GEOLOGICAL SURVEY OF OHIO

FOURTH SERIES, BULLETIN 36
In Cooperation With The Ohio State University
Engineering Experiment Station
and The Ironton Chamber of Commerce

The Lawrence Clay of Lawrence County

By

WILBER STOUT
MYRIL C. SHAW
G. A. BOLE
DOWNS SCHAAF

GEOLOGICAL SURVEY OF OHIO

WILBER STOUT, State Geologist

FOURTH SERIES, BULLETIN 36

In cooperation with The Ohio State University Engineering
Experiment Station and The Ironton Chamber of Commerce

THE LAWRENCE CLAY OF LAWRENCE COUNTY

By WILBER STOUT, geologist; MYRIL C. SHAW, ceramist;
G. A. BOLE, ceramist; DOWNS SCHAAF, chemist

(Published also as Bulletin 67 of the Engineering Experiment Station,
The Ohio State University)

COLUMBUS
1931

Published by authority of the Legislature of Ohio,
under the supervision of the State Geologist.

43

Cleveland, Ohio
The Consolidated Press and Printing Co.
State Printers
1931
Bound at the State Bindery

CONTENTS

CHAPTER I—GENERAL STRATIGRAPHY

CHAPTER II—LAWRENCE FIELD

CHAPTER II—LAWRENCE FIELD—Continued

CHAPTER III—DEAN FIELD

CHAPTER IV—FIREBRICK FIELD

CHAPTER IV—FIREBRICK FIELD—Continued

CHAPTER V—OUTLYING AREAS

CHAPTER VI—UTILIZATION AND POSSIBILITIES OF THE LAWRENCE CLAY

CHAPTER VI—UTILIZATION AND POSSIBILITIES OF THE LAWRENCE CLAY—Continued

CHAPTER VII—METHODS OF TESTING

TABLE

ILLUSTRATIONS

PLATES

FIGURES

Showing curves for volume shrinkage, porosity, and modulus of rupture

MAP

Blank Page

PREFACE

In the course of field work in Lawrence County in 1912 and 1913, the Geological Survey became aware that the area held large bodies of high grade plastic clay that eventually should be very carefully surveyed to determine both its quantity and its quality. A few tests in 1922 proved that this clay has not only a wide range of usefulness, but also has special properties for a few purposes. The present work is a detailed study of the geology, composition, and physical properties of the member.

This report on the Lawrence clay of Lawrence County is a cooperative work between the Geological Survey of Ohio, the Ohio State University Engineering Experiment Station, the Ironton Chamber of Commerce, and private parties owning such clay lands. The field work was done by Wilber Stout, ably assisted by W. R. Maxey of Ironton, Ohio.

Another assignment of the Geological Survey was the chemical analyses, the determinations of which were made by Downs Schaaf. The physical tests were completed at the Roseville Laboratory of the Engineering Experiment Station by Myril C. Shaw under the direction of George A. Bole. The Ironton Chamber of Commerce, through the generosity of Culbertson & Dickens, John Silliman, J. L. Anderson, The Ceramic Clay Company, The Cambria Clay Products Company, The Delta Company, and others, contributed funds to defray a part of the expense.

Blank Page

CHAPTER I

GENERAL STRATIGRAPHY

INTRODUCTION

The Lawrence clay is a distinct and conspicuous unit of the coal formations of Ohio and is a ceramic asset of much value to the State. In a general way the member lies near the middle of the Allegheny series of the Pennsylvanian system. More specifically its position is about midway between the well-known Vanport limestone and the Lower Kittanning coal, the interval of separation of which across Ohio varies from 10 to 45 feet, but measures usually between 15 and 25 feet. The Lawrence clay does not belong to the Lower Kittanning coal, as generally considered, but to a thin shaly coal lying a few feet below the more prominent bed. As coal and clay on this horizon are so well developed near Lawrence Furnace in Lawrence County, the name Lawrence was assigned by W. Stout in 1923 to both the coal and its associated clay. The true succession in southern Ohio in this interval, where all the strata are represented, is as follows:

Coal, *Lower Kittanning*
Clay, *Lower Kittanning*
Shale or sandstone
Coal, *Lawrence*
Clay, *Lawrence*
Shale with ore nodules
Ore, *Ferriferous*
Limestone, *Vanport*

The arrangement of beds shown above, however, is not often present owing to the local variations of rock deposition. The shale and sandstone lying between the Lawrence coal and the Lower Kittanning clay are locally absent, in which case the Lower Kittanning and Lawrence clays coalesce, thus apparently forming one bed. Through the absence of the shale and sandstone, and through a thinning of the Lower Kittanning clay, the top of the Lawrence clay in some areas lies directly below the Lower Kittanning coal. In parts of the field the Lawrence coal and clay and the underlying ore shales are replaced by a massive sandstone which thus forms the roof of the Vanport limestone. Another variation that is apparent in a few regions is the splitting up of the Lawrence clay into two beds with shale intervening, or more likely it is a thinning of the Lawrence clay with the appearance of a lens replacing a part of the ore shales. Thus the strata in the interval between the Vanport limestone and the Lower Kittanning coal were formed under varying swamp and shallow water conditions and therefore frequently show marked changes both laterally and vertically.

LAWRENCE COAL

The Lawrence coal is widely but brokenly distributed across the State. The member extends with many wants from Lawrence County on the south to Columbiana County on the east and in general is most clearly represented at the extremes of the Ohio field. This coal is usually just a soot streak or only a thin layer of carbonaceous shale. Even in its maximum development in Lawrence County, the stratum is not often more than six inches in thickness and there it is more coaly shale than coal. The horizon is best represented by the associated clay.

LAWRENCE CLAY

The clays appearing in this part of the section include both flint and plastic, the latter kind forming the main body of the deposits.

FLINT CLAY

The position of the flint clay is just below the Lawrence coal. In character it is more of a semi-flint than a true flint, as is shown by its hardness and by its development of some plasticity on working. In general this material is dark gray in color through root impressions and through finely dispersed organic matter. Although somewhat soft, it breaks with a conchoidal fracture and is reduced by weathering into angular fragments with sharp edges and corners. The Lawrence flint clay is always smooth in texture, uniform in character, and free from concretionary impurities. In Ohio this particular stratum becomes industrially important only in the Strasburg field of northern Tuscarawas and northwestern Carroll counties, where it is utilized for the manufacture of refractory ware.

In Lawrence County the flint clay of the Lawrence member is equally as persistent as the associated plastic clay. Through its flinty character, dark color, and weathering behavior, the bed stands out as a conspicuous unit, quite apart from the others. From many measurements throughout the county the thickness of the stratum ranges from 1 inch to 2 feet 2 inches. The average measurement, however, is close to 9 inches. The quality of the Lawrence flint clay appears to be uniformly good. It is always of the high aluminous type and is free from visible impurities such as pyrite crystals, ferrous carbonate shot, and sand grains. For all refractory work this flint clay should be included with the best plastic, as it will add instead of detract from the merits of the body. Where plasticity alone is considered this flint clay should be eliminated from the mining.

ALUMINOUS PLASTIC OR "CREAM" CLAY

Where present the plastic clay of the Lawrence member has excellent thickness and uniformity. From many exposures throughout the area the stratum has a mean thickness of 7 feet 7 inches, the minimum and maximum being 4 feet 7 inches and 10 feet 10 inches respectively. Ordinarily the measurements fall between 7 and 9 feet. In general this body of plastic clay is characterized by uniformity both laterally and vertically. For a thick bed of wide distribution this constancy in quality is pronounced. The stratum shows no marked abrupt changes but it gradates from a clay somewhat siliceous in the lower part to one decidedly aluminous in the upper part. The most apparent demarcation takes place about two-thirds of the way down from the upper surface. Thus in a rather definite manner the plastic clay of the Lawrence member is divided into two kinds with different physical and chemical properties.

