	18.2	18.5	18.4
Tot. L. S.	7.2	9.2	10.6	11.3	12.0	11.9
Tot. V. S.	22.0	25.3	29.1	30.9	31.3	31.2
Absorp.	11.3	8.4	4.8	3.4	3.3	2.1
Porosity	24.3	21.9	15.1	11.3	11.3	6.1

Porosity curves on fig. 23.

DATA FOR NO. 62.

Water of plasticity 18.9%
L. D. S. 4.7%w.l. 4.96%d.l.
V. D. S. 12.4%w.v. 14.8%d.v.

At cone	08	06	04	02	1	3
L. F. S.	.2	.7	1.6	2.3	2.0	2.1
V. F. S.	.0	1.5	2.7	6.4	5.8	5.6
Tot. L. S.	4.8	5.2	6.2	6.8	6.5	6.1
Tot. V. S.	11.2	12.4	13.6	16.9	16.4	16.3
Absorp.	12.3	11.8	9.7	10.8	8.5	7.3
Porosity	28.6	24.6	19.4	24.7	23.1	21.9

Porosity curve on fig. 23.

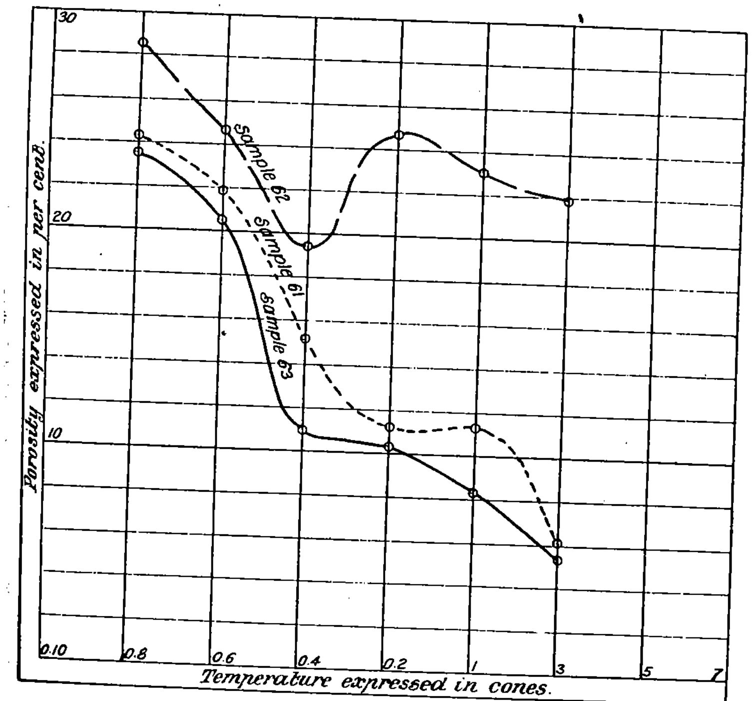


Fig. 23. Porosity Curves for Clays No. 61, 62 and 63.

DATA FOR NO. 63.

Water of plasticity 21.3%
L. D. S. 5.9%w.l. 6.2%d.l.
V. D. S. 16.8%w.v. 20.1%d.v.

At cone	08	06	04	02	1	3
L. F. S.	2.2	3.8	5.3	7.0	6.7	7.6
V. F. S.	6.0	11.3	15.3	17.1	18.9	18.8
Tot. L. S.	7.8	9.8	10.2	11.1	12.0	12.9
Tot. V. S.	21.4	26.2	29.1	31.0	32.8	32.5

Absorp.	11.2	9.4	5.3	4.2	3.3	1.6
Porosity	23.5	20.5	11.0	10.3	8.3	2.3

Porosity curve on fig. 23.

Remarks:—60, 61, and 63 are dark colored clay shales of similar properties. They all work well and dry nicely. All burn to a dark red color. Any of them or mixtures of them are suitable for common or building brick or pavers.

No. 62 is somewhat more sandy and has a smaller shrinkage than the others. The slight difference between the clays is shown in the data and in the porosity curves.

Clay No. 69, Wilburton, Oklahoma.

Location, SE. ¼ sec. 13, T. 6. N., R. 18 E. Thickness of deposit, 5 ft.; area, unlimited; stripping, crops out along hill, has slope of 8°; nearest railroad, 3 miles to M., K. & T. and Rock Island; fuel on the grounds; wood and coal, price $1.50; nearest limestone, ½ mile.

DATA.

Water of plasticity 22.9%

L. D. S. 7.3%w.l. 7.75%d.l.

V. D. S. 19.7%w.v. 24.4%d.v.

At cone	08	06	04	02	1	3
L. F. S.	.6	2.6	2.9	4.0	4.5	4.7
V. F. S.	3.0	7.4	5.8	9.2	11.3	11.1
Tot. L. S.	7.9	9.7	10.0	11.0	11.4	11.1
Tot. V. S.	22.0	25.6	24.3	27.1	28.7	29.1
Absorp.	13.5	11.5	10.0	8.5	7.6	7.2
Porosity	30.5		23.8	23.2	21.6	23.1

Remarks:—Is a rather sandy clay of good working and drying qualities. Burns to light brick red. Should be a good soft mud clay. Suitable for common brick and drain tile.

Porosity curve on fig. 24.

Clay No. 70, Wilburton, Oklahoma.

Location, SE.¼ sec. 13, T. 6. N., R. 18 E. Thickness of deposit, 3 ft.; area, unlimited; stripping, crops out along hill and dips at 8°; nearest railroad, 2 miles; M., K. & T. and Rock Island; nearest fuel on ground; wood and coal; price, coal, $1.50 per ton; nearest limestone ½ mile.

DATA.

Water of plasticity 29%

L. D. S. 11.2%w.l. 12.6%d.l.

V. D. S. 29.9%w.v. 42.6%d.v.

At cone	08	06	04	02	1	3
L. F. S.	6.3	7.3	9.2	8.6	9.6	10.1
V. F. S.	17.6	21.4	27.0	22.2	26.6	28.4
Tot. L. S.	18.7	17.6	19.3	18.7	19.6	20.1
Tot. V. S.	42.3	44.8	48.7	45.0	48.5	49.0
Absorp.	7.3	5.0	1.8	1.8	1.3	.5
Porosity	19.7	15.8	13.5	6.1	8.0	4.1

Remarks:—A soft, blue, very plastic clay shale. Has very high shrinkage, but does not crack in drying and burning. Burns to good bright red color, maturing about cone 02. Its greatest difficulty is the excessive shrinkage. This could probably be overcome to some extent by mixing with sand or a sandy clay such as No. 69. Use is limited to common brick and tile. Porosity curve on fig. 24.

Clay No. 71, Wilburton, Oklahoma.

Location, SE. ¼ sec. 13, T. 6 N., R. 18 E. Thickness of deposit, 8 ft.; area very large; crops out along hill and dips at 8°; distance to railroad, 3 miles; M. K. & T. and Rock Island; fuel on ground; wood and coal, price, coal $1.50 per ton.

DATA.

Water of plasticity 28.6%

L. D. S. 9.8%w.l. 10.8%d.l.

V. D. S. 27.5%w.v. 38.8%d.v.

At cone	08	06	04	02	1	3
L. F. S.	7.6	9.0	9.0	......	7.9	7.7
V. F. S.	21.1	26.0	27.4	......	22.4	23.2
Tot. L. S.	17.2	17.9	17.9	......	17.1	17.3
Tot. V. S.	43.1	46.6	47.7	......	44.1	44.6
Absorp.	5.0	1.2	1.0	......	0.84	0.28
Porosity	9.6	2.6	......	......	1.7	1.9

Remarks:—Very similar to 70 except that it matures earlier. Is vitrified at cone 06 but stands up well at cone 3.

Porosity curve on fig. 24.

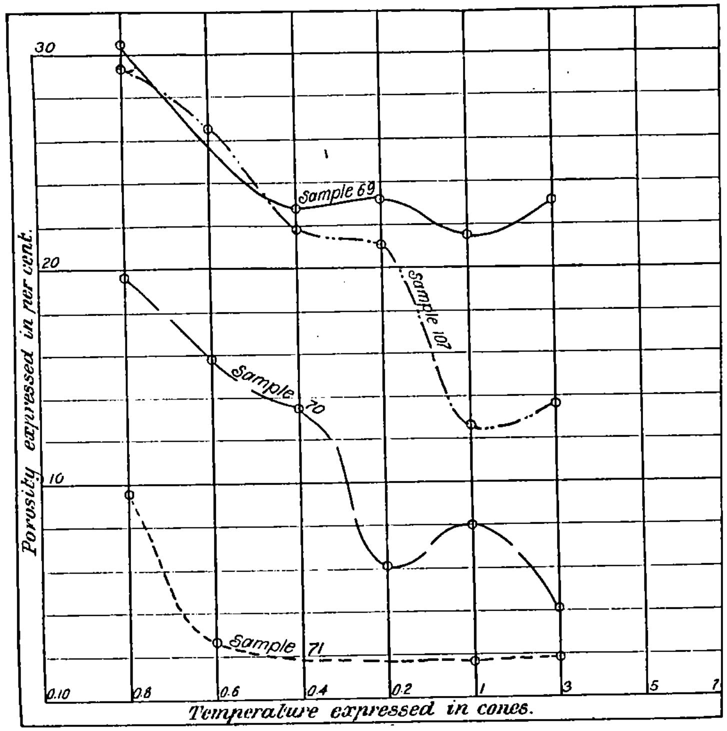


Fig. 24. Porosity Curves for Clays No. 69, 70, 71 and 107.

Clay Nos. 72, 73, and 74, Enid, Oklahoma.

Location, SE.¼ sec. 17, T. 22 N., R. 6 W. Thickness of deposit, 60 ft.; area, 10 acres; stripping, 3 ft.; distance to railroad, 1½ miles; Frisco, Santa Fe and Rock Island. Nearest fuel, Tulsa; coal and oil; price, coal $3.00, oil $1.00 per bbl. Clay has been used for the manufacture of brick.

DATA.

Did not arrive in time to be tested.

Remarks: Nos. 72 and 73 are redbeds shale similar to Nos. 42, 173, 196 and 197.

No. 74 seems to be a fine-grained gray sand similar to Nos. 30 and 31. All three are used in the manufacture of brick at Enid.

Clay No. 78, Lindsay, Oklahoma.

Location, sec. 22, T. 4 N., R. 5 W. Thickness of deposit, not known; area, large; stripping, 6 ft.; nearest railroad, 4 miles; Santa Fe and Rock Island; fuel on ground, wood; coal $3.00.

Remarks:—Material too sandy to bear handling after being made up. Not suitable for clay products.

Clay No. 107, Miami, Oklahoma.

Location, NE. ¼ of the NW. ¼ sec. 18, T. 28 N., R. 23 E. Thickness of deposit, 10 ft.; area, 40 acres; stripping, 5 ft.; nearest railroad, 1 mile; Frisco; nearest fuel, 6 miles; coal, price $2.50; nearest limestone, ½ mile.

DATA.

Waster of plasticity 18.3%
L. D. S. 4.6%w. l. 4.9%d.l.
V. D. S. 12.7%w.v. 14.5%d.v.

At cone	08	06	04	02	1	3
L. F. S.	1.9	2.5	4.5	4.1	6.1	7.0
V. F. S.	5.4	7.6	15.1	13.1	19.1	19.7
Tot. L. S.	6.3	7.8	8.7	8.4	10.3	11.1
Tot. V. S.	17.3	19.3	24.4	25.8	29.7	29.9
Absorp.	12.8	12.1	8.0	8.2	3.7	3.0
Porosity	29.4	26.5	21.1	21.7	12.6	13.6

Remarks: A black shale. Works nicely and dries evenly with slight shrinkage. Burns to rather unsightly light red color. Does not vitrify below cone 3. Suitable for fire-proofing, conduits, etc., and probably for paving brick and sewer pipe. Its color will probably prevent its being used for front brick or roofing tile. Porosity curve on fig. 24.

Clay No. 108, Miami, Oklahoma.

Location, NW.¼ sec. 24, T. 28 N., R. 22 E. Thickness of deposit, 10 ft.; area of deposit, 150 acres; no stripping; nearest railroad, ¼ mile; Frisco; nearest fuel, ½ mile; wood, price $2.00.

DATA.

Water of plasticity 19.2%
L. D. S. 1.9%w.l. 1.9%d.l.
V. D. S. 5.6%w.v. 5.9%d.v.

At cone	08	06	04	02	1	3
L. F. S.	No shrinkage.					
V. F. S.						
Tot. L. S.	1.6	1.3	.9	2.1	2.2	2.0
Tot. V. S.	2.7	5.7	3.9	5.2	5.0	5.2
Absorp.	18.6	19.5	18.2	16.8	17.4	16.0
Porosity	37.7	37.8	35.2	35.5	33.7	33.3

Remarks: A very sandy surface clay with little drying and no burning shrinkage. Should be a good soft mud clay. Use limited to common brick. Porosity curve on fig. 21.

Clay No. 126, Guthrie, Oklahoma.

Location, SE. 1/4 sec. 10, T. 16 N., R. 2 W. Thickness of deposit, unlimited; area, unlimited; stripping, 2 ft.; nearest railroad, Rock Island; competing lines, Santa Fe and Fort Smith and Western and M. K. & T.; nearest fuel, 100 miles to soft coal; gas in Guthrie. Clay has been used for brick by Guthrie Brick & Tile Co.

DATA.

Clay did not arrive at Pittsburg. Lost in transportation.

Remarks:—A red beds shale.

Clay No. 134, Quay, Oklahoma.

Location, NW. 1/4 sec. 29, T. 20 N., R. 6 E. Thickness of deposit, 10 ft.; area, 1500 acres; stripping, 2 ft.; nearest railroad, 1/2 mile; Santa Fe and M. K. & T.: nearest fuel, 15 miles; gas and oil; price oil 50 cents per barrel; nearest limestone, 1 mile.

DATA.

Water of plasticity 23.7%

L. D. S. 8.4%w.l. 9.2%d.l.

V. D. S. 23.9%w.v. 31.4%d.v.

At cone	08	06	04	02	1	3
L. F. S.	2.3	3.8	5.0	4.7	6.3	6.3
V. F. S.	7.0	10.3	16.1	15.1	18.0	17.8
Tot. L. S.	10.4	11.8	13.0	12.7	14.1	14.1
Tot. V. S.	29.9	31.3	36.2	35.3	37.5	37.4
Absorp.	9.6	7.7	3.9	4.1	2.6	1.1
Porosity	20.9	19.4	13.8	14.6	11.6	6.33

Porosity curve on fig. 25.

Clay No. 135, Quay, Oklahoma.

Location, SE. 1/4 sec. 25, T. 20 N., R. 5 E. Thickness of deposit, 6 ft.; area, 1000 acres; stripping, 3 ft.; nearest railroad, 1/2 mile; Santa Fe and M. K. & T.; nearest fuel, 15 miles; gas and oil; price of oil, 3 cents per gallon; nearest limestone 1/2 mile.

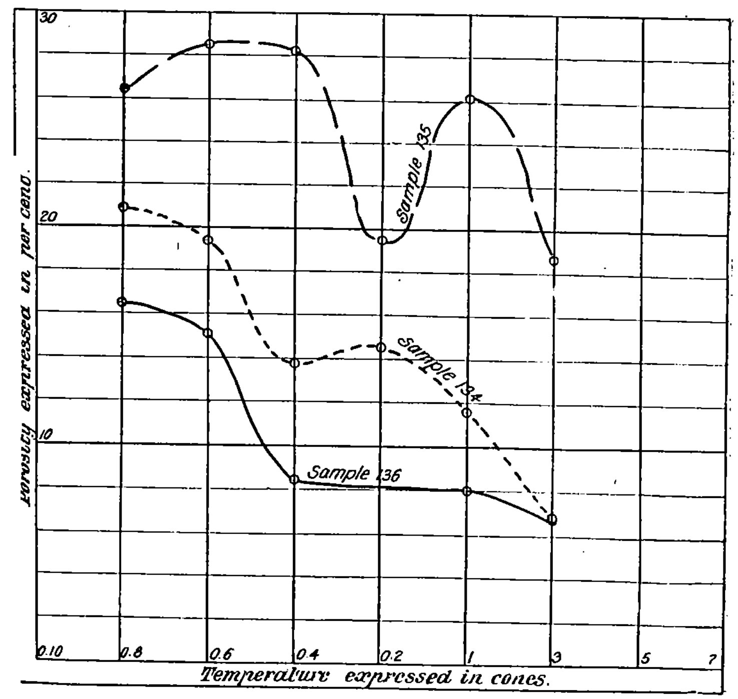


Fig. 25. Porosity Curves for Clays No. 134, 135 and 136.

DATA.

Water of plasticity 23.6%

L. D. S. 9.2%w.l. 10.1%d.l.

V. D. S. 26.1%w.v. 36.4%d.v.

At cone	08	06	04	02	1	3
L. F. S.	2.0	2.1	2.7	3.2	2.5	2.0
V. F. S.	3.6	5.0	5.3	6.4	7.0	6.0
Tot. L. S.	11.0	11.1	11.6	12.1	11.4	11.0

Tot. V. S.	29.1	30.1	30.4	31.1	31.4	30.6
Absorp.	13.1	11.9	8.9	7.2	5.9	5.7
Porosity	26.4	28.4	28.2	19.6	26.1	18.6

Porosity curve on fig. 25.

Clay No. 136, Quay, Oklahoma.

Location, NW. ¼ sec. 6, T. 19 N., R. 6 E. Thickness of deposit, 20 ft.; area, 2500 acres; stripping, 1 foot; nearest railroad, ½ mile; Santa Fe and M. K. & T.; nearest fuel, 15 miles; gas and oil; price of oil, 2 cents per gallon; nearest limestone, ½ mile.

DATA.

Water of plasticity 23.1%
L. D. S. 8.7%w.l. 9.5%d.l.
V. D. S. 24.0%w.v.31.5%d.v.

At cone	08	06	04	02	1	3
L. F. S.	4.5	5.4	6.1	5.0	6.1	6.1
V. F. S.	12.3	16.0	16.3	.....	18.9	18.3
Tot. L. S.	12.8	13.6	14.2	13.2	14.2	14.2
Tot. V. S.	33.3	36.1	36.4	.....	37.8	37.9
Absorp.	8.0	4.3	2.1	.....	.9	.5
Porosity	16.5	15.2	8.4	.....	8.0	6.7

Porosity curve on fig. 25.

Remarks: Nos. 134, 135 and 136 are plastic clay shales of very similar properties. They all work and dry nicely and burn to a red color with a tendency to whitewash.

Nos. 135 and 136 shows the presence of lime particles, which cause a spalling off of the surface when the burned pieces are soaked in water. This would prevent their use for front brick and drain tile. No. 134 did not show the spalling off and could probably be used for drain tile. All are suited for common brick.

The difference in the behavior of the three clays is shown by the data and porosity curves.

Clay No. 137, Rush Springs, Oklahoma.

Location, Block 78, Town of Rush Springs. Thickness of deposit, 3 ft.; area, unknown but large; stripping, 1 to 5 ft.; on Rock Island Railroad; nearest fuel, 1 to 3 miles; wood, price, $3.50.

DATA.

Water of plasticity 23.5%
L. D. S. 9.9%w.l. 12.1%d.l.
V. D. S. 25.7%w.v. 34.5%d.v.

At cone	08	06	04	02	1	3
L. F. S.	1.1	3.0	6.5	6.1	4.8	4.7
V. F. S.	1.6	7.2	15.6	18.4	18.1	20.3
Tot. L. S.	10.7	12.3	15.5	15.2	14.0	13.9
Tot. V. S.	26.5	31.0	.....	39.8	39.1	40.7
Absorp.	11.2	5.8	2.3	1.9	1.1	.4
Porosity	24.2	25.5	8.1	4.4	4.4	2.1

Remarks: A redbeds soft plastic shale. Shows some tendency to crack in burning. Burns to nice red color. Begins to vitrify at cone 04 and to melt and warp at cone 3. Suitable for common and building brick and drain tile.

Porosity curve on fig. 26.

Clay No. 145, Meeker, Oklahoma.

Location, SE. ¼ sec. 18, T. 12 N., R. 4 E. Thickness of deposit, 30 to 50 ft.; area of deposit, 100 acres; stripping, 1 to 5 ft.; nearest railroad, ½ mile to E. O. branch of Santa Fe; nearest fuel, ¼ mile; natural gas, price 10 cents per 1000 ft.

DATA.

Water of plasticity 27.0%
L. D. S. 12.5%w.l. 14.4%d.l.

Cone	010	08	06	04	02	1	3	5	7	9
Por.	18.4	16.1	4.8	2.6	1.7	1.3	1.5	0.5		

Remarks: Chocolate red clay shale; works well. Cracks in drying and burning. Burns to red color, steel hard at cone 04 and bluestones at cone 7.

Not recommended for clay products on account of cracking.

Porosity curve on fig. 26.

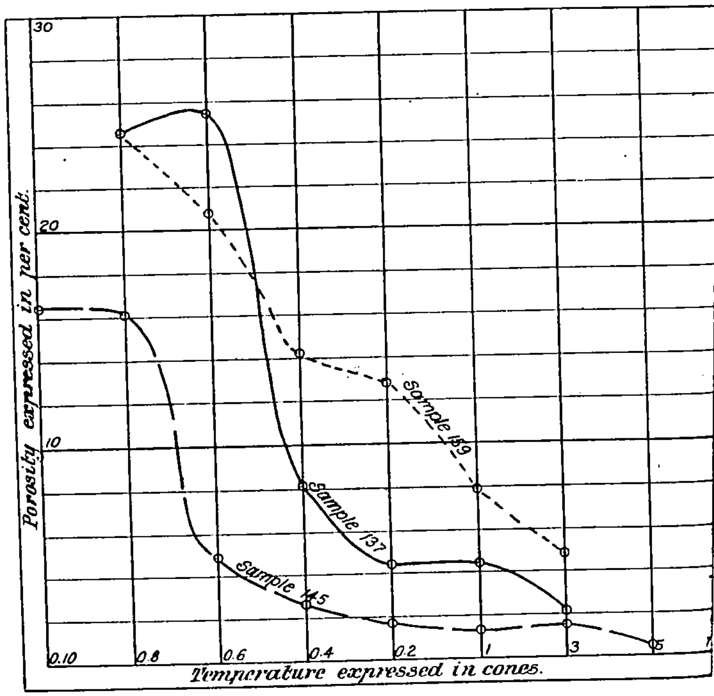


Fig. 26. Porosity Curves for Clays No. 137, 145, 159.

Clay No. 150, Sweetwater, Oklahoma.

Location, NE. ¼ sec. 34, T. 12 N., R. 26 W. Thickness of deposit, 50 ft.; area, unknown; stripping, 15 ft.; nearest railroad, 20 miles; nearest fuel, 20 miles; coal, price $10.25.

DATA.

L. D. S.				4.6%		
Cone	010	08	06	04	02	1
Por.	..........14.6	18.5	15.2	11.3	2.1	2.5

Remarks: Almost white clay shale, very plastic and has considerable lamination. All pieces cracked too badly. Very short temperature range, is light colored below cone 5 and swells badly at cone. Cannot be used for clay products on account of cracking, short temperature range and poor color.

Porosity curve on fig. 27.

Clay No. 151, Sweetwater, Oklahoma.

Location, NE. ¼ sec. 13, T. 11 N., R. 20 W. Thickness of deposit, 2 ft.; area, unknown; crops out on surface; nearest railroad, 16 miles; nearest fuel, 16 miles; coal, price $10.00

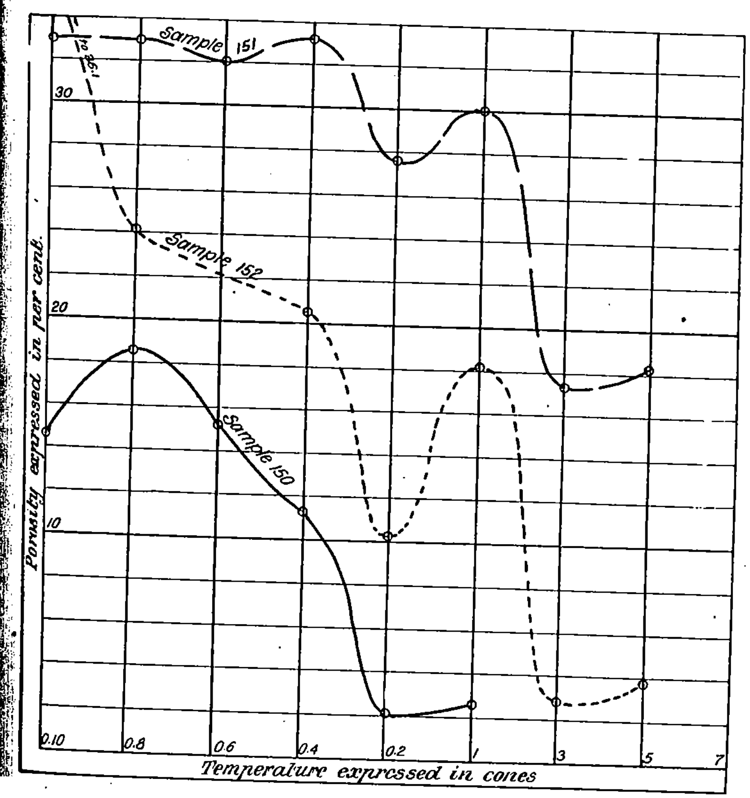


Fig. 27. Porosity curves for clays No. 150, 151, 152.

DATA.

Water of plasticity	24.3%	
L. D. S.	4.6%w.l.	5.3%d.l.
L. F. S. (cone 1)	5.3%	
Tot. L. S.	9.6%	
V. D. S.	17.6%w.v.	21.5%d.v.

V. F. S.	16.5%									
Tot. V. S.	31.2%									
Absorp.	3.8%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	32.9	33.0	32.0	33.1	27.5	30.0	17.4	18.3		

Remarks: Red surface clay. Works well and dries with small shrinkage. Does not burn satisfactorily when made by stiff mud process. Darkens and swells at cones 3, 5 and 7. Gives a nice bright red color and burns fairly well when made on dry press.

Porosity curve on fig. 27.

Clay No. 152, Waurika, Oklahoma.

Location, SE. ¼ sec. 12, T. 5 S., R. 8 W. Thickness of deposit, 3 ft.; area, large; stripping, 0 to 2 ft.; nearest railroad, along Rock Island and near E. & A. Nearest fuel, 65 miles; coal, price $3.00, wood $3.00 per cord.

DATA.

Water of plasticity	20.3%									
L. D. S.	6.9%w.l. 7.4%d.l.									
L. F. S. (cone 3)	4.3%									
Tot. L. S.	10.8%									
V. D. S.	23.5%w.v. 30.6%d.v.									
V. F. S.	13.2%									
Tot. V. S.	33.6%									
Absorp.	1.3%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	36.1	24.1	....	20.5	10.2	8.1	2.8	3.8		

Remarks: Chocolate-red clay shale; works nicely with little lamination. Dries nicely; vitrified at cone 02; stands up well at cone 9. It has some white specks, possibly lime but don't spall off. Some white washing. Suitable for common and sidewalk brick.

Porosity curve on fig. 27.

Clay No. 153, Waurika, Oklahoma.

Location, SE. ¼ sec. 12, T. 5 S., R. 8 W. Thickness of deposit, 6 to 8 ft.; area, several acres; stripping, 5 ft.; along Rock Island right of way, near E. & A. Nearest fuel, coal 65 miles, wood on ground; price, coal $3.00, wood, $3.00 per cord.

DATA.

Water of plasticity	27.0%									
L. D. S.	11.9%w.l. 13.4%d.l.									
L. F. S. (cone 1)	5.9%									
Tot. L. S.	17.1%									
V. D. S.	31.7%w.v. 43.0%d.v.									
V. F. S.	18.9%									
Tot. V. S.	44.6%									
Absorp.	.7%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	18.4	20.4	13.4	12.8	4.2	1.5	1.9	1.7		

Remarks: Red clay shale; works nicely; some lamination. Burns to a red color with dirty white specks. Hard and fair color from cone 06 to 3; begins to melt at cone 5. Suitable for common and sidewalk brick.

Porosity curve on fig. 28.

Clay No. 154, Waurika, Oklahoma.

Location, SW. ¼ sec. 35, T. 4 S., R. 8 W. Thickness of deposit, and area, unknown; stripping, 1 foot; nearest railroad, 1 mile; E. & A. and Rock Island. Nearest fuel, coal, 65 miles, wood on ground; price, coal $3.00, wood $3.00.

DATA.

Water of plasticity	15.1%									
L. D. S.	.7%w.l. 1.0%d.l.									
L. F. S. (cone 5)	.0%									
Tot. L. S.	.7%									
V. D. S.	4.1%w.v. 4.2%d.v.									
V. F. S.	1.4%									
Tot. V. S.	.7%									
Absorp.	12.1%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	33.0	32.0	33.6	33.7	32.0	32.3	31.7	31.2	31.5	31.4

Remarks: Light gray, fine sand with little clay material. Works and dries well. Practically no shrinkage in drying or burning. Buff at cone 010, changes gradually to gray at cone 9. Shows tendency to crack in burning. Porous and open throughout. Suitable for common brick by soft mud process.

Porosity curve on Fig. 28.

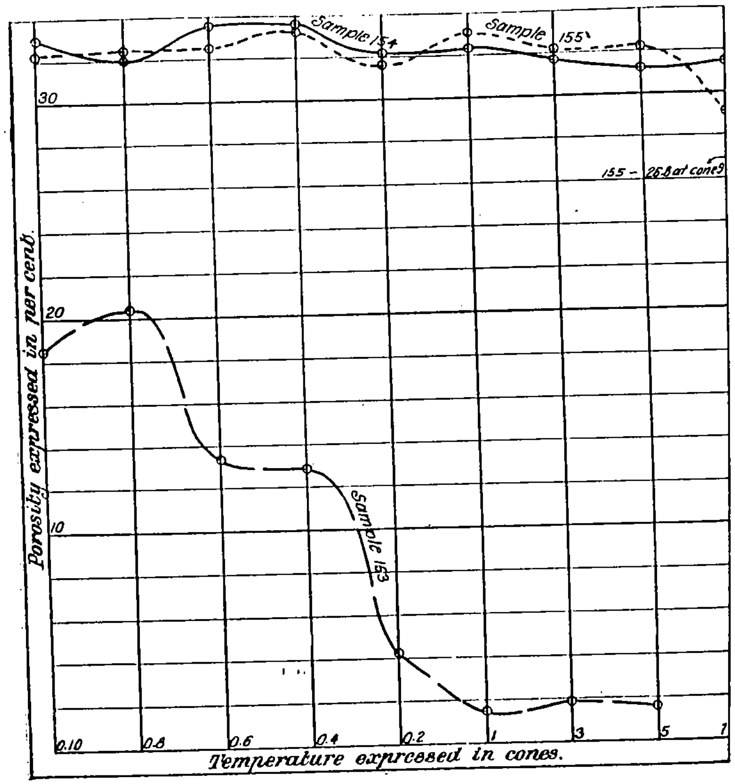


Fig. 28. Porosity curves for clays No. 153, 154 and 155.

Clay No. 155, Calvin, Oklahoma.

Location, ————. Thickness of deposit, 4 ft.; stripping, 1½ ft.; nearest railroad, ½ mile; fuel, wood, $1.75 per cord.

DATA.

Water of plasticity	18.7%	
L. D. S.	2.5%w.l.	2.6%d.l.
L. F. S. (cone 5)	.2%	
Tot. L. S.	.9%	
V. D. S.	11.5%w.v.	13.0%d.v.
V. F. S.	.7%	
Tot. V. S.	10.6%	

Absorp. 12.0%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	32.3	32.5	32.4	33.2	31.6	33.0	32.1	32.2	29.1	26.8

Remarks: Red and very sandy clay. Works very well, but "sandy." Dries easily with little shrinkage. Burns red; gradually darkens and hardens from cone 010 to cone 9. Bluestones at 7 and 9. Some cracking in burning. Suitable for common brick. Would probably work well by soft mud process. Porosity curve on fig. 28.

Clay No. 156, Calvin, Okalhoma.

Location ————. Thickness of deposit, 4 ft.; stripping, 1 to 1½ feet; nearest railroad, ½ mile; fuel, wood, $1.75 per cord.

DATA.

Water of plasticity	28.5%	
L. D. S.	12.2%w.l.	13.8%d.l.
L. F. S.	3.6%	
Tot. L. S.	15.6%	
V. D. S.	31.5%w.v.	46.1%d.v.
V. F. S.	13.4%	
Tot. V. S.	40.6%	
Absorp.	.3%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	22.2	22.1	18.4	19.2	12.3	13.5	12.9	12.2	9.4	

Remarks: Brown surface clay with roots and chert. Packs in dry pan; laminates considerably, but makes smooth column from the machine. About half of the pieces cracked in drying and the others in burning. Burns to a red color; is steel hard at cone 06, bluestones at cone 7. Not recommended on account of the cracking in drying and burning.

Porosity curve on fig. 29.

Clay No. 159, Ramona, Oklahoma.

Location, NW. ¼ sec. 34, T. 24 N., R. 13 E. Thickness of deposit, over 50 feet; area, 60 acres; stripping, 4 to 6 ft. of the weathered shale; Santa Fe Railroad at hand; nearest fuel, 1280 ft.; natural gas; price 1½ to 6 cents per 1000 ft.; nearest limestone ½ mile.

DATA.

Water of plasticity	19.7%					
L. D. S.	4.2%d.l.	4.1%w.l				
V. D. S.	15.1%d.v.	13.1%w.v.				
At cone	08	06	04	02	1	3
L. F. S.	3.2	4.1	6.7	7.3	6.2	6.8
V. F. S.	7.1	12.5	18.0	19.9	20.7	22.0
Tot. L. S.	7.1	8.0	10.5	11.0	10.3	10.8
Tot. V. S.	19.2	23.6	28.7	30.4	31.1	32.2
Absorp.	11.1	8.6	4.2	3.4	1.2	.5
Porosity	24.5	20.8	14.2	12.9	7.9	4.96

Remarks: A light colored clay shale of excellent working and drying properties. Burns to good, dark red color free from discoloration, with a good sound structure. Is vitrified at cones 1 and 3, but stands up well at 5 and 7. Suitable for building, sidewalk and paving brick, fireproofing and drain tile, etc.

Porosity curve on fig. 26.

Clay No. 166, McAlester, Oklahoma.

Location, sec. 19, T. 3 N., R. 11 E. Thickness of deposit, 7 to 18 ft.; area, 5 miles long; stripping, 10 ft.; Ardmore branch of the Rock Island and M., K. & T. Railroads at hand; slack coal at hand, $1.00 per ton; nearest limestone ½ mile.

DATA.

Water of plasticity	28.3%					
L. D. S.	10.4%w.l.	11.5%d.l.				
V. D. S.	29.6%w.v	42.1%d.v.				
At cone	08	06	04	02	1	3
L. F. S.	6.6	7.4	7.6	......	6.8	6.4
V. F. S.	17.9	21.2	20.3	......	18.0	19.7
Tot. L. S.	16.6	17.0	17.3	......	16.4	16.2
Tot. V. S.	42.2	44.5	43.9	......	42.2	43.1
Absorp.	2.5	1.2	.9	......	.7	.0
Porosity	10.9	1.6	2.0	......	1.7	2.0

Remarks: A very soft, fine-grained white clay. Is very plasti[c] and dries slowly with some warping, but without cracking. Shrinkage [is] high. Samples at cone 02 black cored on account of too rapid firing. [Is] vitrified at cone 08 but stands to cone 3. Bluestones above cone 1.

Burns to a light yellow color with dense, brittle structure. Used alone is hardly available for clay products, but if mixed with sand to reduce the shrinkage and to lessen the density of the burned ware it should make good common and building brick. Porosity curve on fig. 29.

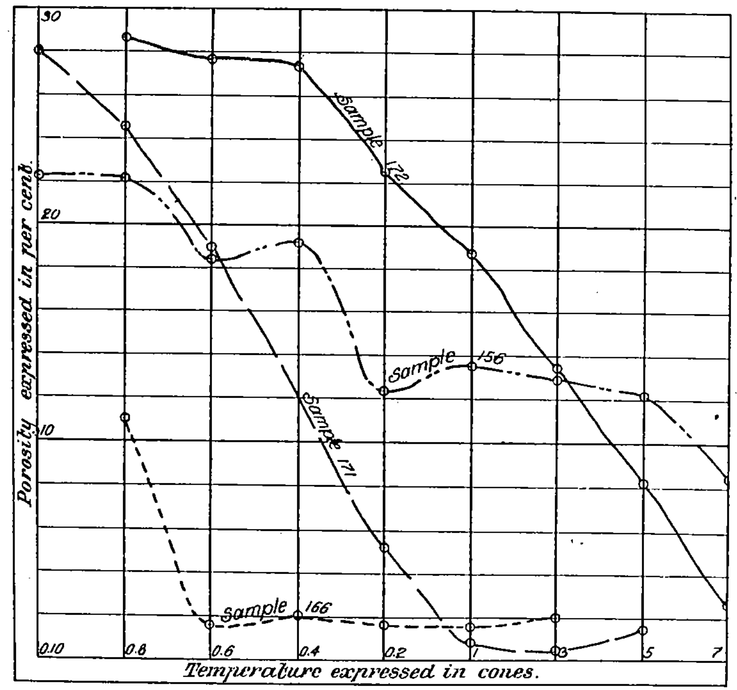


Fig. 29. Porosity curves for clays No. 156, 166, 171 and 172.

Clay No. 171, Poteau, Oklahoma.

Location, SW. ¼ sec. 24, T. 7 N., R. 25 E. Thickness of deposit, unknown; area, unlimited; stripping, 2 ft.; on tracks of Kansas City Southern and Frisco; nearest fuel, 1000 ft.; bituminous coal; price, $2.50. Clay has been used for manufacture of brick.

DATA.

Water of plasticity	25.9%	
L. D. S.	7.9%w.l.	8.5%d.l.
L. F. S. (cone 1)	9.5%	

Tot. L. S.	16.6%									
V. D. S.	21.7%w.v. 27.7%d.v.									
V. F. S.	25.8%									
Tot. V. S.	41.9%									
Absorp.	.2% at cone 1, or 2100°F.									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	28.	24.5	19.0	......	5.2	.9	.4	1.4		

Remarks: All pieces cracked in drying or burning showing lamination. Burns to red color badly discolored by whitewash. Steel hard at cone 02; vitrified at cone 1. Edges begin to melt at cone 5. Not recommended for use by the stiff mud process. Is used to make dry press brick.

Porosity curve on fig. 29.

Clay No. 172, Poteau, Oklahoma.

Location, NW. ¼ sec. 25, T. 7 N., R. 25 E. Thickness of deposit, 3 ft.; deposit under vein of coal; ¼ mile to K. C. S. and Frisco; fuel on ground; coal, $2.50 per ton for mine run. Gas in Poteau. Clay has been used for dry press brick.

DATA.

Water of plasticity	16.4%									
L. D. S.	1.7%w.l. 1.8%d.l.									
L. F. S. (cone 5)	6.9%									
Tot. L. S.	8.5%									
V. D. S.	8.7%w.v. 9.5%d.v.									
V. F. S.	15.8%									
Tot. V. S.	23.7%									
Absorp.	2.9% at cone 5									
Cone	010	08	06	04	02	1	3	5	7	9
Por.		28.6	27.7	27.4	24.5	18.7	13.5	8.2	2.6	melts

Remarks: A stony clay from under 26-inch coal vein. Is rather hard to grind but works well through machine. Is only moderately plastic and shows very little lamination. Dries evenly without warping or cracking. Burns steel hard at cone 02 and begins to melt at cone 9. At cone 5 it burns to a clean light chocolate color and possesses a good but not a dense structure. It is evidently well suited for all kinds of brick, including paving brick, sewer pipe, fire proofing and similar products.