The upper portion of the plastic clay of the Lawrence member has special merit in that it combines excellent plasticity and high refractory qualities with good working properties. In this respect it far surpasses other coal formation clays of Ohio. Due to its excellence and certain physical properties, it is often called by the miners "cream" clay. It is exceptionally fine in texture, has a smooth feel, is light gray to light cream in color, and is usually rather prominently slickensided. This clay is free from damaging impurities such as concretionary matter of any kind and from pyrite either in grains or flakes. Further, free silica and mica are not prominent constituents. The "cream" clay of the Lawrence member has a high plasticity and tackiness which are definitely shown by physical tests and also by its use in bonding molding sand, flint clay, grog, and other hard substances. Through weathering agencies it is readily altered to a soft plastic mud often very prominent along its outcrop. Blunging is also effective in hastily reducing the clay to a thin slip. The thickness of this division of the Lawrence member varies from 3 to 8 feet but averages close to 5 feet.

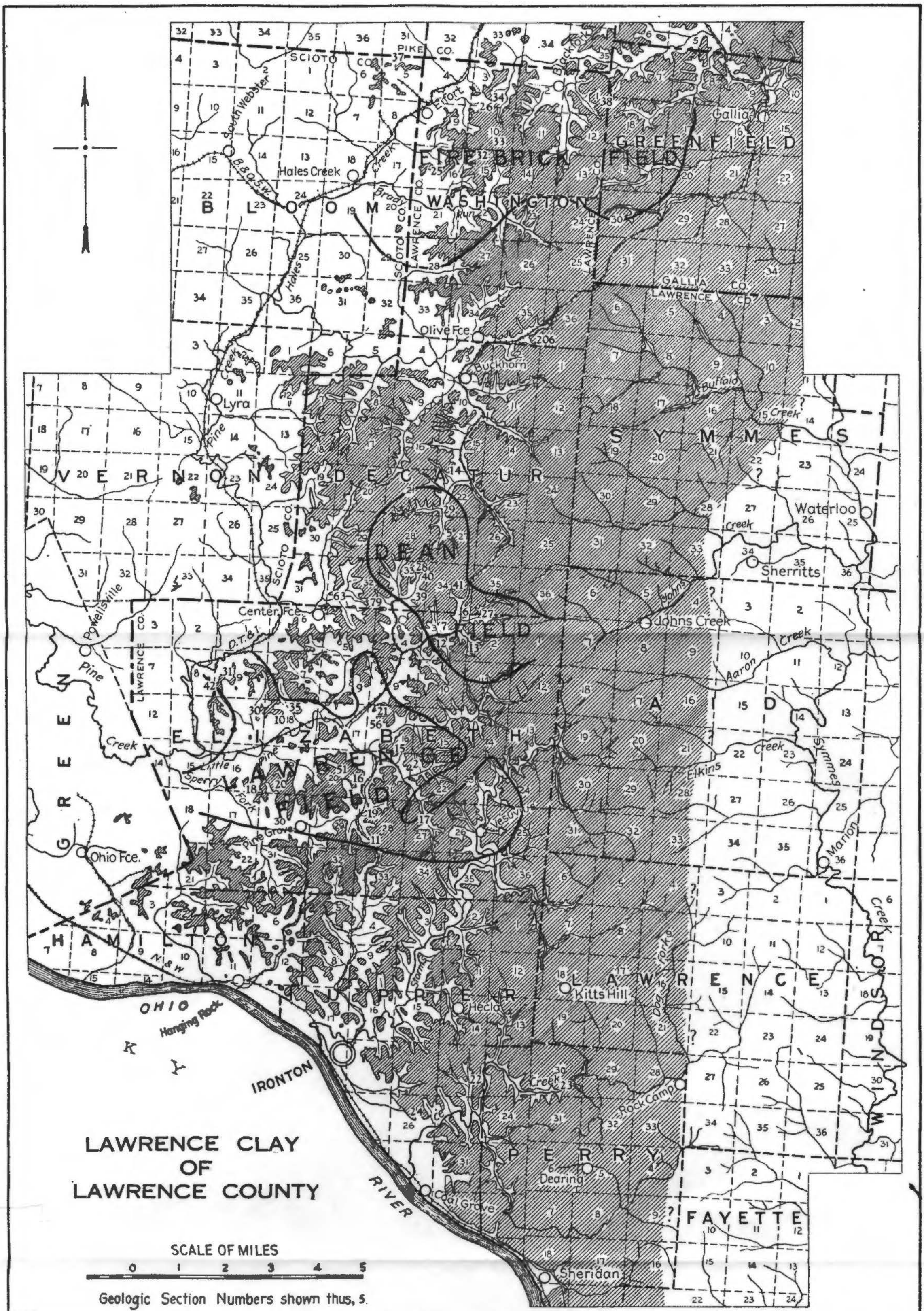
SILICEOUS PLASTIC CLAY

The third division of the Lawrence clay is the lower or basal portion which lies between the "cream" clay and the "ore slates" of the miners. The latter material is the soft gray shale overlying the Ferriferous ore and the associated Vanport limestone. The thickness of the clay stratum is on the average 2 feet 6 inches. The common variation, however, is between 1 foot and 3 feet 6 inches. This clay is always more or less siliceous in character. The content of such matter is least where the clay stratum lies on the "ore slates" and greatest where it is directly underlain by sandstone. In the latter case the siliceous clay gradates into a clay-bonded sandstone. The free silica present in this basal Lawrence clay is in the form of fine quartz grains which are easily detected by the eye or even by the feel. An associated mineral of some prominence in the clay is muscovite or mica in flakes of visible size. Other impurities such as ferruginous concretions, pyrite particles, and gypsum crystals are present only in very minor quantities and in local areas. The usual color of this clay is light gray with a small range in intensity. Through the various processes of weathering it is easily broken down to its ultimate particles, thus forming with water a soft plastic mud with good bonding strength. It machines well and dries safely under the conditions in common practice and burns to a strong body with a clean buff color and with no serious defects. This basal clay of the Lawrence member is thus well fitted for products requiring the siliceous type of clays and it also serves a purpose, when blended with the overlying clays, in reducing shrinkage, promoting drying, decreasing lamination, and lowering vitrification of the body.

As shown in the preceding discussion, the Lawrence member, although a distinct stratigraphic unit, is made up of three clays differing considerably in physical and chemical properties. Its relations to associated beds, such as the Lower Kittanning clay and coal, the "ore shales," and the Vanport limestone, are variable as to detail when traced across the State or even across a county. Its limitations in distribution are due mainly to lack of deposition through unfavorable water conditions. The main fields of Lawrence clay in Lawrence County will now be considered as to geology and extent.

GENERAL CONSIDERATION OF THE FIELDS

The Lawrence clay is due in a wide area in Lawrence County but the member is of economic importance only in isolated fields of a few square miles each. Its presence or its absence is due to the original conditions of sedimentation. The deposition of coal formation clays took place only in marshy basins where infiltrating silts from the uplands were profoundly altered by the direct action of living plants and more intensely by their products of decay. The silts lost heavily in deleterious bases and in silica and consequently were enriched in alumina, one of the more refractory constituents. The soluble products of alteration were carried away in the stream of circulation, thus leaving a material much different from the original silt. The formation of clay through such means necessarily requires the adjustment of several factors. On



LAWRENCE CLAY
OF
LAWRENCE COUNTY

the other hand, the shales were laid down in shallow quiet waters and the sandstones along shore lines with little or no modification except sorting by water. The substitution of one rock for another in these great basins during coal formation time meant only a slight shifting of various factors or conditions, some of which were change of climate or humidity, increase or decrease of subsidence, alteration or deflection of currents, modification of silt supply, etc. In the Lawrence County field the Lawrence clay often gives way in the short distance of a few hundred feet or less to sandstone or to shale. Its replacement by sandstone is common. Further, in local areas this member splits into two separate units divided by a few feet of shale or shaly sandstone. Usually in this case the upper deposit of clay is thin and the lower one considerably contaminated with ore nodules and fine shot. Each bed thus loses in thickness, in quality, and in ease of mining.

The Lawrence clay is locally present or due at the surface in Hamilton, Upper, western Perry, west central Lawrence, Elizabeth, southwestern Aid, Decatur, northwestern Symmes, and Washington townships. As the strata dip eastward and southward it is also present, but below drainage, in the remaining townships which include Fayette, Union, Windsor, Mason, and Rome. The member is of most interest, however, in three rather well-defined fields centering near Lawrence Furnace, near Dean, and near Firebrick.

CHAPTER II

LAWRENCE FIELD

INTRODUCTION

The Lawrence field of Lawrence clay lies entirely within Elizabeth Township. From sections and observations the southern boundary is roughly defined by an east-west line projected through the tunnel of the Detroit, Toledo and Ironton Railroad, near Vesuvius Station. South of this the member becomes very patchy, is divided into two inferior beds, or is completely replaced by sandstone. The above boundary thus fixes rather definitely the assured limit of quality. The northern boundary of the field is somewhat irregular. It extends from the head of Fox Hollow southeastward to Lawrence Furnace, thence northward to the head of Darby Creek, thence southeastward across Cannons Creek to Storms Creek in the northern part of Section 23. The termination here is complete in that the clay gives way to a massive sandstone which forms the roof of the Vanport limestone. A small tongue of sandstone also replaces the clay in central Section 22 and northwestern Section 27. The eastern limit of good clay appears to be along Storms Creek in sections 23 and 26, where the bed lies not far above drainage. Owing to the rise of the rocks to the west, the western margin of the field is fixed by the small patches of clay along the ridges east of Pine Creek in sections 11, 16, and 17, west. The Lawrence field includes the areas at this horizon in sections 11, west; 10, west; 18, 16, 16, west; 19, 20, 21, 29, and 28, and most of those in sections 8, 9, 17, 15, 22, 23, 17, west; 30, 27, and 26. As thus defined the total area of solid clay is close to 8 square miles. Detailed sections with their economic consideration follow.

DETAILED SECTIONS

At the north end of the tunnel of the Detroit, Toledo and Ironton Railroad the following section was obtained on the west wall:

Section No. 11		Ft.	In.
Sandstone, massive, soft		30	0
Coal, poor	*Lower Kittanning*		2¼
Shale, carbonaceous			2¾
Coal, good		3	1
Clay, light, plastic			2
Coal, good			10
Clay, dark, carbonaceous	*Lower Kittanning*		6
Clay, light, plastic, fair		4	5
Clay, drab, siliceous, poor		2	8
Clay, dark, flinty	*Lawrence*		7
Clay, light, plastic, excellent		4	8
Clay, light, plastic, siliceous		3	0
Shale and covered		3	5
Limestone, *Vanport*		3	0

The rapidity with which changes in the Lawrence clay may take place is well shown at this exposure. Here at the north end of the tunnel the clay is normal in structure, character, and thickness, whereas less than one hundred feet to the south in the tunnel it has so given way to shales and sandstones as to be worthless for ceramic purposes. This line of demarcation marks the southern border of the Lawrence field in this locality. At this place the Lawrence clay is far superior to the overlying Lower Kittanning, but for many purposes both beds may be utilized, thus giving a clay section of nearly 16 feet. As most of the Lower Kittanning coal in this part of the field has been exhausted by drift mining and the roof considerably broken, the method of winning the clay would be largely by stripping, for which the conditions are favorable.

A prospect opening for the Lawrence clay was made on the Jefferson Doolin property, lying about one-half mile north of Royersville and east of the Detroit, Toledo and Ironton Railroad. The section obtained is given below:

Section No. 19		Ft.	In.
Sandstone, massive, soft		30	0
Shale, dark, siliceous		2	0
Coal, bony	*Lower Kittanning*		8½
Coal, good		2	7½
Clay, plastic, impure			2
Coal, good			8
Coal, hard, bony			2
Clay, plastic, light to dark, siliceous, *Lower Kittanning*		4	5
Coal, shaly, and clay, dark, *Lawrence*			8
Clay, dark, flinty, good	*Lawrence*	1	1
Coal, bony, local			4
Clay, plastic, light, excellent		4	1
Covered (pit stopped in clay).			

The section thus shows a continuation northward from the tunnel to this place of both the Lower Kittanning and Lawrence clays with normal properties and without separation except for the thin layer of Lawrence coal. The full thickness of the Lawrence member is probably close to eight feet. The bed outcrops well down on the hills so that the covering along the main ridges is more than 100 feet. For mining, both stripping and drifting must be practiced.

Just north of the watering trough at Ellisonville in the central part of Section 27, the strata were well exposed by trenching on the property of the Ceramic Clay Company. A sample for analysis and testing was taken at this place September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. Although taken near the outcrop, the sample should be representative of the clay body as it was cut under good conditions where the weathering was slight. The measurements recorded are given below:

Section No. 17		Ft.	In.
Coal blossom, *Lower Kittanning*		1	0
Clay and shale, with parts covered		4	6
Coal, rotten, *Lawrence*			4
Clay, dark, part flinty, good, not sampled	*Lawrence*	2	2
Clay, dark, coaly, not sampled			1
Clay, light, plastic, excellent, sampled		6	10
Clay, light, plastic, slightly siliceous, sampled		1	2
Clay, light, plastic, slightly shaly, not sampled			11
Shale, with ore nodules		3	6
Limestone, *Vanport*		6	0

The flint clay, at this place more than two feet in thickness, is of good quality but was not included in the sample as a test was desired on the plastic clay alone. Here the "cream" clay is exceptionally smooth and pure and nearly seven feet in thickness. The deposit as a whole is high grade. The conditions for strip mining are satisfactory as the covering is thin over many acres. The overburden is mainly a soft sandstone which, however, would require some shooting. The recovery should also include considerable coal as the Lower Kittanning bed is here more than three feet in thickness and standard in quality. It has been mined to some extent over the entire area. The clay lies at convenient tipple height above the valley and may be reached by an extension of the present switch.

Analysis of the Lawrence clay from the prospect opening on the property of the Ceramic Clay Company, near the watering trough at Ellisonville. Analyst, Downs Schaaf

Chemical analysis	
Water, hydroscopic, H_2O-	2.50
Water, combined, H_2O+	7.10
Silica, SiO_2	57.79
Alumina, Al_2O_3	25.40
Ferric oxide, Fe_2O_3	1.72
Ferrous oxide, FeO	.25
Lime, CaO	.31
Magnesia, MgO	.88
Titanic oxide, TiO_2	1.57
Phosphorous pentoxide, P_2O_5	.21
Sodium oxide, Na_2O	.27
Potassium oxide, K_2O	1.51
Manganous oxide, MnO	.01
Sulphur, S	.05
Zirconium oxide, ZrO_2	trace*
Carbon, organic	.44
Carbon as CO_2 in carbonates	.02

Oxide ratio

$$\left.\begin{array}{ll} K_2O & .059 \\ Na_2O & .011 \\ CaO & .012 \\ MgO & .035 \\ FeO & .071 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{lr} SiO_2 & 2.275 \\ TiO_2 & .062 \\ P_2O_5 & .008 \end{array}\right.$$

$$\begin{array}{ll} RO & .188 \end{array}$$

*Trace means less than 0.01 per cent.