Porosity curve on fig. 29.

Clay No. 173, Oklahoma City, Oklahoma.

Location, Blocks 4 and 5 Dittmer Heights. Thickness of deposit, not known, but pit is 60 ft. deep without finding bottom; area, not known; stripping, 5 ft.; nearest railroad, ½ mile; nearest fuel, Tulsa; natural gas, price 10 cents per 1000 ft.; clay is used for making dry press brick by Oklahoma Brick Co.

DATA.

Water of plasticity	19.4%									
L. D. S.	6.7%w.l. 7.2%d.l.									
L. F. S. (cone 1)	5.9%									
Tot. L. S.	12.2%									
V. D. S.	22.1%w.v. 28.3%d.v.									
V. F. S.	18.1%									
Tot. V. S.	36.2%									
Absorp.	.8%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.		23.3	23.5	24.0	15.3	6.2	6.6			

Remarks: Redbeds shale. Is very plastic but does not laminate badly and gives no trouble in drying. Burns to rich red color free from discoloration. It becomes steel hard at cone 04 and becomes vesicular at cone 3. Should be burned about cone 02 to cone 01. Suitable for building or sidewalk brick, hollow block and drain tile. Porosity curve on fig. 30.

Clay No. 174, Muskogee, Oklahoma.

Location, NW. ¼ sec. 10, T. 14 N., R. 17 E. Thickness of deposit, 100 ft.; area, 25 acres; stripping, 1 to 4 ft.; nearest railroad, ½ mile; nearest fuel, 3 miles, natural gas, price 3 cents per 1000 ft.

DATA.

Water of plasticity	16.6%					
L. D. S.	4.1%w.l. 4.3%d.l.					
V. D. S.	11.5%w.v. 12.9%d.v.					
At cone	08	06	04	02	1	3
L. F. S.	4.1	4.8	7.0	6.9	7.0	6.9
V. F. S.	12.2	14.3	19.7	18.1	19.2	19.7
Tot. L. S.	7.9	9.1	10.7	10.4	10.8	10.4
Tot. V. S.	22.3	24.1	28.8	27.5	28.5	28.8
Absorp.	6.8	5.7	2.7	2.3	2.7	2.1
Por.	21.2	14.6	10.3	11.4	10.5	10.2

Remarks: A laminated shale of excellent working and drying properties. Burns to a rich dark red free from discoloration. Becomes steel hard at cone 06 and is vitrified at cone 3. Stands up well at cones 5 and 7. Suitable for building, sidewalk or paving brick, hollow block and drain tile.

Porosity curve on fig. 30.

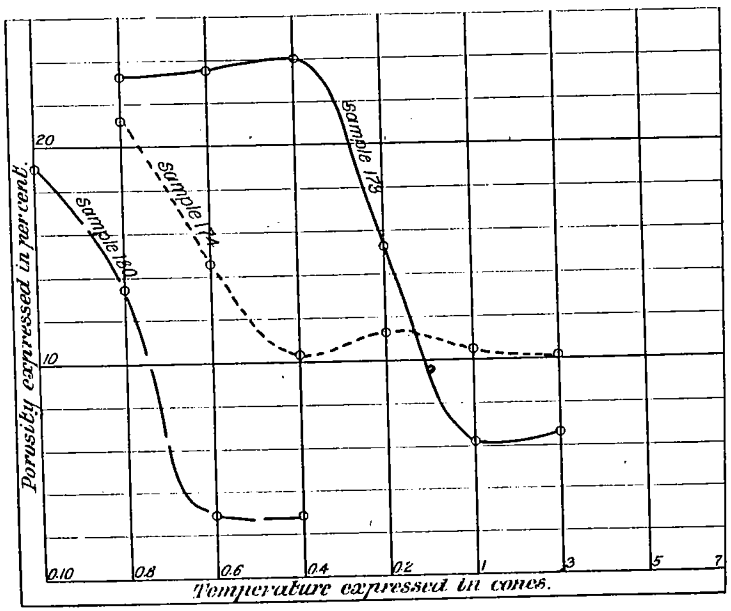


Fig. 30. Porosity curves for clays No. 173, 174 and 180.

Clay No. 177, Hinton, Oklahoma.

Location, SE. ¼ sec. 12, T. 12 N., R. 11 W. Thickness of deposit, 8 to 12 ft.; area, 20 acres; stripping, 2 to 4 ft.; nearest railroad, 2 miles; nearest fuel, 1 mile; wood, price $2.00 per cord.

DATA.

Water of plasticity	10.4%					
L. D. S.	10.8%w.l. 12.2%d.l.					
F. S.	45.2%d.v.					
At cone	08	06	04	02	1	3
Por.	8.9	9.3	12.5			

Remarks: A Redbeds shale. Is very plastic and rather difficult to work. Cracks in drying and burning. Burns to red, discolored by whitewash. Shows tendency to black core. Melts and becomes vesicular at cone 1. Not recommended for commercial use.

No porosity curve.

Clay No. 180, Marlow, Oklahoma.

Clay used at plant of Marlow Brick Co., Marlow, Stephens County.

DATA.

Water of plasticity	25.3%								
L. D. S.	7.4%								
L. F. S. (cone 04)	6.5%								
Tot. L. S.	13.3%								
V. D. S.	20.4%w.v. 26.1%d.v.								
V. F. S.	23.0%								
Tot. V. S.	38.7%								
Absorp.	.2%								
Cone	010	08	06	04	02	1	3	5	7	9
Por.	19.0	13.4	2.9	2.8						

Remarks: A Redbeds shale. Very plastic and shows considerable lamination. Dries nicely. Burns to good red, very slightly discolored by whitewash. Has a very short temperature range, becomes swollen and vesicular at cone 02. Suitable for common brick and drain tile.

Porosity curve on fig. 30.

Clay No. 181, Ravia, Oklahoma.

Distance to railroad, ¼ mile; fuel on ground; wood, price $2.00 per cord; nearest limestone, 1 mile.

DATA.

Water of plasticity	21.8%
L. D. S.	4.6%w.l. 4.8%d.l.

Remarks: Very impure kaolin, containing lumps of green soft material and hard unaltered stuff. Occurs as veins in granite. No burned data; all pieces crumbled after 48 hours. Worthless for clay products.

No curve.

Clay No. 194, Altus, Oklahoma.

Location, SE.¼ sec. 17, T. 2N., R. 20W. Thickness of deposit, 12 ft.; area, hundreds of acres; stripping, 0 to 4 ft.; nearest railroad, 100 yards; Orient, Frisco and W. F. & N. W.; nearest fuel, wood, 6 miles, coal 100 miles; price, $1.80 for slack coal. Clay has been used for vitrified brick.

DATA.

Water of plasticity	22.7%	
L. D. S.	5.0%w.l.	5.3%d.l.
L. F. S. (cone 3)	6.1%d.l.	
Tot. L. S.	10.7%	
V. D. S.	18.8%w.v.	23.3%d.v.
V. F. S.	15.4%d.v.	
Tot. V. S.	37.3%w.v.	
Absorp.	3.7%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.9	22.7	21.0	20.0	7.8	11.1	7.4			

Remarks: Red and greenish gray, mottled. Rather hard to temper, but works finely in machine; very slight lamination. Dries very nicely. Burns to a good red with a little whitewash. Steel hard at cone 06, vitrified at cone 02 and begins to melt at cone 3. Has good dense structure. Suitable for common and building brick, tile and similar products.

Porosity curve on fig. 31.

Clay No. 196, Comanche, Oklahoma.

Location, sec. 30, T. 2 S., R. 7 W. Thickness of deposit, unknown; area, unlimited; stripping, 6 inches; nearest railroad, 2500 ft.; nearest fuel, coal fields; price $4.50 per ton. Clay has been used for the manufacture of building brick.

DATA.

Water of plasticity	21.0%	
L. D. S.	5.6%w.l.	6.0%d.l.
L. F. S. (cone 1)	7.5%	
Tot. L. S.	12.7%	
V. D. S.	19.8%w.v.	24.7%d.v.
V. F. S.	18.9%	
Tot. V. S.	35.0%	
Absorp.	.2%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.3	22.2	15.2	13.6	3.8	.2	1.0	5.0		

Porosity curve on fig. 31.

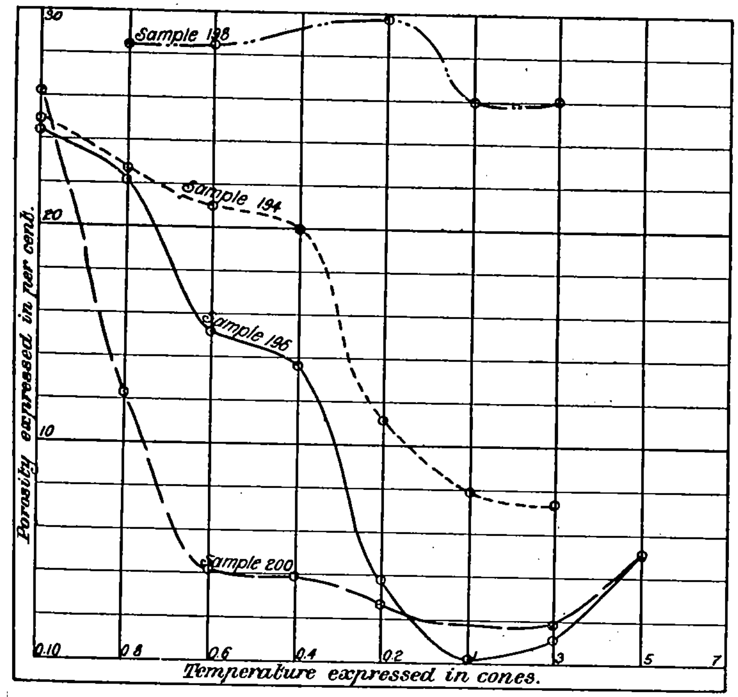


Fig. 31. Porosity curves for clays No. 194, 196, 198 and 200.

Clay No. 197, Comanche, Oklahoma.

Location, sec. 30, T. 2 S., R. 7 W. Thickness of deposit, unknown; area, unlimited; stripping, 6 inches; nearest railroad, 2500 ft.; nearest fuel, coal fields, price $4.50 per ton. Clay has been used for the manufacture of building brick.

DATA.

Water of plasticity	22.8%	
L. D. S.	6.6%w.l.	7.1%d.l.
L. F. S. (cone 1)	7.6%	
Tot. L. S.	13.7%	

V. D. S.	21.7%w.v. 27.7%d.v.									
V. F. S.	19.7%									
Tot. V. S.	37.1%									
Absorp.	.0%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.3	21.8	16.7	12.0	3.1	6.2	.0	.0		

Remarks: Nos. 196 and 197 are entirely similar. Both are plastic red shales of excellent working and drying qualities. They burn to a rich red color free from discoloration, becoming steel hard at cone 02, vitrifying at cone 04 and standing up well at cone 5. They have a very dense, firm structure. Suitable for common or front brick, sidewalk brick, drain tile and hollow block.

Porosity curve on fig. 32.

Clay No. 198, Henryetta, Oklahoma.

Location, NE. ¼ sec. 11, T. 11 N., R. 12 E. Thickness of deposit, 3 ft.; area, unlimited; stripping, 14 inches; nearest railroad, ¾ mile; Frisco and Missouri, Oklahoma & Gulf; nearest fuel ½ mile; soft coal.

DATA.

Water of plasticity	24.6%					
L. D. S.	10.1%w.l. 11.25%d.l.					
V. D. S.	28.5%w.v. 39.9%d.v.					
At cone	08	06	04	02	1	3
L. F. S.	2.1	1.6	3.4	2.7	2.6	2.4
V. F. S.	3.5	2.7	7.1	4.2	4.1	5.6
Tot. L. S.	12.0	11.5	13.1	12.5	12.4	12.2
Tot. V. S.	31.5	30.5	33.6	31.6	31.6	32.7
Absorp.	12.2	12.4	11.4	12.0	11.3	9.8
Porosity	28.4	28.4	.....	29.8	26.0	26.0

Remarks: A surface clay, very plastic and difficult to work. Burns to an indifferent red color. Has a porous structure. Could be used for common brick, but is not a satisfactory clay.

Porosity curve on fig. 31.

Clay No. 199, Henryetta, Oklahoma.

Location, NE. ¼ sec. 13, T. 11 N., R. 12 E. Thickness of deposit, 3 ft.; area, unlimited; stripping, 14 inches; nearest railroad, ¾ mile; Frisco and Missouri, Oklahoma & Gulf; nearest fuel, ½ mile; soft coal.

DATA.

80% of the pieces cracked in drying, the rest in burning.

Remarks: Extremely plastic and has excessive shrinkage both in drying and burning. Has very poor red color when burned. Worthless for clay products.

No porosity curve.

Clay No. 200, McAlester, Oklahoma.

Location, sec. 27, T. 6 N., R. 15 E. Thickness of deposit, 60 ft.; area, 640 acres; stripping, 1 to 3 ft.; nearest railroad, 1 mile; fuel on ground; coal, price $1.00 per ton.

DATA.

Water of plasticity	25.9%									
L. D. S.	9.6%w.l. 10.6%d.l.									
L. F. S. (cone 1)	7.8%									
Tot. L. S.	16.6%									
V. D. S.	24.3%w.v. 32.2%d.v.									
V. F. S.	24.4%									
Tot. V. S.	42.7%									
Absorp.	.6%									
Cone	010	08	06	04	02	1	3	5	7	9
Por.	26.2	13.3	4.1	3.9	2.7	.....	1.8	5.1		

Remarks: Tan colored clay. Works well, but shows considerable lamination. Burns red with marked tendency to crack in drying due to excessive shrinkage. Extreme whitewashing. All pieces of ware on test cracked at cone 1. Not recommended for use unless possibly for dry press brick.

Porosity curve on fig. 31.

Clay No. 201, McAlester, Oklahoma.

Location, sec. 5, T 5 N., R. 15 E. Thickness of deposit, 25 ft.; area, 640 acres; stripping, 1 to 5 ft.; M., K. & T. Railroad near at hand; fuel at pit; coal, price 60 cents to $1.00 per ton. Clay has been used in the manufacture of brick.

DATA.

Water of plasticity	23.1%
L. D. S.	8.7%w.l. 9.6%d.l.
L. F. S. (cone 1)	4.1%

Tot. L. S.	12.5%	
V. D. S.	21.6%w.v.	28.1%d.v.
V. F. S.	15.5%	
Tot. V. S.	34.0%	
Absorp.	.2%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.1	18.6	7.8	9.9	2.7	2.0	1.6			

Remarks: Similar to No. 200, but doesn't whitewash so badly and does not crack. Should be burned at 02 and 01. Whitewashing limits its use to common or sidewalk brick and drain tile.

Porosity curve on fig. 32.

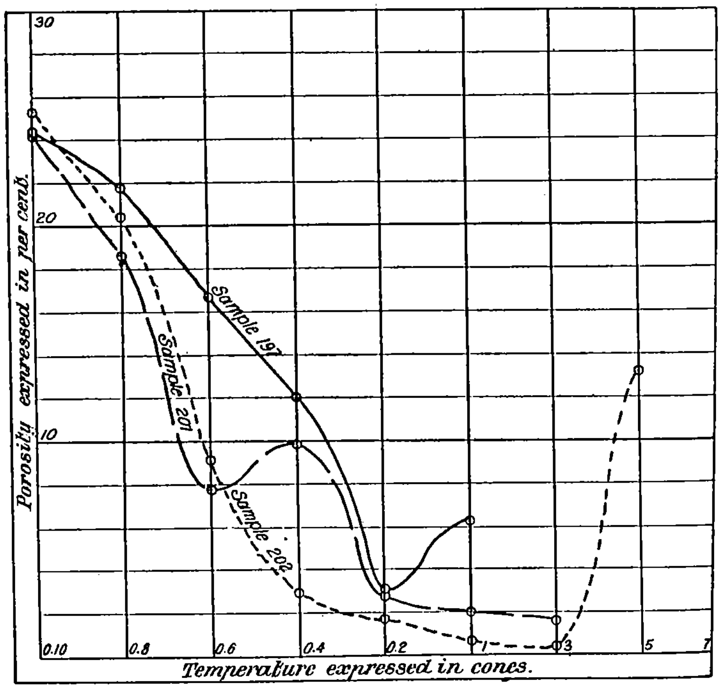


Fig. 32. Porosity curves for clays No. 197, 201 and 202.

Clay No. 202, McAlester, Oklahoma.

Location, sec. 5, T. 5 N., R. 15 E. Thickness of deposit, 225 ft.; area, 640 acres; stripping, 1 to 5 ft.; railroad crosses deposit; coal at pit, price 60 cents to $1.00 per ton. Clay has been used for the manufacture of brick.

DATA.

Water of plasticity	18.8%	
L. D. S.	6.9%w.l.	7.4%d.l.
L. F. S. (cone 1)	7.1%	
Tot. L. S.	13.5%	
V. D. S.	19.1%w.v.	23.5%d.v.
V. F. S.	21.3%	
Tot. V. S.	36.5%	
Absorp.	.1%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	25.3	20.3	9.1	2.9	1.7	.7	.3	13.2		

Remarks: Gray shale; grinds well and works well. Dries nicely. Burns to a rich dark red, free from discoloration. Steel hard at cone 06 and vitrifies at cone 1. Swells at cone 4. Suitable for common, front or sidewalk brick, drain tile and possibly roofing tile and similar products.

Porosity curve on fig. 32.

Clay No. 205, Mangum, Oklahoma.

Location, SW. ¼ sec. 27, T. 5 N., R. 22 W.; area, 160 acres; nearest railroad, ¾ mile; Rock Island and W. F. & N. W. Nearest fuel, McAlester; coal, price $3.00. Clay has been used for the manufacture of brick.

DATA.

Water of plasticity	27.6%	
L. D. S.	7.4%w.l.	8.0%d.l.

Cone	010	08	06	04	02	1	3	5	7	9
Por.	16.1	7.1	2.6	3.1						

Remarks: Cracks in drying, showing lamination. Cracks are very small and drying is regular. Whitewashes; vesicular at cone 02; steel hard at cone 010. Cannot be used by stiff mud process owing to puffing due to decomposition of calcium sulphate. Is successfully used for dry press brick.

Porosity curve on fig. 33.

Clay No. 231, Sparks, Oklahoma.

Location, SE. 1/4 sec. 28, T. 13 N., R. 5 E. Thickness of deposit, 100 ft.; area, 40 acres; nearest railroad, 1 mile; Santa Fe, Rock Island and Frisco; nearest fuel, 5 miles; coal, price $7.00.

DATA.

Water of plasticity	20.5%	
L. D. S.	8.7%w.l.	9.6%d.l.
L. F. S. (cone 3)	4.1%	
Tot. L. S.	12.5%	
V. D. S.	24.3%w.v.	32.1%d.v.
V. F. S.	12.0%	
Tot. V. S.	33.4%	
Absorp.	1.9%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	21.2	21.0	19.1	13.2	6.5	7.0	5.3	9.0		

Remarks: Red shale. Large pieces of argillaceous limestone must be thrown out. Works nicely, but shows some lamination. Dries nicely. Steel hard at cone 010, no swelling at cone 5. Has an excellent red color, and good, sound, stony structure. Unfortunately shows the presence of small lime pebbles. If these could be removed the clay would be well suited for front brick, but with them present the value of the clay is impaired and is suitable only for common brick.

Porosity curve on fig. 33.

Clay No. 241, Nelagony, Oklahoma.

Location, SE. 1/4 sec. 20, T. 25 N., R. 10 E. Is from 10 to 30 ft. deep and composes a hill many acres in extent. A large hill to the southwest seems to be of the same shale. Stripping, 0 to 4 ft.; is along the Midland Valley Railroad and 1/4 mile from the M., K. & T.; nearest fuel, gas within 4 miles

DATA.

Water of plasticity	24.2%	
L. D. S.	7.5%w.l.	8.4%d.l.
L. F. S. (cone 3)	7.4%	
Tot. L. S.	14.3%	
V. D. S.	21.1%w.v.	26.7%d.v.
V. F. S.	17.3%	
Tot. V. S.	37.6%	
Absorp.	.5%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	38.6	35.6	23.1	7.4	5.3	7.0	8.7	1.4		

Remarks: A yellow shale of fairly good working qualities. It shows considerable lamination and in drying there is some cracking along the lines of lamination. From the character of the clay this seems to be due to the action of the auger in the small machine. It would probably work all right in a large machine. Suitable for front and building brick or sewer pipe. Porosity curve on fig. 33.

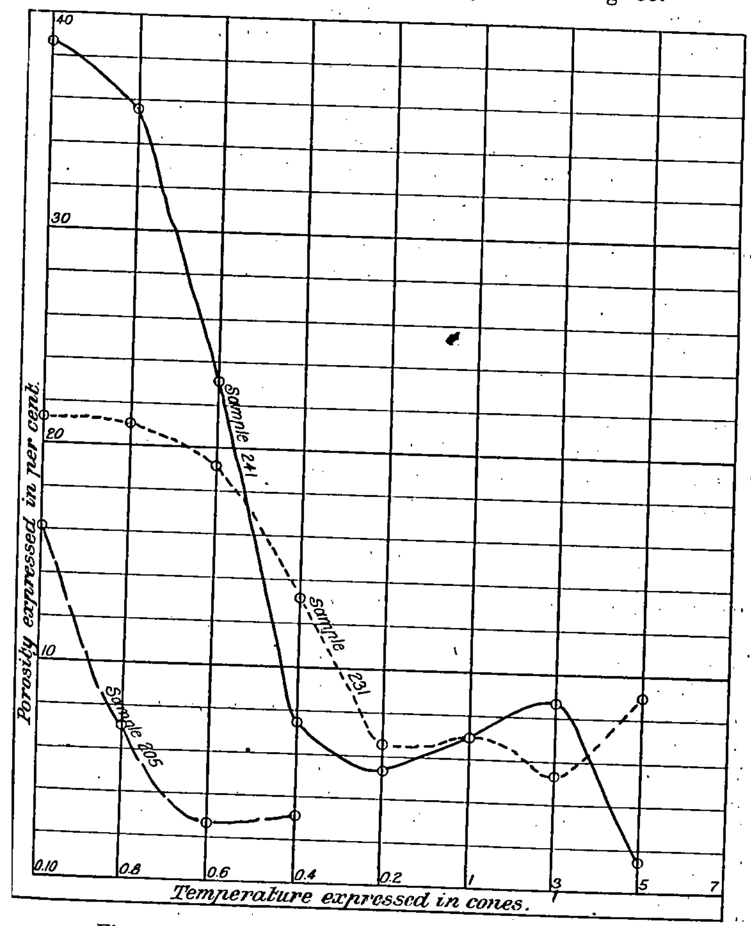


Fig. 33. Porosity curves for clays No 205, 231 and 241.

Clay No. 242, Nelagony, Oklahoma.

Red shale which underlies No. 241.

DATA.

Water of plasticity	28.4%	
L. D. S.	10.7%w.l.	12.0%d.l.
L. F. S. (cone 04)	10.1%	
Tot. L. S.	19.7%	
V. D. S.	25.0%w.v.	33.3%d.v.
V. F. S.	24.8%	
Tot. V. S.	43.6%	
Absorp.	.3%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	27.0	26.5	8.3	1.7	1.1	1.2	.4	1.8		

Remarks: Is very plastic and laminates very badly in the machine. Whitewashes very badly. Cracks along the lines of lamination in drying and burning. Not recommended, unless possibly for common brick by the dry press process.

Porosity curve on fig. 34.

Clay No. 261, Binger, Oklahoma.

Location, SE. ¼ sec. 9, T. 9 N., R. 12 W. Thickness of deposit, 2 to 5 ft.; area, over 15 acres; stripping, 18 inches; nearest railroad, 10 miles; wood on the ground, $3.75 per cord.

DATA.

Water of plasticity	22.4%	
L. D. S.	6.9%w.l.	7.4%d.l.
L. F. S. (cone 3)	5.2%	
Tot. L. S.	11.8%	
V. D. S.	21.9%w.v.	28.0%d.v.
V. F. S.	19.3%	
Tot. V. S.	37.0%	
Absorp.	.8%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	23.1	23.8	23.5	23.7	17.1	6.7	.8	2.4		

Remarks: A dark gray surface clay; very plastic. Dries well, but shows marked tendency to crack in burning. Burns to dark red with dense, stony structure. Its tendency to crack in burning would cause extremely high kiln loss and while it might be used by very careful working, the probabilities are against it.

Porosity curve on fig. 34.

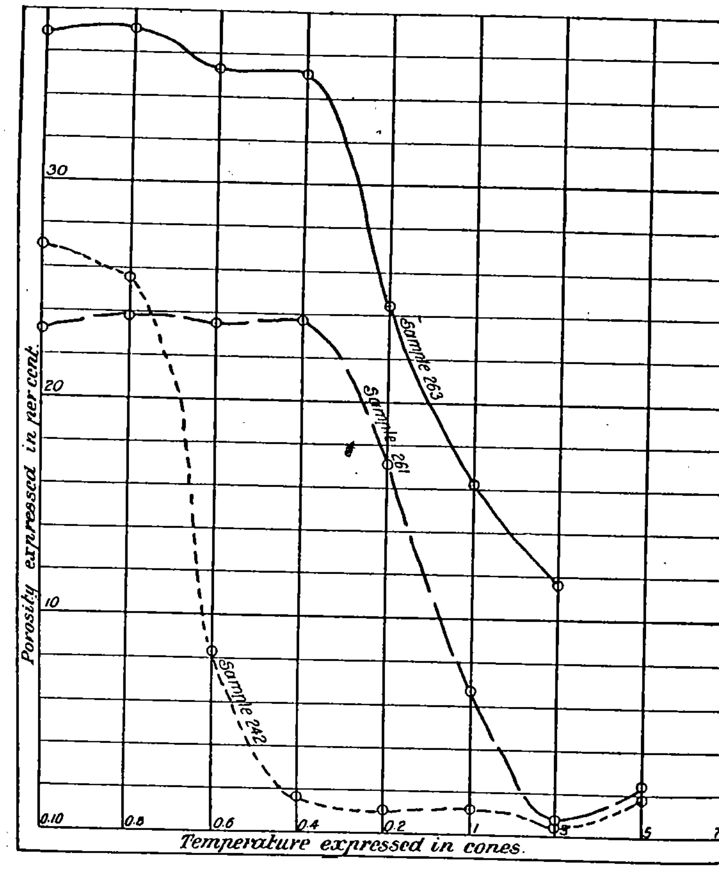


Fig. 34. Porosity curves for clays No. 242, 261 and 263.

Clay No. 263, Ravia, Oklahoma.

Location, three miles southwest of Ravia. Shale stands almost vertical and is exposed as a long belt about 400 ft. wide; no stripping; Another good exposure is about ¼ mile from the Frisco Railroad; fuel, wood on ground.

DATA.

Water of plasticity	25.1%	
L. D. S.	7.0%w.l.	7.5%d.l.
L. F. S. (cone 3)	6.1%	
Tot. L. S.	12.5%	
V. D. S.	17.9%w.v.	21.9%d.v.
V. F. S.	18.6%	
Tot. V. S.	33.2%	
Absorp.	.4%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	36.9	37.1	35.3	35.2	24.4	16.2	11.7			

Remarks: Working and drying qualities excellent. Burns to an indifferent neutral color, but shows a good structure. Owing to its excellent working qualities it is well suited to the manufacture of building brick and tile and also for sewer and sidewalk brick. Might be used for paving brick, but the material seems to be too brittle.

Porosity curve on fig. 34.

Clay No. 271, Bartlesville, Oklahoma.

Location, NW. 1/4 sec. 12, T. 26 N., R. 12 E. Thickness of deposit, 30 ft.; area, 10 acres; stripping, 2 ft.; railroad at hand; gas piped to plant; price 4½ cents per 1000 ft.; clay is used in the manufacture of brick by the Bartlesville Vitrified Brick Co.

DATA.

Water of plasticity	27.8%	
L. D. S.	9.3%w.l.	12.0%d.l.

Cone	010	08	06	04	02	1	3	5	7	9
Por.	25.0	19.6	15.8	......	9.5	2.3	1.9	2.0		

Remarks: A plastic shale which shows considerable lamination in the small machine, and some cracking in drying. Made on the large machine it does not crack. Burns to a good red color and vitrifies at cone 06. Melts and becomes vesicular at cone 1. Suitable for common and building brick, but not for paving brick.

Porosity curve on fig. 35.

Clay No. 277, Bigheart, Oklahoma.

Location, W. ½ of the SW. 1/4 sec. 18, T. 24 N., R. 11 E. Thickness of deposit, 2 to 25 ft.; area, 160 acres; stripping, 2 to 4 ft.; 80 rods to Midland Valley Railroad, which connects with the M., K. & T. at Ne-

lagony and with Frisco, Santa Fe and M., K. & T. at Tulsa. Gas at hand, 3 to 6 cents per 1000 ft.

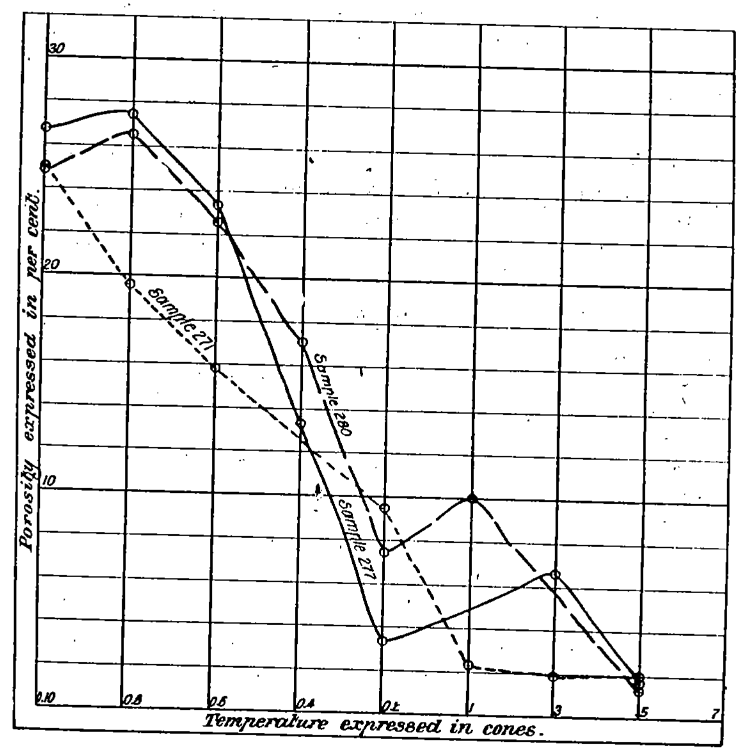


Fig. 35. Porosity curves for clays No. 271, 277 and 280.

DATA.

Water of plasticity	25.5%	
L. D. S.	7.7%w.l.	8.4%d.l.
L. F. S. (cone 3)	7.8%	
Tot. L. S.	14.8%	
V. D. S.	21.7%w.l.	27.6%d.l
V. F. S.	24.8%	
Tot. V. S	40.4%	
Absorp.	.2%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	26.7	27.4	23.3	13.3	3.3	4.7	6.6	1.6		

Remarks: Works well. There is a slight tendency to crack in drying, but this could probably be overcome by use of proper machines and dies. Steel hard at cone 06 and is still firm at cone 5. Gives a fine red color, free from discoloration and a good firm structure. Suitable for common and front brick and for drain tile. Porosity curve on fig. 35.

Clay No. 280, Vinita, Oklahoma.

Location, NE.¼ sec. 14, T. 25 N., R. 20 E. Thickness of deposit, 12 to 15 ft.; area, 10 acres; stripping, 4 ft.; nearest railroad, ½ mile; M., K. & T. and Frisco. Nearest fuel, ½ mile; gas, price 22½ cents per 1000 ft.

DATA.

Water of plasticity	29.6%	
L. D. S.	11.1%w.l.	12.2%d.l.
L. F. S. (cone 3)	7.6%	
Tot. L. S.	17.8%	
V. D. S.	27.7%w.v.	38.4%d.v.
V. F. S.	19.1%	
Tot. V. S.	41.8%	
Absorp.	.6%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.8	26.5	22.6	17.1	7.4	10.0	....	1.2		

Remarks: Soft, light colored, almost white with iron stained partings. Very fine-grained. Made up very soft, but still laminates badly. Dries somewhat irregularly with some cracking and scumming. Burns to a buff color, darkens from cone 02 to a gray. Steel hard at 06 and still very firm at 5. Not suitable for manufacture by the stiff mud process, but makes a very nice buff brick, suitable for face brick, on the dry press. Porosity curve on fig. 35.

Clay No. 285, Midway, Oklahoma.

Location, sec. 36, T. 2 N., R. 10 E. Thickness of deposit, 4 inches; area, several square miles, covers coal vein; railroad at hand; coal at hand.

DATA.

Water of plasticity	23.3%	
L. D. S.	10.0%w.l.	11.1%d.l.

No burned data.

Clay No. 286, Midway, Oklahoma.

Location, sec. 36, T. 2 S., R. 10 E. Thickness of deposit, 7 ft.; area, several miles; railroad at hand; coal on ground.

DATA.

Water of plasticity	28.1%	
L. D. S.	9.4%3.l.	13.4%d.l.
V. D. S.	24.9%w.l.	33.3%d.l.

Remarks: Nos. 285 and 286 are respectively the over line and under line clays of the coal in the mines at Midway. Both contain plant impressions and thin veins of coal. Both crack in drying and scum badly. Neither clay can be oxidized, even the small test pieces black coring, due to the presence of an excess of carbon. This property renders them useless for clay product. No porosity curves.

Clay No. 287, McAlester, Oklahoma.

Location, sec. 4, T. 5 N., R. 15 E. Thickness of deposit, 11 ft.; area, 160 acres; found under coal 260 ft. deep; M., K. & T., and Rock Island railroads at hand; coal on the ground; price 60 cents to $1.00 per ton.

DATA.

Water of plasticity	14.5%	
L. D. S.	5.6%w.l.	6.0%d.l.
L. F. S. (cone 5)	6.4%	
Tot. L. S.	11.9%	
V. D. S.	15.4%w.v.	18.2%d.v.
V. F. S.	20.0%	
Tot. V. S.	32.3%	
Absorp.	1.1%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	26.1	23.1	17.9	17.9	8.6	8.6	2.1	2.2	3.9	7.0

Remarks: Fine gray fire clay. Grinds down completely and works well in pan and machine. Very slight lamination. Dries nicely. Burns to dirty buff color and shows a sound flawless structure. Very similar to the No. 3 fire clays of Ohio and Illinois and is a useful material for the manufacture of fire proofing, conduits and probably for sewer pipe. Could be used for paving brick, but would have to be burned at a higher temperature than is usually used for such work. Porosity curve on fig. 36.

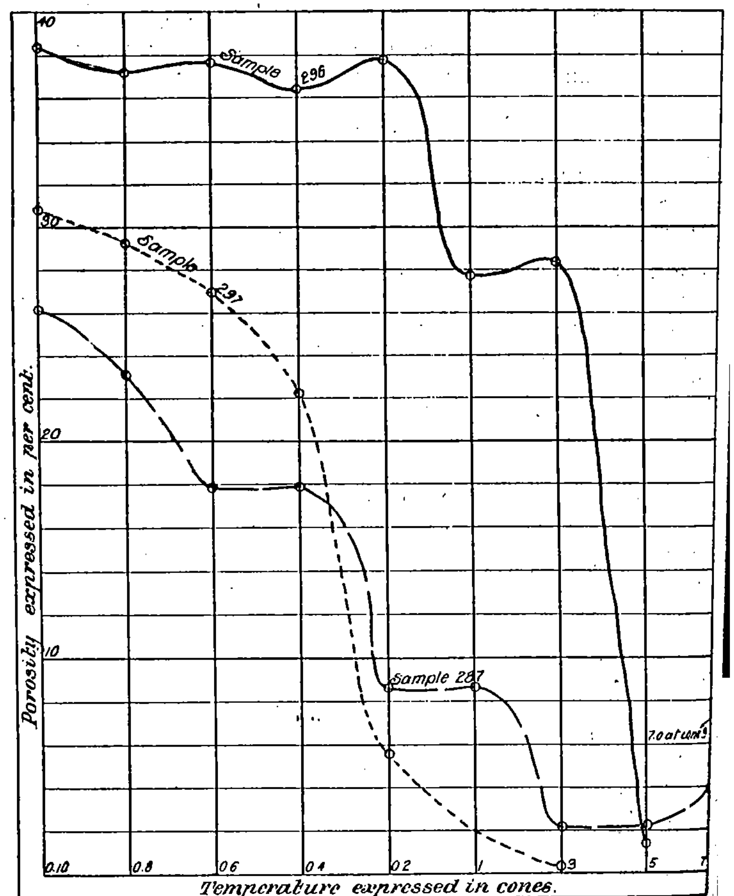


Fig. 36. Porosity curves for clays No. 287, 296 and 297.

Clay No. 296, Doxey, Oklahoma.

Location, sec. 14, T. 10 N., R. 23 W. Rock Island Railroad, 1½ miles distant; occurs in relatively thin layers in clay No. 297.

DATA.

Water of plasticity	21.1%
L. D. S.	9.7%w.l. 10.8%d.l.
L. F. S. (cone 3)	%

Tot. L. S.	%
V. D. S.	9.4%w.v. 10.4%d.v.
V. F. S.	21.6%d.v.
Tot. V. S.	22.6%w.v.
Absorp.	1.7%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	38.3	37.2	37.6	36.3	37.8	27.7	28.3	1.4		

Remarks: Salmon pink up to cone 02; burn light gray color with white specks at cone 02 and 1; steel hard and vitrifies at cone 3; begins to melt and darken in color at cone 5. Useful for building brick and tile, but not for paving brick. Porosity curve on fig. 36.

Clay No. 297, Doxey, Oklahoma.

Description and location same as No. 296.

DATA.

Water of plasticity	24.6%
L. D. S.	5.3%w.l. 5.7%d.l.
L. F. S.	No burned data.
V. D. S.	19.4%w.v. 24.0%d.v.
V. F. S.	
Tot. V. S.	
Absorp.	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	30.7	29.3	26.9	22.2	5.6	.....	.3	.....	.....	.....

Remarks: Melted down at cone 1 in which kiln the large pieces were placed by mistake. Dries well. Good red color and firm structure below cone 02. Vitrifies and darkens at cone 02. Suitable for common, building and sidewalk brick and drain tile. Porosity curve on fig. 36.

Clay No. 298, Atoka, Oklahoma.

Location, sec. 15, T. 2 S., R. 11 E. Thickness of deposit, 600 to 1000 ft.; area, 9 sq. miles; stripping, 20 ft.; nearest railroad, 100 yards; M., K. & T.; wood and gas close at hand.

DATA.