Physical tests
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 21.93 per cent
Drying shrinkage
  Volume: 16.19 per cent
  Linear: 5.7 per cent
Dry modulus of rupture: 502 pounds per square inch
Time of slaking: 63.3 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	19.71	9.58	2.06	2.57	13.94	4.87	2,532	Cream
01	15.37	7.35	2.09	2.47	13.84	5.95	3,958	Light buff
1	14.46	6.99	2.11	2.45	14.00	5.35	4,172	Light buff
3	11.64	5.33	2.15	2.44	15.65	5.50	4,493	Medium buff
5	6.96	3.10	2.24	2.41	20.91	7.52	4,549	Dark buff
7	3.87	1.39	2.27	2.29	21.71	7.83	4,844	Brownish gray
9	1.77	0.78	2.27	2.31	22.50	8.15	5,272	Gray
11	0.79	0.37	2.12	2.30	20.90	7.56	3,965	Bluestone gray
13	1.74	0.85	2.05	2.08	12.84	4.46	3,894	Bluestone gray
16	3.06	1.61	1.89	1.95	7.75	2.64	3,646	Bluestone gray
20	4.15	2.35	1.77	1.84	4.25	1.43	3,604	Bluestone gray

Porosity: The porosity decreases steadily from 11.64 per cent at cone 3, where it becomes steel hard, to 0.79 per cent at cone 11, and then it increases slightly to 4.15 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 15.65 per cent at cone 3, where it becomes steel hard, to 22.50 per cent at cone 9, and then it drops to 4.25 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.7 per cent
Burning shrinkage at cone 7	7.83 per cent
Total shrinkage	13.53 per cent

Modulus of rupture: The strength of this clay increases steadily from 2,532 pounds per square inch at cone 03 to 5,272 pounds per square inch at cone 9, and then drops off to 3,604 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 3.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 3 to cone 13.

Softening point: Cone 29.

Utilization: Clay from this property is now used for terra cotta, sanitary and decorative tiling, buff and gray quarry and promenade tile, faience pottery, sagger clay, refractory bonding clay for many purposes, salt-glazed brick, dry-press fire brick, and face brick.

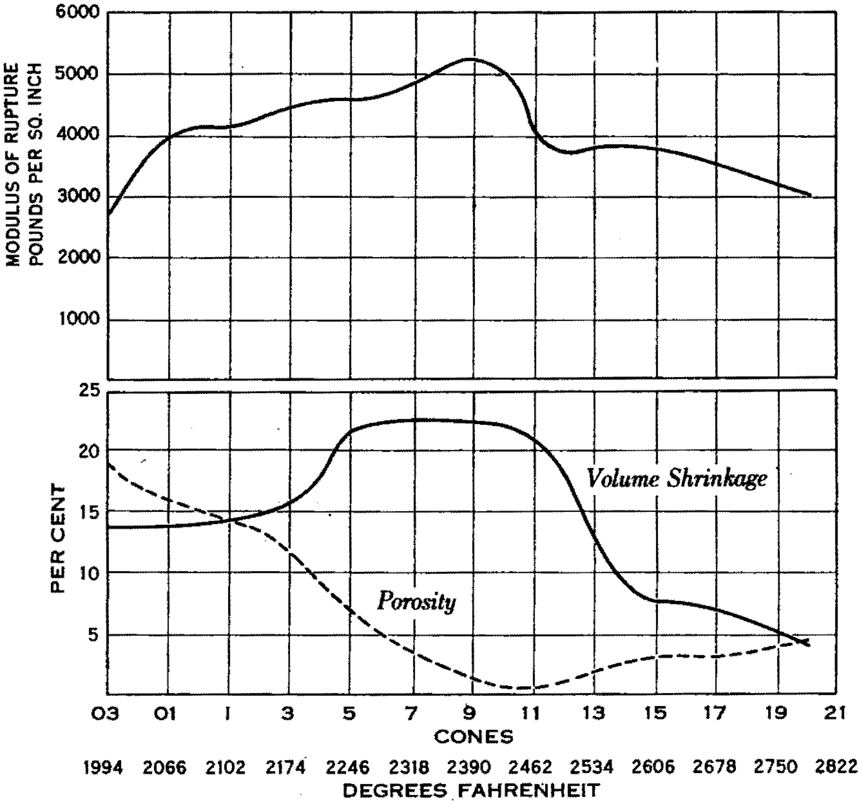


Figure 1—Sample No. 17, Ceramic Clay Company, Ellisonville

Along the road east of the divide between Ellisonville and Vesuvius Furnace, this part of the Allegheny series of rocks is exposed. The Lawrence clay appears to be about normal in thickness and quality. It is overlain by 4 inches of Lawrence coal and this in turn by more than 3 feet of shale and shaly sandstone.

Near the forks of the hollow one-fourth mile north of Etna Furnace or Pedro in the northwestern part of Section 22, the following strata were exposed on the property of the Ceramic Clay Company:

Section No. 2		Ft.	In.
Sandstone, massive, thick, not measured			
Shale, gray, siliceous		3	0
Coal, shaly	*Lower Kittanning*	1	0
Coal, good, weathered		2	10
Clay, plastic, dark			2¼
Coal, good			10¾
Clay with some bone shale	*Lower Kittanning*		10
Clay, plastic, fair quality		1	9
Clay, dark, flinty	*Lawrence*		7
Clay, light, plastic, excellent		6	6
Clay, light, plastic, siliceous		1	10
Shale and covered		5	6
Limestone, not well exposed, *Vanport*		4	0

The section is not unusual except that the Lower Kittanning clay is very thin, which is the common condition in part of the Dean and Firebrick fields. The Lawrence member is normal in every respect as is also the Lower Kittanning coal. On account of the clay stratum outcropping near the base of the hills, the method of mining will be confined mainly to drifting. The only opportunity afforded for stripping is along the brow of the hills, which are relatively steep. As the rock section shows, the real roof of the mine is the massive sandstone overlying the Lower Kittanning coal. Under such conditions the recovery will thus include the Lawrence clay, 8 feet 11 inches in thickness, the Lower Kittanning clay, 2 feet 7 inches, and the Lower Kittanning coal, 3 feet 9 inches of clean fuel. The partings in the coal and the overlying bone coal and shale would necessarily be "gobbed."

Near the old Frecka ice pond about one-half mile south of Etna Junction in the east central part of Section 20, on land of the Ceramic Clay Company, a sample from an open trench on the point of the hill was taken for testing. The sample was cut October 1, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The clay was solid but slightly stained by weathering. The composite section is given below:

Section No. 16		Ft.	In.
Sandstone, massive, soft		20	0
Shale and bone coal	*Lower Kittanning*		10
Coal, good		2	10
Clay, impure			2
Coal, good			10

		Ft.	In.
Clay, light to dark, siliceous, *Lower Kittanning*		2	2
Shale and shaly sandstone		4	8
Coal, very shaly, *Lawrence*			7
Clay, flint, dark, good, not sampled	*Lawrence*		10
Clay, plastic, dark, excellent, sampled		2	2
Clay, plastic, light, good, sampled		5	2
Clay, plastic, light, siliceous, not sampled			8
Shales with ore nodules		3	6
Ore, *Ferriferous*			4
Limestone, *Vanport*		7	0

A few scattered ore balls, probably only of local occurrence, were noticed in the lower part of the clay stratum. As shown above, shale and sandstone are present between the Lawrence and the Lower Kittanning clays, a condition found commonly in the north central part of the Lawrence field. This stratum of sandy material is sufficiently strong for a roof for drift mining the underlying Lawrence clay.

Analysis of the Lawrence clay from the property of the Ceramic Clay Company, near the Frecka ice pond. Analyst, Downs Schaaf

Chemical analysis

Water, hydroscopic, H_2O-	2.41
Water, combined, H_2O+	7.12
Silica, SiO_2	58.69
Alumina, Al_2O_3	25.25
Ferric oxide, Fe_2O_3	1.16
Ferrous oxide, FeO	.24
Lime, CaO	.34
Magnesia, MgO	.92
Titanic oxide, TiO_2	1.55
Phosphorous pentoxide, P_2O_5	.24
Sodium oxide, Na_2O	.25
Potassium oxide, K_2O	1.49
Manganous oxide, MnO	.01
Sulphur, S	.04
Zirconium oxide, ZrO_2	trace
Carbon, organic, C	.25
Carbon as CO_2 in carbonates, C	.05

Oxide ratio

K_2O	.059	Al_2O_3	1.00		
Na_2O	.010			SiO_2	2.324
CaO	.014			TiO_2	.061
MgO	.036			P_2O_5	.010
FeO	.051				
MnO	.000				
RO	.170				

Physical tests
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 21.40 per cent
Drying shrinkage
  Volume: 16.92 per cent
  Linear: 6.1 per cent
Dry modulus of rupture: 465 pounds per square inch
Time of slaking: 39.26 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	19.31	9.89	1.95	2.42	12.13	4.17	2,568	Cream
01	17.24	8.30	2.02	2.39	13.95	5.61	3,439	Cream
1	14.97	7.23	2.07	2.44	14.16	4.90	3,620	Light buff
3	14.25	6.77	2.11	2.46	15.46	5.40	4,089	Light buff
5	11.51	5.28	2.18	2.46	16.99	6.02	4,111	Light buff
7	6.08	2.66	2.28	2.43	22.31	8.07	4,397	Medium buff
9	4.75	2.47	2.25	2.28	21.11	7.59	4,141	Medium buff
11	3.76	1.67	2.26	2.25	20.75	7.44	4,054	Dark buff
13	4.92	2.26	2.17	2.26	19.36	6.90	3,417	Bluestone gray
16	6.48	3.32	1.95	2.17	17.15	6.07	2,915	Bluestone gray
20	8.72	4.13	1.88	1.96	15.90	5.61	2,179	Bluestone gray

Porosity: The porosity gradually decreases from 11.51 per cent at cone 5, where it becomes steel hard, to 3.76 per cent at cone 11, and then steadily increases to 8.72 per cent at cone 20.

Volume shrinkage: The volume shrinkage steadily increases from 16.99 per cent at cone 5, where it becomes steel hard, to 22.31 per cent at cone 7, and then gradually drops to 15.90 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	6.1 per cent
Burning shrinkage at cone 7	8.07 per cent
Total shrinkage	14.17 per cent

Modulus of rupture: The strength of this clay increases from 2,568 pounds per square inch at cone 03 to 4,397 pounds per square inch at cone 7 and then drops to 2,179 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 5 to cone 13.

Softening point: Cone 28.

Possibilities: Clay from this ridge has a wide field of usefulness, ranging from heavy duty products, such as building brick, sewer pipe, conduits, and fireproofing, to the finer grades of ware such as floor and wall tile, yellowware, and terra cotta.

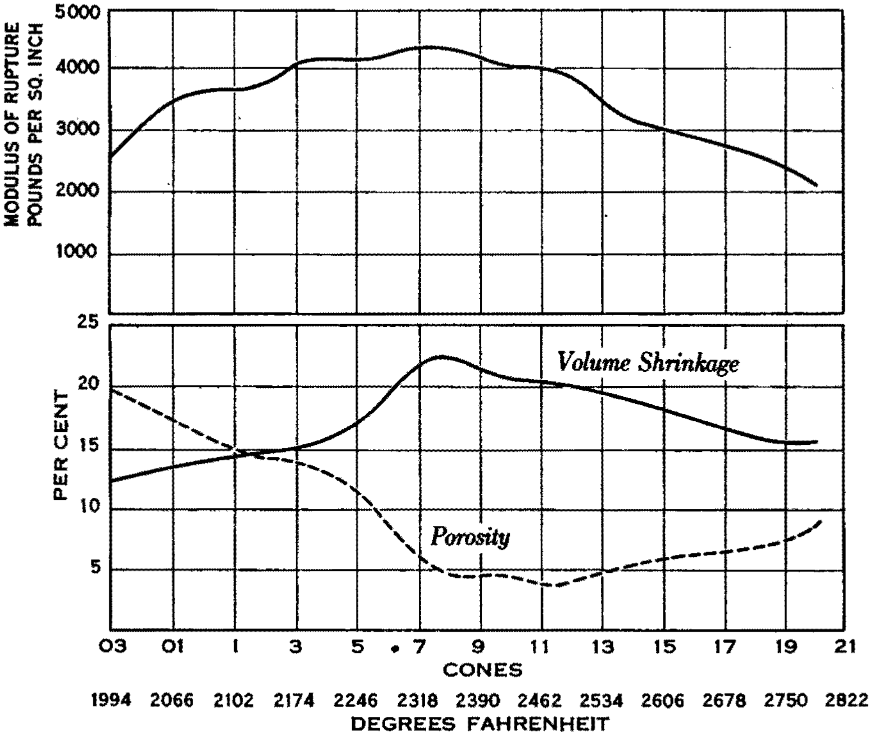


Figure 2—Sample No. 16, Ceramic Clay Company, Frecka Ice Pond

Another section illustrating the same condition as seen at the Frecka ice pond was taken at the old limestone mines of the Hanging Rock Iron Company, now the W. M. Jefferys estate, in the central part of Section 20, west of Etna Station. The measurements are recorded below:

Section No. 51		Ft.	In.
Sandstone, massive		30	0
Coal, good	*Lower Kittanning*	2	5
Clay, impure			7
Coal, good			10
Clay, plastic, siliceous, *Lower Kittanning*		1	6
Shale, drab, siliceous		2	0
Sandstone, shaly		1	6
Shale, siliceous			1
Sandstone, shaly		1	0
Shale, siliceous		1	6
Coal, shaly, *Lawrence*			1
Clay, flint, dark, good	*Lawrence*	1	0
Clay, plastic, dark, excellent		1	6
Clay, light, plastic, lower part siliceous		4	6
Shale, drab, argillaceous			6
Ore, nodules in shale			6
Shale, drab, argillaceous		1	6
Ore, blocky, *Ferriferous*			5
Limestone, *Vanport*		6	6

Such a strengthening of the roof of the Lawrence clay allows it to be mined alone with fair recovery. The thickness of the bed, 7 feet, is ample for ease in working. This body of shale and sandstone appears at the expense mainly of the Lower Kittanning clay.

Just north of the deep sandstone cut known as Sand Cut on the main road about one-half mile north of Pine Grove Furnace in the south central part of Section 19 on land of John Silliman, the Lawrence clay was properly faced for sampling. A 200-pound sample was taken September 29, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The measurements secured are given below:

Section No. 20		Ft.	In.
Sandstone, massive		20	0
Old mine, *Lower Kittanning* coal, covered		3	0
Clay, shale and covered		5	0
Coal smut, *Lawrence*			1
Clay, plastic, dark, good, sampled	*Lawrence*		6
Clay, plastic, light, excellent, sampled		6	0
Clay, plastic, light, slightly siliceous, sampled		1	3
Clay, plastic, light, siliceous, not sampled			10
Shale with ore nodules		4	0
Limestone, *Vanport*, about in position		....	....

On the whole this section is not far different from the one given on the land of the Hanging Rock Iron Company. The Lawrence stratum is normal in thickness and in quality, but the Lower Kittanning clay is partially replaced by shale and sandstone. The member lies about 100 feet below the summit of the highest ridges, hence drifting must be resorted to under the heavy part of the hills, but stripping may be practiced along the slopes and on the points.

Analysis of the Lawrence clay from the John Silliman property, Sand Cut. Analyst, Downs Schaaf

Chemical analysis	
Water, hydroscopic, H_2O-	3.00
Water, combined, H_2O+	7.22
Silica, SiO_2	58.21
Alumina, Al_2O_3	25.13
Ferric oxide, Fe_2O_3*	1.70
Ferrous oxide, FeO	.28
Lime, CaO	.32
Magnesia, MgO	.86
Titanic oxide, TiO_2	1.59
Phosphorous pentoxide, P_2O_5	.14
Sodium oxide, Na_2O	.21
Potassium oxide, K_2O	1.15
Manganous oxide, MnO	.01
Sulphur, S	.05
Zirconium oxide ZrO_2*	trace
Carbon, organic, C	.17
Carbon as CO_2 in carbonates, C	none

Oxide ratio					
K_2O	.046				
Na_2O	.008				
CaO	.013			SiO_2	2.316
MgO	.034	Al_2O_3	1.00	TiO_2	.063
FeO	.072			P_2O_5	.006
MnO	.000				
RO	.173				

---

*All the Fe, other than the ferrous oxide, FeO, is reported as ferric oxide, Fe_2O_3. This includes the Fe held in pyrite as FeS_2. The content of ZrO_2 is less than .01 per cent.