Water of plasticity	20.5%
L. D. S.	6.7%w.l. 7.2%d.l.
L. F. S. (cone 3)	4.5%

Tot. L. S.	10.8%
V. D. S.	20.2%w.v. 25.4%d.v.
V. F. S.	15.5%
Tot. V. S.	32.6%
Absorp.	1.3%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	22.7	23.7	22.0	......	8.1	12.6	3.7	5.2		

Remarks: A tan colored shale with excellent working and drying properties. Burns to a red color, badly discolored by whitewash. The discoloration limits its use to common and sidewalk brick and drain tile. Porosity curve on fig. 37.

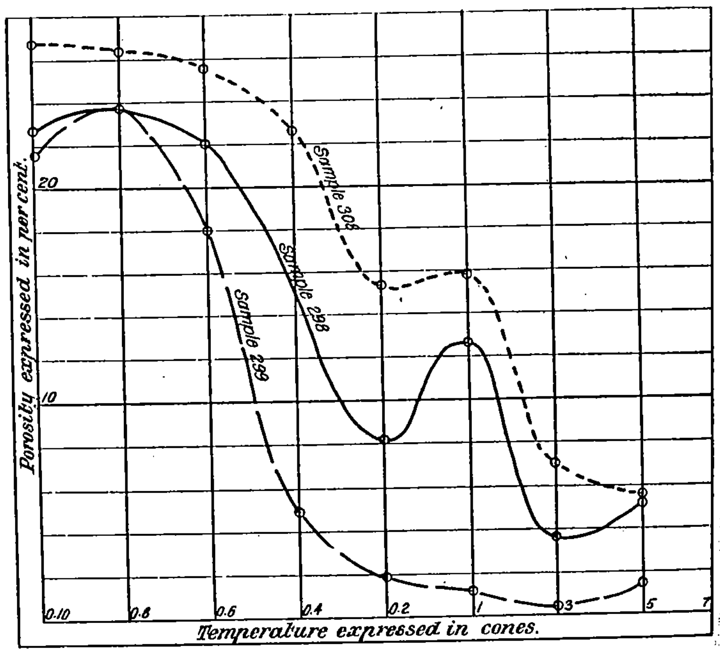


Fig. 37. Porosity curves for clays No. 298, 299 and 308.

Clay No. 298, Atoka, Oklahoma.

Location, sec. 16, T. 2 S., R. 11 E. Thickness of deposit, 600 to 1000 ft.; area, 9 square miles; stripping, 10 ft.; nearest railroad, 1 mile; M., K. & T.; wood and gas near at hand.

DATA.

Water of plasticity	26.1%
L. D. S.	8.7%w.l. 9.6%d.l.
L. F. S. (cone 1)	5.6%
Tot. L. S.	13.8%
V. D. S.	24.8%w.v. 33.0%d.v.
V. F. S.	15.1%
Tot. V. S.	30.1%
Absorp.	.1%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	21.5	23.7	18.0	5.0	1.9	1.3	.4	1.5		

Remarks: Very similar to clay No. 298, except that it whitewashes worse. Porosity curve on fig. 37.

Clay No. 308, Ardmore, Oklahoma.

Located in yard of Ardmore Brick & Tile Co., 8 to 10 ft. deep; area, about 1 acre; stripping, 4 ft. which can be used with shale for brick. On switch from Santa Fe Railroad; fuel, gas from Wheeler field at 10 cents per 1000 ft.

DATA.

Water of plasticity	23.2%
L. D. S.	7.5%w.l. 8.4%d.l.
L. F. S. (cone 3)	5.1%
Tot. L. S.	12.2%
V. D. S.	22.5%w.v. 29.1%d.v.
V. F. S.	22.5%
Tot. V. S.	16.1%
Absorp.	1.4%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	26.7	26.4	25.5	22.6	15.4	15.8	7.0	5.7		

Remarks: A red shale. Works and dries well. Burns to red, badly discolored by whitewash. Lime specks show on surface prohibiting its use for drain tile. Good only for common brick. Porosity curve on fig. 37.

Clay No. 310, Madill, Oklahoma.

Clay No. 310 was shipped from Madill but was lost in transportation.

It is a gray shale located along the right of way of the A. & C. division of the Frisco Railroad. The shale is extremely plastic and contains many veins of calcite about 1-16 inch thick. A brick plant was formerly in operation here, but has suspended operations several years since. Judging from the appearance of the clay and its similarity to No. 325, it is probable that much difficulty would be encountered in working it owing to its extreme plasticity and great excess of lime carbonate in the form of the calcite veins.

Clay No. 312, white — Ardmore, Oklahoma.

Located 6 miles southwest of Ardmore; thickness, 20 ft.; outcrop shows for 300 ft.; no stripping required; nearest railroad, 3 miles.

DATA.

Water of plasticity	23.9%	
L. D. S.	.6%w.l.	.6%d.l.
L. F. S. (cone 5)	.8%	
Tot. L. S.	1.4%	
V. D. S.	4.7%w.v.	5.0%d.v.
V. F. S.	11.1%	
Tot. V. S.	15.3%	
Absorp.	17.9%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	36.2	35.9	35.6	31.8	32.6	32.7	31.9	32.4	31.7	30.9

Remarks: Course grained silicious clay of light gray color. Shows 87.1% Si 0_2. Required extra time in grinding and working in wet pan. Worked very nicely through the machine. No lamination. Drying behavior good. Very little shrinkage in drying or burning. Burns to a white with pink specks. Is soft and porous at cone 9. Begins to melt at cone 30. There is no doubt that it is an excellent material for boiler work as it possesses sufficient plasticity and working qualities it can be manufactured into fire bricks at a low cost. The clay could also be used for the manufacture of common brick though its value would probably be too high for this purpose. It is well suited to the manufacture of fire proofing or similar products. It is especially adapted to such purposes owing to its high porosity which causes it to possess low heat conductivity and sudden temperature changes. Porosity curve on fig. 38.

Clay No. 312, Red — Woodville, Oklahoma.

Located 1 mile southeast of Woodville, Marshall County. Thickness, 10 to 30 ft.; area, unlimited; many square miles of the country near Red River is covered with this clay. Red River division of the Frisco Railroad crosses the deposit in several places. Fuel, wood at hand or coal shipped in.

DATA.

Water of plasticity	21.7%	
L. D. S.	3.0%w.l.	3.2%d.l.
L. F. S.	.8%	
Tot. L. S.	2.2%	
V. D. S.	13.4%w.v.	15.4%d.v.
V. F. S.	.7%	
Tot. V. S.	%	
Absorp.	12.8%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	27.5	35.6	34.8	33.0	-	35.0	33.3	33.2	30.4	29.0

Remarks: Is a very sandy red clay. It burns to a very clean and bright red, and shows an open sandy structure and possesses long range of vitrification. It is a typical soft mud brick clay and would probably work better by this process than any other. Suitable for common brick, but probably for no other purpose owing to sand. Porosity curve on fig. 38.

Clay No. 317, — Bristow, Oklahoma.

Location, SE.1/4 sec. 19, T. 16 N., R. 9 E. Thickness of deposit, unknown; area, also unknown; outcrop shows for two or three miles; stripping, 0 to 20 ft.; Frisco Railroad at hand; gas at hand, at 3 cents per 1000 ft.

DATA.

Water of plasticity	22.0%	
L. D. S.	6.7%w.l.	7.2%d.l.
L. F. S.	5.0%	
Tot. L. S.	11.3%	
V. D. S.	20.6%w.v.	24.6%d.v.
V. F. S.	14.3%	
Tot. V. S.	31.8%	
Absorp.	1.0%	

Cone	010	08	06	04	02	1	3	5	7	9
Por.	25.0	24.6	24.1	20.8	10.6	14.1	7.5	7.9	3.9	4.8

Remarks: Light gray, fine-grained, soft shale with reddish streaks. Works nicely, but shows some lamination. Dries evenly and without cracking. Burns to dense firm structure. Has a clean light brown color at cone 3; bluestones to a nice gray at cone 5. Owing to its fairly high drying and burning shrinkage it probably would not be suited for the manufacture of products where exact dimensions must be maintained. It is well adapted, however, to all sorts of building brick, but not for pavers or sewer pipe. Its unique color would make it useful for front brick. Porosity curve on fig. 39.

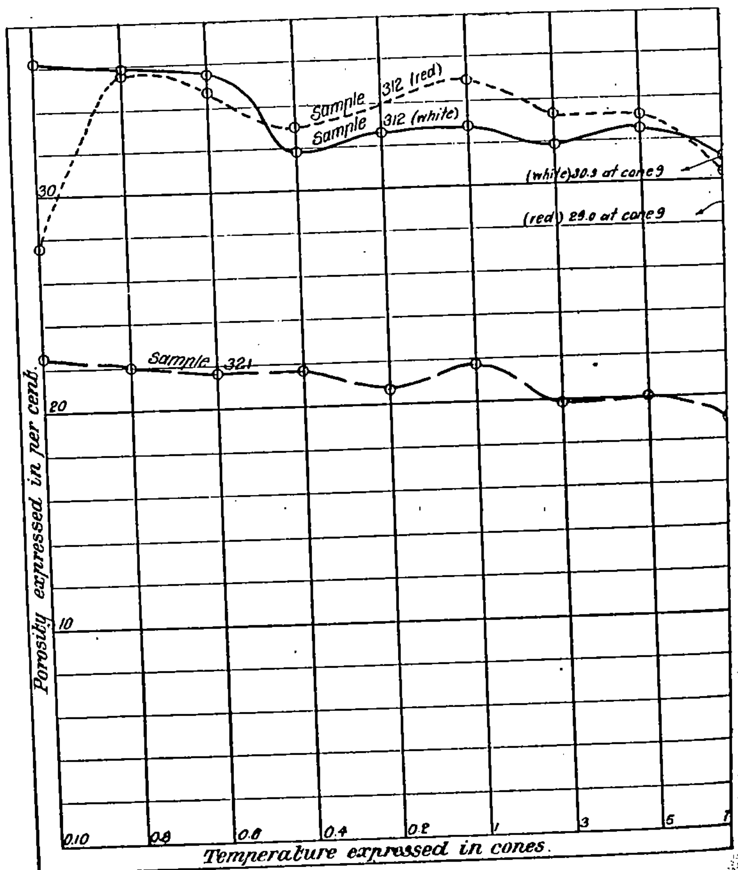


Fig. 38. Porosity curves for clays No. 312 (white), 312 (red) and 327.

Clay No. 319, Antlers, Oklahoma.

Surface clay from flat land 2 miles southwest of Antlers. Near Frisco Railroad.

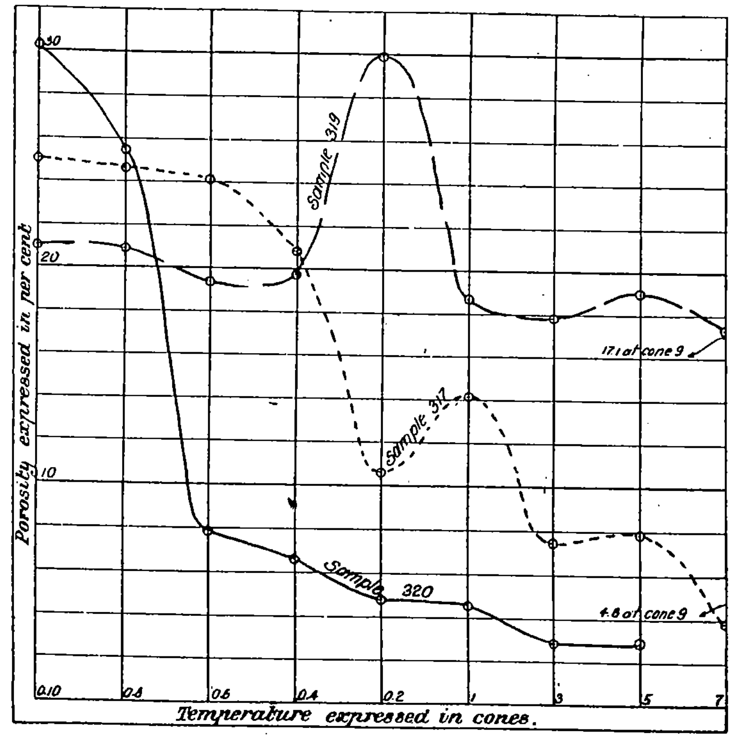


Fig. 39. Porosity curves for clays No. 317, 319 and 320.

DATA.

Water of plasticity	31.6%
L. D. S.	13.9%w.l. 15.6%d.l.
L. F. S.	1.6%
Tot. L. S.	14.8%
V. D. S.	35.2%w.v. 54.4%d.v.
V. F. S.	3.9%
Tot. V. S.	37.7%
Absorp.	5.0%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	21.1	20.8	19.4	19.7	29.9	18.7	17.8	19.0	17.3	17.1

Remarks: A white surface clay, color probably due to leaching by standing water. Extremely plastic and difficult to work on machine. Has excessive drying shrinkage and cracks badly in drying. Burns to unsatisfactory red color and is still porous at cone 7. Not recommended for clay products.

Porosity curve on fig. 39.

Clay No. 320, Antlers, Oklahoma.

Shale from 1 mile north of Antlers along Frisco Railroad. Exposure is about 100 yards wide and extends back from the track in both directions. Its steeply tilted, but a vast quantity can be obtained by surface working.

DATA.

Water of plasticity	20.4%
L. D. S.	6.1%w.l. 6.5%d.l.
L. F. S.	6.8%d.l.
Tot. L. S.	12.5%w.l.
V. D. S.	18.3%w.v. 22.4%d.v.
V. F. S.	%
Tot. V. S.	%
Absorp.	%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	30.2	25.5	7.9	6.6	4.8	4.6	2.9	2.9		

Remarks: A black shale of excellent working and drying properties. Vitrifies at cone 06 and is slightly deformed at cone 1. Best burning temperature about cone 04 to cone 02. Burns to a bright vermillion red with a pronounced self glaze. Suitable for common or front brick and for drain tile. Porosity curve on fig. 39.

Clay No. 321, Antlers, Oklahoma.

Location, along the Frisco right of way 1 mile south of Antlers. A layer 8 to 12 feet thick covers many acres. The upper two feet is very sandy and the lower portion is a very stiff somewhat sandy clay. Fuel: wood at hand and coal can be shipped from Poteau.

DATA.

Water of plasticity	35.5%
L. D. S.	8.7%w.l. 9.6%d.l.
L. F. S.	3.8%
Tot. L. S.	12.2%
V. D. S.	27.7%w.v. 38.4%d.v.
V. F. S.	11.3%
Tot. V. S.	35.9%
Absorp.	6.1%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	24.5	24.0	21.7	21.7	20.7	21.7	19.9	20.0	19.0	

Remarks: Works and dries nicely. Burns to a peculiar brick red, free from discoloration. Structure is sound. Is well suited for common brick and drain tile. Porosity curve on fig. 38.

Clay No. 322, Garvin, Oklahoma.

Location, NW.¼ sec. 18, T. 7 S., R. 23 E. Thickness of deposit, 6 ft.; area, 40 acres; ¼ mile from Frisco Railroad; no stripping; fuel, wood, $1.50 per cord.

DATA.

Water of plasticity	28.3%
L. D. S.	8.4%w.l. 9.1%d.l.
L. F. S.	.8%
Tot. L. S.	7.6%
V. D. S.	26.4%w.v. 35.9%d.v.
V. F. S.	1.5%
Tot. V. S.	27.5%
Absorp.	14.4%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	33.4	31.8	33.4	33.2	32.0	33.0	32.5	32.8	27.6	32.2

Remarks: Works and dries nicely. Burns to a peculiar brick red, free from discoloration. Structure is sound. Is well suited for common brick and drain tile. Porosity curve on fig. 40.

Clay No. 323, Garvin, Oklahoma.

Location, sec. 13, T. 7 S., R. 22 E. Thickness of deposit, 10 ft.; area, 40 acres; nearest railroad, ½ mile; wood on the ground for $1.50 per cord.

DATA.

Water of plasticity	27.4%
L. D. S.	7.8%w.l. 8.4%d.l.
L. F. S.	.8%
Tot. L. S.	7.0%
V. D. S.	24.0%w.v. 31.5%d.v.
V. F. S.	1.6%
Tot. V. S.	25.2%
Absorp.	14.2%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	34.0	34.2	33.2	33.4	33.0	33.5	33.4	32.6	32.7	32.9

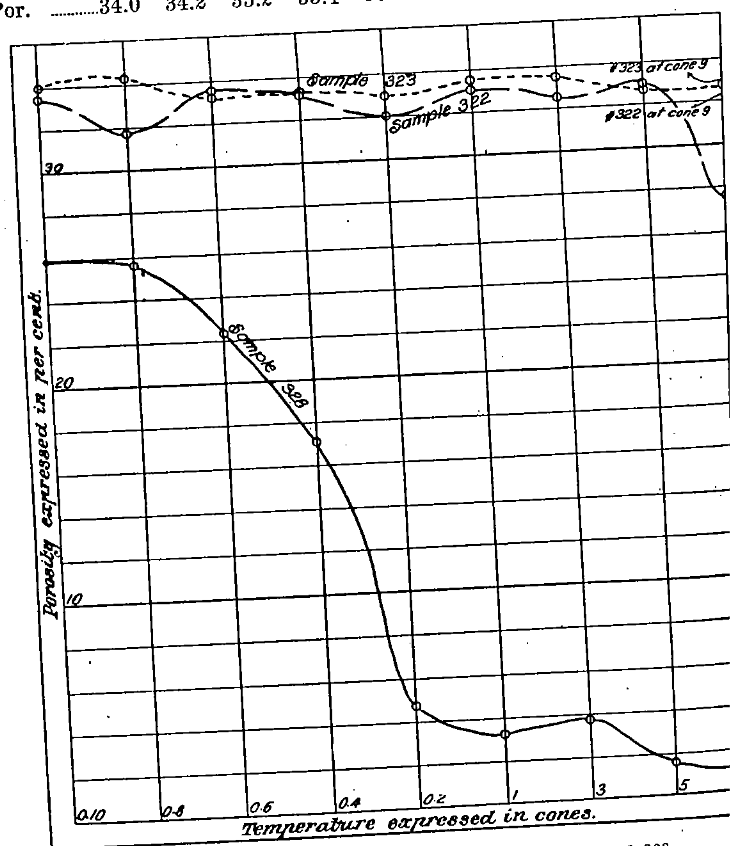


Fig. 40. Porosity curves for clays No. 322, 323 and 328.

Remarks: Surface clay with small iron concretions. Very sandy and only slightly plastic. Peels up and gives rough surface through machine. Crumbles easily. Dries nicely. Brown color due to presence of manganese. A very sandy clay which even at cone 5 does not burn to satisfactory hardness. Structure is not sound, but is what is called punky. Nothing to hinder its being used in the manufacture of common brick as it works well in machine, dries well and burns safely, but evidently not suitable for the manufacture of production other than common brick or tile. Porosity curve on fig. 40.

Clay No. 324, Garvin, Oklahoma.

Location, SE.¼ sec. 13, T. 7 S., R. 22 E. Area, 40 acres; thickness, 8 ft.; nearest railroad, ½ mile; wood on ground at $1.50 per cord.

DATA.

Water of plasticity	26.3%
L. D. S.	6.0%w.l. 6.8%d.l.
L. F. S. (cone 5)	%
Tot. L. S.	%
V. D. S.	23.3%w.v. 30.5%d.v.
V. F. S.	.2%
Tot. V. S.	%
Absorp.	12.9%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	34.0	34.0	33.2	32.4	32.7	32.1	31.8	31.8	32.0	31.8

Remarks: A very sandy clay and difficult to work. Has a poor red color and open porous structure. Cracks badly in burning. No value for clay products. Porosity curve on fig. 41.

Clay No. 325, Garvin, Oklahoma.

Location, NE.¼ sec. 14, T. 7 S., R. 22 E. Thickness of deposit, 12 ft.; area, 120 acres; nearest railroad, 1 mile; wood on ground at 1.50 per cord.

DATA.

Water of plasticity	31.5%
L. D. S.	12.9%w.l. 14.8%d.l.
L. F. S.	%
Tot. L. S.	%
V. D. S.	30.1%w.v. 43.0%d.v.
V. F. S.	%

Tot. V. S.	%
Absorp.	%
Cone.	
Por.	

Remarks: Shale containing veins of calcite and some fossils (lime), is very plastic and shows extreme lamination, with great difficulty in working through the machine. All discs cracked to pieces in drying. Burns to unsatisfactory red color. Could not be used for clay products. No porosity curve.

Clay No. 326, Garvin, Oklahoma.

Located on tram road 3 miles south of Garvin. About 20 ft. thick, stripping, 10 to 20 ft., part of which can be used for brick.

DATA.

Water of plasticity	28.0%
L. D. S.	9.9%w.l. 10.9%d.l.
L. F. S.	5.0%
Tot. L. S.	14.3%
V. D. S.	26.5%w.v. 36.1%d.v.
V. F. S.	14.1%
Tot. V. S.	36.9%
Absorp.	4.3%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	29.8	29.7	25.6	19.8	18.5	18.2	17.2	17.0		

Remarks: A plastic shale which works and dries well. Vitrifies at cone 3, and stands up well at cone 7. Has peculiar red color. Suitable for common brick and tile. Porosity curve on fig. 41.

Clay No. 327, Durant, Oklahoma.

Location, W. ½ of the SW. ¼ of sec. 31, T. 6 S., R. 9 E. Thickness of deposit, 50 ft.; area, 8 acres; stripping, 10 ft.; nearest railroad ¾ mile; M., K. & T. and M., O. & G. Nearest fuel, 50 miles; coal, price $3.00.

DATA.

Water of plasticity	43.7%
L. D. S.	7.1%w.l. 7.7%d.l.
L. F. S.	4.7%
Tot. L. S.	10.2%

V. D. S.	21.2%w.v. 26.8%d.v.
V. F. S.	10.1%
Tot. V. S.	29.3%
Absorp.	6.9%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	28.6	29.1	23.7	21.0	19.8	17.5	16.7	14.2	9.2	

Remarks: Clay shale of excellent working and drying properties. Burns to light red color; steel hard at cone 02, bluestones at cone 5. Is an excellent material for common brick, sidewalk brick and drain tile. Its color is not satisfactory for front brick or roofing tile. Porosity curve on fig. 41.

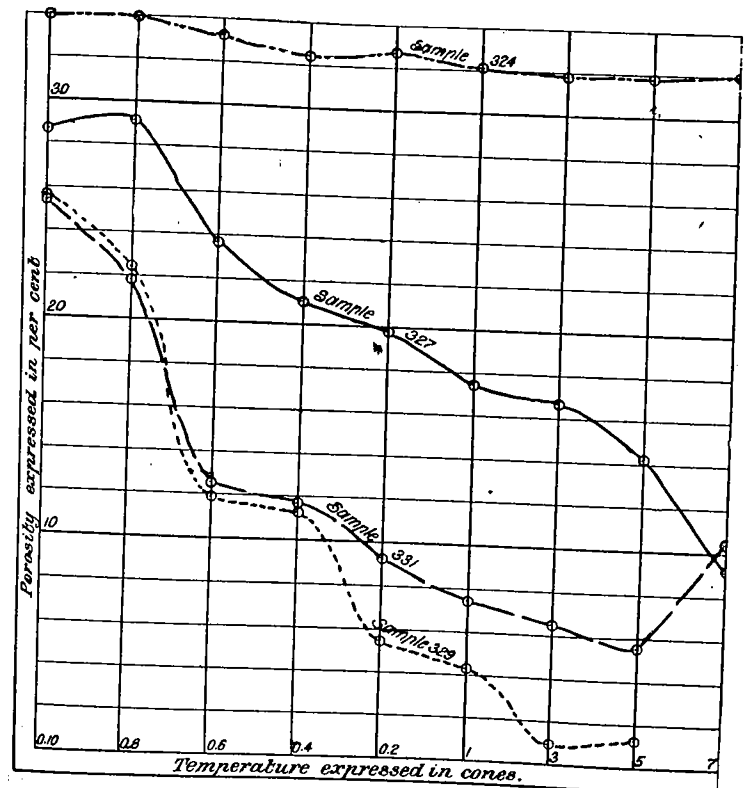


Fig. 41. Porosity curves for clays No. 324, 327, 329 and 331.

Clay No. 328, Avant, Oklahoma.

Located on a large hill south of Avant; thickness, 30 to 40 ft.; area, several acres; 1/8 mile from Midland Valley Railroad; fuel, gas at hand at about 5 cents per 1000 cu. ft.; limestone at hand.

DATA.

Water of plasticity	22.4%
L. D. S.	6.2%w.l. 6.7%d.l.
L. F. S. (cone 3)	6.0%
Tot. L. S.	11.8%
V. D. S.	18.6%w.v. 22.4%d.v.
V. F. S.	17.8%
Tot. V. S.	33.1%
Absorp.	.4%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	27.9	25.6	22.3	17.1	4.7	3.4	3.8	1.7	1.2	

Remarks: A black shale with some small ironstone concretions. Good working and drying qualities. It burns to a dense, firm structure, vitrifying at cone 02 and standing well at cone 5. Has a red color slightly discolored by whitewash. Suitable for common or sidewalk brick, and drain tile. By sorting, face brick could probably be secured. Porosity curve on fig. 40.

Clay No. 329, Avant, Oklahoma.

Composes a large hill northeast of Avant, 1/4 mile from Midland Valley Railroad. Thickness, 20 to 50 ft.; area, many acres. Fuel, gas at a very low price.

DATA.

Water of plasticity	25.6%
L. D. S.	8.3%w.l. 9.0%d.l.
L. F. S. (cone 3)	6.7%
Tot. L. S.	14.3%
V. D. S.	24.1%w.v. 31.7%d.v.
V. F. S.	20.5%
Tot. V. S.	39.7%
Absorp.	.4%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	25.7	22.4	11.9	11.3	5.5	4.3	.9	1.3		

Remarks: A yellow clay shale with some ironstone concretions. Has excellent working and drying qualities. Vitrifies between cones 04 and 02 and could be burned safely up to cone 3. At cone 3 it burns to a very admirable effect. The structure is sound and practically impervious. It is well adapted to the manufacture of all kinds of building brick, especially front brick. It can also be used for drain tile. Porosity curve on fig. 41.

Clay No. 331, Woodville, Oklahoma.

Location, 5 miles north of Woodville, 1 mile east of Frisco Railroad; thickness, 20 ft.; stripping, 2 to 12 ft. Fuel, wood.

DATA.

Water of plasticity	28.3%
L. D. S.	10.7%w.l. 12.0%d.l.
L. F. S. (cone 5)	5.7%
Tot. L. S.	15.8%
V. D. S.	27.7%w.v. 38.4%d.v.
V. F. S.	18.1%
Tot. V. S.	40.8%
Absorp.	2.1%

Cone	010	08	06	04	02	1	3	5	7	9
Por.	25.4	21.8	12.5	11.7	9.3	7.5	6.5	5.5	10.4	

Remarks: A dark colored clay shale, some layers somewhat sandy. Works well, but requires care in drying. Burns to a dark red, somewhat marred by white specks. Structure good. Good for the manufacture of brick and tile. Porosity curve on fig. 41.

No. 332.

The clay shale used by the Pawhuska Vitrified Brick & Tile Co., at their plant 1 mile northwest of Pawhuska was tested by the Richardson-Lovejoy Engineering Co., Columbus, Ohio. A summary of their report follows:

Physical characteristics. The material is a bluish (yellow when oxidized) shale, medium hard and quite fine grained. It contains some sand in a finely divided condition. Is very slightly carbonaceous, and contains no visible nodules or concretions. Lime and mica are not present except in very small quantity. The shale grinds easily and when pugged develops fine plasticity without stickiness. No cracks or flaws developed in severe drying tests and dried ware is quite strong. Dried blocks show considerable white scum (whitewash).

Burning tests. Burn without difficulty if oxidized sufficiently.

Marked change in color and shrinkage (with beginning of vitrification) at cone 02. Vitrification is of a stony character. Burning range from cone 07 to cone 5—vitrification range from cone 02 to cone 5. Slight increase in size from cone 3 to 5. Color salmon red at cone 07, darkens to cone 1, brownish tendency at cone 3 with darker browns at cones 5 and 7. Scumming or whitewash is bad feature of the red colors but burns off above cone 3.

Availability. Is suitable for common building brick and drain tile. Scumming mars ware for red face brick or roofing tile, but fine grade of brown face brick can be produced. Absorption of burned ware is rather high for paving brick. Possibly good for sewer pipe although scumming might interfere with its taking a salt glaze.

DATA.

Drying shrinkage—5 to 7 per cent. of wet length according to amount of water used in making up.

Burning shrinkages. (Extremes of 3 burns.)

Cone 07—2.0 per cent. to 2.7 per cent. dry length.
Cone 04—5.4 per cent. to 7.4 per cent. dry length.
Cone 02—7.6 per cent. to 8.2 per cent. dry length.
Cone 1—7.8 per cent. to 8.1 per cent. dry length.
Cone 3—7.7 per cent. to 8.2 per cent. dry length.
Cone 5—7.4 per cent. to 7.7 per cent. dry length.
Cone 7—7.0 per cent. to 7.5 per cent. dry length.

Absorption of burned pieces. (a) and (b) represent different burns:

Cone	a.	b.
07	10.0	3.6
04	4.1	5.5
02	2.7	3.5
1	1.0	3.1
3	2.1	2.7
5	2.4	2.6
7	2.1	2.2

The chemical analysis as reported for this clay is:

Silica (SiO_2)	61.60
Alumina (Al_2O_3)	18.57
Iron oxide (Fe_2O_3)	4.80
Lime (CaO)	1.04
Magnesia (Mg O)	1.46
Ignition loss	7.50
Alkalies (K_2O & Na_2O)	5.03 (by difference)

The following clays were tested at the Ceramics laboratory of the University of Illinois under the direction of A. V. Bleininger. The reports of the tests were not received in time to have the porosity curves drawn for this report or to have the clays represented in the table of data at the end of the chapter. The remarks on the working and burning properties are by Mr. Bleininger.

Shale from Jenks. Location S.½ SW.¼, sec. 30, T. 18 N., R. 13 E. Thickness, 12 feet known. Area, 80 acres known. Transportation facilities, three-fourths mile to Midland Valley Railroad. Fuel, two gas wells in less than one mile. Gas pipe line passes through property.

DATA.

Water of plasticity	22.1%
L. D. S. (% dry length)	5.3%
L. F. S. (at cone 03)	7.8%

Porosity at cone:

07	05	03	01	2	3
21.06	12.51	6.79	5.16	4.66	8.74

Remarks: This material seems to be a sandy shale of moderate plasticity requiring 22.12% water of plasticity. It does not work well in the auger machine as does the average shale but with a good lubricating die it should form a satisfactory column. It dried without difficulty and showed a drying shrinkage of 5.3%.

Burning. The shale burnt to a red body showing yellowish grains of apparently a sandy nature. It forms a sound body showing considerable toughness. Its vitrification range is wide and it would hence be a safe burning material. A peculiar feature observed with this material was that it did not reach zero porosity but became more porous after having been burnt to cone 2. The minimum porosity reached was 4.66%. As this appeared somewhat strange this was repeated and this time a porosity of 3.75% was determined at the same temperature, cone 2. In spite of this fact it is believed that this material may produce satisfactory paving brick as its toughness was well defined and its temperature range makes it a distinctly safe material.

Black shale from Nowata. Locality and occurrence are given on page ——.

DATA.

Water of plasticity	18.5%
L. D. S. (% dry length)	4.3%
L. F. S. (at cone 03)	.9%

Porosity at cone:

07	05	03	01	1	3
38.8	36.14	32.27	32.04	24.12	fused to slag.

Remarks: This material also shows good working qualities and produces a perfect column on the auger machine. Its water of plasticity is 18.5%. It dries very easily and shows a drying shrinkage of only 4.25%. It will hence stand any kind of abuse in drying.

Burning. This shale evidently is calcareous in nature as it burns to a clean cream color. The lime, however, is disseminated uniformly and in exceedingly fine grains and there is not the slightest evidence of larger particles which might cause trouble. Like in all calcareous materials the initial porosity is high due to the expulsion of carbon dioxide. The safe burning limit of this material is somewhat above cone 1 when it softens and fuses quite rapidly. When burnt at cone 03 the clay possesses good hardness and this would be about its average commercial temperature, far enough removed from the danger of overburning and softening. Any attempt to vitrify this shale would be futile as it could not be done commercially.

This shale could be manufactured into cream colored building brick similar to the well known Milwaukee product.

Light colored shale from Nowata. Locality and occurrence as above. Underlies Black shale.

DATA.

Water of plasticity	24.3%
L. D. S. (% dry length)	5.2%
L. F. S. (at cone 03)	8.5%

Porosity at cone:

010	08	06	04	02	1
27.65	22.09	15.67	1.20	1.17	15.27 (vesicular)

Remarks: This shale works up to a good plastic mass, requiring 24.31% of water. It also seems to work well in the auger machine, as it is shaped into a perfect bar. On drying it shows a shrinkage of 5.1% in terms of the dry length and offers no difficulty whatever. It evidently could be dried safely under the conditions of any commercial dryer.

Burning. This material burns to a good red color with some tendency to whitewash. Its limiting temperature is evidently cone 02

3

ised to slag.

working qualities and ne. Its water of plas- a drying shrinkage of ouse in drying.

in nature as it burns lisseminated uniformly the slightest evidence Like in all calcareous expulsion of carbon al is somewhat above hen burnt at cone 03 be about its average n the danger of over- this shale would be

1 colored building

and occurrence as

(vesicular)

ic mass, requiring auger machine, as shrinkage of 5.1% whatever. It evi- f any commercial