Physical tests
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 22.35 per cent
Drying shrinkage
  Volume: 15.3 per cent
  Linear: 5.3 per cent
Dry modulus of rupture: 458 pounds per square inch
Time of slaking: 60.87 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	24.96	12.79	1.95	2.60	7.14	2.04	2,673	Light buff
01	22.18	11.40	2.00	2.57	12.57	4.35	2,758	Light buff
1	19.52	9.61	2.03	2.53	14.15	4.98	3,607	Light buff
3	15.20	7.43	2.04	2.51	16.50	5.46	3,832	Light buff
5	13.80	6.41	2.15	2.50	18.75	6.67	3,956	Medium buff
7	8.71	3.85	2.26	2.48	22.00	8.23	4,844	Medium buff
9	3.75	1.10	2.26	2.32	24.41	8.90	5,202	Medium buff
11	1.90	1.13	2.25	2.31	24.00	8.74	3,837	Dark buff
13	1.25	0.91	2.25	2.29	23.90	8.30	3,060	Dark buff
16	1.17	0.59	2.00	2.02	23.83	8.66	2.750	Bluestone gray
20	1.90	1.00	1.92	1.92	22.40	8.11	2,145	Bluestone gray

Porosity: The porosity in this clay gradually decreases from 13.80 per cent at cone 5, where it becomes steel hard, to 1.17 per cent at cone 16, and then increases to 1.90 per cent at cone 20.

Volume shrinkage: The volume shrinkage gradually increases from 18.75 per cent at cone 5, where it becomes steel hard, to 24.41 per cent at cone 9, and then gradually decreases to 22.40 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.3 per cent
Burning shrinkage at cone 7	8.23 per cent
Total shrinkage	13.53 per cent

Modulus of rupture: The modulus of rupture of this clay increases steadily from 2,763 pounds per square inch at cone 03 to 5,202 pounds per square inch at cone 9, and then drops to 2,145 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay does not overburn until after cone 16 is reached.

Best apparent burning range: From cone 5 to cone 16.

Softening point: Cone 27.

Possibilities: A clear burning, refractory clay suitable for terra cotta, sanitary, decorative, and promenade tiling, intermediate heat duty refractory ware, the common grades of pottery, refractory bonding clay for mortars, plasters, and cements, and face, salt-glazed, and enameled brick.

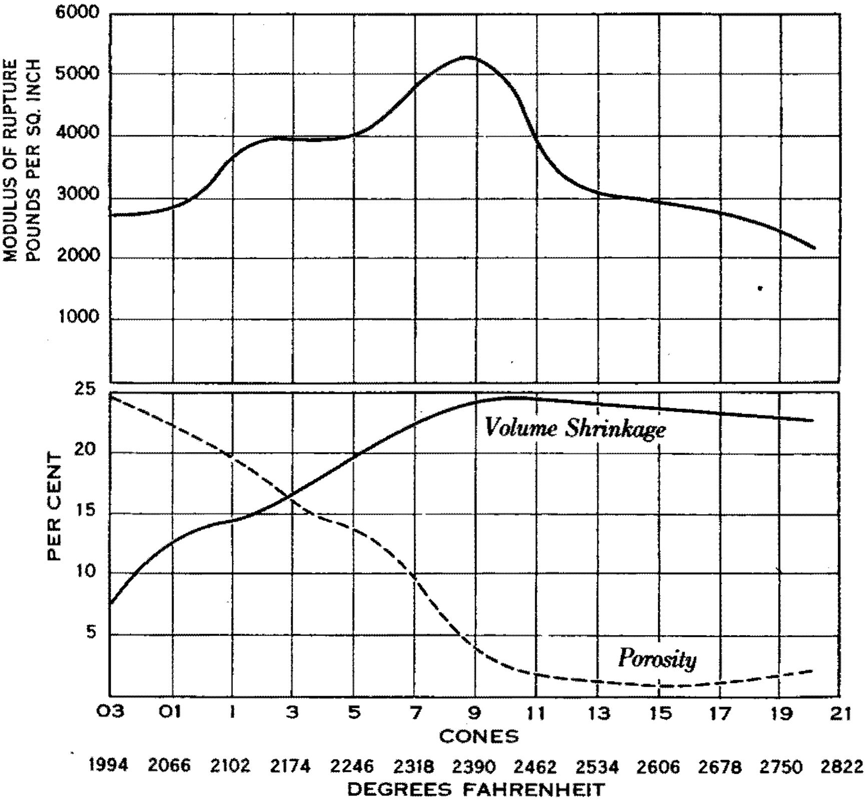


Figure 3—Sample No. 20, John Silliman, Sand Cut

A good clean exposure of the rocks from the Vanport limestone to the Lower Kittanning coal had been made by a prospect opening on land of John Silliman, located north of Sperry Fork and south of Little Pine Creek in the south central part of Section 16, west. Where thus faced, a sample of Lawrence clay was cut for testing, October 1, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, John Silliman, and Wilber Stout. The following record shows in detail the stratigraphic relations:

Section No. 18		Ft.	In.
Sandstone, massive, soft		20	0
Shale, gray, siliceous			8
Coal, bony	*Lower Kittanning*		4
Coal, good		2	11½
Clay, impure			2
Coal, good			6½
Coal, hard, bony			2½
Clay, plastic, dark	*Lower Kittanning*		2
Clay, plastic, light, fair quality		2	7
Clay, plastic, with carbonaceous bands			4
Clay, plastic, light, fair quality			7
Coal, very shaly, *Lawrence*			3
Clay, flint, dark, good, not sampled	*Lawrence*		8
Clay, plastic, dark, good, sampled			10
Clay, plastic, light, excellent, sampled		6	5
Clay, plastic, light, siliceous, not sampled			10
Shale, drab, siliceous		1	9
Ore, *Ferriferous*			4
Limestone, *Vanport*		5	0

Analysis of Lawrence clay from the John Silliman property on Sperry Fork. Analyst, Downs Schaaf

Chemical analysis	
Water, hydroscopic, H_2O-	2.57
Water, combined, H_2O+	7.27
Silica, SiO_2	59.90
Alumina, Al_2O_3	25.04
Ferric oxide, Fe_2O_3	.54
Ferrous oxide, FeO	.22
Lime, CaO	.32
Magnesia, MgO	.80
Titanic oxide, TiO_2	1.60
Phosphorous pentoxide, P_2O_5	.18
Sodium oxide, Na_2O	.22
Potassium oxide, K_2O	1.10
Manganous oxide, MnO	.01
Sulphur, S	.04
Zirconium oxide, ZrO_2	trace*
Carbon, organic, C	.30
Carbon as CO_2 in carbonates, C	trace*

Oxide ratio					
K_2O	.044	Al_2O_3 1:00	SiO_2	2.392
Na_2O	.009		TiO_2	.064
CaO	.013		P_2O_5	.007
MgO	.032			
FeO	.028			
MnO	.000			
RO	.126			

---

*Less then .01 per cent.

Physical tests of entire bed
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 23.22 per cent
Drying shrinkage
    Volume: 16.54 per cent
    Linear: 6.1 per cent
Dry modulus of rupture: 458 pounds per square inch
Time of slaking: 23.75 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	24.44	12.89	1.89	2.51	9.26	3.17	2,005	Cream
01	22.13	11.17	1.98	1.54	13.12	4.79	2,841	Cream
1	21.42	10.81	1.98	2.52	13.69	4.54	3,136	Light buff
3	20.00	9.68	2.00	2.61	14.08	4.90	3,327	Light buff
5	14.42	6.82	2.12	2.47	17.36	6.17	3,376	Light buff
7	9.69	4.29	2.26	2.50	21.93	7.91	4,392	Medium buff
9	4.94	2.14	2.31	2.43	23.66	8.58	5,376	Medium buff
11	3.07	1.39	2.21	2.28	24.10	8.78	4,133	Dark buff
13	1.66	0.72	2.30	2.34	24.50	8.94	3,766	Light bluestone gray
16	2.53	1.48	1.93	2.21	22.30	8.07	3,353	Bluestone gray
20	14.33	7.62	1.80	1.97	20.40	7.32	2,989	Bluestone gray

Porosity: The porosity decreases steadily from 14.42 per cent at cone 5, where it becomes steel hard, to 1.66 per cent at cone 13, and then increases rapidly to 14.33 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 17.36 per cent at cone 5, where it becomes steel hard, to 24.50 per cent at cone 13, and then decreases slowly to 20.40 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	6.1 per cent
Burning shrinkage at cone 7	7.91 per cent
Total shrinkage	14.01 per cent

Modulus of rupture: The strength increases from 2,005 pounds per square inch at cone 03 to 5,376 pounds per square inch at cone 9, and then decreases to 2,989 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay overburns at cone 16.

Best apparent burning range: From cone 5 to cone 16.

Softening point: Cone 29.

Possibilities: This clay, possessing excellent chemical and physical properties and burning to a light buff color, is suitable for structural wares such as terra cotta, floor and wall tile, quarry and promenade tile, fireproofing, sewer pipe, and salt-glazed, enameled, and face brick, for pottery such as faience ware, yellowware, and stoneware, for refractory products such as fire brick, ladle brick, and refractory cements, and for the bonding ingredient of molding sands, grinding wheels, and various ceramic bodies. If washed it is one of the most promising clays of the field for use in the whiteware industry.

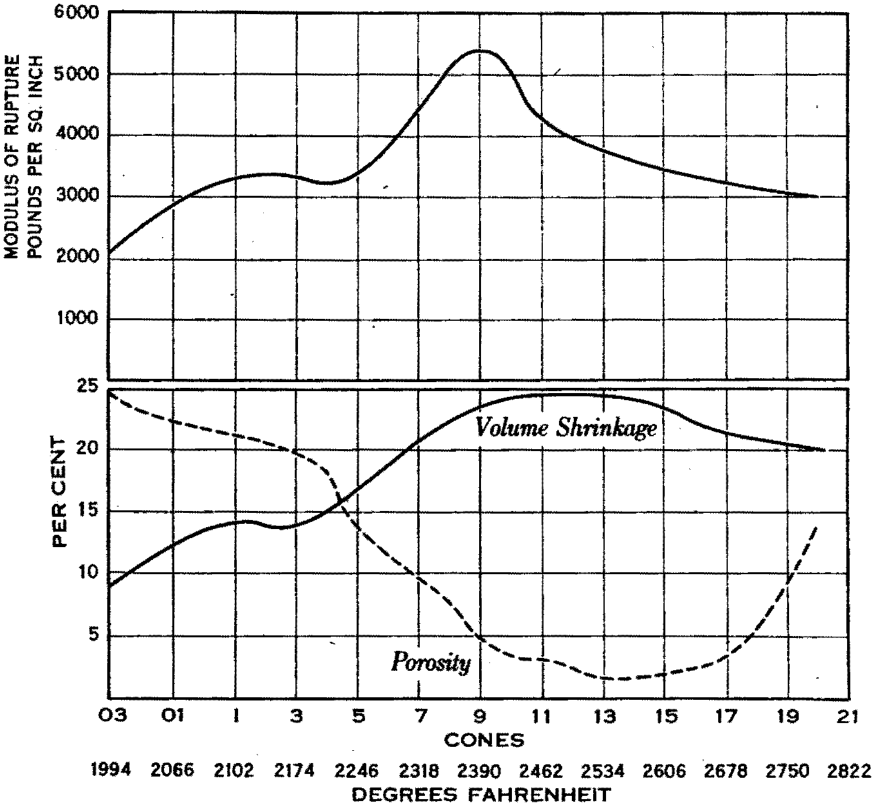


Figure 4—Sample No. 18, John Silliman, Sperry Fork, entire bed

At the same location on the John Silliman property, the separate units of the Lawrence clay were sampled in May, 1931, by M. C. Shaw, W. R. Maxey, John Silliman, and Wilber Stout. The section is as follows:

Section No. 18a		Ft.	In.
Coal, *Lawrence*			3
Clay, flinty, ferruginous, rejected	*Lawrence*		7
Clay, dark, somewhat flinty, (sample A)		1	3
Clay, plastic, light, excellent (sample B)		3	7
Clay, plastic, light, siliceous (sample C)		2	7
Clay shale			

Analyses of the different layers. Analyst, Downs Schaaf

	Sample A top clay 1 ft. 3 in.	Sample B middle clay 3 ft. 7 in.	Sample C bottom clay 2 ft. 7 in.
Water, hydroscopic, H_2O-	3.07	2.50	2.50
Water, combined, H_2O+	8.04	7.28	6.48
Silica, SiO_2	55.96	59.62	62.40
Alumina, Al_2O_3	26.40	25.14	21.11
Ferric oxide, Fe_2O_3	1.58	.72	2.15
Ferrous oxide, FeO	.20	.20	.21
Lime, CaO	.36	.32	.30
Magnesia, MgO	.20	.79	.75
Titanic oxide, TiO_2	1.73	1.61	1.35
Phosphorous pentoxide, P_2O_5	.18	.11	.11
Sodium oxide, Na_2O	.20	.22	.46
Potassium oxide, K_2O	1.10	1.20	2.04
Manganous oxide, MnO	.01	.01	.01
Sulphur, S	.04	.02	.04
Zirconium oxide, ZrO_2	trace	trace	trace
Carbon, organic, C	.88	.34	.32
Carbon as CO_2 in carbonates, C	trace	trace	trace

Oxide ratio

Sample A

$$\left.\begin{array}{ll} K_2O & .042 \\ Na_2O & .008 \\ CaO & .014 \\ MgO & .007 \\ FeO & .061 \\ MnO & .000 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.120 \\ TiO_2 & .065 \\ P_2O_5 & .007 \end{array}\right.$$

$$\begin{array}{ll} RO & .132 \end{array}$$

Sample B

$$\left.\begin{array}{ll} K_2O & .048 \\ Na_2O & .009 \\ CaO & .013 \\ MgO & .031 \\ FeO & .034 \\ MnO & .000 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.372 \\ TiO_2 & .064 \\ P_2O_5 & .004 \end{array}\right.$$

$$\begin{array}{ll} RO & .135 \end{array}$$

Sample C

$$\left.\begin{array}{ll} K_2O & .097 \\ Na_2O & .022 \\ CaO & .014 \\ MgO & .035 \\ FeO & .102 \\ MnO & .000 \end{array}\right\} Al_2O_3 \quad 1.00 \left\{\begin{array}{ll} SiO_2 & 2.956 \\ TiO_2 & .064 \\ P_2O_5 & .005 \end{array}\right.$$

$$\begin{array}{ll} RO & .270 \end{array}$$

Physical tests of top clay
by M. C. Shaw

Properties in green state

Workability: Very good plasticity
Water of plasticity: 26.77 per cent
Drying shrinkage
  Volume: 21.48 per cent
  Linear: 7.75 per cent
Dry modulus of rupture: 340 pounds per square inch
Time of slaking: 38 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
01	16.29	9.52	1.71	2.04	16.30	5.76	1,625	Cream, nearly white
1	12.80	5.83	1.74	1.94	18.10	6.80	1,650	Cream
4	10.99	6.42	1.71	1.92	20.51	7.36	1,680	Light gray
5	8.10	9.07	2.17	1.90	23.53	8.54	1,725	Gray
7	7.21	4.13	1.75	1.88	26.76	9.84	1,810	Darker gray
9	5.22	2.98	1.75	1.87	24.28	8.82	1,820	Brownish gray
11	4.10	3.08	1.78	1.88	23.57	8.58	1,850	Dark gray, brownish
13	1.46	0.63	2.30	1.90	26.69	9.83	1,830	Dark gray
15	1.42	0.65	2.30	1.90	35.38	13.55	1,725	Dark gray

Porosity: The porosity decreases steadily from 10.99 per cent at cone 4, where it becomes steel hard, to 1.42 per cent at cone 15.