color with some vidently cone 03

	Water of Plasticity.	Lin. Drying Shrinkage in per cent of wet length.	Lin. Drying shrinkage in per cent of dry length.	Lin. fire shrinkage in per cent of dry length.	Total linear shrinkage in per cent of wet length.	Vol. Drying shrinkage in per cent of wet volume.	Vol. Drying shrinkage in per cent of dry volume.	Vol. fire shrinkage in per cent of dry volume.	Total volume shrinkage in per cent of wet volume.	Absorption.	POROSITY AT CONE.									
											010	08	06	04	02	1	3	5	7	9
4. Boynton	15.2	2.2	2.3	6.0	8.1	7.8	8.4	16.5	22.9	4.3	......	30.9	29.1	21.6	21.8	16.1	14.4	......	......	......
10. Coalgate	14.6	5.3	5.6	5.9	10.8	13.7	16.0	18.5	29.8	2.7	......	21.4	20.6	13.4	9.7	9.7	9.3	......	......	......
11. Coalgate	18.1	6.5	7.0	9.5	15.1	18.2	22.3	40.1	.5	.5	......	22.4	12.3	6.8	4.0	3.9	4.5	......	......	......
12. Coalgate	26.9	8.2	8.9	10.3	17.8	23.4	30.1	27.6	47.8	.6	......	13.4	3.9	2.4	3.1	2.8	1.7	......	......	......
16 Claremore	32.2	13.1	15.1	......	......	30.5	43.8	......	......	......	21.2	18.2	10.4	2.4	16.7	15.0	9.3	......	......	......
17. Claremore	21.8	6.7	7.2	1.9	8.5	20.2	25.3	4.8	24.0	......	24.5	24.6	23.8	23.7	20.9	22.0	16.3	18.6	17.6	......
30. Perry	0.0	0.0	0.0	12.5	12.5	0.0	0.0	33.1	33.1	10.8	10.8	.00	42.8	32.8	37.4	30.6	31.6	25.3	27.8	19.6
33. Stigler	24.4	2.4	2.4	9.8	12.0	7.0	7.6	32.1	36.9	.9	34.6	34.4	25.8	27.2	17.0	22.9	3.7	3.3	......	......
34. Stigler	31.6	2.3	2.3	14.7	16.6	4.7	4.9	39.1	41.8	.3	42.6	37.8	21.1	7.2	2.0	0.2	0.8	0.5	......	......
38. Muskogee	21.8	6.4	6.8	8.9	14.7	19.2	23.8	24.8	39.2	.4	......	22.3	19.0	9.2	3.3	4.5	2.6	......	......	......
39. Muskogee	25.6	6.4	6.9	3.8	9.8	16.9	20.3	13.0	27.5	12.3	......	36.1	34.1	32.0	32.1	27.3	29.5	......	......	......
40. McAlester	23.1	7.1	7.7	9.7	16.1	18.4	22.5	25.2	38.9	.3	29.6	26.8	15.2	11.9	4.2	2.7	1.5	1.0	4.6	......
42. Oklahoma	20.4	5.9	6.2	3.8	9.5	18.0	21.9	14.0	29.5	.5	28.2	......	27.2	27.1	23.2	12.7	13.6	......	......	......
44. Hartshorne	16.0	3.1	3.2	......	......	11.4	......	......	......	......	38.4	35.8	31.5	28.2	23.2	21.1	19.7	16.8	14.0	13.7
45. Hartshorne	14.6	3.4	3.5	......	......	8.4	8.9	......	......	......	43.5	42.9	40.2	34.0	33.5	30.3	29.9	27.8	15.8	15.4
46. Alderson	17.1	3.9	4.0	8.8	12.3	14.1	16.4	19.4	30.8	3.5	29.7	19.8	18.3	8.1	8.1	7.2	7.1	5.7	......	......
47. Alderson	18.9	6.3	6.7	7.1	12.8	17.2	20.8	18.3	32.3	.4	26.9	22.1	17.6	14.6	9.1	6.2	1.4	......	5.6	8.9
53. Blackwell	20.6	3.0	3.2	1.8	4.6	12.7	14.5	.8	13.4	34.8	52.2	52.0	53.0	22.1	55.6	54.0	15.8	4.5	......	......
60. Cleveland	20.4	6.0	7.6	7.9	13.2	17.1	20.6	21.7	35.0	.4	......	20.1	14.5	6.8	6.2	3.6	2.0	......	......	......
61. Cleveland	20.5	6.0	6.3	6.6	11.9	15.6	18.5	18.4	31.2	2.1	......	24.3	21.9	15.1	11.3	11.3	6.1	......	......	......
62. Cleveland	18.9	4.7	4.9	2.2	6.8	12.4	14.8	5.6	16.3	7.3	......	28.6	24.6	19.4	24.7	23.1	21.9	......	......	......
63. Cleveland	21.3	6.0	6.2	7.6	12.9	16.8	20.1	18.8	32.5	1.6	......	23.5	20.5	11.0	10.3	8.3	5.2	......	......	......
69. Wilburton	22.9	7.3	7.7	4.7	11.1	19.7	24.4	11.7	29.1	7.9	......	30.5	......	23.8	23.2	21.6	23.1	......	......	......
70. Wilburton	29.0	11.2	12.7	8.6	18.7	29.9	42.6	22.2	45.0	1.8	......	19.7	15.8	13.5	6.1	8.0	4.1	......	......	......
71. Wilburton	28.6	9.8	10.8	7.9	17.1	27.5	38.8	22.4	44.1	.8	......	9.6	2.6	.5	......	1.7	1.9	......	......	......
107. Miami	18.3	4.6	4.9	7.0	29.9	12.7	14.5	29.9	19.7	3.0	......	29.4	26.5	21.7	21.1	12.6	13.6	......	......	......
108. Miami	19.2	1.9	1.9	......	2.0	5.1	5.9	-.4	5.2	16.0	37.7	37.8	35.2	35.5	33.7	33.3	......	......	......	......
134. Quay	23.7	8.4	9.2	6.3	14.1	23.9	31.4	17.8	37.4	1.7	......	20.9	19.4	13.8	14.6	11.6	6.8	......	......	......
135. Quay	23.6	9.2	10.1	2.0	11.0	26.1	36.4	6.0	30.6	5.7	......	26.4	28.4	28.2	19.6	26.1	18.6	......	......	......
136. Quay	23.1	8.7	9.5	6.1	14.2	24.0	31.5	18.3	37.9	.5	......	16.5	15.2	8.4	......	8.0	6.7	......	......	......
137. Rush Springs	23.5	9.9	12.1	4.7	13.9	25.7	24.5	20.3	40.7	.4	......	24.8	25.5	8.1	4.4	4.4	2.1	......	......	......
145. Meeker	27.0	12.5	14.4	......	......	......	......	......	......	......	16.4	16.1	4.8	2.6	1.7	1.3	1.5	.5	......	......
150. Sweetwater	......	......	......	......	......	......	......	......	......	......	14.6	18.5	15.2	11.3	2.1	2.5	......	......	......	......
151. Sweetwater	24.3	4.6	4.9	5.3	9.6	17.6	21.5	16.5	31.2	3.8	32.9	33.0	32.0	33.1	27.5	30.0	17.4	18.3	......	......
152. Waurika	20.5	6.9	7.4	4.3	10.8	23.5	36.0	13.2	33.6	1.3	36.1	24.1	......	25.0	10.2	18.1	2.8	3.8	......	......
153. Waurika	27.0	11.9	15.4	5.9	17.1	31.7	43.0	18.9	44.6	.7	18.4	20.4	13.4	12.8	4.2	1.5	1.9	1.7	......	......
154. Waurika	15.1	1.0	1.0	0.0	.7	4.1	4.2	-1.4	4.0	12.1	33.1	32.0	33.6	33.7	32.0	32.3	31.7	31.2	31.5	31.4
155. Calvin	18.7	2.5	2.6	-.2	.9	11.5	13.0	-.7	10.6	12.0	32.3	32.5	32.4	33.2	31.6	33.0	32.1	32.2	29.1	26.8
156. Calvin	28.5	12.2	13.8	3.6	15.6	31.5	46.1	13.4	40.6	.3	22.2	22.1	18.4	19.2	12.3	13.5	12.9	12.2	9.4	......
159. Ramona	19.7	4.1	4.2	6.8	10.8	13.1	15.1	22.0	32.2	.5	......	24.5	20.8	14.2	12.9	7.9	4.9	......	......	......
166. McAlester	28.3	10.4	11.5	7.6	17.3	29.6	42.1	20.3	43.9	.9	......	10.9	1.6	2.0	......	1.7	2.0	......	......	......
171. Poteau	25.9	7.9	8.5	9.5	16.6	21.7	27.7	25.5	41.9	.2	28.0	24.5	19.0	......	5.2	.9	.4	1.4	......	......
172. Poteau	16.4	1.7	1.8	6.9	8.5	8.7	9.5	15.8	23.7	2.9	......	28.6	27.7	27.4	24.5	18.7	13.5	8.2	2.6	......
173. Oklahoma City	19.4	6.7	7.2	5.9	12.2	22.1	28.3	18.1	36.2	.8	......	23.3	25.5	24.0	15.3	6.2	6.6	......	......	......
174. Muskogee	16.6	4.1	4.3	6.9	10.4	11.5	12.9	19.7	28.8	2.1	......	21.2	14.6	10.3	11.4	10.5	10.2	......	......	......
177. Hinton	10.4	10.8	......	......	......	......	......	......	......	......	......	8.9	9.3	12.5	swollen					
180. Marlow	25.3	7.4	8.0	6.5	13.3	20.4	26.1	23.0	38.7	.2	19.0	13.4	2.9	2.8	......	......	......	......	......	......
181. Ravia	21.8	4.6	4.8	......	......	16.1	18.2	......												
194. Altus	22.7	5.0	5.3	6.1	10.7	18.8	23.2	15.4	37.3	3.7	24.9	22.7	21.0	20.0	7.8	11.1	7.4	......	......	......
196. Comanche	21.1	5.6	6.0	7.5	12.7	19.8	24.7	18.9	35.0	.2	24.3	22.2	15.2	13.6	3.8	0.2	1.0	5.0	......	......
197. Comanche	22.8	6.6	7.1	-7.6	13.7	21.7	27.7	19.7	37.1	0.0	24.3	21.8	16.7	12.0	3.1	6.2	0.0	0.0	......	......
198. Henryetta	24.6	10.1	11.2	2.4	12.2	28.5	39.9	5.6	32.7	9.8	......	28.4	28.4	......	29.8	[illegible]	26.0	......	......	......
200. McAlester	25.9	9.6	10.6	7.8	16.6	24.3	32.2	24.4	42.7	.6	26.2	13.3	4.1	3.9	2.7	1.8	5.1	......	......	......
201. McAlester	23.1	8.7	9.6	4.1	12.5	21.6	28.1	15.5	34.0	......	24.1	18.6	7.8	9.9	2.7	2.0	1.6	......	......	......
202. McAlester	18.8	6.9	7.4	7.1	13.5	19.1	23.5	21.3	36.3	.1	25.3	20.3	9.1	2.9	1.7	.7	.3	13.2	......	......
205. Mangum	27.6	7.4	8.0	......	......	19.5	24.5	......	......	......	16.1	7.1	2.6	3.1	......	......	......	......	......	......
231. Sparks	20.5	8.7	9.6	4.1	12.5	24.3	32.1	12.0	33.4	......	21.2	21.0	19.1	13.2	6.5	7.0	5.3	9.0	......	......
241. Nelagony	24.2	7.5	8.4	7.4	14.3	21.1	26.7	17.3	37.6	.5	38.6	35.8	23.1	7.4	5.3	7.0	.9	1.4	......	......
242. Nelagony	28.4	10.7	12.0	10.1	19.7	25.0	33.3	24.8	43.6	.3	27.0	26.5	8.3	1.7	1.1	1.2	.4	1.8	......	......
261. Binger	22.4	6.9	7.4	5.2	11.8	21.9	28.0	19.3	37.0	.8	23.1	23.8	23.5	23.7	17.4	6.7	.8	2.4	......	......
263. Ravia	25.1	27.0	7.5	6.1	12.5	17.9	21.9	18.6	33.2	.4	36.9	27.1	35.3	35.2	24.4	16.2	11.7	......	......	......
271. Bartlesville	27.8	9.3	10.0	......	......	28.6	40.1	......	......	......	25.0	19.6	15.8	13.8	9.5	2.3	1.9	2.0	......	......
277. Bigheart	25.5	7.7	8.4	7.8	14.8	21.7	27.6	24.8	40.4	.2	26.7	27.4	23.3	13.8	3.3	4.7	6.6	1.6	......	......
280. Vinita	29.6	11.1	12.2	7.6	17.8	27.7	38.4	19.1	41.8	.6	24.8	26.5	22.6	17.1	7.4	10.0	......	1.2	......	......
287. McAlester	14.5	5.6	6.0	6.4	11.9	15.4	18.2	20.9	32.3	1.1	26.1	23.1	17.9	17.9	8.6	8.6	2.1	2.2	3.9	7.0
296. Doxey	21.1	9.7	10.8	......	......	9.4	10.4	21.5	22.6	1.7	38.3	37.2	37.6	36.3	37.8	27.7	28.3	1.4	......	......
297. Doxey	24.6	5.3	5.7	......	......	19.4	24.0	......	......	......	30.7	29.3	26.9	22.2	5.6	......	.3	......	......	......
298. Atoka	20.5	6.7	7.2	4.5	10.8	20.2	25.4	15.5	32.6	1.3	22.7	23.7	22.0	......	8.1	12.6	3.7	5.2	......	......
299. Atoka	26.1	8.7	9.6	5.6	13.8	24.8	33.0	15.1	36.1	.1	21.5	23.7	18.0	5.0	1.9	1.3	0.4	1.5	......	......
308. Ardmore	23.2	7.5	8.4	5.1	12.2	22.5	29.1	16.1	35.0	1.4	26.4	25.5	22.6	15.4	15.8	7.0	5.7	......	......	......
312. Ardmore	23.9	.6	.6	.8	1.4	4.7	5.0	11.1	15.3	17.9	36.2	35.9	35.6	31.8	32.6	32.7	31.9	32.4	31.7	30.9
312. Woodville	21.7	3.0	3.2	-.8	2.2	13.4	15.4	-.7	......	12.8	27.5	35.6	34.8	33.0	......	35.0	33.3	33.2	30.4	29.0
317. Bristow	22.0	6.7	7.2	5.0	11.3	20.6	24.6	14.3	31.8	1.0	25.0	24.6	24.1	20.8	10.6	14.1	7.5	7.9	3.9	4.8
319. Antlers	31.6	13.9	15.6	1.6	14.8	35.2	54.4	3.9	37.7	5.0	21.1	20.8	19.4	19.7	29.9	18.7	17.8	19.0	17.3	11.1
320. Antlers	20.4	6.1	6.5	12.5	18.3	22.4	......	......	......	......	30.2	25.5	7.9	6.6	4.8	4.6	2.9	2.9	......	......
321. Antlers	35.5	8.7	9.6	3.8	12.2	27.7	38.4	11.3	35.9	6.1	24.5	21.7	21.7	20.7	21.7	19.9	20.0	19.0		
322. Garvin	28.3	8.4	9.1	.8	7.6	26.4	35.9	1.5	27.5	14.4	33.4	31.8	33.4	33.2	32.0	33.0	32.5	32.8	27.6	32.2
323. Garvin	27.4	7.8	8.4	-.8	7.0	24.0	31.5	-1.6	25.2	14.2	34.0	34.2	33.2	33.4	33.0	33.5	33.4	32.6	32.7	32.9
324. Garvin	26.3	6.0	6.8	......	......	23.3	30.5	.2	......	12.9	34.0	34.0	33.2	32.4	32.7	32.1	31.8	31.8	32.0	31.8
326. Garvin	28.0	9.9	10.9	5.0	14.3	26.5	36.1	14.1	36.9	4.3	29.8	29.7	25.6	19.8	18.5	18.2	17.2	17.1	......	......
327. Durant	23.7	7.1	7.7	4.7	10.2	21.2	26.8	10.1	29.3	6.9	28.6	29.1	23.7	21.0	19.8	17.5	16.7	14.2	9.2	......
328. Avant	22.4	6.2	6.7	6.0	11.8	18.6	22.4	17.5	33.1	.4	27.9	25.6	22.3	17.1	4.7	3.4	3.8	1.7	11.9	......
329. Avant	25.6	8.3	9.0	6.7	14.3	24.1	31.7	20.5	39.7	.4	25.7	22.4	11.9	11.3	5.5	4.3	.9	1.3	......	......
331. Woodville	28.3	10.7	12.0	5.7	15.8	27.7	38.4	18.1	40.8	2.0	25.4	21.8	12.5	11.7	9.3	7.5	6.5	5.5	10.4	......

and it is easily overburnt on exceeding this temperature. Its tendency to become vesicular at a higher heat as well as its comparative lack of toughness render it unsuitable for the manufacture of paving brick. It, however, is well adapted for making building brick, sewer brick, drain tiles, etc.

CHAPTER VIII.

THE DISTRIBUTION AND DEVELOPMENT OF THE CLAYS OF OKLAHOMA

INTRODUCTION.

It is impossible in the present state of knowledge to discuss the distribution of the clays and shales of the State by counties, therefore, in this chapter only a preliminary report will be attempted. As far as possible the State is divided into more or less well defined stratigraphic and topographic districts. Each district is discussed wth reference to its stratigraphy. An effort is made to tie the formations up with county boundaries, streams, towns and railroads where ever possible. Advantage is taken of the reports which have been published dealing with the geology of the State, namely; those of Taff for the eastern and southeastern parts of the State; of Gould for the western part; and of Ohern and Siebenthal for the northeastern portion. Where possible, the results of their investigations are supplemented by the writer's observations with reference to the clays and shales. The present development is noted in some detail, short descriptions of all the plants now operating in the State being given with especial reference to the nature and available supply of the material used.

THE STRATIGRAPHY OF OKLAHOMA

General Statement.

The oldest rocks in Oklahoma are exposed in the Arbuckle and Wichita Mountains, in the south-central part of the State. These mountains consist of central cores of granite, apparently of Archean age, surrounded by belts formed by the edges of the steeply dipping strata of older Paleozoic rocks. Lying almost level on the extension of these older Paleozoic rocks is an immense thickness of Carboniferous rocks entirely surrounding the Wichita Mountains and on the west, north and east sides of the Arbuckles. These reach to the Arkansas, Kansas and Texas lines, on the east, north and west, respectively.

From the Arbuckle Mountains north and east the Carboniferous rocks belonging to the Pennsylvanian system. South of Arkansas river the rocks are practically all sandstones and shales while north of that river there are several ledges of limestone. Arkansas River thus divides the area of Pennsylvanian rocks into two regions. To the west and northwest the rocks are of Permian age and are known as the Redbeds on account of their color. In the southeast corner of the State are the Ouachita Mountains, which consist of an immense thickness of Carboniferous and Silurian rocks extensively folded and faulted. The southeastern extension of the Ozark Uplift occupies the northeastern portion of the State and consists of rocks of Mississippian, Devonian and Silurian age. Cretaceous rocks occupy a belt north of Red River and south of the Arbuckle and Ouachita Mountains and several small areas in western Oklahoma. Tertiary rocks lie above Redbeds in the extreme northwestern portion of the State.

For the purpose of fuller discussion the State is divided into the following parts:

(1) The Arbuckle Mountain region.
(2) The Ouachita Mountain region.
(3) The Mississippian area or Ozark Mountain region.
(4) The area of Pennsylvanian rocks north of Arkansas River, including a small area of Permian rocks.
(5) The area of Pennsylvanian rocks south of Arkansas River.
(6) The western or Redbeds area, comprising the upper or red portion of the Pennsylvanian rocks, the red Permian rocks, the Wichita Mountains, some small areas of Cretaceous rocks and the Tertiary rocks.
(7) The Cretaceous area south of the Arbuckle and Ouachita mountains.

These areas will be taken up in turn and the distribution and character of the shales and clays will be considered with as much detail as is possible with the limited amount of field work which has been done.

THE ARBUCKLE MOUNTAIN REGION.

Location and Area.

The Arbuckle Mountains occupy an area 60 miles long and 10 to 30 miles wide in the south-central part of the State. The area includes southern Murray, northern Carter, the greater portion of Johnston, south-central Pontotoc and a small portion of southwestern Coal counties. The surface is hilly and much of the land is suitable for grazing.

Stratigraphy.

The Arbuckle Mountains consist of a central core of granite surrounded by belts of consecutively older rocks. The latter usually have high dips away from the granite although the direction of this dip is often changed by folding and faulting. The following is a generalized section of the region.

Age			
Pennsylvanian	Franks conglomerate (North of Mountain)		
	Glenn formation (South of Mountain)		
Mississippian	Caney shale		1600′
Mississippian (?)	Sycamore limestone	0-	200′
Devonian (?)	Woodford chert		650′
Siluro-Devonian	Hunton limestone	0-	300′
Silurian	Sylvan shale	60-	300′
Ordovician	Viola limestone	500-	700′
	Simpson formation	1200-	2000′
Cambro-Ordovician	Arbuckle limestone	4000-	6000′
Cambrian	Reagan sandstone	50-	500′
Archean	Tishomingo granite	....	........′

The formations from Reagan to the Caney were apparently laid down in a horizontal position over the granite, but in middle or late Pennsylvanian time were elevated into a dome and eroded. The Franks conglomerate and later Pennsylvanian rocks were deposited and still lie almost horizontally on the upturned edges of the older rocks.

The Tishomingo granite outcrops in three areas, one east of Washita river, which comprises approximately the southern half of T. 2 S., in R. 5, 6 and 7 E., all of T. 3 S., R. 5 E. and the north half of T. 3 S., in R. 6, and 7 E. and two small areas west of the river in T. 2, S., R. 1 E., and in T. 1 S., R. 1 E. and R. 1 W. The granite in these areas usually comes near the surface and the covering of residual clay is seldom thick enough to be available as a material for the manufacture of clay products. Where there is a sufficient thickness the clay usually contains considerable quantities of disintegrated granite so that its use for products except common brick is very questionable. Common brick are reported to have been made successfully from this material near Tishomingo.

Kaolin is known to occur in small quantities in veins and cavities in different places in the mountains, but no deposit of commercial importance has yet been reported.

The Reagan sandstone outcrops as a narrow belt around the granite. It is thicker toward the west end of the mountains and contains some shale in this portion. It is exposed in a very rough country and is so far removed from transportation that its development for clay manufacture is extremely improbable, even if shale beds of workable thickness should be found in the formation.

The Arbuckle limestone occupies a broad table land in Townships 1 and 2 S., Ranges 1 E., and 1 W., and in Townships 1 and 2 S., and 1 and 2 N., in Ranges 5 and 6 E. The surface is a rocky upland and there is no residual clay of any importance.

The Simpson formation outcrops as a belt around the Arbuckle limestone table land. The formation is much softer and more easily eroded than the Arbuckle and Viola limestone, which occur on either side of it, so it is worn down into a valley between the Arbuckle table land and the rows of knobs of the Viola. The valley is usually timbered.

The Simpson consists of from 1200 to 2000 feet of sandstones, shales and limestones. Taff gives the following general section(1) of the Simpson on the south side of the uplift west of Washita River, the beds being given from above downward:

1.	Thin limestone with green shales interstratified	400′
2.	Sandstone	90′
3.	Limestones and shales interbedded	400′
4.	Sandstone	100′
5.	Shaly limestone	195′
6.	Sandstone	33′
7.	Thin bedded limestone and shales interstratified	295′
8.	Greenish shales with few thin limestone layers	245′
	Thin sandstone.	
9.	Granular crystalline limestone in thin beds	350′
10.	Thin limestone and shales interstratified with occasional thin sandstone	29′
11.	White to light brown sandstone, occurring locally	0-100′

The Simpson formation is much thinner on the north side of the mountains due to the absence of the lower beds. The whole formation is more siliceous to the north. The Simpson is well exposed along the Gulf, Colorado & Santa Fe Railway, in the gorge of Washita River southwest of the village of Crusher. Here the shales in the lower part of the formation are not of workable thickness. Some of the

(1) U. S. G. S., Prof. paper, No. 31, Page 23.

greenish shales of the upper Simpson are 20 to 40 feet thick and might be available. The whole formation, at this place, is standing almost on edge and there is much deformation and local folding in the formation. (See fig. 42). The Simpson is also exposed along the St. Louis & San Francisco Railroad, in three localities between Ada and Ravia, but no detailed work has been done on these exposures. A sample (No. 267) from one mile southwest of Ravia is probably from the Simpson, but time was not taken to determine the horizon accurately. This clay is a greenish, clay shale of good qualities. It burns to a peculiar mottled, dark buff and is one of the few non-red burning clays so far found in the State.

All things being considered, it is not probable that the Simpson formation will ever be an important horizon for development of the clay industries. The shale members are as a rule, too thin and contain too many thin layers of limestone to be worked profitably. With the exceptions already noted the exposures of the formation are in a rough. thinly settled country and are not available to transportation.

The Sylvan shale which is from 60 to 300 feet thick, lies above the Simpson formation and is separated from it by the Viola limestone. It outcrops as wooded valleys between the high prairie knobs of the Viola limestone and the lower knobs of Woodfort chert which are overgrown with jack oak. The basal portion of the Sylvan is a black shale, somewhat bituminous and calcareous. The greater part of the formation is a uniform, greenish clay shale free from concretions or irregularly distributed matter. The exposures of the Sylvan are always near those of the Simpson. The Oklahoma Portland Cement Company at Ada obtains its shale from the Sylvan south of that city. The following analysis furnished by that company shows the composition of the shale at that place:

ANALYSIS OF SYLVAN SHALE SOUTH OF ADA.

Silica	42.30
Ferric oxide	5.92
Alumina	12.36
Lime	12.86
Magnesia	5.50
Loss on ignition	18.11

Alkali not determined.

This analysis shows the shale to be high in lime and magnesia Burning tests would be necessary before its suitability for the manu

facture of clay products can be determined. To the writer's knowledge no burning tests have been made on the Sylvan shale. Owing to its geographical location and the nature of the exposures it will probably not be utilized to any large extent in the near future.

The *Hunton formation, Woodford chert* and *Sycamore limestone* contain no shale or clay members capable of development.

The *Caney shale,* 1500 to 1600 feet in thickness, lies above the Sycamore limestone or the Woodford chert where the Sycamore is absent. The whole formation is greatly broken by faulting and in different places in the Arbuckle Mountains it is brought into contact with all the lower sedimentaries except the Reagan sandstone.

The outcrop of the Caney shale is level or very gently undulating. so that natural exposures are rare. The principal areas of the Caney shale are in the northwestern part of the Atoka quadrangle in townships 1 and 2 S., R. 8 E. There is also a belt from one-half mile to two miles wide in the central part of the mountains, starting about the center of T. 2 S., R. 5 E. and extending northeast to the vicinity of Dougherty in which the Caney shale and the Glenn formation which overlies it in this region, are so folded together as to be indistinguishable. The Caney shale also appears in several rather small areas along the north side of the Ouachita Mountains, farther to the east. The Caney shale is described by Taff[1] as follows:

"The Caney shale in its lower part consists of black, bituminous. fissile shale with spherical, calcareous segregations, and irregular, dense. blue limestone bodies. This bituminous shale is succeeded by clay shales which include small ironstone concretions and occasional calcareous septaria."

No tests of this shale have been made, but from the above description it can be considered as suitable for only the lower grade wares such as common brick and drain tile. The calcareous and iron segregations would prevent its use for the more refractory wares.

The only probable location for development of this shale at present seems to be at Wapanucka where the Missouri, Oklahoma and Gulf Railway and the Ardmore branch of the Chicago, Rock Island & Pacific Railway cross the outcrop. The shale has a very level outcrop at this place and is covered by only a few feet of soil which could probably be used with the shale. Material thrown from wells at this

1. U. S. G. S., Atoka folio, p. 4.

locality shows the blue shale with iron concretions. No calcareous segregations were noted.

The Caney shale seems to have been deposited over large areas and it is believed to practically surround the Arbuckle Mountains although in many placs it is buried beneath younger rocks and is not exposed. At the end of the deposition of the Caney, conditions began to change and as a result the overlying rocks present three distinct phases. In the central part of the Arbuckle uplift and to the south and southwest the Caney shale is overlaid by a series of lenticular shales and sandstones known as the Glenn formation; to the north and northeast the Caney is presumably covered by the Franks conglomerate, while to the east of the main range of the Arbuckle Mountains and north of the Ouachita Mountains, the Wapanucka limestone lies conformably on the Caney shale.

Of these three formations the Franks conglomerate and the Wapanucka limestone do not contain any bodies of shale sufficiently large for development as a source of clay products. The shale from the basal portion of the Wapanucka limestone is used for the manufacture of Portland cement at Hartshorne. Some of the residual clays of the Franks conglomerate near Sulphur appear to be suitable for common brick and tile, but they have not been tested and no definite statements can be made concerning them.

The principal outcrop of the Glenn formation is in the structural depression south of the west end of the Arbuckle Mountains, which is known as the Ardmore Basin. The formation consists of irregularly stratified and lenticular shales with some sandstones, limestone and limestone conglomerate. The rocks have been felded into several folds generally parallel with those of the Arbuckle Mountains. The shales are extremely "pockety" in nature, and a given shale bed can usually be traced for only a short distance.

The shales of the Glenn formation are well exposed in the vicinity of Ardmore. The Ardmore Brick and Tile Co. uses these shales at its plant at the crossing of the Ardmore branch of the Chicago, Rock Island and Pacific Railway and the main line of the Gulf, Colorado and Santa Fe Railway at the north side of the city.

In the pit, which covers less than one acre, there are four kinds of shale shown. Immediately southwest of the plant the material is a red clay shale, which rapidly changes to the south to a yellowish brown and this in turn to a mottled red and gray shale with some iron concretions. These different phases of the material are all at the same level and seem to grade into each other. A thin yellow layer is fairly constant at the bottom of the variable stratum and this is underlaid by a fine-grained, gray to blue shale which weathers rapidly and soon becomes soft and plastic. Two or three "pockets" of a pink shale within a radius of a mile of the plant have been worked out and hauled to the plant in wagons. A body of uniform blue clay shale one and one-half miles northwest of the plant is also worked and the material hauled in wagons. This deposit has an areal extent of about five acres and a known thickness of 30 feet.

The removal of the plant to this locality has been considered as it is only one-fourth mile from the railroad, and as the shales at the plant do not give good results by the dry process. There is some cracking in burning when the blue shale is used, but not sufficient to prevent its use.

The plant is equipped with a Frost 8-foot dry pan and a Berg 4-mold dry press. Two rectangular updraft and two round downdraft kilns are used. The output is about 15,000 common building brick per day. Most of the brick are used in Ardmore. Those shipped are loaded onto cars on a switch from the Gulf, Colorado and Santa Fe Railway. Gas piped from the Wheeler field is used for fuel. About 25 men are employed at the plant and in hauling the clay from the deposits previously mentioned.

The nearest approach to a high grade fire clay so far found in the State is a white, siliceous clay, presumably from the Glenn formation which is found 6 miles southwest of Ardmore. This clay was represented by sample No. 312 (white) and the details of its occurrence and properties are given in Chapter VII.

General Conditions in the Arbuckle Mountains.

The formations of the Arbuckle Mountains region which contain shale sufficient for development are the Sylvan, Caney and Glenn. These occur around the margin of the mountains. None of them can be considered available for high grade wares, but any of them could probably be used for common brick and drain tile. The country is very rough and hilly and is thinly settled. There is some wood available for fuel, but for development on a large scale coal will have to be shipped from the McAlester district or gas obtained from Wheeler. The Gulf, Colorado and Santa Fe Railway and Red River division St. Louis and San

Francisco Railroad cross the mountains from north to south and the Ardmore branch of the Chicago, Rock Island and Pacific Railway follows the southeastern margin for considerable distance. Development will necessarily be along these lines of transportation. In view of these facts it does not seem probable that this region will be the seat of any extensive development of the clay industries in the near future although there is opportunity for the establishment of small plants, similar to the one at Ardmore, to supply local demands.

THE OUACHITA MOUNTAINS.

Location and Area.

The Ouachita Mountain region is in southeastern Oklahoma, south and east of the Choctaw fault—which extends from the Arkansas line west through the central part of LeFlore and Latimer counties and then southwest to Atoka—and north of the belt of the Cretaceous rocks which lies north of Red River. The region comprises the south half of Le Flore and Latimer counties, southwestern Pittsburg and northeastern Atoka counties and the northern two thirds of Pushmataha and McCurtain counties.

Stratigraphy.

The Ouachita Mountains are made up of five formations. The section as given by Taff for the northeastern corner of the Atoka quadrangle is as follows:

Jackfork sandstone	3800 feet	
Standley shale	6100 feet	
Talihina chert	1150 feet	
Stringtown shale	600 feet	(base not shown)

Of these formations the Stringtown shale and Talihina chert are certainly Ordovician. The question of the age of the Standley shale and Jackfork sandstone has given rise to considerable discussion. They were first considered of Silurian age by Taff and mapped as such in the Atoka folio. His reason for so classifying them was that limestone bowlders which he thought to represent a continuous thin ledge, were found above the Jackford sandstone, and contained Silurian fossils and that the Talihina chert is manifestly of Ordovician age. Later he discovered that the limestone bowlders did not represent a continuous ledge, but were erratics deposited in the basal portion of the Caney shale and are probably derived from the Arbuckle Mountain Paleozoic limestones. This left the age of the Standley shale and Jackfork sandstone in doubt. David White classes some poorly preserved plant remains found in the Standley as Carboniferous. Girty[1] correlates the fauna of the Caney shale which lies above the Jackfork sandstone with the Upper Mississippian of Arkansas. This together with White's determination of the plant remains of the Standley as of Carboniferous age places the Standley, Jackfork, and Caney in the Mississippian, giving that system a thickness of about two and a half miles of rocks, which is a much greater thickness than that of the Mississippian in any known region.

The structure of the Ouachita Mountains is very different from that of the Arbuckles. Instead of being a dome, the Ouachitas consist of a number of steeply tilted fault blocks, so that the different formations do not occur as successive belts around a central core as in the Arbuckles, but they are repeated many times on the surface. The surface of the region consists principally of long hills and ridges of the Jackfork sandstone with intervening valleys of Standley shale. The Talihina chert sometimes forms rounded knobs which are surrounded by a level plain which is the outcrop of the Standley shale.

The Stringtown shale is exposed in small areas, the principal one being a strip about one-fourth mile in width, paralleling the main line of the Missouri, Kansas and Texas Railway from Atoka to Stringtown. No detailed examinations nor tests of the material have been made and nothing is known as to its availability for the manufacture of clay products.

The Talihina chert contains a large amount of shale, but it occurs in the form of thin bands between the layers of chert and consequently cannot be used for manufacturing purposes.

The Standley Shale is estimated to be 6100 feet thick and as previously mentioned, the faulting brings it to the surface in several places. The lower slopes of the mountains of Jackfork sandstone, and the valleys between them such as the valleys of McGee and Jackfork creeks and of the Kiamichi River, are occupied by the Standley. The formation is described by Taff[2] as follows:

"This formation follows the Talihina chert in gradual transition. Siliceous chert, black shale, and greenish clay shales occur in alternate members for nearly 800 feet above the base. There are two cherty mem-

1. U. S. G. S., Bulletin No. 377.
2. Atoka Folio, p. 4.

bers, 30 and 40 feet in thickness which were noted in sec. 7, T. 2S., R. 12 E., 550 and 800 feet, respectively, above the base of the formation. These cherty strata resemble many of the thin and more shaly cherts, found in the Talihina formation. Continuing upward in the section, there are greenish and dark shales alternating with drab or brown and moderately hard sandstones until the formation reaches an estimated thickness of 6000 feet. Distinct sandstone members range in thickness from 20 to 100 feet and are separated by shales or shales interstratified with sandy beds 140 to 200 feet in thickness."

The Standley shale is exposed in several places along the Paris branch of the St. Louis and San Francisco Railroad which follows the valley of Kiamichi River through the mountains. It also outcrops in a plain from 3 to 4 miles in width and parallels the main line of the Missouri, Kansas and Texas Railway northeast from Atoka to Stringtown. The northeastern edge of the outcrop is from one-half mile to one mile distant from the railroad.

The only locality in the Standley shale which has been observed in detail by the writer is along the Paris branch of the St. Louis and San Francisco Railroad 1 mile north of Antlers where the lower portion of the formation is exposed. The shale is a black fissile clay shale tilted to the south at about 30.° It shows for over 100 feet along the railroad and could be worked back indefinitely in either direction. An inexhaustible supply is in sight with very little or no stripping. A full discussion of the properties of this shale is given in the report of the tests on sample No. 320.

It is certain that in such a thick deposit of shale that variations should be found and it is probable that many different products could be produced from the Standley shale.

Higher Formations. So far as known the Jackfork sandstone contains no shale beds of workable thickness. The Caney shale and the Wapanucka limestone lie above the Jackfork sandstone and are exposed around the north margin of the mountains. These have already been described in connection with the Arbuckle Mountains.

General Conditions of the Ouachita Mountain Region.

The surface of the Ouachita Mountains is extremely rough and consequently the region is thinly populated. The home market for clay products of plants in this region will necessarily be limited and large plants would have to depend upon shipping the greater part of their

product. Wood or fuel is abundant and the coal fields lie to the north and west of the mountains. The St. Louis and San Francisco Railroad follows the course of Kiamichi River through the mountains and furnishes the only transportation facilities for the region. Although the Standley shale furnishes an immense amount of raw material for the manufacture of clay products, the mountainous nature of the region, with consequent paucity of population and transportation facilities will prevent the region from being an important manufacturing center. There is no development of the clay industries at present.

THE OZARK UPLIFT.

Location and area. The southwestern extension of the Ozark uplift in Oklahoma lies in the extreme northeast corner of the State. The western boundary is an irregular line entering the State from Kansas about ten miles northeast of Miami and extending in a general southwesternly direction to Pryor Creek, from there south to within about five miles of Wagoner, thence in a zig-zag line with general southeasterly direction to about the middle of the south line of T. 13 N., R. 23 E.; and thence northeast, leaving the State directly east of Stilwell. The area comprises all of Delaware County and the adjacent portions of Ottawa, Craig, Mayes, Cherokee and Adair Counties and a small portion of northeastern Wagoner county.

Stratigraphy.

The surface of this area is principally an upland formed of Mississippian limestone, through which the streams have cut narrow valleys into the older underlying rocks. There are several outliers of Pennsylvanian rocks upon the higher hills in the western and southern part of the area. The stratigraphy of the region is shown by the following section[1] of the Tahlequah quadrangle.

		feet
Pennsylvanian	Winslow formation with Akins shale member	900
	Morrow formation with Hall sandstone lentil	80-210
Mississippian	Pitkin limestone	3- 80
	Fayetteville formation with Wedington sandstone member at top	20-160
	Boone formation	100-375

1. Taff, J. A., U. S. G. S., Tahlequah Folio.

Devonian	Chattanooga formation with Sylamore sandstone member	0-140
Silurian	St. Clair marble	100
Ordovician	Tyner formation	60-100
	Burgen sandstone	5-100

As previously indicated, the Boone formation occupies by far the greatest area of any of these formations while the older rocks occur in the deeper stream valleys, and the younger ones on tops of the hills near the boundary between this area and the area of Pennsylvanian rocks.

Character and Development of the Clays.

The Burgen sandstone, St. Clair marble, Boone formation and Pitkin limestone contain no shale members of importance. The clays of the other formations are well described by Taff in the Tahlequah folio and his description will be used here.

"Clay shales occur in abundance in the Tyner, Chattanooga, Fayetteville, Morrow, and Winslow formations. All of these clay-shale deposits vary in their different parts in percentages of lime, sand and iron, but none were found of sufficient purity to produce a clay of high grade. A large part of the Tyner formation consists of greenish or bluish clay shale. There are thick beds of moderately soft, even-textured shale of this formation exposed in the valleys of Illinois River and Barren Fork northeast of Tahlequah.

"The Chattanooga shale is invariably an even, hard, laminated, siliceous clay shale containing an intimate mixture of finely divided bituminous matter. On burning or long weathering it changes to whitish hues. The Fayetteville shale is similar in character to the Chattanooga, but less homogeneous and softer. It contains less bituminous matter in the upper part, but more iron, which occurs in the form of ocherous concretions.

"The shales of the Morrow formation occur in the middle and upper parts. Those in the middle lie between beds of limestone and probably contain a large percentage of lime. The shales of the upper part are thicker, but more variable in constituents of lime and siliceous sand, being interstratified with both limestone and shaly sandstone beds. There are beds of even-textured shale, however, which may produce a brick clay.

"It is estimated that one-half of the Winslow formation consists of shales, which occur chiefly in the lower and upper parts. They range from very sandy deposits to clay shales which may be utilized in the production of bricks. Clay shales of the better quality outcrop in Skin Bayou Valley. They invariably contain a percentage of disseminated iron, but are believed to be almost free from lime. That part of the Akins member of the Winslow which is exposed in the Tahlequah quadrangle consists almost entirely of shales, a large part of which are similar to the better grades found in the upper part of the Winslow formations. These shales disintegrate readily, forming clay soils, and are not usually exposed."

The principal exposure of the Tyner and Chattanooga formations that promises favorably for development is in the valley of Barren Fork of Illinois River in T. 17 N., R. 24 E. The Muskogee branch of the St. Louis and San Francisco Railroad follows the outcrop of these shales for about six miles and careful work should show locations suitable for development.

The shales of the Morrow and Winslow are exposed in several hills near the line of the Kansas City Southern Railroad from Westville south to the limits of the area. These formations are exposed over wide areas in the region of Pennsylvanian rocks to the west and south and will receive more attention in that connection.

General Condition.

The shales of this area are confined to the deeper river valleys and to the higher hills. The country is a highly dissected plateau and for the most part is rather thinly settled. The St. Louis and San Francisco Railroad has four lines of railroad in the region; the main line from Vinita northeast through Afton; a branch north from Afton; the branch from Muskogee east through Tahlequah and Westville and a line east from Grove. Only one of these crosses the entire region. The Kansas City Southern Railroad enters the State at Stateline and continues to the southwest through Westville and Stilwell. Wood is plentiful over much of the area and oil, gas and coal occur in the region to the west. The comparative scarcity and small areal extent of the shales, the rough topography, and lack of railroads will prevent any extensive development of the clay industries in the region for the present, although there are opportunities for development in a smaller way to supply local demands. Soft mud brick are made on a small scale at Westville. This is the only attempt at development in the area.

THE PENNSYLVANIAN AREA NORTH OF ARKANSAS RIVER.

LOCATION AND AREA.

The area of Pennsylvanian rocks north of Arkansas River includes all of Washington, Nowata, Rogers, Wagoner, and Osage counties with the greater parts of Craig, Mayes and Tulsa counties. For convenience the non-red Permian rocks in Kay County are discussed in connection with this area.

STRATIGRAPHY.

INTRODUCTION.

The Pennsylvanian rocks of the State have recently been divided into four groups[1], the Muskogee, Tulsa, Sapulpa, and Ralston. These groups are the equivalents of forty-six formations, consisting of alternating limestones and shales which have been identified and mapped in Kansas. However, about the latitude of the Kansas-Oklahoma line these formations rapidly lose their identity; the limestones become lenticular and pinch out; the shales thicken greatly and two or more may coalesce due to the disappearance of the intervening limestones; sandstones come in and thicken very rapidly to the south. Very few of the formations named in Kansas have been traced as far south as Arkansas River and none of them appear beyond the river. It was consequently necessary to adopt some new basis of classification and the four groups were established to give this basis. The group names apply to the whole area of Pennsylvanian rocks but as the rocks and the formation names differ north and south of Arkansas River the two parts of the area are discussed separately in this report. The areas of each group are shown on the accompanying map (Plate 11). The two research bulletins[2] of the University of Oklahoma have been used extensively in the discussion of the Stratigraphy of the area north of the Arkansas.

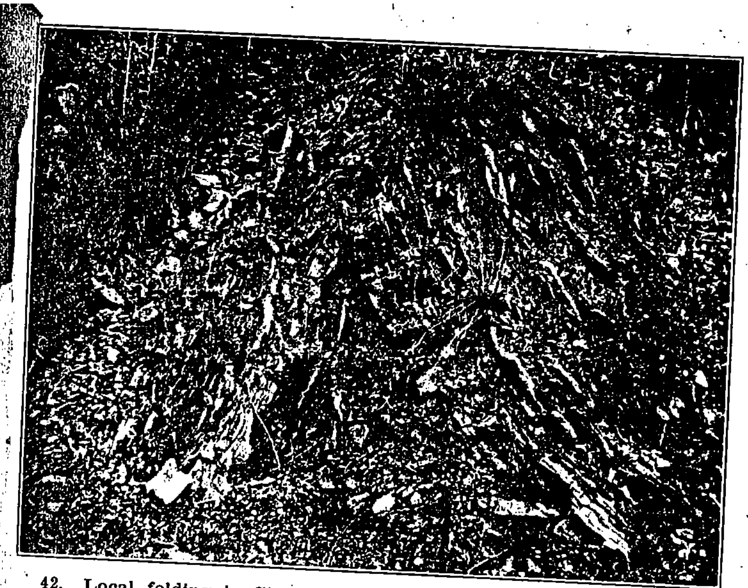
THE MUSKOGEE GROUP.

This group includes the series of sandstones and shales lying between the unconformity at the top of the Mississippian series to the east and the base of the Claremore (approximately the Ft. Scott of

1. Gould, C. N., Ohern, D. W., and Hutchison, L. L., Uni. of Okla. Res. Bull. No. 3.

2. No. 3. Proposed groups of Pennsylvania rocks of eastern Oklahoma by C. N. Gould, D. W. Ohern, and L. L. Hutchinson.

No. 4. The stratigraphy of the older Pennsylvanian rocks of northeastern Oklahoma, by D. W. Ohern.



42. Local folding in Simpson formation. Cut of Gulf Colorado and Santa Fe Railway south of Crusher.

Fig. 43. Top of Nowata shales under Lenapah limestone at Tulsa.

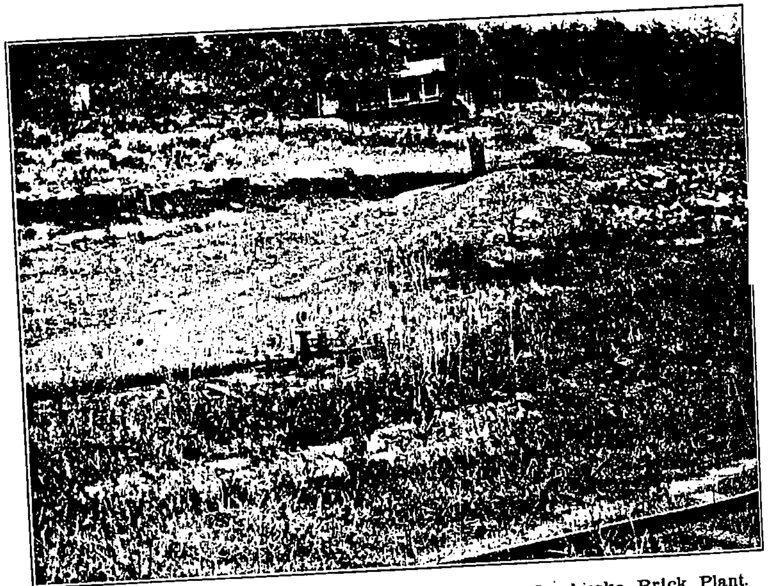


Fig. 44. Hill of shale capped by Elgin sandstone at Pawhuska Brick Plant.

Fig. 45. Steam shovel in pit of Pawhuska Vitrified Brick and Tile Company.

Kansas) formation and its approximate southern equivalent, the Calvin sandstone of the Coalgate quadrangle.

Vinita Formation.

The area north of Arkansas River is crescent shaped, bending around the Ozark uplift and terminated by the Kansas and Arkansas lines. The rocks of this area are all included in the Vinita formation by Ohern[1] which is approximately equivalent to the Cherokee shales of the Kansas geologists. He gives the following section from Pryor Creek to Claremore:

14.	Shale, with a few interbedded sandstones	135	feet
13.	Massive, medium-grained sandstone	17	feet
12.	Shaly sandstone	3	feet
11.	Argillaceous, heavily-bedded, fossiliferous limestone	2½	feet
10.	Bluish shale	35	feet
9.	Carbonaceous shale, capped by six inches of ferruginous, siliceous limestone	3	feet
8.	Gray, fine-grained sandstone	7	feet
7.	Arenaceous shale	70	feet
6.	Alternating shales and sandstones	70	feet
5.	Argillaceous, fossiliferous limestone	8	feet
4.	Massive, medium-grained sandstone	37	feet
3.	Shaly sandstone	8	feet
2.	Massive, medium-grained sandstone	14	feet
1.	Bluish shale, weathering to a light yellow, and a few interstratified sandstones	500	feet
		960	feet

The Cherokee shales or Vinita formation thickens enormously to the south and in the Muskogee quadrangle Taff differentiates three formations occupying the horizon of the Cherokee shales of Kansas. These are the Morrow, the Boggy and the Winslow. Since these have not been differentiated north of this quadrangle and since there is no development of the clay industries in the areas which have been differentiated north of the Arkansas, these formations will not be discussed in connection with this area. They will be noticed more fully in the discussion of the area south of Arkansas River. The only development of the

1. Loc. Cit. p. 12.

clay industry in the northern part of the Vinita formation is at Pryor Creek, Vinita and Claremore

At Pryor Creek the outcrop of the shale at the base of the formation (No. 1 of Ohern's section) spreads out in a broad, level plain to the west and northwest of the town. Over much of this plain the residual clay formed by the weathering of the shale is several feet in depth. A small plant, which uses this residual clay, is established about one-half mile north of the depot along the Missouri, Kansas and Texas Railway. The plant has been established very recently and only one or two kilns have been burned. The pit has been opened to a depth of about 12 feet over a small area. The material is light colored, rather sandy, stiff, residual clay. It is worked by picks and shovels and hauled to the plant in a bottom-dump car, by a hoisting drum. A corrugated-roll crusher prepares it for a 10-foot single-geared pug mill. A small auger machine is used. Bensing automatic cutters for drain tile and for end-cut brick are installed. Drying is conducted in closed rooms with a slotted floor. The end-cut brick show strong lamination, and some cracking in drying. It seems to require a comparatively high burning temperature to burn the brick hard enough to withstand the weather and to produce a sufficiently dark red color to be agreeable. The attempts at burning so far have not been entirely successful in regard to the brick, but it should be possible to produce good common brick from this material when its properties are understood. The drain tile have a good structure and appear to be burned hard enough to be satisfactory. They should of course, be tried in a small way before being used extensively. If they prove satisfactory there should be a good market for them, since almost all the land in the vicinity of Pryor Creek will be greatly improved by draining.

At Vinita, the plant of the *Vinita Brick Company* utilizes a blue shale which is apparently a part of the same horizon as the shale just discussed, i. e. No. 1 of Ohern's section, the massive shale at the base of the formation. The pit opening shows a section as follows:

Sandy soil	3 feet 0	inches
Soft sandstone	4-5	inches
Uniform blue clay shale	30 feet 0	inches

The blue shale is known to extend much deeper than the present level of the workings. The company controls 6 acres of the shale which may be considered an inexhaustible deposit for working purposes.

The shale grinds easily and works nicely through the auger machine. No trouble is experienced from cracking in drying, but the brick scums considerably. In burning, the brick whitewash badly from the scum, and there is also considerable trouble with melting and deformation of the arch brick and with black coring of the brick above the arches. Part of this trouble is probably due to not having the brick sufficiently dry when set in the kilns, and a great deal of it certainly arises from raising the temperature too rapidly during the early stages of burning. All of the troubles with the exception of the whitewashing can be overcome by careful drying and burning.

The plant is equipped with bottom-dump cars and hoisting drum, 9-foot dry pan, Fate single-geared pug mill and auger machine of 35-000 daily capacity, American 5-wire rotary automatic cutter, and 2-mold repress. An intermittent 5-track dryer heated by gas, and three rectangular updraft kilns are used. Gas was formerly used for fuel, but oil burners have been recently installed. Only common brick are made and few are shipped. The plant usually runs four months out of a year, the brick produced in this time being sufficient to supply the local demand. Sixteen men are employed when the plant is running.

The top of the Vinita formation, No. 14 of the section given, underlies the town of Claremore and is used at the plant of the *Howard Brick Company* which is located near the intersection of the St. Louis and San Francisco Railroad and St. Louis, Iron Mountain and Southern Railway at the north side of town. The pit workings cover about one-half acre and are 12 to 15 feet in depth. The material is a dark blue to black shale which is somewhat arenaceous. There is one thin layer of sandstone 4 to 6 inches in thickness. This is not used. The shale works nicely and burns to a good red color slightly discolored by whitewash. Common building brick and vitrified repressed brick for sidewalks are made.

The shale is blasted loose, thrown by hand into dump-cars and hauled to the plant by a hoisting drum. The equipment of the plant consists of a 9-foot dry pan; 12-foot single geared pug mill; auger machine of about 35,000 capacity; 6-wire, automatic, rotary cutter; and 2-mold repress. The dryer consists of 10 tunnels 80 feet long. The kilns are four in number and are of the rectangular, updraft type. A large percentage of the brick are loaded into cars on a switch from the St. Louis and San Francisco Railroad. Gas is used for fuel.

One of the few buff burning clays of the State is a fine-grained white clay which occurs in this formation about one and a half miles northeast of Vinita. It is very plastic and has too high a shrinkage to be suitable for manufacture by the stiff mud process but works well in the dry press. Details as to its occurrence and properties are given in the report of the test on Sample No. 280.

THE TULSA GROUP.

This group includes all the rocks between the base of the Claremore-Calvin formation and that of the Lenapah limestone. As shown on the accompanying map the part of the group north of Arkansas River is a strip extending in a northeast-southwest direction with a width of 12 to 20 miles, and including the northeastern part of Craig County, about two thirds of Nowata County, the northwestern half of Rogers County and eastern Tulsa County.

Stratigraphy.

The Tulsa group consists of the following formations named from the bottom upward: Claremore formation, Labette shales, Oolagah formation, and Nowata shales.

The Claremore formation is a succession of three limestones and intervening shales, with one prominent bed of sandstone and one or more beds of coal. It is approximately equivalent to the Fort Scott of Kansas. The thickness in the area under consideration varies from 50 to 150 feet. The lower shale of the Claremore reaches a workable thickness, but as it usually occurs in the vicinity of thicker and more accessible beds it has not been utilized. So far as is known, no tests have been made upon it.

The Labette Shales lie above the Claremore formation. In Kansas these shales are from 30 to 80 feet thick while in Oklahoma they thicken to the southward, and are about 135 feet thick northwest of Claremore and probably 200 feet thick in the Coody's Bluff region. They lie in the depression between the ridges formed by limestones of the Claremore and Oolagah formations. The outcrop is usually about two to three miles in width. From Coody's Bluff to Catoosa, Verdigris River follows the outcrop and the greater part is buried beneath the alluvium. The only development of clay industries in the Labette shales is a small plant at Broken Arrow.

This plant which is operated by W. R. Sullivan, is located on the Tulsa branch of the Missouri, Kansas and Texas Railway, just west of the town of Broken Arrow. The clay worked is a surface or residual clay, which has been worked to a depth of 12 feet. The material is carted to the plant. The soft mud process is used and the clay is prepared and molded in an "Iron Quaker" soft mud machine of 8000 daily capacity. Drying is by the rack and pallet system and is conducted in closed sheds as the clay is too tender to permit of drying in the sun or wind. Three updraft rectangular kilns of 100,000 capacity each are used. The daily output is 8000 of common building brick of good qualtiy. Gas is used for fuel.

The Oolagah formation lies above the Labette shales. In the southern part of the area under discussion the formation consists of layers of siliceous and cherty limestone. Near Talala the limestone split into two divisions which are separated by a shale which thickens to the northward and is continuous with the Bandera shale of Kansas. The lower limestone is equivalent to the Pawnee of Kansas, and the upper to the Altamont. The Bandera shale varies in thickness from nothing at Oolagah to 100 feet at the Kansas line. The exposures are all at some distance from any railroad and there has been no development of this shale in Oklahoma.

The Nowata shales form a very important horizon for the development of the clay industries of the State and deserve detailed description. For this purpose the portion of Ohern's paper dealing with them is given in full.

"Lying above the Oolagah formation and constituting the highest beds of the Tulsa Group, is a series of shales with a few interstratified sandstones and at least one bed of coal, for which the name Nowata shales is here proposed. The name is from the town of Nowata where the shales are widely exposed, and well developed. It is used by Hutchison in his unpublished work. (Fig. 43 shows the Lenapah limestone and the top of the Nowata shales at Tulsa.)

"Area: Near the Kansas line and east of Verdigris River, the Nowata shales occupy, but a narrow band between the escarpments of the subjacent and superjacent limestones. They also occupy irrregular areas along Snow, Crow, Hollow and Cedar creeks, generally lying on the slopes of elevations which are capped by the Lenapah limestone. West of the Verdigris they are first seen near the mouth of Hickory Creek three miles north of Lenapah, where, as shown on the map, they occupy but a narrow zone. The width of the outcrop at the vicinity of Talala is 5 miles. In the Claremore quardangle the width is still greater, the area being the most conspicuous in the quadrangle. East of Tulsa it is 8 miles, and not less than 10 at Arkansas River.

"The belt is a broad, flat plain whose monotony of surface is broken occasionally by the effect of thin sandstones. South of Nowata the belt is united with that formed by the shales lying near the base of the Sapulpa Group, the Lenapah limestone offering but feeble resistance to erosion.

"Thickness: The Nowata shales in their northward extension in Oklahoma are probably less than 50 feet thick, although Siebenthal gives the thickness as 55 feet near Coffeyville. At Nowata the drill shows that the thickness has increased to 130 feet. This increase continues until at Tulsa it is about 600 feet and probably still greater south of Arkansas River.

"For the most part the Nowata shales have no lithologic feature which is not possessed by others of the region. They generally are bluish or greenish in color, but give almost always, on weathering, a soil, green or buff according to the stage of oxidation of the iron. They are essentially clay shales, but not infrequently are highly arenaceous.

"Stratigraphy: The stratigraphy of the Nowata shales is simple. The lower part is almost wholly a mass of shale. Near Oolagah a massive sandstone about three feet thick lies about 35 feet above the base. This makes a well marked scarp which can be traced for a considerable distance along the strike.

"In the vicinity of the mouth of Rabb Creek other sandstones make noticeable escarpments, but sufficient data are not at hand to say whether they are more than mere local lenses.

"One of the most persistent stratigraphic features of the Nowata shales is a bed of coal. The most northernly point at which is was observed by the writer is about midway between Talala and Watova and two miles west of the railroad. From here southward, its outcrop follows a sinuous course passing just west of Talala and three miles west of Oolagah. Outcrops are frequent near Collinsville where the coal is mined, as well as in the vicinity of Coal Creek and near Dawson whence it is usually called the Dawson coal.

"In its northward extension the coal lies about 100 feet above the top of the Oolagah limestone, or about the middle of the Nowata shales. and maintains this relative position somewhat persistently. Hence its outcrop lies about midway between those of the Oolagah and Lenapah limestones.

"The coal is from 20 to 30 inches thick and seems to extend far to the southward of Arkansas River as shown by Taff[1].

"Correlation: The Nowata shales are at present to be correlated with the Walnut shale of Kansas. Whether the former are the exact equivalent of the latter, paleontological evidence must determine. But the limestones which limit the Nowata above and below are continuous with those which demark the Walnut shales in Kansas."

Development.

The only formation of the Tulsa group which has been developed is the Nowata shales. These shales are being worked at three localities in the area north of Arkansas River, at Nowata, at Collinsville and four and one-half miles east of Tulsa.

The shale worked by the *Star Brick Company* (west of the city of Nowata) is at the top of the Nowata shales and immediately beneath the Lenapah limestone, which forms stripping from nothing to 8 feet in thickness. This is used extensively for walks and walls in Nowata and almost all is removed without expense to the operators of the plant by parties wishing to use it. The shale is a uniform, blue shale which grinds easily, works nicely in the pug mill and auger machine and dries evenly, and with slight shrinkage. The burning color is a rich dark red. The shale from near the surface shows no whitewash, but that from a second bench, which has been started, shows some discoloration. The only trouble encountered is that fragments of limestone from the stripping occasionally get into a brick and cause it to be deformed in burning if carried to vitrification, or cause spalling or bursting of softer burned brick when they take up moisture. The rate of vitrification is slow and the paving block produced are very hard and tough. There are practically no overburned or deformed brick. The paving block are being used for pavements under construction in Nowata.

The plant is equipped with Raymond machinery consisting of a 9-foot dry pan, elevators, piano wire screens, No. 2 pug mill, "777" brick machine, rotary automatic cutter, and two Victor represses. Continuous tunnel dryers heated by gas, are built of brick and concrete. Three updraft rectangular kilns of 250,000 capacity are used for burning common brick and three, round, multiple stack, downdraft kilns. 30 feet in diameter, for repressed sidewalk brick and paving block. Gas is used for fuel. The plant is about one-half mile from the railroad

1. Bull. 260, U. S. G. S., 1905, pp. 396, 397.

and the brick which are exported must be hauled that distance in wagons. A large percentage of the output goes to supply the local demand.

A sample of a hard clay shale, which occurs about three miles southeast of Nowata, was shown at the plant just described. This shale occurs at the surface, is about 14 feet thick, covers several acres and is exposed about 1 mile from the St. Louis, Iron Mountain and Southern Railway and within 100 yards of the line of the proposed road to the southeast of Nowata. The material has been made up into trial briquets and burned on top of paving block which were fully vitrified. Under these conditions it burns to a light buff color and is very soft and porous. See report of test on page 191.

The horizon of the coal about the middle of the formation is also an important horizon for the clay industries as two large plants are using the shale above the coal in this region, at Collinsville and east of Tulsa.

The plant at Collinsville is operated by the *Coffeyville Vitrified Brick and Tile Company,* of Coffeyville, Kansas. The plant is located about one-fourth mile north of Collinsville on a switch from the Independence and Tulsa branch of the Atchison, Topeka and Santa Fe Railway. The company owns 30 acres of shale. Permanent buildings of brick have been erected for grinding, engine, boiler and machine rooms and development is on an extensive scale. Water is pumped from Caney River.

The shale is a hard, blue shale, free from concretions. The thickness varies with the contour of the hill. Over 30 feet has been worked in the middle of the hill. A vein of coal 28 to 30 inches thick underlies the shale about 20 feet below the present working level. The overburden is about 10 feet of weathered shale and sandstone. There are large quantities of sandstone bowlders which must be thrown out. The blue shale works nicely and gives no trouble, except some whitewash, which, as the shale is used for paving block and common brick, does not impair the usefulness of the material. The burned color is a good dark red, some brick showing the whitewash while others are free from it. The paving block are tested in a rattler at the plant and shows losses of from 15 to 23 per cent.

The pit is worked by a Vulcan Steam shovel and the shale hauled up an incline to the plant, by a hoisting drum, in rocking-dump cars of 2 cubic yards capacity. The mechanical equipment consists of two

9-foot dry pans, bucket elevators, stationary inclined piano-wire screens. storage bin with automatic feed by conveyor belt to pug mill, 15-foot single-geared pug mill, auger machine of 75,000 block capacity, rotary automatic cutter with four sets of eight wires, and four 2-mold represses and a large number of steel dryer cars. A traveling overhead electric crane with Francis automatic setter takes the brick from the dryer cars at the exit of the dryer and sets them in the kilns. All the machinery is of American Clay Machinery Company's manufacture.

The dryer consists of twelve tunnels, 100 feet long, built of brick and heated by waste heat which is drawn from the kilns by a large fan. There are three updraft rectangular kilns, each of 250,000 blocks capacity, with steam pipes arranged so that the heat may be returned through flues in the walls of the kilns. A large continuous kiln of 750,0000 block capacity is used. It is reported to be satisfactory for common brick, but to require too long a period of hard firing to produce vitrified block.

The power plant is equipped with three boilers, two high pressure and one low pressure. A 250 H. P. Corliss engine furnishes power for the pug mills, auger machine and represses. A 75 H. P. Atlas engine drives an alternating current generator and a 90 H. P. Erie engine drives a direct current generator which furnish power for a 35 H. P. motor that drives the dry pans, to operate the traveling crane and automatic setter, to light the plant and also furnish light for town, and to pump water from Caney River. Gas is used for fuel under the boilers and in the kilns.

The plant of the *Tulsa Paving and Building Brick Company* has recently been installed four and one-half miles east of Tulsa near Dawson, on a switch from the Oklahoma branch of the St. Louis and San Francisco Railroad. The buildings are permanently constructed of brick and the equipment is all new.

The shale worked is that overlying the Dawson coal and seems to be very similar to that worked at Collinsville. In the small opening so far made, about 18 inches of soil is stripped, below this is 10 feet of the brown shale and then 10 feet of the blue shale to the coal vein. The thickness to the coal vein will vary from 30 to 40 feet back in the hill. The shale gives no difficulty in drying or burning except for some whitewash. It is blasted loose and thrown into bottom-dump cars by hand and hauled up an incline to the plant by a hoisting drum.

The plant is well equipped with C. W. Raymond Company's machinery consisting of three 9-foot dry pans, bucket elevators, stationary piano-wire screens, large single-geared pug mill, "999 special" brick machine, 23 wire rotary automatic cutter, three represses, and a Berg 4-mold dry press with automatic feeder. A 500 H. P. Corliss engine drives the machinery.

Ground is leveled for a 20-tunnel, continuous, gas fired dryer of which only six tunnels are built. Two scove kilns have been built and filled, but only one has been burned (Feb. 1911). The brick show a dense, firm structure, and a good red color. Some brick whitewash rather badly while others are entirely free from discoloration. Judging from the brick in the arches, the shale should make a good vitrified body with little danger of over burning or melting. Ground is leveled for the construction of permanent updraft and downdraft kilns. One hundred men will be employed when the plant is running.

THE SAPULPA GROUP.

Stratigraphy.

This group includes all the rocks above the Lenapah limestone and below the base of the Pawhuska limestone. The outcrop occupies a belt 25 to 30 miles wide. North of Arkansas River it includes Washington County, eastern Osage County and western Tulsa County. The stratigraphy of the lower part of the group in this region is discussed by Ohern in Research Bulletin No. 4. The upper part exposed in the Pawhuska quadrangle, has been worked out by the United States Geological Survey, but the results have not been published. The group is equivalent to a large number of well defined formations in Kansas consisting of alternating limestones and shales. In Oklahoma, the nature of the rocks changes rapidly; the limestones thin out and disappear or become lenticular, the shales thicken and become more arenaceous, and many sandsones come in and thicken to the southward.

In the Nowata quadrangle, north of a line passing east and west, about 2 miles south of Ramona, Ohern[1] gives the following formations: (1) Lenapah limestone, (2) Curl formation, (3) Wann formation, consisting of the Hogshooter limestone and Copan members with two limestone lenses, the Dewey and Avant, and (4) Stanton limestone.

Of these, the Curl formation, and Copan member of the Wann formation are discussed in this connection.

The Curl formation consists of clay shale of a greenish or bluish

1. Op. Cit., p. 25 et seq.

color in the lower portion and of arenaceous shales and sandstones in the upper part. The thickness is about 300 feet. The outcrop is a belt 6 to 10 miles in width extending from the Kansas line nearly south through western Nowata County. These shales are available to railroad transportation at Elliott and Lenapah on the St. Louis. Iron Mountain and Southern Railway, and east of Ramona on the Independence-Tulsa branch of the Atchison, Topeka and Santa Fe Railway. There has been no development of these shales and so far as known, no tests have been made.

The Copan member of the Wann formation consists of a succession of shales and sandstones with limestone lentils, two of which, the Dewey and Avant are conspicuous. It is practically the equivalent of the Wilson formation, as mapped in the Independence (Kans.) quadrangle. The outcrop near the Kansas line is about 12 miles wide, but narrows to the southward. The thickness is about 250 feet. Sandstones predominate in the basal portions and near the top of the formation. With the exceptions of certain limestone lentils, the middle portions are shale.

The shale just below the Dewey limestone is exposed in several small areas to the east of Bartlesville. Here it is a brown to blue color (depending on degree of oxidation), arenaceous and micaceous shale. A hill about 40 acres in extent just northeast of Bartlesville about the middle of the north line of section 8, T. 26 N., R. 13 E., offers favorable opportunities for development.

A chemical analysis of a sample of this shale, taken at the point where the interurban line turns to the north in going from Bartlesville to Dewey, gave the following results:

Silica	
Iron oxide	68.60%
Alumina	4.91%
Lime	14.99%
Magnesia	1.32%
Sulphur trioxide	1.63%
Loss on ignition	none
	4.70%
Total (alkalies not determined)	96.15%

The shale would probably run rather high in alkalies as it is micaceous.

From the analysis the shale should be suitable for any of the ordinary clay products and should not give any particular difficulty in manufacture. No burning tests have been made.

The shales from about the same horizon were formerly used at a small plant at Ochelata. This plant has not been operated for the past 4 or 5 years. The shale from above the Hogshooter limestone near the base of the Copan beds at Ramona was tested for this report. The description of the occurrence and report of test on the sample (No. 159) is given in Chapter VII.

The shales of the upper part of the member immediately above the Avant limestone lens are well exposed at Avant. The hills to the northwest and southeast of the townsite on the opposite sides of Bird Creek are both composed of shale. A well on top of the hill to the southwest penetrated over 50 feet of blue shale containing small ironstone concretions without reaching the bottom of the deposit. The hill to the northeast seems to be of precisely similar material although the surface shows a brown color due to the oxidation of the blue shale. Ironstone concretions are present. This hill is a fine location for a clay products plant. The supply is practically inexhaustible as the hill is over 70 feet high and covers an area of 100 or more acres. A switch less than one-half mile in length could be built from the Midland Valley Railroad over level ground to the foot of the hill. Gas is already at hand in abundance at a very low price. The properties of the shales are given in the reports on samples 328 and 329 in Chapter VII. No. 328 is the blue shale from the hill southwest of the townsite and No. 329, the oxidized shale from the hill to the northeast.(1)

The shales of the top of the Copan beds or Wilson formation are well exposed in cuts of the Midland Valley Railroad at Big Heart. Sample No. 277 shows this material to be well adapted for the manufacture of brick and tile. The railroad is at hand and gas for fuel can be had at a very low price.

From the line between the Nowata and Claremore quadrangles south to Arkansas River, Ohern divides the Sapulpa group into the Skiatook formation and Ramona formation.

The Skiatook formation consists largely of shales with some sandstones. The continuation of the Lenapah limestone lies at the base and is immediately succeeded by 150 feet of clay shales. The outcrop of the formation is a belt 6 to 15 miles wide extending west of south from Ramona to Arkansas River between Tulsa and Wekiwa. The shales of the formation are available at Skiatook and Turley on the

(1) Since the above was written a brick plant of 50,000 daily capacity has been installed at this location.

Midland Valley Railroad and the lower portions at Tulsa where they are utilized by three plants.

The formations of the Sapulpa group exposed above the Stanton limestone have not been definitely named in Oklahoma. The formations mapped in the Independence quadrangle continue to the southwest, but as is the case with the lower formations there is a decided increase in the arenaceous element and the limestones largely disappear. The following outline of the stratigraphy of the Pawhuska quadrangle is given by E. Z. Carpenter who has spent two field seasons in the quadrangle. Beginning at the bottom of the section:

(1) Approximate equivalent of the of the Wilson formation of the Independence quadrangle (Wann formation of Ohern)—— feet.

(2) Approximate equivalent of the Buxton formation of the Independence quadrangle.

Subdivided as follows:

(a)	Sandstone called Bigheart sandstone, by Hutchison in unpublished thesis[1]	175 feet.
(b)	Sandy and clay shales	85 feet.
(c)	Sandstone (Nelagony sandstone)	40 feet
(3)	Elgin sandstone	90-150 feet.

The nature of the shales in the Wilson formation has been discussed in the preceding paragraphs.

The shales (b) of the Buxton (?) formation are shown at the crossing of the Midland Valley and the Missouri, Kansas and Texas railroads at Nelagony. The hills on the southeast and southwest of the townsite are composed of shale represented by sample No. 241. The hill to the southwest is capped by sandstone (Nelagony sandstone); but most of it has been eroded so that the stripping would not exceed 6 to 8 feet and a very large amount of the shale is available with little or no stripping. The sample was obtained from a test hole 15 feet deep near the foot of the hill and the base of the sandstone is at least 25 feet above the level of the top of the hole. The thickness is therefore over 40 feet. This shale is apparently underlaid by a red shale represented by sample No. 242. The thickness of this shale could not be determined, but over 10 feet shows in a small gully, along the Midland Valley Railroad. Water for manufacturing purposes can be obtained from Bird Creek and gas for fuel can be piped from a distance of 4 or 5 miles. Owing to these conditions and the excellent

1. Univ. of Okla. Library., 1907.

transportation facilities this is certainly a good location for a clay products plant. Northwest of Pawhuska the upper division of the Buxton (?) forms a large hill which is capped with the Elgin sandstone.

Development.

The development of the clay industries in the Sapulpa group north of the Arkansas consists of plants at Bartlesville, Sapulpa and at Pawhuska.

Bartlesville. The lower part of the shale between the Dewey and the Stanton limestone is worked by the *Bartlesville Vitrified Brick Company,* at their plant one mile southwest of the Bartlesville station along the Missouri, Kansas and Texas Railway. The pit covers about one-half acre and has been worked to a depth of about 20 feet, the upper 10 feet being soil and weathered shale and the lower 10 feet a hard blue shale. The soil contains some fragments of limestone which cause white spots in the brick or sometimes cause them to burst. The fresh blue shale shows some discoloration from whitewash. The properties of the clay are more fully discussed in the report of tests for sample No. 271. The pit is worked by a Marion steam shovel and the shale hauled to the plant in bottom-dump cars by a hoisting drum. The machinery consists of two Raymond 7-foot dry pans, an American auger machine of 60,000 capacity, Raymond No. 2 cutter, and two 2-mold represses. The dryer has twenty-one tunnels, each tunnel holding eleven transfer cars. These are five rectangular updraft kilns of 250,000 to 300,000 capacity and six 30-foot round downdraft kilns. The product is practically all common building brick although some repressed brick are sold for sidewalk and paving purposes. The brick are loaded onto cars on a switch connecting with the Missouri, Kansas and Texas and Atchison, Topeka and Santa Fe Railroads. Gas is used for fuel. The plant employs about forty men.

Tulsa. The plant of the *Tulsa Vitrified Brick and Tile Company* is located along the Missouri, Kansas and Texas tracks about one-half mile northwest of the passenger depot. The company owns seven and one-half acres of shale which makes a low hill at this point.

The pit shows the following section from the top down:

Residual brown to red clay	4- 6 feet
Brown oxidized shale	10-15 feet
Blue shale	10-12 feet

The whole face is worked together, the surface clay being mixed

with the shale. The workings cover about one-fourth acre. The blue shale has been prospected to a depth of 40 feet below the bottom of the present pit so that the supply is practically inexhaustible. The working qualities of the shale are excellent and, except when too great a proportion of the surface clay is used, there is practically no drying or kiln loss. The majority of the brick burn to a pleasing dark red color free from discoloration, but considerable whitewash shows in part of them. This is probably due to a greater proportion of the blue, unleached shale being used. Vitrified paving block and common building brick are made. The vitrified block show a uniform shape and good firm structure. They have been used for face brick in several buildings in Tulsa.

The pit is worked by a Thew automatic shovel and the shale hauled to the plant in rocking-dump cars by a hoisting drum. The mechanical equipment consists of a Raymond and a Stephenson 9-foot dry pan, elevators, stationary inclined screens, Freese pug mill and auger machine of 60,000 brick capacity, Freese automatic rotary side-cut cutter, a Victor and an Eagle repress. An Atlas 120 H. P. engine drives the dry pans and a Sampson engine the other machines.

The dryer consists of twenty tunnels directly heated by gas. The action is continuous. Six rectangular updraft kilns and two round downdraft kilns are used. The rectangular kilns have capacities of from 150,000 to 400,000 block and the downdraft of 50,000 block. Gas is used for fuel throughout the plant. Forty men are employed.

The plant of the *Tulsa Brick Company* is located at the foot of a large hill of shale at the north side of the city. A pit opening 80 feet deep has been made in the side of the hill. The face shows 5 to 8 feet of soil and weathered shale which is stripped and 75 feet of homogeneous blue shale. This is blasted loose and hauled to the plant in dump cars by means of a hoisting drum and wire cable.

The dry-press process is used. The equipment consists of a Frost 9-foot dry pan, elevators and inclined screens, and an American 4-mold dry press of 20,000 daily capacity. The brick are set directly into the kilns which are of the rectangular updraft type and four in number. Gas is used for fuel. The product is a good grade of red face brick and common builders. Most of the product is disposed of in Tulsa. The brick which are shipped must be hauled to a loading switch one-half mile distant.

The plant of the *Acme Brick Company* is located on the opposite side of the hill from that of the Tulsa Brick Company. The plant is of the same size and capacity and the raw material, product and manufacturing conditions are the same.

Pawhuska. The shale underlying the Elgin sandstone is used by the *Pawhuska Vitrified Brick and Tile Company* at their plant one-fourth mile northwest of the city limits of Pawhuska along the Midland Valley Railroad. The company owns 5 acres of land which is underlaid by shale over 100 feet in thickness. Fragments of sandstone occur plentifully on the surface of the hill, but not in sufficient quantity to prevent their being used along with the shale. (fig. 44.)

The shale is a clay shale of concretionary structure and varies in color from tan to steel blue. Its working, drying, and burning qualities are excellent. The shrinkage is slight and there is practically no cracking in drying or burning. The burned color is a good dark red somewhat marred by whitewash. The vitrified brick from the arches show a good firm body and there is very little melting or deformation. There is a very gradual change from salmon brick to the vitrified brick and all the appearances indicate a long vitrification range. This with the other properties of the shale renders it well adapted for use as paving brick or vitrified face brick.

The pit is worked with a Thew steam shovel (fig. 45) and the shale hauled up an incline to the plant in a rocking-dump steel car of 2 cubic yards capacity, by a hoisting drum. The plant is equipped with Raymond machinery consisting of a 9-foot dry pan, single geared pug mill, "777" brick machine of 50,000 capacity, No. 2 automatic rotary cutter and two 2-mold represses. There are three intermittent drying sheds built of brick with galvanized iron roofs. Gas pipes are laid in trenches under the car tracks. Two permanent rectangular updraft kilns have been built and there are four adobe (scove) kilns which are to be replaced by permanent ones. It is planned to build downdraft kilns for burning vitrified paving brick. The brick are loaded from the kilns directly into cars on a switch from the Midland Valley Railroad. Gas is used for fuel throughout the plant. About twenty-five men are employed. The report of the tests on this shale may be found on page 189.

THE RALSTON GROUP.

This group lies above the Sapulpa group and outcrops in a belt lying to the west of that of the latter group. The outcrop is about 20 miles wide and includes the western parts of Osage and Pawnee Counties and eastern Payne County. North of Arkansas River the

group consists of limestone, sandstones and shales which are gray to brown in color. South of this river the limestones die out and the shales become red in color. In other words the group merges with the Redbeds. This change is shown on the accompanying map (Plate 11). None of the formations recognized north of the Arkansas have been definitely traced as far south as the Cimarron.

Stratigraphy.

The stratigraphy of this group north of the Arkansas is as follows[1], beginning at the bottom:

(1)	Pawhuska formation	165 feet
(2)	Sandstones and shales and limestones	250 feet
(3)	Limestones and shale (Burlingame of Kansas)	175 feet
(4)	Wreford limestone. Base of Permian.	

The sandstones, limestones and shales between the Pawhuska and the Wreford are in great measure lenticular so that a detailed section in one locality will not correspond to a section a short distance away.

Some of the shales of this region may be thick enough to be considered as available for development, but there has been so little detailed field work that it is impossible to discuss any of them in this report. There is at present no development of the clay industries anywhere in the territory occupied by the outcrop of the Ralston group. It lies just outside the present oil and gas field and unless these fuels are found cannot be considered as promising any great development in the future, since gas burned brick can be shipped in as cheaply as the brick can be burned with imported fuel.

THE NON-RED PERMIAN AREA.

As shown on the accompanying map (Plate 11) there is a triangular area of non-red Permian rocks comprising most of Kay County and the extreme western part of Osage County. The rocks of this region consist of alternating limestones and shales, the limestones being much more prominent. The shales are thin and usually calcareous so that there is little prospect of extensive development in this section. South of Arkansas River the rocks change to a red color and merge with the Redbeds.

1. For this section I am indebted to Mr. E. Z. Carpenter.

Development.

The only development of the clay industries in this region is at Blackwell, where the shales near the line between the red and non-red Permian are worked by the *Blackwell Oil and Gas Company*. The plant is located one mile southeast of Blackwell on the Wellington-Tonkawa branch of the Atchison, Topeka and Santa Fe Railroad.

The pit is worked to a depth of 15 feet in shale, the top 6 feet of red shale and the remaining 10 feet of blue shale. Five to six feet of gravel is stripped from the surface and is used as ballast by the railroad. There is a layer of gypsum 4 to 12 inches thick at the bottom of the blue shale. The shale works and dries well, and burns to a dark, brick-red color somewhat marred by white spots due to lumps of some substance in the clay, possibly gypsum. Small cracks often appear in the brick, starting from these white lumps. They do not, however, apparently appear to weaken the brick. The white lumps and this cracking could probably be avoided by finer grinding and screening.

The pit is now drained by pumping, but a cut which is being made through the hill will soon give drainage for the whole pit. The shale is worked by a Marion steam shovel and is hauled up an incline to the plant in bottom-dump cars, by a hoisting drum. The plant is equipped with Raymond machinery consisting of a 9-foot dry pan. elevators, perforated screens, 12-foot single geared pug mill, "777" auger brick machine, 15-wire rotary automatic cutter, 2-mold repress and small auger machine for drain tile. The dryer has eight tunnels. 90 feet long, built of brick with a brick subtunnel for gas pipe. Three rectangular updraft kilns, each of 400,000 capacity, and one rectangular downdraft kiln of 185,000 capacity are used. The output is all common brick, no drain tile having been made.

THE PENNSYLVANIAN AREA SOUTH OF ARKANSAS RIVER.

LOCATION AND AREA.

This area is bounded on the northeast by Arkansas River on the east by Arkansas, on the south by the Arbuckle and Ouachita mountains and on the west by the eastern line of the Redbeds. (The lower portion of the Redbeds is of Pennsylvanian age, but for convenience all of the Redbeds are placed in one area for discussion in this report.) There is also a small area of rocks of Pennsylvanian age south of the Arbuckle Mountains (The Ardmore Basin), but as these rocks were involved in the uplift of the Arbuckle Mountains they have been considered in the Arbuckle Mountain region. As limited in this report the area under consideration includes all or part of the following counties: LeFlore, Sequoyah, Haskell, Latimer, Pittsburg, McIntosh, Tulsa. Pawnee, Creek, Okmulgee, Okfuskee, Hughes, Seminole, Pontotoc, Garvin and Murray.

STRATIGRAPHY.

The Pennsylvanian rocks south of the Arkansas are divided into the same groups as those north of the river.

MUSKOGEE GROUP.

The area of this group includes Haskell, McIntosh, Muskogee and Coal, the eastern parts of Okmulgee and Hughes, and the northern parts of Atoka, Pittsburg, Latimer, and LeFlore counties.

Stratigraphy and Development.

This group is represented by the Vinita formation in the area north of Arkansas River and is only 450 feet thick at the Kansas line. It thickens rapidly toward the south, probably both by normal thickening of the beds and by overlap until in the Coalgate quadrangle it has reached the enormous thickness of 9000 feet. In the Muskogee quadrangle the group is about 1500 feet thick. Here Taff[1] names two formations, the Winslow, 800 to 1000 feet thick and the Boggy, 500 feet thick. In the Coalgate quadrangle (Coal and southern Hughes County) the same author names the following formations, the oldest below:[2]

Senora formation	140- 485 feet
Stuart shale	90- 280 feet
Thurman sandstone	80- 280 feet
Boggy shale	2000-2600 feet
Savanna sandstone	1000 feet
McAlester shale	1800-2000 feet
Hartshorne sandstone	150 feet
Atoka formation	3100 feet

The outcrop of the formations from the Atoka to and including the Boggy, extend to the east through the coal fields of Pittsburg, Latimer and LeFlore counties, where they have been mapped by Taff[3].

1. U. S. Geol. Survey, Muskogee Folio. 1906.
2. U. S. Geol. Survey, Coalgate Folio, 1901.
3. U. S. Geol. Survey, 19th Annual Rept., Pt. III, and 22nd Annual Rept., Pt. II.

The Atoka formation outcrops over an area of between 200 and 300 square miles in the valley of Clear Boggy Creek in the northern portion of the western extension of Atoka County and in southern Coal County, and as a belt from 2 to 18 miles wide which extends northeast from Atoka and lies along the north side of the Choctaw fault. There are also exposures in the eroded anticlines to the north of the eastern portion of the coal fields. At the Oklahoma-Arkansas state line the formation has a thickness of between 6000 and 7000 feet[1] and consists largely of blue clay and sandy shales with occasional ferruginous concretions. There are four groups of sandstone strata, each about 100 feet thick, separated by intervals of approximately 1000 feet. To the west the two lower groups of sandstone are cut out by the Choctaw fault and the two upper groups cannot be traced beyond western LeFlore or central Latimer counties. The combined thickness of the shales is about five times that of the sandstones.

In the western portion of the outcrop, in southern Coal and northwestern Atoka counties, the Atoka formation is much thinner than in the eastern portion. The following description[2] applies to this region:

"With the exception of thin lentils of limestone and of calcareous cherty sandstone near the base in the northwest and northeast corners of the quadrangle, the rocks of the Atoka formation are sandstone and shale. They are estimated to be nearly 3000 feet in thickness, the shale as a whole being very much thicker than the sandstones. The formation is divided by the sandstone strata into shale members varying from thin sheets to beds several hundred feet in thickness.

"The shales are friable clays and sandy clay shales and crop in smooth valleys and in the lower slopes of ridges and hills. Under such conditions fresh exposures of the shales are exceptional and little is known of their original color or physical appearance. When partly weathered, however, they show various shades of yellow and blue. Some fresher exposures in sec. 11, T. 2 S., R. 9 E., on Clear Boggy Creek and in Delaware Creek Valley, show dark-blue to black clay shales

"The sandstone beds are many, and vary from thin plates embedded in shale to massive strata making prominent sandstone members. These thicker sandstones are generally variable in thickness and would be classed as lentils. Several of these occur in the upper part of the formation east of Clear Boggy Creek and make prominent ridges, especially in their northern outcrops. Another member near the base makes local rough sandstone hills southeast of Wapanucka..........

In the northeast corner of the Atoka quadrangle and in the southeast corner of the Coalgate quadrangle west of the great fault, the lower beds of the Atoka formation have been so folded and faulted that the same beds are repeated many times in long, narrow, parallel belts for a width of nearly a mile. Southeast of this faulted strip the sandstone and shale beds are folded and steeply inclined toward the southeast."

1. Taff, J. A., U. S. Geol. Survey, 22nd Annual Rept., Pt. II, 1900, p. 273.
2. Taff, J. A., U. S. Geol. Survey, Atoka Folio, 1902, p. 5.

The Atoka formation is exposed near railroads in several localities. The western part of the outcrop is crossed by the Missouri, Oklahoma and Gulf Railway north of Wapanucka and by the Ardmore branch of the Chicago, Rock Island and Pacific between Wapanucka and Olney. The main line of the Missouri, Kansas and Texas Railway follows or lies near the outcrop from 2 miles south of Atoka for 12 or 15 miles to the north. In the eastern part of the exposure the belt along the north side of the Ouachita Mountains is crossed by the main line of the Chicago, Rock Island and Pacific Railway between Folsom and Wilburton; by the Paris branch of the St. Louis and San Francisco between LeFlore and Folsom, and by the Kansas City Southern between Houston and Thomasville. No detailed work with reference to location of available clay deposits has been done in any of these localities, but such work would certainly reveal workable deposits near transportation. There is no development of clay industries in this formation and the only samples have been tested from it are Nos. 298 and 299 from Atoka and 69, 70, and 71 from Wilburton. These samples are entirely suitable for common brick and tile, and probably for face brick. It should be borne in mind that these samples represent only small portions of a vast thickness of clay shales of great areal extent and that shales of the same formation from different localities or from different horizons in the formation may show widely different properties. Samples 69, 70, and 71 are from the Atoka formation near Wilburton in the eastern part of the outcrop. They are from different levels of the formation and show considerable variation. The shrinkage of 70 and 71 is very high, but this may be due to the samples being slightly weathered. The shrinkage could be reduced by adding a sandy clay like No. 69. All of the outcrop of the Atoka formation is near the coal fields so that the fuel question need not be a serious one.

The McAlester shale lies above the Atoka formation and is separated from it by the Hartshorne sandstone. It includes a belt in southern Coal County which starts at the northeast corner of T. 1 N., R. 12 E., and extends southwest to Coalgate. This portion of the outcrop is from 2 to 3 miles wide. At Coalgate the outcrop swings to the south and widens until it is about 6 miles in width, but gradually narrows southward and directly west from Atoka turns to the northeast and continues along the south side of the McAlester and Eastern Choctaw coal fields as a narrow belt from one-half to two miles in width which lies just north of the belt of the Atoka formation previously mentioned and is separated from it by a range of hills composed of the Hartshorne sandstone.

Near the Arkansas line the outcrop widens greatly and most of the area of T. 6, 7 and 8 N., in R. 26 and 26 E., is underlaid by this formation. A belt from 2 to 5 miles wide extends around the north side of Cavanal Mountain, Potato Peaks and San Bois Mountain, and connects with the southern belt at Red Oak. As in the case of the Atoka formation there are possibly exposures of the McAlester shale in the anticlines to the north of the eastern coal fields but the exposures have not been worked out.

The nature of the McAlester shale is shown by the following quotations from Taff.

For the western part of the outcrop he gives the following description[1]:

"Shale, sandstone, and clay constitute this formation. Its thickness is estimated to be nearly 2000 feet, and the total thickness of the shales is nearly ten times that of the sandstones. The shales are laminated and are blue and black when freshly exposed. They are chiefly clay shales, though sandy shales and shaly sandstones occur interstratified with them. Two local beds of sandstone in the lower half of the formation, separated by nearly 400 feet of shaly strata, outcrop in low ridges west and southwest of Lehigh. Two or more thin beds of sandstone occur also in the upper part of the formation, and in places make low hills, but their ledges usually do not outcrop. In the western part of the Lehigh basin, where the rocks dip at low angles, the various beds occur in broader areas. Between the low ridges of sandstone the shale surfaces are spread in wide, flat, and shallow prairie valleys. In the eastern part of the basin where the formation is steeply upturned, the outcrops are narrow. The surface is more elevated and the harder beds make rough low hills and ridges. Like the Hartshorne sandstone the sandstones of this formation occur in the western part of the Lehigh basin, while in the eastern portion many of the sandstone beds are replaced by chert coglomerates."

1. U. S. Geol. Survey, Atoka Folio, 1902, p. 5.

For the eastern part of the coal fields the following description is given:[1]

"This formation occupies the largest area of any occurring in this coal field, and its coal beds are the most numerous and the most economically important. On account of the soft nature of its beds the surface is worn down nearly to a level, and the generally low dips of its rocks permit successful mining of its coal beds in relatively large areas..

"The McAlester shale is estimated to range from 2000 to 2500 feet in thickness. The measurement in the western part of the field gives nearly 2000 feet and in the eastern part about 2500 feet of strata. Since the dips are variable both along and across the strike, the estimates for thickness are only roughly approximate.

"Several sandstone beds occur in the McAlester shale, but none are continuous, so far as can be determined, throughout the field. As a whole, however, they become generally thicker and more prominent at the surface from west to east. Many of the sandstone beds can be traced several miles, but none can be accurately mapped, even within the limits of their occurrence. These sandstones are generally thin bedded, though locally they are massive and form ridges. Like most other sandstones in the Coal Measures in this field, they are fine grained in texture and brown in color, and are usually hard, but are sometimes friable, when they are worn down with the shales so that their edges are concealed. Where the sandstone beds are thickest and are not cut down by streams they form low, nearly level-topped ridges. Such ridges occur between Redoak and Wilburton, in the vicinity of Fanshawe, and between Wister and Howe, north of the Choctaw, Oklahoma and Gulf Railroad. In Brazil Creek Valley north of Redoak some upper layers of these sandstones are exposed on the low arch of the Brazil anticline and produce low, irregular hills. North of Brazil post office and between Cameron and Shady Point some of the sandstone beds are locally much increased in thickness. North of Brazil, especially, one of the sandstones occurs in massive beds, making a wide ridge. The prominence of this ridge, however, is due in part to the structure, the sandstone being nearly horizontal.

1. Taff. J. A., and Adams, G. I., U. S. Geol. Survey, 22nd Annual Rept., Pt. II, pp 275 and 276, 1900.

"'The shales of this formation probably aggregate more than five times the thickness of the sandstones, though their natural exposure can rarely be found. The occurrence and areal extent of these shales may be determined with comparative ease and accuracy by studying the soil and the surface configuration of the country. On careful examination of the surface it will be found that the most insignificant sandstone bed makes its presence known by a ridge or rising ground or by its undecomposed talus or debris. The soil of the country above the shale outside of the flood plains of the streams has been produced by decomposition of the rock in place, so that the soil becomes an index to the nature of the rocks beneath. Outside of the immediate stream valleys the shales produce a clay loam and usually form prairie lands. The shale of the McAlester formation, as shown by the prospect drill and other artificial means, as well as by occasional natural exposures by streams, is generally some shade of blue, although black bituminous shales are commonly associated with the coal seams. The shales are always laminated or stratified in thin beds, and vary from bed to bed in the quantity of sandy material they contain."

The McAlester shale is excellently situated with regard to railroads. It is available from the following railroads: Atoka-Oklahoma City branch of the Missouri, Kansas and Texas Railway from two miles west of Atoka to Coalgate; the Ardmore branch of the Chicago. Rock Island and Pacific from its crossing with the Oklahoma Central Railroad to Cairo; the main line of the Chicago, Rock Island and Pacific for most of the distance from McAlester to the Arkansas line: the Paris line of the St. Louis and San Francisco, between Pocahontas and Wister, and between Poteau and Jennison; the Kansas City Southern Railroad between Panama and Shady Point, and between Poteau and Heavener. (See Fig. 46); the main line of the Missouri, Kansas and Texas in the vicinity of McAlester; and the Fort Smith and Western Railroad at different localities between Coal Creek and Quinton.

The McAlester shale is the great productive coal horizon of the State, the Hartshorne coals occurring near the bottom of the formation and the McAlester coals in the upper portion. The immense thickness of shale in the formation, combined with the extensive outcrop and the good railroad facilities together with an unfailing source of fuel at hand will certainly make this region one of the principal sections in the development of the clay industries in the future. Fig. 46 shows the outcrop of the Hartshorne coal at the base of the McAlester shale near Heavener.

The only development in this shale at present is at McAlester where the *McAlester Brick Company* works the shale represented by Sample No. 40. The stiff mud process is used and a large number of building and paving brick have been turned out. The slightly over burned brick have been used to excellent advantage as face brick in the construction of the Busby theatre in McAlester. The earlier street paving in the same city was constructed of these brick. Sufficient care was not taken in rejecting soft brick and the pavements are wearing somewhat rapidly. If properly vitrified the shale should be a good paving material.

The clays which form the floors and the roofs of the coal mines in this formation, should be investigated more in detail than has been possible for the preparation of this report. Only a few samples have been tested so that any general statements made concerning these clays must be regarded as tentative.

In general none of these clays seem to be high grade, i. e. No. 1 or No. 2 fire clays. Several of them are No. 3 fire clays, for example, Nos. 287 from McAlester, 47 from Alderson, and 10 from Coalgate. Others are so carbonaceous that it is impossible to oxidize them in a commercial way, e. g. 44 and 45 from Hartshorne, and 285 and 286 from Midway. The majority of the underlying clays in the western part of the coal fields seem to be of this character as small samples sent to the Survey laboratory from Lehigh and Atoka, are very carbonaceous. As mentioned above, No. 10, an underlying clay from Coalgate, can be oxidized. There is also considerable variation from clay from different beds in the same region for instance, sample 44 and 45 from the roof and floor of the Rock Island Coal Mining Company's Mine No. 8 at Hartshorne, cannot be oxidized, while samples 46 and 47 the roof and floor respectively of the same company's Mine No. 5 at Alderson are both good material, the roof giving a magnificent red color and fine structure for face brick, roofing tile or paving brick and the floor promising well for paving brick and sewer pipe. While no high grade fire clays are known to occur in this region, only a small percentage of the available deposits have been tested and it is entirely possible that such material may be found.

The Winslow formation. North of the region just described, along Arkansas River the Atoka, Hartshorne, and McAlester formations cannot be separated and the rocks equivalent to the three formations are grouped into the Winslow formation, named from Winslow, Arkansas. The lower 200-400 feet of the Winslow is believed to represent the

Atoka and Hartshorne while the remainder is equivalent to the McAlester[1].

The Winslow outcrops in eastern Muskogee County and northern Haskell and LeFlore counties. The thickness is from 800 to 1000 feet in Muskogee County, but increases toward the east to 1500 feet at the Arkansas line.

The following excerpts from Taff's description of the formation as given in the Muskogee folio show the nature of the formation:

"The Winslow formation consists of bluish and blackish clay shale, sandy shale, brown sandstone, and thin beds of coal. The sandstone beds for the most part occur in two groups, one near the base and the other above the middle of the formation.

"The rocks near the base and below the lower body of sandstone are interstratified sandstone and shale beds. The sandstones are for the most part thin or shaly, but in places are thick and massive and occur at the base in contact with the limestone of the under lying Morrow formation. Locally they are coarse grained at the base and may contain small rounded pebbles of quartz. * * *

"On the lower group of sandstone and shaly beds rests a deposit of shale composed chiefly of clay. Locally sandy shale or thin sandstone may occur in this position, but not of sufficient thickness or hardness to become apparent in the surface of the land. * * *

"The upper group of sandstones consists of yellowish-brown beds interstratified with bluish clay shales. These beds are in part ferruginous and are generally soft, except where segregations of iron have locally indurated the rock. * * *

"From the top of the upper group of sandstone beds shale continues to the top of the formation. Locally variable shaly sandstone beds and beds of thin coal occur in the shale. Accurate determinations could not be made, but it is estimated that the thickness of this shale does not exceed 100 feet."

This formation is worked at Muskogee. The plant of the *Muskogee Vitrified Brick Company* is located on a switch from the Missouri, Oklahoma and Gulf Railroad, one mile north of the Missouri, Kansas and Texas depot on Mill Street. Forty acres of land underlaid by shale are controlled by the company and an opening 25 feet deep has been made over an area of about an acre. The deposit reaches a considerable depth below the level of the present pit. The shale is a dark blue to black, somewhat carbonaceous material, overlaid by 3 to 4 feet of soil which is used with the shale. The working qualities are good and no difficulty is encountered except some cracking when too large a proportion of the surface material is used. The burned color is a rich, dark red free from whitewash. Owing to its carbonaceous nature, rather slow firing is necessary to prevent black coring. The shale is blasted loose and thrown by hand into bottom-dump cars and hauled up an incline to the plant by a hoisting drum.

1. Taff, J. A., U. S. Geol. Survey, Muskogee Folio, p. 4, 1906.

The plant is equipped with the American Clay Machinery Company's machinery consisting of three 9-foot dry pans, elevators and stationary screens, pug mill and auger machine of 100,000 daily capacity and 8-wire rotary automatic cutter and two 2-mold represses. There are two dryers, one of 12 tunnels heated by direct heat and one of 17 tunnels heated by waste heat. Nine round downdraft kilns, each of 55,000 capacity, are used. Power is furnished by a 250 H. P. Corliss engine. The product is principally common building brick, but a large number of repressed pavers are made. These have been used for paving in Muskogee with satisfaction.

Sample No. 38, a clay shale from one mile southwest of Muskogee and 39, a sandy shale from 2 miles northeast of Muskogee are from the Winslow formation.

The Savanna formation lies above the McAlester shale. In the eastern Choctaw coal field it consists of basal, middle and lower sandstones with two beds of shale. The whole thickness of the formation in this region is 1200 to 1500 feet. It outcrops in the lower slopes of the mountains such as Cavanal, San Bois and Poteau. In the McAlester district the formation forms ranges of hills on one of which the town of (South) McAlester is built. In this district there are five sandstone beds separated by shales. To the southwest in the Lehigh-Coalgate region the sandstones become cherty. The formation is well exposed as ranges of hills which extend southwest from McAlester past Savanna to near Coalgate. Here the outcrop splits on account of folding, one branch runs south in the direction of Atoka, a second extends west and south passing just east of Coalgate and Lehigh and turns to the east uniting with the first branch; in other words it surrounds the syncline known as the Lehigh Basin. Another branch extends west from Coalgate past Nixon.

The shales of this formation equal or exceed the thickness of the sandstones, but on account of the great resistance of the sandstones to weathering they appear to form the bulk of the formation. The shales as a rule, are lighter in color and are more sandy than those of the McAlester formation. They are worked by the *Choctaw Pressed Brick Company* at the plant one mile east of McAlester on the Chicago, Rock Island and Pacific Railroad.

The company owns 6 blocks of land and has a pit opening covering about one-half an acre to a depth of 25 to 30 feet. The upper 10 feet is residual clay and weathered shale with sandstone fragments, the lower 20 feet of brown shale grading into blue at the bottom. The shale is blasted loose, loaded by hand into dump cars and hauled up an incline to the plant by a hoisting drum. Two 9-foot dry pans are used for grinding and two Ross-Keller 6-mold presses for molding.

There are five rectangular updraft kilns, one of 620,000 capacity and four of 280,000 each. Wood is used as fuel for water smoking and slack coal for finishing. The product is dry-press common and face brick. About half of the product is used in McAlester, and the other half shipped to neighboring towns. The brick are of a clear dark red color and of very dense structure for dry press. No difficulty is encountered in manufacture.

The shales of the Savanna formation are worked at Poteau at the plant of the *Poteau Brick Company* in the northwest part of the city. The plant is reached from the St. Louis and San Francisco and Kansas City Southern Railways. The pit is worked to a depth of 10 to 16 feet. The shale is blasted loose and shoveled onto horse carts. A Frost 9-foot dry pan is used for grinding and a Ross-Keller 4-mold dry press for molding. The brick are burned in three rectangular updraft kilns of a capacity of 225,000 each. Natural gas is used for fuel. The shale used is that represented by Sample No. 171.

The fire clay underlying the coal vein in the vicinity of Poteau is represented by Sample No. 172. It is an excellent material. Details of its occurrence and properties are given on page 156.

The Savanna formation is well exposed in San Bois Mountain, but thins very rapidly to the north and apparently disappears before the south line of the Muskogee quadrangle is reached, so that in the region immediately south of Arkansas River the Winslow, the upper part of which is equivalent to the McAlester, lies directly beneath the Boggy.

The Boggy shale lies above the Savanna formation in the south part of the area under consideration and above the Winslow formation in the northern part of the same area. The Boggy is exposed over large areas in northern Coal, southeastern Hughes, and western and northwestern Pittsburg, central Latimer and LeFlore counties. In the last two counties it forms the upper portions of Cavanal, Poteau and San Bois mountains and of Potato Peaks. (see fig. 47.) For these regions it has been mapped and described by Taff in his different papers. The same author maps an area of the Boggy formation in the southwest portion of the Muskogee quadrangle (south-central Muskogee and northeastern McIntosh counties). The formation doubtless outcrops in considerable area in the Canadian quadrangle, (northern Pittsburg and most of McIntosh counties) and in the San Bois quadrangle, (Haskell, northeastern McIntosh and southeastern Muskogee counties) but nothing has been published on the stratigraphy of this region.

The following quotations from Taff give descriptions of the formation in different parts of its area.

In the eastern Choctaw coal field, he describes it as follows:(1)

"To those acquainted with the surface rock of Cavanal and San Bois mountains the word 'shale' doubtless would not seem to be appropriately applied to this formation, because of the great mass of sandstone bowlders and talus known to occur in many places on its upper slopes. In spite of the apparent prominence of the sandstone, it makes relatively a very small part of the formation when compared to the shale. The sandstone strata altogether will not much exceed 400 feet, while there is nearly 2000 feet of shale in this field. Excepting one mass of sandstone, which occurs about 400 feet below the crest of Cavanal Mountain, the beds very much resemble those of the formations below in character and composition. They are chiefly thin bedded, brown in color, and of fine texture. The single sandstone referred to is generally massive and has a thickness of nearly 100 feet. In places it is white or a light shade of pink, and resembles very much a consolidated deposit of pure sand. The shale, as in other formations in this field, is rarely well exposed. In the mountains it is usually concealed by sandstone talus and debris. Immediately below the massive sandstone referred to there is about 400 feet of even-textured blue clay shale. This section is exposed at the west end of the main peak of Cavanal Mountain. The lower part of the Boggy shale as well as that above the main sandstone is, on the whole, more sandy, as shaly sandstone and sandy shale are interstratified with the clay shale. Exposures of this shale are very limited in extent. As in the lower forma-

(1) U. S. G. S., 22nd Ann. Rept., Pt. II.

tions, the determination of the character of the shaly beds is a matter of interpretation from surface indications of soil and disintegrated rock."

The following description[1] applies in the Atoka and Coalgate quadrangle:

"Above the Savanna sandstone there is a mass of shales and sandstone interstratified aggregating a thickness of 1200 to 2000 feet. This collection of strata has been named the Boggy shale because of the broad extent of their outcrop in the Boggy Creek valleys. There are probably in the formation not less than 20 sandstone beds, ranging in thickness from thin strata to probably 50 feet and separated by shales which in some places exceed 600 feet.

"The sandstones vary but little in physical character, and are generally brownish or gray, and in places rather ferruginous. The shales are exposed only to a very limited extent on account of the generally low relief of the land and the wide, shallow valleys of the streams; but in the few steep slopes and stream cuttings where fresh exposures were observed they consist of laminated, bluish clay shale, containing small ironstone concretions and thin wavy sandstone plates and shaly sandstone beds. * * * In the larger area, in the central part of the quadrangle, the beds are generally nearly horizontal. By erosion the soft clays and shale beds are removed, leaving the sandstone capping low flat hills and mesas and low gently-sloping ridges with terraces upon the exposed ledges.

"As a result of the broad exposures of sandstone and shale due to the low dip of the rocks, there are produced on their surfaces quite extensive stretches of hilly timber land and still broader areas of smooth grassy plains, corresponding respectively to the sandstone and shale areas."

The lower portion of the Boggy as exposed in the southwest corner of the Muskogee quadrangle is described as follows:[2]

"Character. The Boggy formation is composed of bluish clay shale, sandy shale, and gray or brown sandstone. The shale and sandstone occur in alternate strata, and the shale in the aggregate is thicker than the sandstone. There are twelve or more groups of sandstone beds separated by thicker deposits of shale which include thin sandstone and shaly sandstone strata.

(1) U. S. G. S., Coalgate Folio.
(2) U. S. G. S., Muskogee Folio.

"In the Muskogee quadrangle only the lowest sandstone and its inclosing shale members are exposed. The basal deposit is a comparatively soft shale, approximately 200 feet thick * * *. The lowest shaly strata, lying above the sandstone, occur in the southwest corner of the quadrangle. A bed of bituminous coal, 2 feet 6 inches thick, occurs in this shale near the base. It should be found to crop out across the southwest corner of the quadrangle. * * *

"The greatest development of the sandstone members of the Boggy formation is found along the Canadian River Valley in the Canadian quadrangle, which adjoins the Muskogee quadrangle on the southwest. From the Canadian Valley, both toward the southwest and northeast, there is a gradual thinning of the sandstone beds and of the formation as a whole. In both directions there is an introduction of limy strata in the shale, with thinning of the sandstones. This thinning of the sandstones or their gradation into shaly deposits becomes so pronounced farther north that the formation cannot be distinguished north of Arkansas River. Formations lying above the Boggy have been traced from Arkansas River to the Indian Territory-Kansas line, showing that the 2000 feet or more of the Boggy formation in the Canadian River Valley must be correlated with a part of the Cherokee shales of southeastern Kansas."

The Boggy shale is accessible to transportation at several localities in the portions of its outcrop which have been mapped and there are doubtless many localities in the region which has not been mapped where the shale is exposed near railroads. This is especially true of the territory along the Ft. Smith and Western Railroad in eastern Hughes, northern Pittsburg and southern Haskell counties. The northern part of the outcrop is in the oil and gas field and the southern part in the coal fields, so that fuel is abundant.

At present there is no development in the area of the Boggy which has been mapped. Plants are located at Crekola, Wainwright and Boynton which use shale which is almost certainly from the upper part of the Boggy, although the field work which has been done is not sufficient to determine this definitely. It may be that they belong to a higher horizon, possibly that of the Stuart shale of the Coalgate quadrangle.

The plant of the *Muskogee Pressed Brick Company* is located at Crekola, 8 miles southwest of Muskogee on the Fayetteville-Muskogee branch of the St. Louis and San Francisco Railroad. The location is also accessible from the Missouri, Oklahoma and Gulf Railroad. The shale occurs in a large hill to the north of the station. The shale is blue in color and apparently of uniform composition. Sample No. 174 is from this deposit.

The pit, which has recently been opened, is worked by hand, the shale being shoveled onto dump wagons and hauled to the plant. The product is dry press brick of a red color and of good structure. The plant is equipped with a 9-foot dry pan and a Berg 4-mold dry press. Two rectangular updraft kilns of 150,000 each are used. Gas is used for fuel.

The Wainwright Adamant Brick Company has recently established a plant at Wainwright, 18 miles southwest of Muskogee on the Missouri, Oklahoma and Gulf Railway. The shale bed is on almost level ground one-fourth mile southwest of the depot. The pit is at present opened to a depth of 10 feet in a brown clay shale which is somewhat micaceous, with an over burden of 3 feet of sandy soil. At the bottom of the pit the shale becomes blue. The pit is drained by a ditch. The dried brick show considerable lamination, but no cracking. The color of the vitrified brick is rather dull, dark red with small black spots. There is some melting in the arches and some kiln loss due to cracking. The latter is probably due to the presence of too large a proportion of the sandy soil which is used with the shale.

The shale is blasted loose, loaded by hand in a bottom-dump car and hauled up an incline by a drum hoist. The plant is equipped with Raymond machinery consisting of a 9-foot dry pan, bucket elevators, inclined perforated screens, pug mill and auger machine of 50,000 daily capacity and an 11-wire rotary automatic cutter. The dryer consists of twelve tunnels, directly heated by gas. There are four updraft rectangular kilns of 250,000 to 300,000 capacity each. Gas from wells southwest of the town is used for fuel.

The best equipped brick plant in Oklahoma and one of the best in the entire country is that of the *Francis Vitric Brick Company*, which is located at *Boynton*, 19 miles southwest of Muskogee on the Fayetteville-Okmulgee branch of the St. Louis and San Francisco Railroad.

The company owns 80 acres of land, all of which is under-laid with shale. Forty acres is a hill of from 30 to 50 feet above the level of the plant. The pit opening is being made in the end of this hill, and now has a face of about 20 feet in height. This will increase to 30 to 40 feet back in the hill. The shale shows for 45 feet in a

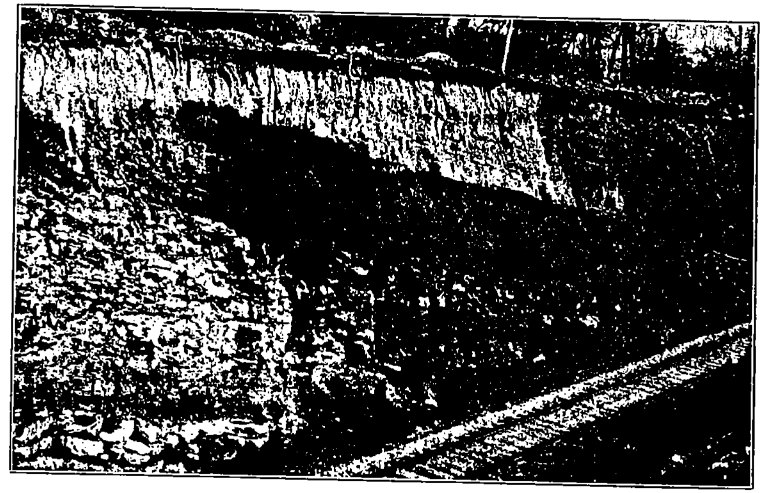


Fig. 46. Exposure of Hartshorne Coal near the base of the McAlester shale (Near Heavener, Le Flore County.)

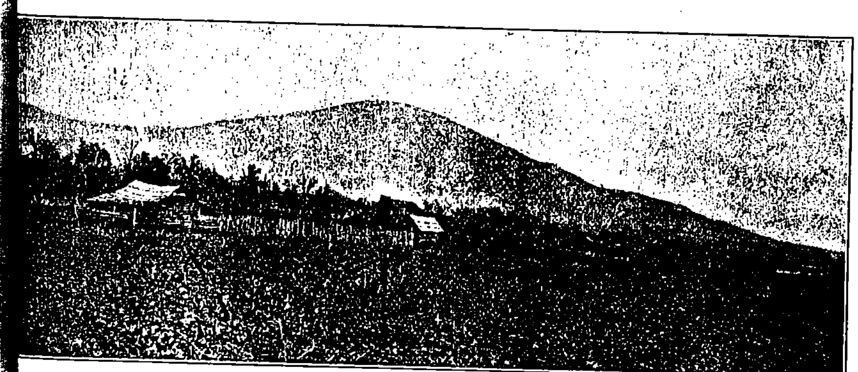


Fig. 47. Sugar-loaf Mountain near Poteau. (Boggy Shale.)

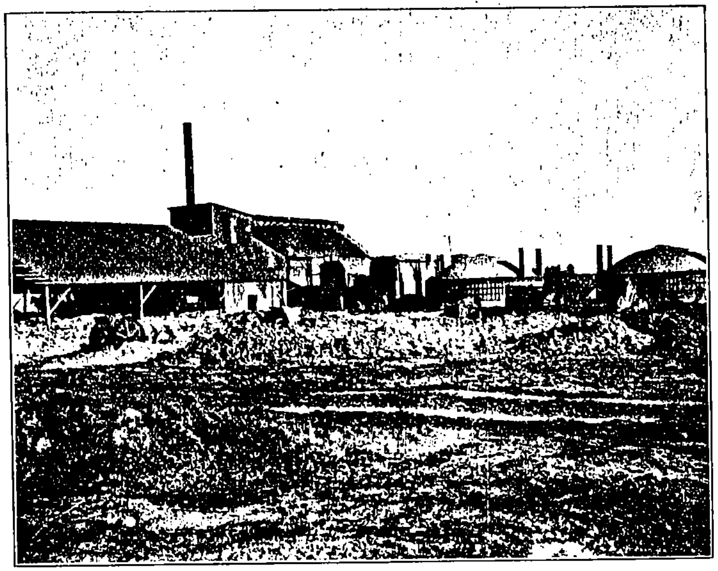


Fig. 48. Plant of Ardmore Brick and Tile Company at Ardmore.

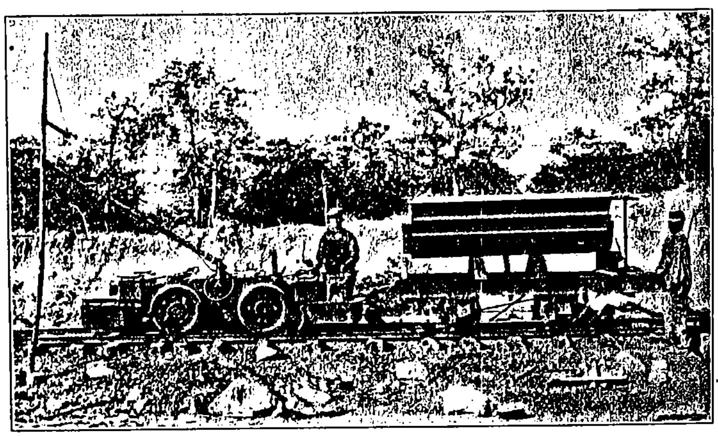


Fig. 49. Motor car and rocking-dump car used at Cleveland.

well at the plant which was started 20 feet below the bottom level of the pit workings. This shows the thickness of the shale bed to be at least 110 feet. In other words the deposit is practically inexhaustible.

Before the plant was located here a large hole was dug to a depth of over 30 feet on top of the hill, and a carload of the clay from it was shipped to Coffeyville and Cherryvale, Kansas, and tried out with the well known shales used at the plants there. It proved to be very similar in working and burning properties to those shales and is reported to stand up well at temperatures at which the Cherryvale shale was deformed.

The pit is worked by a 95-ton Vulcan steam shovel, and the clay loaded on side-dump motor cars, operating on a third rail track. Two cars are used, a small siding giving passing room. From the shovel to the siding the cars are controlled by switches at the shovel and from the siding to the plant by switches at the dumping floor.

The shale is dumped into a large bin, fed through a Climax jaw crusher and elevated to an automatic feeder for the dry pan. The latest type of 12-foot dry pan is used. The grinding floor under the mullers is mounted separately from the screening floor and at a higher level. The floor under the mullers has a speed of 90 revolutions per minute while the screening floor has a speed of only 20 revolutions per minute. With this construction there are no sweeps to return the large pieces under the mullers. Only a small amount remains on the screens and this is re-elevated and passed under the mullers again.

From the dry pan, the ground shale is elevated to a long, concave, conveyor belt which passes over large storage bins which have a capacity of two weeks run for the plant (1,500,000 block). The belt passes through an automatic tipple, which divides the stream of clay equally and delivers it to both sides. This tipple may be set over any part of the bins or so as to deliver directly into the automatic feeder for the pug mill.

From the automatic feeder the clay passes through a large double-geared pug mill and down into a Giant auger brick machine with a daily capacity of 100,000 brick. A new type of rotary automatic cutter is being installed.

A new model 4-mold repress is used and another of the same type is being installed; most of the product is repressed. From the repress or the off-bearing belt, the brick or block are set up in units of 1142 brick upon a platform which consists of an endless apron revolving slowly so that as soon as one unit is completed it has moved far enough to give space on the platform for another. These units are picked up by a Francis automatic setter suspended from an electric traveling crane having a capacity of 7 1-2 tons and a span of 70 feet.

The dryer and kiln shed is built at right angles to the building containing the machinery and storage bins, and is 70 feet wide and 300 feet in length, built of structural steel, with a corrugated iron roof. The track for the electric crane extends the whole length of the shed. The dryer is of the open top type to permit the use of the automatic setter. The walls are built of brick and concrete and the slotted floor is of concrete. There is a large central tunnel running the length of the dryer with branch tunnels beneath the slotted floors. The waste heat used in the dryer is drawn from the kilns by a large fan.

The kilns are of the rectangular updraft type with steam jets arranged to return the heat through flues built in the walls. This type of kiln is used extensively in the Kansas plants with marked success. Only two large kilns have so far been built, but others will be constructed as soon as the plant is in full operation.

Power is furnished for the plant by a 275 H. P. Buckeye gas engine which drives a 250 volt, direct current generator. Each machine in the plant is driven by a separate motor supplied with power from the large generator. This arrangement eliminates all line shafting and belting. The power of the motors used varies from 5 H. P. for some of the elevators to 85 H. P. for the auger machine. The plant is lighted by electricity.

Gas for fuel is obtained from three wells owned by the company. These wells are located near Wainwright and show capacities of from 10,000,000 to 15,000,000 cubic feet per day. The gas is carried to the plant through 5 miles of 5-inch pipe line. Water for cooling the engine and for tempering the clay is pumped from Cloud Creek by an electrically driven pump.

The plant has its own machine shops equipped with all necessary machinery. All the buildings are of permanent construction of brick and steel. The whole plant is arranged to permit of doubling the present capacity without adding to the buildings except by the construction of another dryer and kiln shed, which is to be built on

the side of the machine room opposite to the shed now used. This will transform the building from an "L" to a "T" shape.

The Stuart shale is the next formation which contains shale in commercial quantities. It lies above the Boggy formation and is separated from it by the Thurman sandstone. The Stuart shale is composed of three members, an upper and a lower shale separated by a sandstone of variable thickness. The lower member consists chiefly of bluish and black laminated clays, which have a thickness of 120 feet in southern Hughes and northern Coal counties. The upper member is composed of bluish shales 50 to 120 feet thick. The lower member outcrops as a plain to the north and west of the high, stony hills of the Thurman sandstone. The upper member ordinarily outcrops in the slopes of the hills capped by the overlying Senora formation. The formation is well exposed at Stuart on the Chicago, Rock Island and Pacific Railway from which town the formation takes its name. No tests have been made on these shales and there is at present no development at this horizon.

The Senora formation lies immediately above the Stuart shale. It has a thickness of about 500 feet in northern Coal and southern Hughes counties, of which the lower 320 feet is of sandstone which forms high and rugged hills. This grades through sandy shales into a shale member, which is about 160 feet thick. This shale member is composed of blue, clay shales and brownish, sandy shales. There have been no tests on shales from this formation in the region where it has been mapped and there is no development at present.

The formations above the Boggy have not been mapped to the north of Canadian River. The Thurman, Stuart and Senora can probably be mapped through eastern Hughes, and Okmulgee and western McIntosh and Muskogee counties, although it may be necessary to apply other names as the sandstones probably thin out and disappear to the north.

In eastern Hughes and Okmulgee counties the shale horizon at the top of the Senora contains coal. One vein has been mined at Dustin, Lamar, Henryetta and Morris and farther north at Broken Arrow, Catoosa, Claremore and Chelsea. Good deposits of shale are reported from this horizon at Dustin and Henryetta, but no official tests have been made.

The clay above this coal vein is worked by the *Okmulgee Coal and Brick Company* at their plant at Gaither, four miles east of Okmulgee on the Fayetteville-Okmulgee branch of the St. Louis and San Francisco Railroad. The shale pit has been worked to a depth of about 15 feet over an area of one and three-fourths acres. The overburden consists of from 2 to 3 feet of soil which is used with the shale. The shale for the upper 10 or 12 feet is slightly weathered and is of a brown color. The lower 2 to 3 feet is a dark blue color. The shale is often concretionary in structure and there are several kidney shaped ironstone concretions. The iron in these seems to be all limonite. The larger concretions are thrown out as the cars are loaded. A three and one-half foot vein of coal underlies the shale a few feet below the pesent workings. The clay under the coal is only 18 inches thick and is reported useless.

There is no trouble experienced with the shale at any stage of the manufacturing process. There is very little lamination, slight shrinkage and practically no cracking in drying or burning. The burned color is rich, rather dark red, free from whitewash. The vitrification range is long and there is very little evidence of overburning even in the arch brick. The paving block from the downdraft kilns are completely vitrified, but show little kiln marking. The vitrified brick are very tough. Rattler tests have been made at Guthrie where the brick were used for paving, in which an average loss of 9 per cent. is reported.

The shale is loaded by a steam shovel onto steel rocking-dump cars of 2 cubic yards capacity and hauled up an incline to the plant by a hoisting drum. The mechanical equipment of the plant consists of a 9-foot dry pan, bucket elevator, stationary inclined screens, a combined 12-foot double geared pug mill and auger machine of 75,000 brick daily capacity, an 8-wire rotary automatic cutter and Eagle repress. All machinery is American Clay Working Machinery Company's make. A Frey-Scheckles 2-mold dry press is installed, but no dry press brick have been made for some time. The brick are dried in a continuous dryer, built of brick, of 32 tunnels, 40 feet in length. A subtunnel for the heat extends under the entire length. Each tunnel has a stack and there is no forced circulation.

There are seven rectangular updraft kilns of 225,000 capacity and eight round downdraft kilns, 30 feet in diameter with capacities of 40,000 paving block or 50,000 common brick. Four of the downdraft kilns are connected to a central stack, and the other four are of the multiple stack type, each having four stacks. Gas is used for fuel. About 45 men are employed in all parts of the plant.

The plant of the *Morris Brick and Coal Company* is located about 300 yards southeast of that of the Okmulgee Coal and Brick Co. The same bed of shale is used at both plants, but that from the Morris pit differs from the other in showing a strong tendency to whitewash. Since the shale in this pit is used down to the coal vein while in the other pit the 2 or 3 feet immediately above the coal is not used it seems probable that the soluble salts are in this portion and the whitewashing might be avoided by discarding this shale. The overburned brick also puff badly and some black coring was noticed. Owing to these qualities the use of the shale from this pit as material for paving brick is doubtful. It makes a good firm common brick, however.

The pit is worked with drag scrapers and the shale loaded on to a bottom-dump car through a trap, and hauled up an incline to the plant by a hoisting drum. The mechanical equipment consists of a 9-foot dry pan, bucket elevator, inclined stationary screen, Fate combination pug mill and auger machine of 40,000 daily capacity, and a Bensing automatic ("Ferris wheel") side-cut cutter. A long off-bearing belt carries the brick to the front of the kilns and they are set in the kilns without drying.

Six rectangular updraft kilns are used each holding 280,000 brick. Gas is used for fuel under the boilers and in the kilns. Only common brick are produced by this plant. About twenty-five men are employed.

THE TULSA GROUP.

Stratigraphy.

The Tulsa group south of Arkansas River consists of shales, sandstones, and an occasional limestone lens. Only a very small portion of this area, the extreme northwestern corner of the Coalgate quadrangle. has been mapped. In this region Taff describes four formations which fall in this group. These are in descending order:

Holdenville shale	250 feet
Wewoka formation	700 feet
Wetumka shale	120 feet
Calvin sandstone	200 feet

The outcrop of the east line of the Calvin sandstone is approximately shown on the occompanying map (Pl 11). It contains no shale members of any importance.

The Wetumka shale has been traced north from the Coalgate quadrangle across the Wewoka quadrangle, (northern Hughes and southern Okfuskee counties), but the maps have not been published. The formation in the Coalgate quadrangle is composed of friable, laminated. clay shales, 120 feet thick and has an outcrop of about two miles in width. The surface of the outcrop is a belt of rolling land lying between the hills of the Calvin sandstone to the east and those of the Wewoka formation to the west. The formation is named from the town of Wetumka in Hughes County. The level land around Okmulgee is probably the outcrop of this formation. The formation has not been traced to the southwest of the region which has been mapped in the Coalgate quadrangle. Clay shales, which occur at Ada, are probably at this horizon.

The Wewoka formation consists of seven members of alternating sandstones and shales. The shales vary in thickness from 40 to 120 feet. For the most part they are blue clay shales with large numbers of fossils. No tests have been made on these shales and no detailed field work has been done for this report so it is impossible to say anything specific concerning their availability.

The Holdenville shale has been mapped only in the extreme northwestern part of the Coalgate quadrangle, although it is known to occupy extensive areas farther to the north. Taff(1) describes it as follows:

"This shale, 250 feet in thickness, rests upon the Wewoka formation and its crop in this quadrangle is limited to a small triangular area in the northwestern corner. The surface of the formation becomes broader northward in the more level country about Holdenville, 3 miles north of the border of the quadrangle.

"The formation is composed of friable, blue clay shale with local thin beds of shelly limestone and shaly calcareous sandstone in the upper part. The sandstone ledges outcrop in terraces around the slopes of the hills bordering the north side of Little River. The thin limestone occurs about 35 feet below the top of the formation, and its outcrop is usually covered by the sandstone and conglomerate debris from the overlying formation. In its usual exposure 1 to 2 feet only of shaly limestone may be seen. At other places a bed of shell breccia loosely cemented is found, representing the thin hard plates of the shelly rock. The shales are rarely exposed. The smooth grass-covered prairie soil, however, even in the steep slopes, bears evidence of the friable shale beneath."

The area in eastern Okfuskee and western Okmulgee counties may be regarded as the northern extension of the formations just described

(1) U. S. G. S., Coalgate Folio p. 5.

or as the southern extension of the formations of the Tulsa group described by Ohern(1). However, the limestones which occur north of the Arkansas, disappear before or soon after crossing that river and since the limestones are usually taken as the limits of formations to the north, it is improbable that the formation names used by Ohern will apply south of the river.

Development.

The only development of the clay industries in the Tulsa Group south of Arkansas River is at the extreme south end of the outcrop at Ada. The horizon is not definitely known but it is probably that of the Wetumka shale. The plant which is operated by Messrs. Cooper and Bones is located 2 miles southeast of Ada on the Atoka-Oklahoma City branch of the Missouri, Kansas and Texas Railway. The material used is a soft, brown clay shale. An excavation 20 to 30 feet deep has been made over an area of 1 acre. The material is very uniform. Only dry-press brick have been made. The material has been tried by the stiff-mud process for brick and hollow ware, but it shows a strong tendency to crack in drying so that the attempt to work it by this process has been abandoned.

The clay is blasted loose and hauled to the plant by scrapers. It is ground in a 9-foot dry pan and molded in a Ross-Keller 4-mold dry press of 20,000 daily capacity. There are two round downdraft, one rectangular downdraft, and two rectangular updraft kilns. The brick burn to a dark red color and are of good structure. They are well suited for use as common and face brick. The plant has a switch from the railroad and a large part of the production is loaded on to cars. Coal is used for fuel. Twelve men are employed under ordinary conditions.

THE SAPULPA GROUP.

Stratigraphy.

This group south of the Arkansas consist of a great, but undetermined thickness of shales and sandstones, which outcrop in Seminole, Okfuskee and Creek and in eastern Pawnee and Lincoln counties. No detailed mapping has been done and the formations are unnamed except for the Seminole conglomerate which occurs at the base of the group. In eastern Payne and Lincoln counties this group grades into the Redbeds and forms part of the "Chandler beds" of Gould[1].

(1) Univ. of Okla., Research Bull. No. 4.
(1) See Page 254.

Development.

The only development of the clays in the Sapulpa group in this area is the extreme northern portion at Sapulpa in Creek County, and Cleveland in Pawnee County. The shale which is worked at Sapulpa is the southern extension of the Skiatook shales, while that at Cleveland is almost certainly near the horizon of the shales at Pawhuska, which have already been described. An interesting shale at Bristow is represented by sample 317.

The descriptions of the plants at Sapulpa and at Cleveland follow:

The plant of the *Sapulpa Brick Company* is located about one mile west of the St. Louis and San Francisco Railroad station on the north side of the track of the Monett-Quanah division. The same shale which forms the bed rock under the town here forms a pronounced ridge. The plant has been recently installed and so far only a small opening about 25 feet in depth has been made in the shale. About 10 feet of the top of the bank is slightly weathered and is a brown color while the lower part is a dark blue. There is no stripping and except for a thin strata of iron ore (principally limonite) which varies from six inches to one foot in thickness the deposit is remarkably uniform and the whole depth of the deposit is used. There is little difference in working or burning properties of the weathered and unweathered shale. Borings for water wells show that the blue shale reaches a thickness of over 80 feet below the present bottom of the pit. The company controls 16 acres of the shale, a supply which may be considered inexhaustible. The working, drying, and burning properties of the shale are excellent. There is practically no lamination produced by the auger and the drying shrinkage is very slight. Cracking either in drying or burning is very unusual, the average loss from all causes including soft and overburned brick being less than 2 per cent. The burning shrinkage is about 10 inches for a kiln set 41 high. The burned color is a clean, bright, vermillion shade of red. Only common brick have been made so far and no attempt has been made to produce vitrified ware. However, where the brick have been vitrified in the arches the structure is very firm and dense and the color a bright red which is decidedly pleasing and should be popular for face brick. The vitrified brick are extremely tough under the hammer, and promise very well for paving brick. Judging from the appearance of the brick the rate of vitrification is slow as there is a gradual change from salmon brick to the dark red color and also as there is usually no distortion or sticking of the arch brick although they are fired very strongly.

The shale is blasted from the bank, loaded by hand into rocking-dump steel cars of 2 cubic yards capacity, hauled up an incline by a hoisting drum, and dumped by the side of two 9-foot dry pans. From the pans it is elevated in bucket elevators and screened through stationary inclined screens. The pug mill and auger machine have a daily capacity of 100,000. The cutter is a rotary, automatic, side cut with 23 wires. Two 2-mold represses are installed. From the off-bearing belt or the re-presses the brick are stacked on steel dryer cars and transferred to the dryers. All the machinery is from the American Clay Machinery Company. Power for the plant is furnished by two 150 H. P. boilers, and a 250 H. P. Monarch Corliss Engine. A separate 18 H. P. engine drives the fan for the drying system.

The dryer is a 20-tunnel, continuous dryer, 96 feet long. The subtunnels for the heat extend back from the exit for 20 feet. A large fan is used to draw the heat through the tunnels. The tunnels will hold the daily output and about 24 hours are required for a car to pass through.

There are six updraft rectangular kilns varying in capacity from 350,000 to 500,000 brick. Two more are under construction. Gas at three cents per thousand feet is used for fuel in the kilns and dryer and under the boilers. About twelve days is required to burn a kiln. The last two days are required for "finishing" with the gas pressure at 10 pounds. From the kilns the brick are loaded directly onto cars on a switch from the St. Louis and San Francisco Railroad. Thirty-five to forty men are employed when the plant is operated at full capacity.

The Sapulpa Pressed Brick Company operates a plant diagonally across the railroad track to the southeast of the plant just described. A narrow gap through which the railroad is built separates the two hills of shale. The deposits are continuous in the lower portions. The shale is similar in appearance and in working, burning and drying qualities, to that on the north side of the track. This plant has been in operation for eight years and about one-half of an acre has been excavated to a depth varying from 20 to 60 feet. The company has 30 acres under lease.

The clay is hauled up an incline to the plant in rocking-dump cars. The mechanical equipment consists of a 9-foot dry pan, elevators, stationary inclined piano-wire screens, a 12-foot pug mill, an auger machine of 60,000 capacity, a rotary automatic cutter with 18 wires, and a Berg 4-mold dry press. The dryer is a six tunnel continuous dryer heated with steam from the boilers. The dryer has a capacity of 30,000 brick and as 24 hours are required for drying, the stiff mud capacity of the plant is limited to this number. There are four rectangular updraft kilns. Gas is used for fuel. The brick are loaded from the kilns directly onto cars on a switch from the Frisco. Both dry-press and stiff-mud common building brick are produced, but only enough of the former to supply the local demand. The plant employs 28 men when operating at full capacity.

One of the up-to-date brick plants in Oklahoma is that of the *Cleveland Vitrified Brick Company,* located at *Cleveland,* in northeastern Pawnee County.

The company controls 10 acres of shale which has been worked to a depth of 100 feet without reaching the bottom. The shale is a dark gray to blue color and is very uniform from top to bottom except for one layer about 5 feet thick which is more sandy than the rest. So far no stripping has been required but farther back in the hill it will be necessary to remove a few feet of soft sandstone. The shales are represented by samples Nos. 60, 61, 62 and 63, which are described in Chapter VII.

The shale is removed from the bank by an automatic steam shovel and hauled up an incline to the plant in steel rocking-dump cars, by a trolley motor car. (fig. 49.)

At the plant, (fig. 50) which is a permanent building of brick, the shale is dumped by the side of three 9-foot dry pans. The step box of each pan is mounted on two heavy "I" beams, the ends of which are embedded in the concrete walls of the shaft. The pans have no bottoms, and the clay falls through the screens into the shaft which leads at an incline to the elevator shaft.

After the clay is ground it is elevated to a double-geared pug mill and made up into a very stiff mud. It is fed down into a large auger machine of 100,000 daily capacity. The column from the machine is cut by a side cut, automatic rotary cutter, cutting 20 brick per revolution. From the off bearing belt the brick are stacked on steel dryer cars, about 600 brick on each car.

The dryers consist of 20 tunnels built of brick and concrete, each tunnel having a capacity of 13 cars. The heat is supplied by gas which is burned in tunnels under the floors. These tunnels extend back from the exit for about twenty feet. The heat is passed up into the drying tunnels through openings in the floor and is then drawn through the

length of the tunnels into a stack by a large fan. About thirty-six hours are required for a car to pass through the dryer. Room for a cooling floor is provided at the end of the tunnels. From the cooling floor the cars of dried brick are taken by an electric transfer car to the kilns.

The kilns are fourteen in number, six round downdraft, one rectangular downdraft and seven rectangular updraft.

From the kilns the brick are loaded directly onto cars on a spur switch from the Missouri, Kansas and Texas Railway. Storage room is provided across the track from the kilns, but for some time the product has been disposed of as rapidly as it could be turned out and it has been necessary to work night shifts a good share of the time. For this purpose an electric light system is installed throughout the plant and loading floors.

The product is principally common building brick of a fine red color. No difficulty in working, drying or burning is encountered. The greater portion of the product has been sold in Oklahoma City. Morris & Co. used 8,000,000 of these brick in the construction of their packing plant and the Schwartzchild and Sulzberger plant an equal number.

A Boyd 4-mold dry press has been recently installed, and represses are to be installed immediately. The plant will then be able to produce face and paving brick. The shale vitrifies very slowly and seems to be eminently suited for the latter product.

Power for the plant is furnished by a Monarch 250 H. P. engine. A 70 K. W. generator furnishes the power for the trolley system, and a 6 K. W. generator for the lighting system. The fans for the dryer are driven by a separate small engine. Gas is used for fuel under the boilers, in the dryers and for burning. The plant is equipped throughout with the American Clay Working Machinery Company's machines. The offices of the company are in Oklahoma City.

THE REDBEDS AREA.

The Redbeds area includes, with some minor exceptions, all of the State west of the line which enters the State from Kansas near Caldwell and extends southeast past Blackwell, Tonkawa, and Red Rock, swings south, passing east of Cushing, Stroud, and Prague, turns slightly west and south past Maud, Konawa and Vanoss, to Davis, then swings west around the Arbuckle Mountains. From the west end of the Arbuckle Mountains it extends south to Red River. The areas west of this line which are not Redbeds consist of the (1) Wichita Mountains. (2) several small isolated areas of Cretaceous limestone or shell rock capping hills in Washita, Custer, Dewey, Woodward, Harper and Beaver counties, (3) the sand hills along the Salt Fork of Arkansas, Cimarron and Canadian rivers, and (4) Tertiary areas in the northwestern part of the State occupying almost all of Texas, Cimarron and Beaver counties, and portions of Ellis and Woodward counties.

AGE OF THE REDBEDS.

The question of the age of the Redbeds has given rise to much discussion. This arose from the fact that in Kansas, where much study has been given them, they have so far proved to be absolutely unfossiliferous. In Oklahoma, however, some invertebrate fossils have been found near Eddy, Whitehorse, Chickasha, and Altus and a few vertebrates have been found at Orlando, and in Texas many vertebrate remains have been discovered, all of which lead to the conclusion that the Redbeds are of Permian age. In Kansas a great thickness of the underlying light-colored rocks is also Permian in age. The Wreford limestone has been usually regarded as the base of the Permian, but Beede has recently placed the contact lower in the series and now tentatively regards the Elmdale limestone as the base of the Permian.

The lower light-colored members of the Permian of Kansas, such as the Wreford, Winfield and Herrington limestones cross the line into Oklahoma but soon pinch out and are replaced by red shales and sandstones. In other words the line of contact between the red and non-red rocks swings east across the outcrop so that successively older and older rocks are included in the Redbeds. The line between the red and non-red deposits crosses the Pennsylvanian-Permian contact near Cushing and continues to the southeast so that the lower or eastern portion of the Redbeds in Oklahoma is of Pennsylvanian age. Taking the Wreford limestone as the base of the Permian in Kansas, Kirk[1] has traced the contact between the Pennsylvanian and Permian in Okahoma. He found that the Wreford was replaced by a red sandstone (Payne sandstone) which extends southwest through western Lincoln, eastern Oklahoma and central Cleveland counties.

The approximate line between the red and non-red deposits as well as the approximate Pennsylvanian-Permian contact is shown on the map accompanying this chapter. (Plate 11.)

1. Okla. Dept. of Geol. and Nat. Resources, 3rd Biennial Report.

CONDITIONS OF SEDIMENTATION.

The Redbeds were deposited during a period of gradual withdrawal and shallowing of the waters of the Pennsylvanian sea. It seems also to have been a time of increasing aridity. Under these conditions the waters became more and more concentrated so that the mineral content became so great as to prohibit animal life. This concentrating process seems to have begun at the south and to have proceeded northward. This is shown by the red color of the rocks descending to lower and lower geological horizons on going from Kansas into Oklahoma. The red color of the rocks in itself is strong evidence of the scarcity or absence of life. The red is due to the presence of the oxide of iron (ferric). If much organic matter had been present in the water it would have settled to the bottom with the mud and sand which formed the shale and sandstone. As decay took place the ferric or red iron compounds would have been reduced to ferrous compounds which give the blue and black colors of rocks. The remarkable scarcity of fossils also indicates that animals with shells were very rare in the waters in which the beds were deposited.

In the latter part of the time occupied by the deposition of the Redbeds, this area seems to have been a great land-locked basin, or one which had very little connection with the main ocean. The principal source of deposits seems to have been to the south since in Texas the deposits are of the nature of deltas and also contain many fossils of land and shore animals. The waters gradually became concentrated until finally great beds of gypsum, interstratified with red gypsiferous and saliferous clays were deposited. The water was finally completely evaporated leaving the entire area a land surface.

LATER HISTORY OF THE AREA.

A considerable part of the western Redbeds was again submerged in early Cretaceous times, but all except the extreme northwestern portion was re-elevated before late Cretaceous. The record of the Cretaceous submergence is preserved in the limestone which has already been mentioned as capping many of the hills in Washita, Custer, Dewey, Woodward, and Beaver counties. The greater portion of the Cretaceous rock has been removed by erosion so that we have no knowledge of the extent of the Cretaceous sea in this part of the State. Dakota sandstone of late Cretaceous age was probably laid down over much of the northwestern portion but with the exception of a small area in Cimarron County, it has been removed by erosion or covered by Tertiary deposits which were washed down from the Rocky Mountains. The Tertiary deposits consist largely of unconsolidated beds of gravel, sand and clay.

STRATIGRAPHY OF THE REDBEDS.

Pennsylvanian Series.

The Chandler Beds. The name Chandler Beds was applied by Gould[1] to all the red colored rocks of Pennsylvanian age, i. e. the portion of the Redbeds east of the Pennsylvanian-Permian contact. Their outcrop comprises the western part of Pawnee, all of Lincoln and Pottawatomie, and the eastern parts of Noble, Payne, Logan, Oklahoma, Cleveland, McClain and Garvin, and northwestern Murray counties. The rocks consist of alternating red clay shales and red and white sandstones. The sandstones are often 5 to 20 feet thick and sufficiently hard to produce considerable relief. The shales are often quite arenaceous. This region is mostly well timbered.

The shales of this region were formerly worked at Chandler in Lincoln County. The plant has not been in operation for several years, but the brick made are still to be noticed in sidewalks and in depot platforms in many of the towns in the central part of the State. Judging from the appearance of these brick the shale is very similar to those described from Oklahoma City and to sample No. 231 from Sparks a few miles from Chandler (See page 166). Samples Nos. 145 and 146 from Meeker also represent the shales of this vicinity.

Similar shales are at present utilized by the plant of the *Shawnee Pressed Brick Works,* one-half mile southwest of Shawnee. The red shale is plowed loose and hauled to the plant in wheeled scoops, ground in a 9-foot dry pan and molded on a Freese Union machine. The dryer is heated by gas. Three rectangular updraft kilns with a capacity of 200,000 each are used. The output averages 18,000 common and pressed brick per day.

The Permian Series.

Gould[2] gives the following classification of the Permian Redbeds:

1. Gould, C. N., Water Supply & Irrigation Paper No. 148. U. S. G. S.
2. U. S. G. S., Water Supply and Irrigation Paper No. 148, p. 39.

Greer formation	Mangum dolomite member Collingsworth gypsum member Cedar Top gypsum member Haystack gypsum member Chaney gypsum member Kiser gypsum member	300 feet.
Woodward formation	Day Creek dolomite member Red Bluff sandstone member Dog Creek shales member	425 feet.
Blaine formation	Shimer gypsum member Medicine Lodge gypsum member Ferguson gypsum member	100 feet.
Enid formation		1500 feet.

The Enid formation includes the portion of the Redbeds from the base of the Permian to the lowest of the gypsum ledges of the Gypsum Hills. The area comprises all of Kingfisher, Garfield, Grant and Alfalfa counties; the western parts of Kay, Noble, Payne, Logan, Oklahoma, Cleveland, McClain and Garvin, and the eastern parts of Woods, Major, Blaine, Canadian, and Grady counites. Eastern Stephens and Jefferson and western Carter and Love counties probably belong in this area although the stratigraphy in that part of the State has not yet been worked out.

The Enid formation consists of red clay shales with thin soft sandstones. The sandstones are usually red, but are sometimes white or gray (See Figs. 51 and 52). The relative amount of sandstone decreases toward the top of the formation. The clays of the upper portion are often gypsiferous and contain thin layers of selenite. The thickness of the Enid formation is probably between 1200 and 1500 feet.

The Blaine formation consists of three ledges of gypsum separated by red clay shales. The total thickness is about 75 feet. The gypsum ledges being harder than the red clay shales stand out as pronounced ridges and hills known as the Gypsum Hills. This escarpment extends northwest from north-central Canadian County through Blaine, Major, Woodward, Harper and Woods counties. The outcrop is a belt a few miles in width, lying between the North and South Canadian rivers and extending parallel to these streams. Southeast of central Canadian County the gypsum ledges disappear and the Enid and Woodward formations are not separated.

The Woodward formation consists of about 300 feet of shales, sandstones and dolomites. Shales predominate in the lower member, sandstone in the middle or Whitehorse member and dolomite in the upper or Day Creek member. The Woodward formation outcrops as a broad belt extending from the Kansas line southeast through Harper, Woods, Woodward, Major, Dewey, Custer, Blaine, Canadian and Caddo counties and farther to the southeast where it merges with the Enid and has not been separated from it.

The Greer formation consists of five gypsum members separated by red and green clay shales. A thin ledge of dolomite occurs at the top of the formation. It outcrops over a broad belt extending from northwestern Stephens County northwest through Grady, Caddo, Washita, Custer, Dewey and Roger Mills counties. An arm extends west through southern Washita County and connects the belt just mentioned to a second area which comprises all of Harmon and the contiguous portions of Jackson, Greer and Beckham counties.

Undifferentiated Permian. As may be seen from the above classification the gypsum ledges are the principal factor in the subdivision of the Permian series. On approaching the Wichita Mountains these ledges die out and the whole series is a mass of red clay shales with some sandstone. The rocks of this portion of the area have never been separated into formations, although they undoubtedly contain the southern equivalent of the Enid, Blaine, and Woodward formations. This area of undifferentiated Permian comprises all of Kiowa, Swanson, Comanche, Stephens, Jefferson and Tillman, eastern Jackson, and western Love, Carter, Garvin and McClain counties, with the exceptions of the relatively small areas of igneous and early Paleozoic rock in Comanche, Kiowa and Swanson counties and a sand hill area in Tillman county.

Cretaceous Rocks.

The Lower Cretaceous rocks in western Oklahoma consist of small isolated areas, the remnants of a large area which formerly connected the Lower Cretaceous of Kansas with that of Texas. Almost all of these rocks have been removed by erosion so that we have no knowledge of their original extent. They consist largely of shell limestones which lie on the eroded surface of the Redbeds. The Dakota sandstone of Upper Cretaceous age outcrops in the extreme northwest portion of Cimarron County. It consists of a series of sandstones and shales lying on the eroded surface of the Lower Cretaceous and the Redbeds.

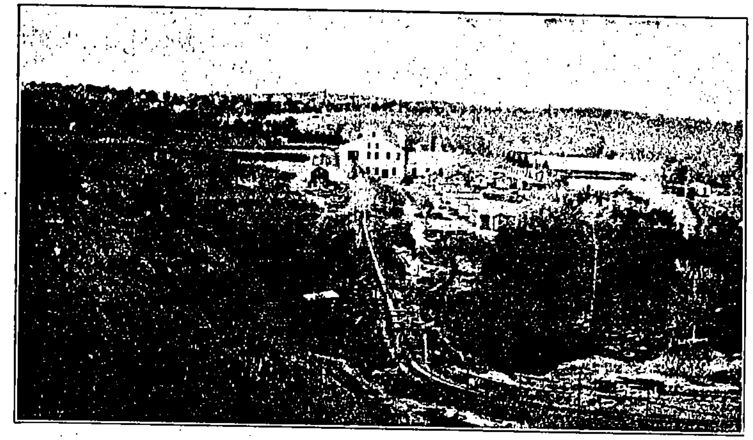


Fig. 50. View of plant at Cleveland.

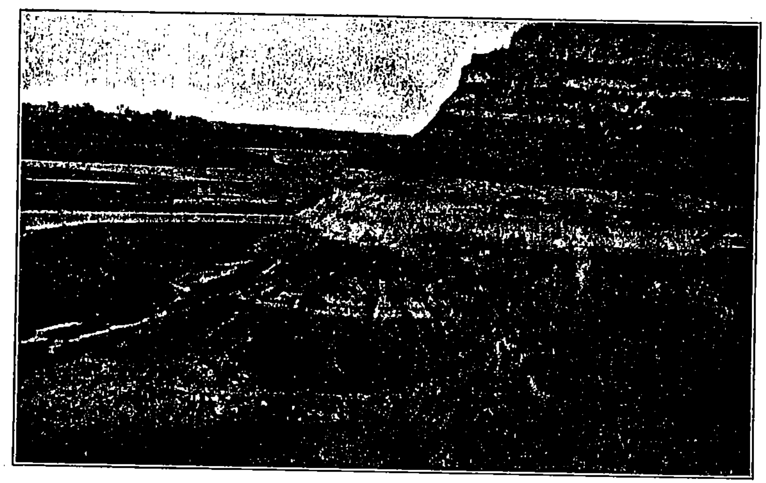


Fig. 51. Cliff along Salt Fork of Arkansas River at Jet, showing nature of the Enid formation.

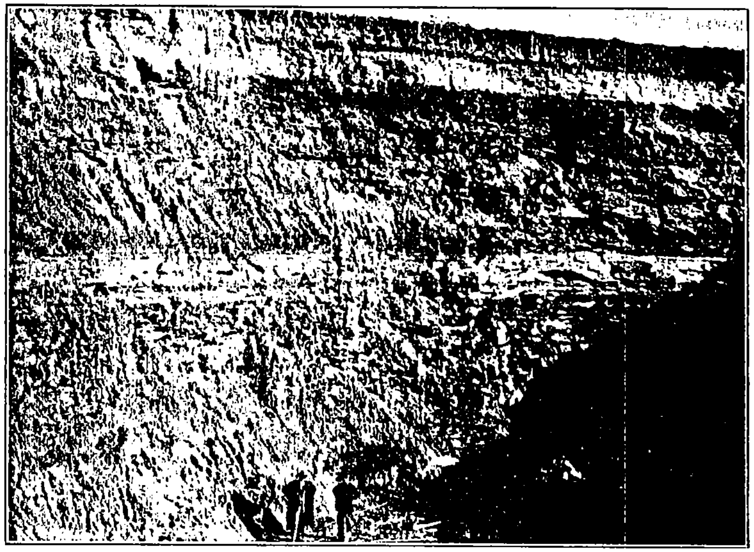


Fig. 52. Shale pit of the Enid Vitrified Brick and Tile Co.

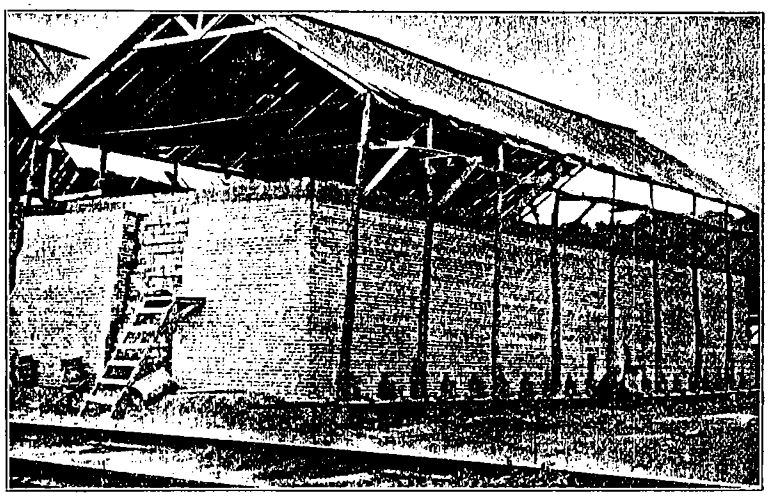


Fig. 53. Up-draft rectangular kiln at Pawhuska.

The Tertiary Rocks.

The Tertiary deposits, whose exact age has not been determined, occupy extensive areas in northwestern Oklahoma. The streams have cut canyons through these deposits down into the Cretaceous rocks and into the Redbeds which lie unconformably below the Tertiary. This leaves the Tertiary capping the hills and high divides between the streams. Almost the whole area of Cimarron, Texas and Beaver counties and extensive areas on the divides between Cimarron and South Canadian rivers in Harper, Woodward and Ellis counties are occupied by these deposits. There are many smaller areas farther to the east. These deposits consist of clay, sand and gravel irregularly stratified and, as a rule, loosely consolidated. Quartz and other pebbles form a considerable portion of the rock and as they remain behind when the rock is eroded they form a conspicuous feature of the hill sides and stream beds.

The Tertiary deposits differ from the older rocks of the region in being fresh water or land deposits instead of being of marine origin. They are probably the wash from the Rocky Mountains at a time when the mountains were much higher relative to the plains than they are at present.

Sand Hills.

Along the valleys of Arkansas, Cimarron, North and South Canadian and Red rivers there are large belts of windblown or dune sand, known as Sand Hills. This has probably been blown up from the river beds by the prevailing winds acting through immensely long periods of time. The belts are often several miles in width along the north side of the rivers, but in a few cases along the south. In these cases it is possible that the stream has shifted its channel in comparatively recent time, or that the sand hills represent the remains of buttes which were composed largely of sandstone.

GEOGRAPHY AND TOPOGRAPHY.

The Redbeds area may be divided into the following topographic regions (1) the sandstone hills region, practically co-extensive with the Chandler beds, (2) the low plains or area occupied by the Enid formation, (3) the Gypsum Hills or the area of Blaine, Woodward and Greer formations, (4) the High Plains or area of Tertiary rocks, (5) the Wichita Mountins, (6) the Sand Hills region.

(1) The Sandstone Hills region occupies the outcrop of the

Chandler beds and the lower part of the Enid formation. It has a rolling topography due to the streams cutting through the shales and sandstones which compose the country rock. There are occasional rather steep bluffs along the streams. The country is well timbered principally with oak and hickory. (2) The low plains occupy the outcrop of the greater part of the Enid formation and lie to the west of the Sandstone Hills. The country rock is principally shale with only a few thin ledges of soft sandstone which are not resistant enough to give any pronounced topographic effects. The country is almost level. The streams have broad channels only a few feet below the general level. The country is all prairie except for a little timber along the streams. (3) The Gypsum Hills, which are the outcrop of the Blaine and Greer formations, stand as an escarpment of from 200 to 300 feet in height above the low plains to the east. The streams have cut narrow canyons through this escarpment and have broken the ridge into a number of hills. There is little timber in the region. (4) The High Plains region is a level, priarie, table land into which the streams have cut broad and shallow valleys. The High Plains are underlaid (principally) by Tertiary rocks. (5) The Wichita Mountains consist of several granite peaks entirely surrounded by the level Redbeds plain. A range of limestone hills lies to the north of the granite peaks. The formations exposed in the Arbuckle Mountains are supposed to be present in the Wichitas but, with the exception of the range of Arbuckle limestone and two or three knobs of Viola limestone, they are so deeply buried beneath the Redbeds as to be inaccessible. (6) The location and topography of the Sand Hills region has already been noticed.

NATURE OF THE SHALES.

The shales of the Redbeds are principally red clay shales although in the higher formations there are some greenish and bluish shales. Interstratified with the red shales there are occasional strata of soft, white fine-grained sandstone with considerable clay matter. These layers of sandstone vary from less than 1 inch up to about 3 feet in thickness. (See figs. 51 and 52.) The red shales are colored by iron (ferric) oxide, the percentage varying from 5 to 20 per cent so that they all burn to a dark red color. They are extremely fine-grained and very soft so that they weather rapidly and are easily prepared for manufacture. Owing to the fineness of grain, they require a considerable amount of water to render them plastic and consequently have rather high shrinkage but are tough enough to resist cracking and, unless gypsiferous, burn to a very dense body.

To the east in the Chandler beds the shales are often arenaceous but farther west the proportion of sand is usually less. Gypsum occurs in practically all the shales above the lower portion of the Enid formation. In the shales of the Enid the gypsum usually occurs as irregularly distributed concretions, while in the shales of the higher formations, the Blaine, Woodward and Greer, thin bands of selenite and satin spar are very common. The greenish shales usually contain a considerable amount of evenly disseminated gypsum. Some of these shales run very high in gypsum as is shown by the following analysis of a gypsiferous green clay from the slope of the Gypsum Hills, near Mount Heman, eastern Woodward County[1].

Calcium sulphate	58.05 per cent.
Calcium carbonate	5.35 per cent.
Magnesium carbonate	3.49 per cent.
Water	15.38 per cent.
Oxides of iron and alumina	3.27 per cent.
Silica and Insoluble residue	13.58 per cent.

It is manifestly impossible to utilize shales with so large a percentage of gypsum in the manufacture of clay products. The composition of the red clays from these formations is shown by the following analysis of a clay from near Ferguson, in Blaine County:

Silica	64.17 per cent.
Calcium oxide	1.34 per cent.
Iron oxide	8.10 per cent.
Aluminum oxide	18.40 per cent.
Magnesium sulphate	5.57 per cent.
Magnesium carbonate	.27 per cent.
Water	6.54 per cent.

These shales cannot be used by the plastic process as they are so fine-grained that the resulting body is too dense to permit the escape of the gases formed by the decomposition of the sulphates during burning. They can be used for common dry-press brick, as the dry-press body is sufficiently porous to permit the escape of the gases. There is always a strong discoloration by whitewash even in the dry-press ware. A good example of this clay is Sample No. 205 which is used for dry press brick at Mangum.

The shales of the lower portion of the Enid formation which have been tested, do not usually contain enough gypsum to cause damage

1. Water Supply and Irrigation Paper No. 148, U. S. G. S., p. 43.

from whitewashing or puffing in burning. There is a great amount of variation in these shales, however, and it is almost impossible to make generalizations from the small number of samples tested. However, the statement is true for shales from Oklahoma City, Blackwell, Enid and Chickasha. The variations between the shales in small areas is well shown by the two samples from Oklahoma City, No. 42 from the pit of the American Brick and Tile Company, and No. 173 from that of the Oklahoma Brick Company. Both are used for dry-press brick with good results. When made up into stiff mud, however, No. 42 has a porosity of 13.6 per cent at cone 3, while the porosity of No. 173 is down to 6.6 per cent. No. 173 melts rapidly above cone 3 while No. 42 retains its shape up to cone 7.

The true stratigraphic relations of the shales from Chickasha. Rush Spring, Marlow and Comanche is doubtful because, as has already been mentioned, the Blaine formation does not appear southeast of El Reno and the Enid and Woodward coalesce and farther south the stratigraphy has not been worked out. The succession of rocks and their nature however, is very similar to the Enid formation and the eastern part of the area called "Undifferentiated Permian" is probably the same age as the Enid.

The Dog Creek shales of the Woodward formation are principally dull red clay shales having a total thickness of from 100 to 225 feet. The samples from Binger (No. 261) and Hinton (No. 177) are the only ones tested from this horizon where it has been mapped.

The Greer formation contains a great amount of red and green clay shales interstratified with gypsum and soft sandstones. The stratification is very irregular, the shales often giving place to gypsum or sandstone in short distances. The red and green colors are irregularly mixed in most of the shale beds. The shales are quite gypsiferous and hence not well adapted for use in manufacturing. The only sample tested from this formation (No. 205) is from Mangum where the red and green mottled shale is well exposed.

The Quartermaster formation consists largely of red clay shales which become more arenaceous toward the top of the formation. The shales as a rule contain less gypsum than those of the Blaine, Woodward, or Greer formations, and more nearly resemble those of the Enid. A sample of the red shale (No. 297) from Doxey in Beckham County, is very similar to those from Oklahoma City and Comanche. A thin stratum in the same vicinity (No. 296) is the only non-red burning clay so far found in western Oklahoma. An extremely fine-grained white clay (No. 150) is found near Sweetwater but it is not satisfactory for manufacturing purposes.

The clays of the Cretaceous and Tertiary in western Oklahoma have never been investigated in detail and no tests have been made upon them.

MANUFACTURING CONDITIONS IN THE REDBEDS AREA.

The principal difficulty encountered in the manufacture of clay products in this region is the lack of cheap fuel. In only a very few places is wood available in sufficient quantity for use as fuel; the nearest coal is the McAlester-Lehigh field which is 100 miles from the nearest cities of the Redbeds area and 200 to 300 miles from the majority of the towns of the region. Except in the immediate vicinity of the Wichita Mountains, oil or gas has never been found in commercial quantities in the Redbeds and the geological structure renders it highly improbable that these products will ever be found here. The distance from the oil and gas fields prevents piping these products to many of the towns. Oklahoma City and Guthrie are the only cities at present supplied with gas from the main field. This feature will prevent the Redbeds area from ever being a great center of the clay industries.

The transportation facilities of the region are fair; the Atchison, Topeka and Santa Fe, Chicago, Rock Island and Pacific, St. Louis and San Francisco, and Kansas City, Mexico and Orient railways give north and south connection and the same roads (except the Kansas City, Mexico and Orient) have several east and west connecting branches.

The population of the region is increasing rapidly and towns such as Oklahoma City, Guthrie, Enid, El Reno, Chickasha, Hobart, Alva: Cordell, Lawton, Anadarko, Altus, Snyder, and many others are doing a vast amount of permanent building for which clay products are required.

PRESENT DEVELOPMENT OF THE CLAYS OF THE REDBEDS.

Plants which use the Redbeds shale or clay derived from it are located at several towns in the State.

The shales of the Enid formation are used at Oklahoma City, Guthrie, Enid, Kingfisher, Hennessey and Alva.

Oklahoma City. The plant of the *Oklahoma Brick Company* is located on north 13th street. The pit opening covers about 1 acre to a depth of 30 to 50 feet. Three to four feet of soil is stripped. The qualities of the shale are described under the description of clay No. 173. The shale is worked with a Vulcan steam shovel and hauled to the plant in a steel, rocking dump car of 2 cubic yards capacity, by a wire roep and hoisting drum.

The plant is equipped with two Frost 9-foot dry pans, elevators. screens, and two Berg 4-mold dry presses. The brick are burned in four updraft rectangular kilns, one having a capacity of 360,000 and the other three of 200,000 each. Gas is used for fuel. The plant has no railway facilities and practically all of the product goes to supply the home demand.

The *American Brick and Tile Company's* plant is located west of Oklahoma City along the Chicago, Rock Island and Pacific Railway, about one mile south and west of the Oklahoma Brick Company's plant. The material used is a red shale tested and described as No. 42. The pit opening covers about one acre to a depth of 30 to 50 feet. There is no stripping.

The shale is worked by a Vulcan Steam shovel and hauled to the plant in rocking-dump cars of 2 cubic yards capacity. Three American and two Frost 9-foot dry pans are used. There are two dry-presses. a Berg and a Boyd 4-mold press. A Fernholtz dry-press is to be added. The stiff mud equipment consists of a pug mill, auger machine and rotary automatic cutter of 100,000 daily capacity. A 12 tunnel continuous, gas-fired dryer is used. There are 5 updraft rectangular kilns and a large continuous updraft kiln is under construction. The stiff-mud machinery has been recently installed and at the present writing, (April, 1911) some difficulty has been encountered. The shale is very fine-grained and grinds down into a very tough, plastic mass so that considerable power is required to force it through the die at a sufficiently rapid rate. The machinery can certainly be adjusted to the needs of the clay and when this is done the stiff-mud brick will undoubtedly be a popular product as they are free from imperfections and have a rich red color and a dense, firm structure. The dry-press brick are a dark red color, with small light specks. The structure is unusually firm for dry-press ware. They are burned at cone 3. The plant has a switch from the Chicago, Rock Island and Pacific Railway but the greater portion of the production goes to supply the home demand.

The shale pit of the *Enid Vitrified Brick and Tile Company,* 1

mile southeast of Enid, shows a typical section of the Enid formation. (fig. 52). The section exposed in the pit is as follows:

1.	Soil	2—3 feet.
2.	Soft, fine-grained white sandstone	3 feet.
3.	Red clay shale	20 feet.
4.	Soft, fine-grained white sandstone	30 inches
5.	Red clay shale	20 feet.
6.	White sand	3 feet.
7.	Red clay shale	30 feet Bottom not shown.

The shale and sandstone are blasted down and used together. The material is hoisted up an incline to the plant in dump cars by a hoisting drum, ground in a Frost 9-foot dry pan and molded in a Boyd 6-mold dry press. From the dry press the brick are set into the updraft kilns of which there are three, with a capacity of 500,000 brick each.

The stiff-mud process was used at a former location of the plant about 80 rods west of the present location where the same deposit is worked. The machinery from the old plant consisting of a 9-foot dry pan, pug mill and auger machine of 35,000 daily capacity, and repress is being moved to the new plant and ground has been leveled for dryer room.

The dry-press brick are of a dark red color, and exceptionally firm dense structure. There is considerable whitewash on the sides of the brick which are exposed to the kiln gases but none on the faces. The arch brick often burn to a chocolate color with metallic luster and sometimes are blackened and roughened. These "over burned" brick have been used as face brick for several residences in Enid with good effect. Buildings faced with the brick from the middle benches of the kilns compare favorably with those faced with Kansas dry press brick. The stiff mud brick made at the old location show rather high shrinkage, but no cracking and burn to a fine, dark red color and an exceedingly dense, stony body. Sidewalks in Enid built of the vitrified repressed brick are in excellent condition after years of service. Altogether the shale seems to be almost precisely similar to the samples tested from Oklahoma City and from Comanche. (See report of tests of Nos. 42, 196, and 197.)

Coal is used for fuel, the estimated cost of fuel for burning being about two dollars per thousand brick. There is no railroad switch to the plant and coal must be hauled from, and the brick which are shipped must be hauled to the railroad 1 mile distant. Most of the output, however, finds a ready market in Enid. The company controls 10 acres of the shale and employs about 40 men including those engaged in hauling brick and coal.

Alva. A stiff-mud plant is operated at Alva by Z. W. Cox. The plant is located in the city. The Chicago, Rock Island and Pacific and Atchison, Topeka and Santa Fe railways furnish transportation facilities. The material used is a rather sandy surface clay which is worked and hauled to the plant in scrapers. The clay is pugged and molded by a Leader No. 15 stiff-mud machine. Drying takes place in an open shed. Three round downdraft kilns, each of 60,000 capacity, are used for burning. Coal is used for fuel. The output is common brick of which about 10,000 are produced daily.

Guthrie. The plant of the *Guthrie Brick and Tile Company* is located near the Chicago, Rock Island and Pacific Railway, one-half mile east of Guthrie. The material worked is a Redbeds clay shale. The pit workings are 40 feet square and 40 feet deep. The shale is carried from the bottom of the pit to the plant by a car operating in a tower. The dry-press process is used. The mechanical equipment consists of a 9-foot dry pan, elevators and screens and a Fernholtz 4-mold dry press. There are three rectangular updraft kilns of 260,000 capacity each. Wood and slack coal are used as fuel. The product is a red face and common brick of good structure. The daily output is 20,000.

Hennessey. The Hennessey Pressed Brick plant is located one-fourth mile west of town. The pit workings are about 20 feet deep. Scrapers are used to haul the shale to the plant. A 9-foot dry pan and a combined pug mill and auger machine of 30,000 daily capacity are used for grinding, tempering and molding. Drying sheds are used. There are two rectangular updraft kilns each of 260,000 capacity. Wood and coal are used for fuel. The daily output is 30,000 of common brick. Fourteen men are usually employed.

Kingfisher. The Kingfisher Brick Works are located on the Chicago, Rock Island and Pacific Railroad inside of the city limits. The workings are 12 feet deep in a sandy surface material. The material is loosened with pick and shovels and hauled to the plant in dump carts. The soft mud process is used. A Martin 6-mold soft mud machine of 20,000 daily capacity performs the tempering and molding. Rack and pallet dryers are used. Two rectangular updraft kilns of

225,000 capacity each, are used. Wood and coal are used as fuel. About 15 men are usually employed.

There are several plants in the area surrounding Wichita Mountains and in the western part of the old Indian Territory which has been referred to as the area of undifferentiated Permian rocks. These plants are located at Chickasha, Marlow, Duncan, Comanche, Addington, Waurika, and Hobart. Plants were formerly operated at Gotebo and Purcell.

Chickasha. The plant of the *Western Shale Brick Company* is located 3 miles south of Chickasha along the Cihcago, Rock Island and Pacific Railroad, where the company controls 20 acres of land. The workings cover about one-fourth acre to a depth of 20 feet. The shale is a red clay shale with thin veins of white soft sandstone irregularly distributed through it. These veins seem to decrease in number and thickness with increasing depth. The white material is used with the red and seems to have no bad effects. The working, drying and burning qualities of the shale are very similar to those of the shales at Enid and Oklahoma City, which have been described. The shale is worked with drag scoops and dumped through a trap into a bottom-dump car which is hauled to the plant by a hoisting drum. It is ground in a Frost 9-foot dry pan, elevated, screened, pugged in a single-geared, 12-foot pug mill, and molded by an auger machine of 35,000 daily capacity. A rotary automatic cutter with 14 wires and an Eagle Repress are used. Drying is conducted by the rack and pallet system under a covered shed with removable sides. The brick are taken from the off-bearing belt and stacked on pallets on a car which is "jacked" up so that the pallett will clear the rack as the car is pushed between them. When it is brought to the desired place the car is lowered until the pallett rests on the racks and the car can be removed from under it. The capacity of the dryer is 200,000 bricks. One rectangular updraft kiln is used of about 250,000 capacity. Coal is used for fuel. The plant is operated intermittently only 1,000,000 brick being made the past year.

Marlow. The plant of the Marlow Brick Company is located one-half mile south of Marlow near the Chicago, Rock Island and Pacific Railroad. The material worked is a Redbeds shale (represented by sample 180) and the residual clay derived from it. The pit workings cover an area of 1 acre to a depth of 8 feet. Scrapers are used to secure the material and to haul it to the plant. A Brewer No. 8 stiff-mud machine is used for molding. Drying is in the open air. A rectangular updraft kiln with a capacity of 100,000 is used and is fired with wood and coal. 20,000 of common brick are produced daily while the plant is operating. Ten to 15 men are employed.

Comanche. A plant is operated at Comanche by J. A. Cameron which uses the shale represented in Nos. 196 and 197 and the full description of the behavior of the shale when worked by the stiff-mud process is given in the description of the tests on these samples. Fifteen acres of the hill of shale are under long time leases. The plant is located 1 mile southwest of Comanche, one-half mile west of the Chicago, Rock Island and Pacific Railroad, at the end of a large hill. The hill is capped by 4 to 5 feet of hard, coarse-grained sandstone which breaks off in large blocks. There is, however, a large amount of material available without stripping. The shale has been worked to a depth of 25 feet, and a hole sunk 20 feet further without reaching the bottom of the shale. There is some white sand irregularly distributed through the shale as at Enid and Chickasha, but it does no damage.

The shale is plowed loose and hauled in drag scrapers down grade to a Frost 9-foot dry pan, and after grinding is elevated to 15 foot stationary inclined screen, and molded in a Ross-Keller 4-mold dry press. The brick are burned in two updraft rectangular kilns of 240,000 capacity each. Wood and coal are used for fuel at a cost of $1.50 to $2.00 per thousand brick. The brick have a good sound structure and clear red color. The plant operates intermittently and employs 12 men when working. Power is furnished by a 50 H. P. Atlas Engine. Water for the boilers is secured from wells in the valley of a small creek near by. Most of the product is disposed of in Comanche and vicinity although several carloads have been shipped.

Addington. The plant of the Addington Brick Company is situated near the depot at Addington in Jefferson County. The material used is the residual clay from the Redbeds shale. This is blasted loose and hauled to the plants in dump carts. It is ground in an Eagle 10-foot dry pan, elevated, screened through stationary inclined screens and molded in a Berg 4-mold dry press. The kilns are two in number and of the rectangular updraft type each of 300,000 capacity. Wood and coal are used as fuel.

Waurika. A small plant at Waurika uses the surface material just north of town for the manufacture of dry press brick. The material is described and the report of the tests given under samples No. 152 and 153. The clay is obtained by drag scoops, shoveled into a Fernholtz disintegrator, elevated and screened through stationary perforated screens, and molded by a Boyd 2-mold dry press. There are two updraft rectangular kilns, 30 by 20 feet in dimension.

Hobart. The plant of the Hobart Pressed Brick Company is located one-fourth mile west of the city of Hobart. The material worked is a typical Redbeds shale. The deposit is opened to a depth of 20 feet and can be worked much deeper. The shale is blasted loose and shoveled into dump cars which are hauled up an incline to the plant by a hoisting drum and wire rope. The stiff-mud process is used. The shale is ground in a 9-foot dry pan and tempered in a 10-foot single geared pug mill. A "777" brick machine and rotary automatic cutter are installed. A waste heat dryer with a capacity of 30,000 per day is used. The kilns are of the rectangular updraft type, and have a capacity of 250,000 each. Wood and coal are used for fuel. The product of the plant is at present limited to common brick. Twelve to fifteen men are employed.

Geary. The only development of the shales of the Woodward formation is one mile southwest of Geary where the plant of the Geary Brick Company is located on a spur from the Rock Island Railway. The material—a red clay shale—is blasted loose, shoveled into dump cars and hauled to the plant by a hoisting drum. The dry-press process is used; the clay is prepared in a pulverizer, screened and molded in a 2-mold U. S. (Erie, Pa.) dry press. The brick are burned in two updraft kilns of 300,000 each. Wood and coal are used for fuel. The product is common brick. 15 men are employed.

Mangum. The Mangum Brick Company works the mottled red and green shales of the Greer formation at their plant at Mangum. The pit opening is 30 feet deep over an area of over one-half acre. The shale is blasted loose and hauled up an incline to the plant in a dump car. It is ground in a 9-foot dry pan and molded in a Berg 4-mold dry press. Four round downdraft kilns with a single stack are used. Another set of four kilns was being built at the time of the writer's visit to the plant. The shale from this plant is represented by sample No. 205. It could probably not be used by the plastic processes but on the dry press gives a good firm structure and shows very little whitewash.

THE CRETACEOUS AREA.

Location and area. The principal area of Cretaceous rocks in Oklahoma is in the extreme southern portion, south of the Arbuckle and Ouachita mountains. It includes eastern Love, southwestern

Carter, southern Johnston, Atoka, Pushmataha and McCurtain and all of Marshall, Bryan and Choctaw counties.

Stratigraphy. The Cretaceous deposits consist of sandstones, shales and limestones which lie upon the granite and upon the upturned edges of the older Paleozoic sedimentaries to the south of the Arbuckle and Ouachita mountains. Taff gives the following section for the south part of the Tishomingo and Atoka quadrangles:

Formation Name.	Character of Rocks.	Thickness.
Silo sandstone	Brown, friable sandstone, locally indurated by ferruginous cement, shale, and shaly sandstones.	200-
Unconformity.		
Bennington limestone	Blue shell limestones	10-15
Bokchito formation	Red and blue shale, with thin ferruginous limestone, and lentils of friable sandstone.	140
Caddo limestone	Yellow and white limestone interstratified with thin marly beds.	60
Kiamichi formation	Blue friable shale with thin shell limestone beds in lower portion.	150
Goodland limestone	Massive white limestone	25
Trinity sand	Fine yellow sand with conglomerate beds locally at the base.	200-400

All of these formations lie almost level on the granite and on the upturned edges of the older Paleozoic rocks. The outcrop of each formation is a belt having a general east and west direction. The Trinity sand is very loosely consolidated and is easily eroded. The outcrop is usually nearly level land with a very sandy soil. The Goodland limestone usually outcrops as a bluff 20 to 25 feet in height above the Trinity sand. The Kiamichi is a soft easily eroded formation and outcrops as a valley between the more resistant ledges of the Goodland and Caddo limestones and the Bokchito occurs in similar relations between the Caddo and the Bennington limestones.

While the Kiamichi formation contains a great amount of shale and clay it is very calcareous, being filled with calcite veins and with lime fossils. The Bokchito is the only formation of the Cretaceous of the State which gives promise of becoming important as a source of clay products. Samples from this formation at Durant (No. 327) and at Woodville (No. 331) are suitable for the commoner clay products. The descriptions and data on the tests of these samples will give a fair idea as to their properties and modes of occurrence. Large quantities of a red, sandy clay of uncertain age overlies the Cretaceous rocks near Red River. This is available for soft mud brick. (See report on Sample 312, red, from Woodville and on 322, and 323 from Garvin).

The Cretaceous area is partly forested and wood for fuel can be obtained in most localities. There is an oil field developed at Madill and a possibility of further development in the region. Two lines of the St. Louis and San Francisco and the main line of the Missouri, Kansas and Texas cross the region from north to south and the Hope, Hugo and Ardmore branch of the St. Louis and San Francisco extends almost the entire length of the area from west to east.

GENERAL SUMMARY.

In the development of any center of the clay industry there are at least four essential factors to be noted. These are first: the supply of raw material; second, fuel; third, transportation facilities; and fourth, markets. It is the purpose of this article to show that Oklahoma possesses advantages in all of these essential features which should make her one of the great centers of the clay working industries.

In the matter of raw material, Oklahoma is certainly as well supplied as any other state. The eastern portion of the State, except the extreme southern part, is underlaid by the sandstones and shales of the Carboniferous system. These shales are of the same age as those of Ohio and Pennsylvania. Some of them are the southern continuation of the beds that are worked at Cherryvale and Coffeyville, Kansas, with excellent results. The beds are often many feet in thickness and easily accessible. The few tests that have been made show that practically all these shales are suitable for either common brick, front brick, or paving brick. Fire clays should occur in connection with the coal. Some veins of fire clay have been tested, but proved not to have high refractoriness, however, as there are several other veins to be tested, suitable material may yet be found.

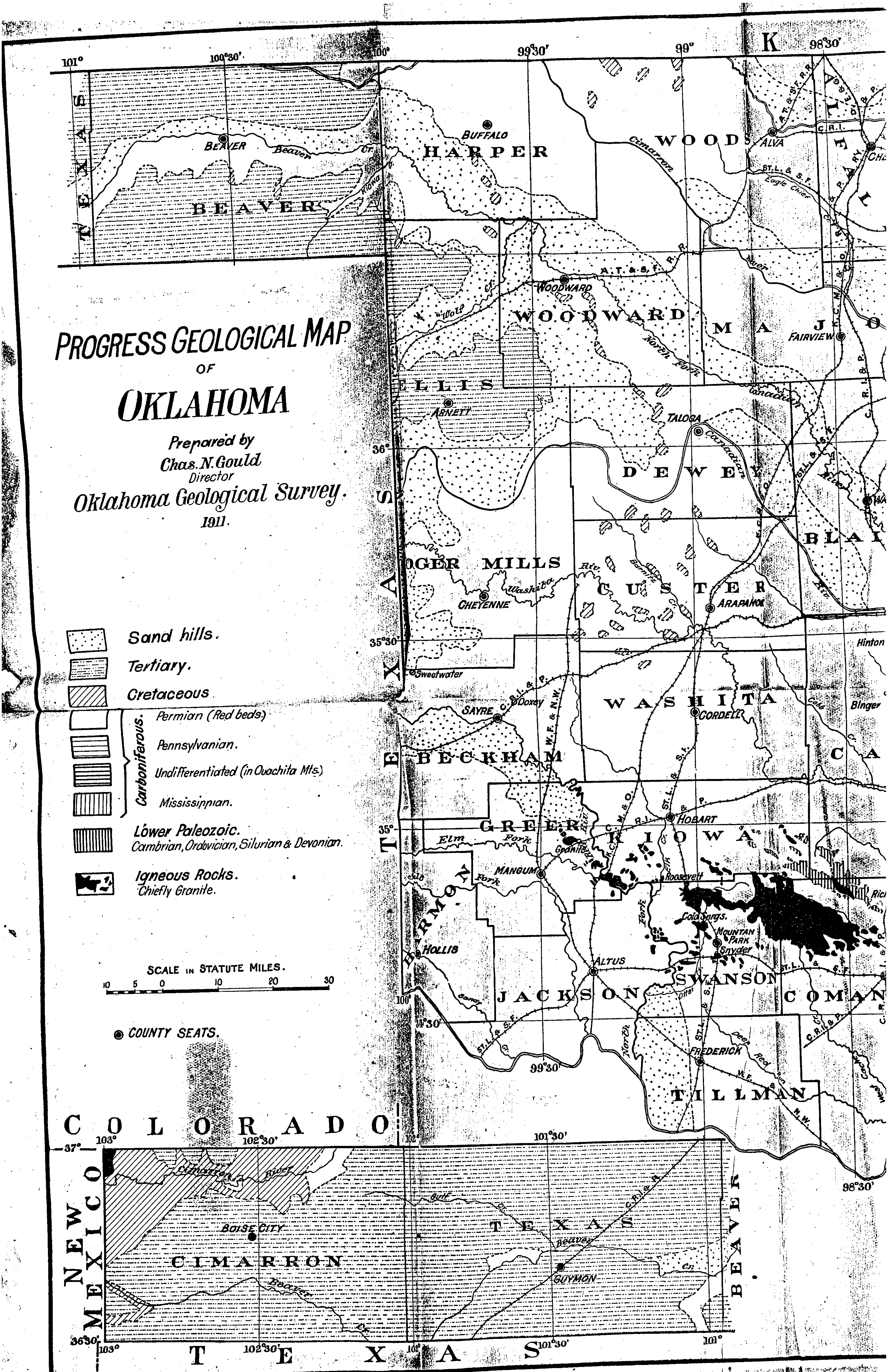
Farther west the clays become red on account of the high percentage of iron they contain. These shales have proved valuable, so far, only for common and building brick. The supply for this purpose is inexhaustible as red shales occur throughout the entire western half of Oklahoma. In the southern portion of the State the shales usually occur in thinner beds than in the eastern area, but there are many localities with beds of workable thickness, well situated with regard to fuel and transportation.

In regard to the second essential factor, that of fuel, it is only necessary to state that the northeastern counties, where the Carboniferous shales occur in greatest abundance, lie in the midst of the world's greatest oil and gas fields. The gas may be obtained for manufacturing purposes at a few cents per thousand feet. The field is being constantly enlarged and shows no signs of failure of supply. There are also smaller fields in the southwest and south-central parts of the State. Just south of the oil and gas belt lie the coal fields, which will supply an abundance of cheap fuel for years to come. The western portion is not so fortunate in this respect, but in no part would the cost of fuel be prohibitive.

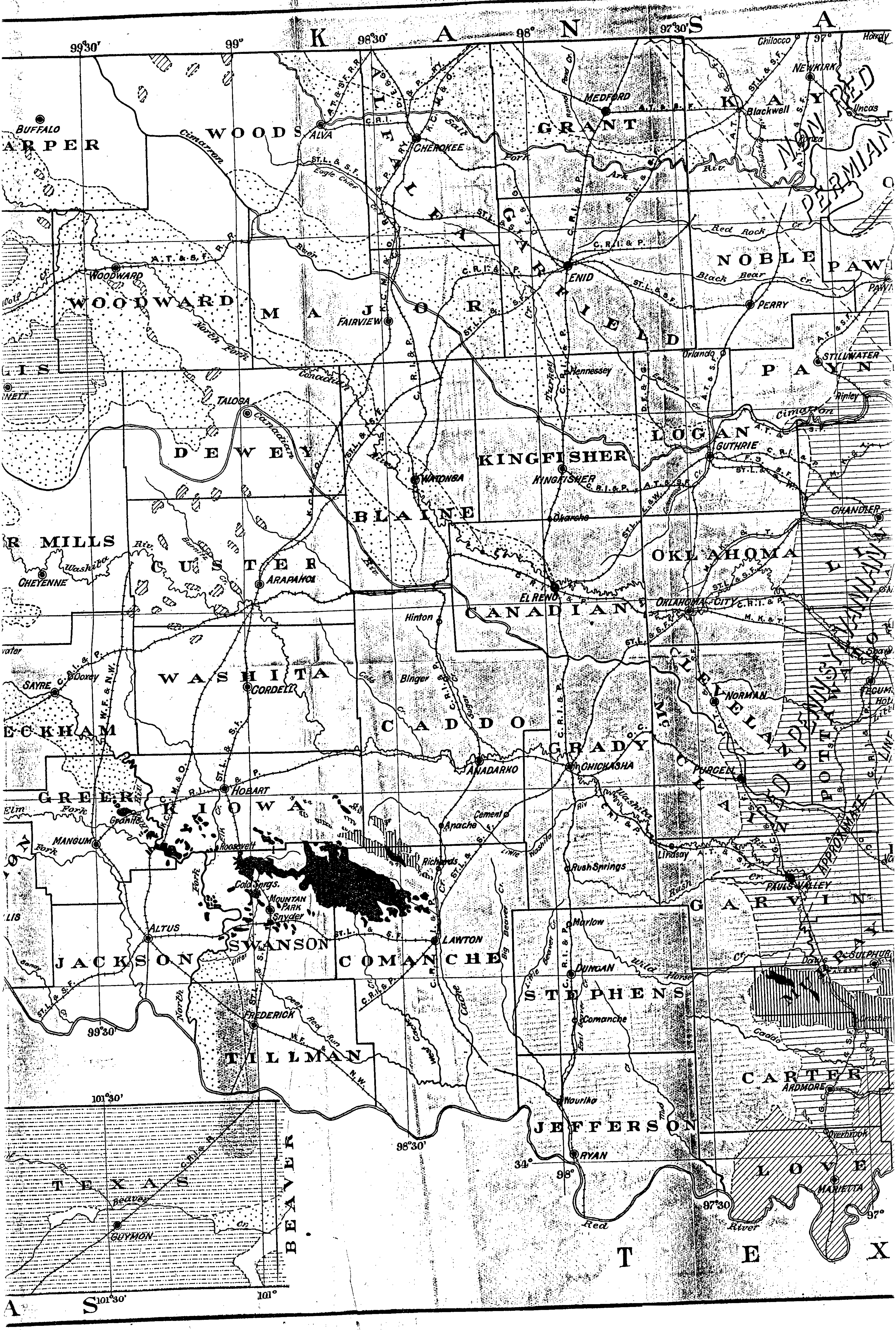
All parts of Oklahoma are well supplied with railroads, the eastern portion, where the better shales and the fuel are most plentiful, being especially so. The main lines of the Missouri, Kansas and Texas and the St. Louis and San Francisco systems traverse this portion of the State from north to south. Each system has many branches or cross lines which connect the two systems at several points. The St. Louis, Iron Mountain and Southern has a line from Kansas City to Fort Smith. The Midland Valley crosses the field from northwest to southeast. The Fort Smith and Western, and Chicago, Rock Island and Pacific give east and west connections through the coal fields. Through the Redbeds region, the Atchison, Topeka and Santa Fe, the Chicago, Rock Island and Pacific, St. Louis and San Francisco, and Kansas City, Mexico and Orient give excellent service in all directions.

In regard to markets it should be noted that the rapid growth of such cities as Oklahoma City, Muskogee, McAlester, Ardmore, Durant and many others creates a demand, which at present is much larger than the supply. Several plants have been installed in the State, but the greater portion of the clay products used are still imported from the older states. No one who has investigated the conditions doubts that the era of permanent building in Oklahoma is just beginning and that the demand for all sorts of clay products will steadily increase.

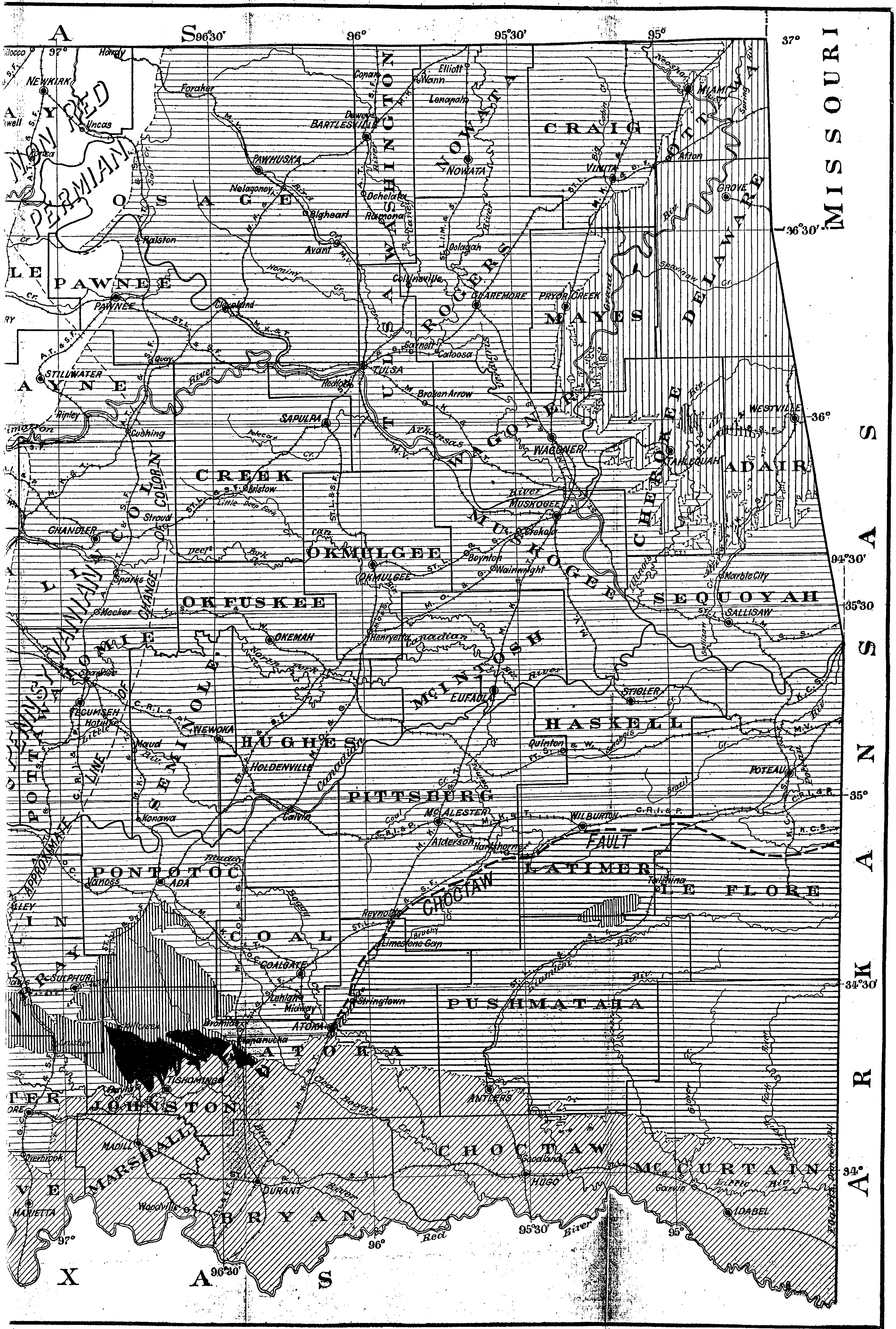
Although at present no deposits of high grade fire or pottery clay are known, the tests made have only covered a small portion of the area, hence it is probable that such deposits will yet be found. Even if these materials should not be found in the State, the abundance of shales suitable for building and paving brick, drain tile, sewer pipe, etc., combined with the advantages in the way of fuel, transportation and markets should make Oklahoma one of the great centers of the clay industry.



PROGRESS GEOLOGICAL MAP
OF
OKLAHOMA
Prepared by
Chas. N. Gould
Director
Oklahoma Geological Survey.
1911.
Sand hills.
Tertiary.
Cretaceous.
Carboniferous.
Permian (Red beds)
Pennsylvanian.
Undifferentiated (in Ouachita Mts.)
Mississippian.
Lower Paleozoic.
Cambrian, Ordovician, Silurian & Devonian.
Igneous Rocks.
Chiefly Granite.
SCALE IN STATUTE MILES.
10 5 0 10 20 30
COUNTY SEATS.
COLORADO
NEW MEXICO
TEXAS
BEAVER
CIMARRON
HARPER
WOODS
WOODWARD
MAJOR
ELLIS
DEWEY
ROGER MILLS
CUSTER
BLAINE
WASHITA
BECKHAM
GREER
KIOWA
HARMON
JACKSON
TILLMAN
COMANCHE
SWANSON
Beaver
Buffalo
Alva
Woodward
Fairview
Arnett
Taloga
Cheyenne
Arapaho
Sayre
Cordell
Hobart
Mangum
Granite
Roosevelt
Cold Sprgs.
Mountain Park
Snyder
Hollis
Altus
Frederick
Boise City
Guymon
Sweetwater
Doxey
Hinton
Binger
Cimarron River
Beaver Cr.
North Fork
Canadian
Washita Riv.
Elm Fork
Salt Fork
Red River
101° 100°30' 100° 99°30' 99° 98°30'
103° 102°30' 102° 101°30' 101°
37° 36° 35°30' 35° 34°30' 36°30'



KANSAS
TEXAS
WOODS
GRANT
KAY
ALFALFA
GARFIELD
NOBLE
WOODWARD
MAJOR
DEWEY
BLAINE
KINGFISHER
LOGAN
CUSTER
CANADIAN
OKLAHOMA
WASHITA
CADDO
GRADY
CLEVELAND
McCLAIN
GREER
KIOWA
JACKSON
SWANSON
COMANCHE
TILLMAN
STEPHENS
GARVIN
JEFFERSON
CARTER
LOVE
BEAVER
HARPER
ROGER MILLS
BECKHAM
PAYNE
POTTAWATOMIE
NON RED
PERMIAN
RED PENNSYLVANIAN
APPROXIMATE LINE
BUFFALO
ALVA
CHEROKEE
MEDFORD
NEWKIRK
Blackwell
Chilocco
Hardy
Uncas
ENID
PERRY
WOODWARD
FAIRVIEW
Hennessey
Orlando
STILLWATER
Ripley
TALOGA
GUTHRIE
WATONGA
KINGFISHER
Okarche
CHANDLER
CHEYENNE
ARAPAHOE
El RENO
OKLAHOMA CITY
Hinton
Binger
SAYRE
Doxey
CORDELL
NORMAN
ANADARKO
CHICKASHA
PURCELL
HOBART
Granite
MANGUM
Roosevelt
Cement
Apache
Richards
Lindsay
Rush Springs
PAULS VALLEY
Cold Sprgs.
Mountain Park
Snyder
ALTUS
LAWTON
Marlow
DUNCAN
SULPHUR
Davis
Comanche
FREDERICK
ARDMORE
Waurika
RYAN
MARIETTA
Overbrook
GUYMON
Cimarron
Salt Fork
Ark. Riv.
Chikaskia Riv.
Eagle Chief
Red Rock Cr.
Black Bear Cr.
North Fork
Canadian
Canadian Riv.
Cimarron
Washita Riv.
Barnitz Cr.
Wolf Cr.
Cobb Cr.
Sugar Cr.
Elm Fork
North Fork
Otter Cr.
Deep Red Run
Cache Cr.
West Cache Cr.
Big Beaver Cr.
Little Beaver Cr.
East Beaver Cr.
Wild Horse Cr.
Rush Cr.
Caddo Cr.
Mud Cr.
Red River
Beaver Cr.
Turkey Cr.
A.T. & S.F.
A.T. & S.F. R.R.
C.R.I. & P.
ST.L. & S.F.
K.C.M. & O.
W.F. & N.W.
D.E. & G.
M.K. & T.
G.C. & S.F.
F.S.
C.R.I. & P. RY.
99°30′
99°
98°30′
98°
97°30′
97°
101°30′
101°
34°



K A N S A S
MISSOURI
ARKANSAS
T E X A S
96°30′
96°
95°30′
95°
97°
37°
36°30′
36°
35°30
35°
34°30′
34°
94°30′
NON RED
PERMIAN
PENNSYLVANIAN
COLOR
CHANGE OF COLOR
APPROXIMATE LINE OF
CHOCTAW
FAULT
O S A G E
PAWNEE
WASHINGTON
NOWATA
CRAIG
OTTAWA
DELAWARE
ROGERS
MAYES
TULSA
CREEK
WAGONER
CHEROKEE
ADAIR
OKMULGEE
MUSKOGEE
SEQUOYAH
OKFUSKEE
McINTOSH
HASKELL
POTTAWATOMIE
SEMINOLE
HUGHES
PITTSBURG
LATIMER
LE FLORE
PONTOTOC
COAL
PUSHMATAHA
ATOKA
JOHNSTON
MARSHALL
BRYAN
CHOCTAW
McCURTAIN
Newkirk
Uncas
Ponca
Hardy
Foraker
Pawhuska
Nelagoney
Bigheart
Avant
Ralston
Pawnee
Cleveland
Stillwater
Ripley
Cushing
Chandler
Stroud
Bristow
Sapulpa
Tulsa
Redfork
Broken Arrow
Bartlesville
Dewey
Copan
Wann
Elliott
Lenapah
Nowata
Ochelata
Ramona
Oolagah
Collinsville
Claremore
Catoosa
Pryor Creek
Vinita
Afton
Miami
Grove
Wagoner
Muskogee
Tahlequah
Westville
Okmulgee
Boynton
Wainwright
Marble City
Sallisaw
Okemah
Henryetta
Eufaula
Stigler
Quinton
Poteau
Sparks
Meeker
Shawnee
Tecumseh
Maud
Wewoka
Holdenville
Calvin
Konawa
McAlester
Alderson
Hartshorne
Wilburton
Talihina
Ada
Vanoss
Reynolds
Limestone Gap
Coalgate
Lehigh
Midway
Stringtown
Atoka
Sulphur
Mill Creek
Bromide
Tishomingo
Antlers
Madill
Durant
Woodville
Marietta
Overbrook
Goodland
Hugo
Garvin
Idabel
Arkansas
Canadian
Red River
Cimarron
Grand
Neosho

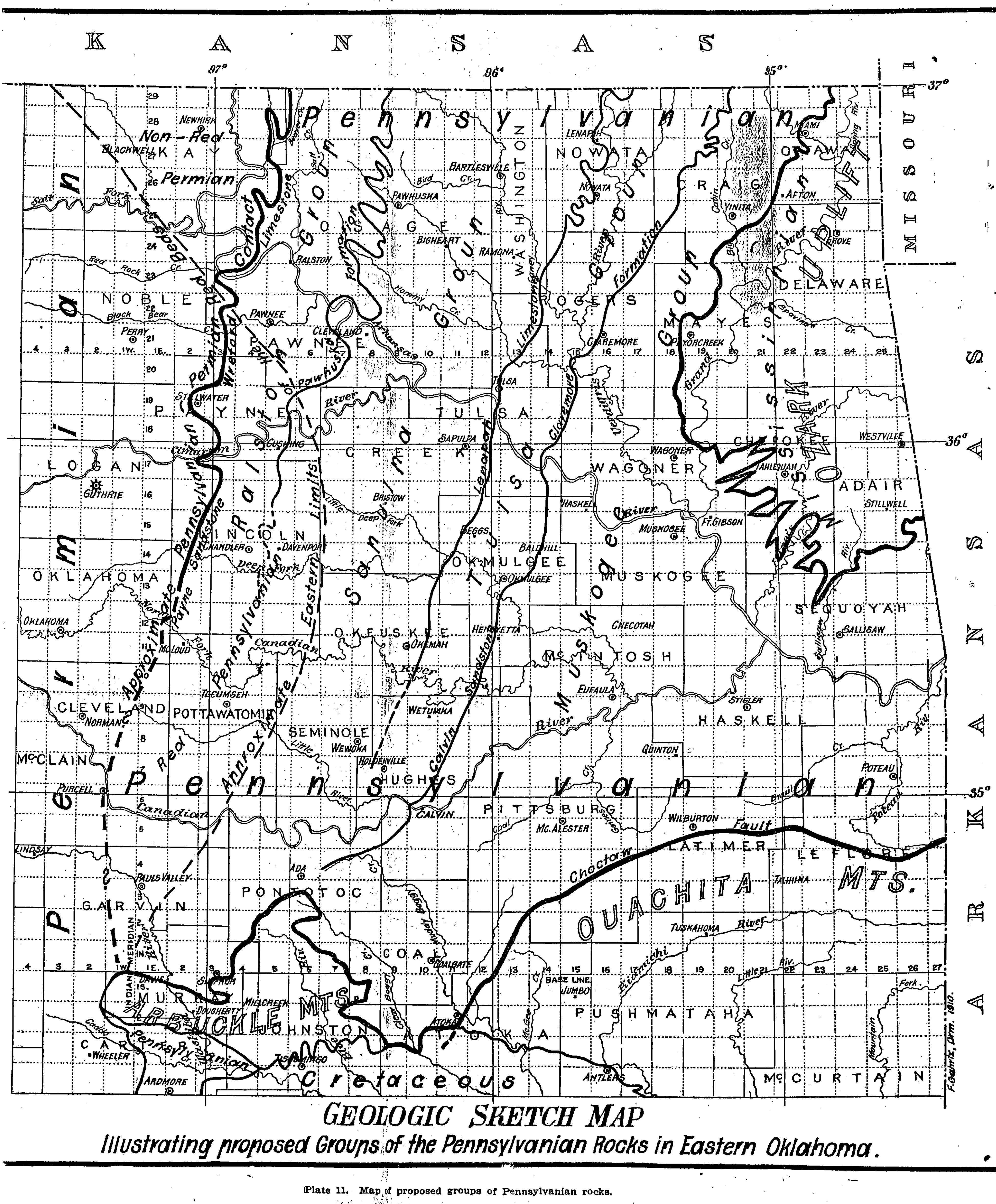


Plate 11. Map of proposed groups of Pennsylvanian rocks.