Volume shrinkage: The volume shrinkage increases steadily from 20.51 per cent at cone 4, where it becomes steel hard, to 35.38 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	7.75 per cent
Burning shrinkage at cone 7	9.84 per cent
Total shrinkage	17.59 per cent

Modulus of rupture: The strength of this clay increases steadily from 1,625 pounds per square inch at cone 01 to 1,850 pounds per square inch at cone 11, and then drops to 1,725 pounds per square inch at cone 15.

Steel hardness: This clay is steel hard at cone 4.

Overburning temperature: This clay does not overburn until after cone 15 is reached.

Best apparent burning range: From cone 4 to cone 15.

Softening point: Cone 30.

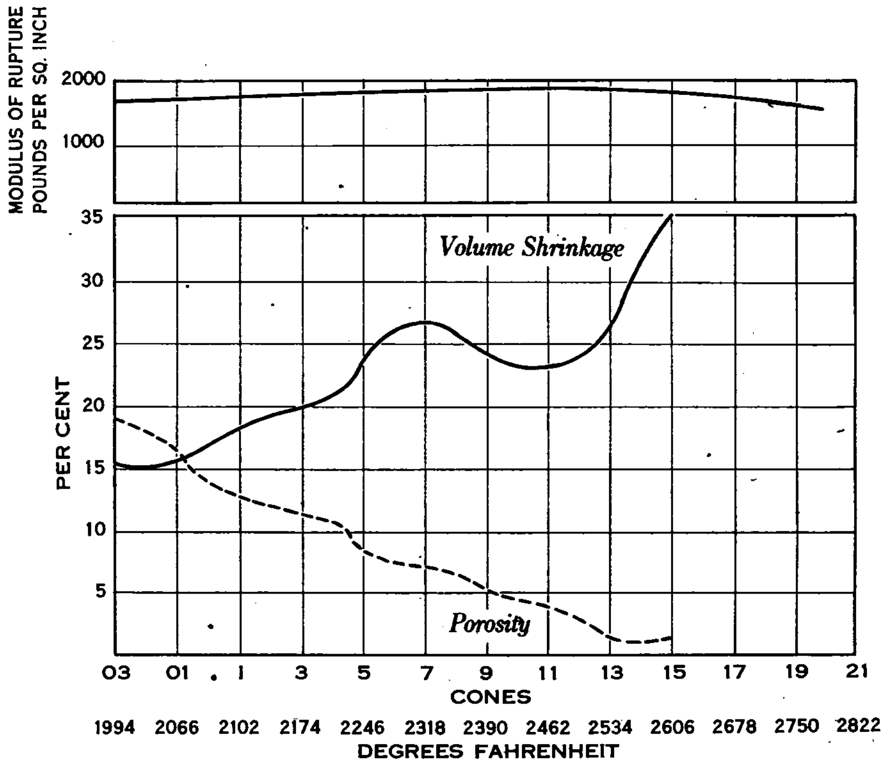


Figure 5—Sample No. 18a, John Silliman, Sperry Fork, top clay

Physical tests of middle clay
by M. C. Shaw

Properties in green state

Workability: Very good plasticity
Water of plasticity: 28.03 per cent
Drying shrinkage
  Volume: 21.64 per cent
  Linear: 7.79 per cent
Dry modulus of rupture: 410 pounds per square inch
Time of slaking: 29.76 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
01	22.32	11.48	1.94	2.50	13.38	4.65	1,625	Cream
1	21.10	8.24	2.13	2.59	18.80	6.70	1,710	Very light gray
4	18.83	9.44	1.99	2.46	20.75	7.05	1,625	Light gray
5	17.80	8.53	1.98	2.56	21.80	5.24	1,710	Light gray
7	15.28	7.19	2.13	2.51	23.70	7.71	1,825	Gray
9	11.06	5.07	2.18	2.45	25.45	9.32	1,800	Brownish gray
11	8.92	4.20	2.12	2.33	25.00	7.91	1,825	Dark brownish gray
13	5.30	4.26	2.29	2.31	25.45	9.31	1,910	Dark bluestone gray
15	3.27	1.49	2.21	2.29	22.18	7.99	1,870	Dark bluestone gray

Porosity: The porosity drops steadily from 18.83 per cent at cone 4, where it becomes steel hard, to 3.27 per cent at cone 15.

Volume shrinkage: The volume shrinkage increases steadily from 20.75 per cent at cone 4, where it becomes steel hard, to 25.45 per cent at cone 13, and then drops to 22.18 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	7.79 per cent
Burning shrinkage at cone 7	7.71 per cent
Total shrinkage	15.50 per cent

Modulus of rupture: The strength of this clay steadily increases from 1,625 pounds per square inch at cone 01 to 1,910 pounds per square inch at cone 13, and then drops to 1,870 pounds per square inch at cone 15.

Steel hardness: This clay is steel hard at cone 4.

Overburning temperature: This clay overburns at cone 15.

Best apparent burning range: From cone 4 to cone 15.

Softening point: Cone 29.

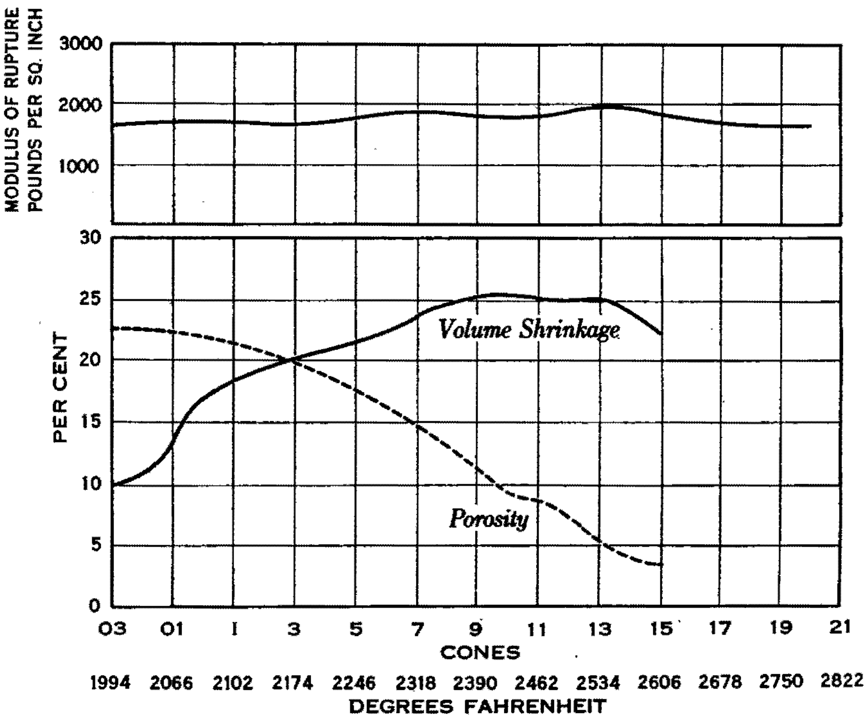


Figure 6—Sample No. 18a, John Silliman, Sperry Fork, middle clay

Physical properties of bottom clay
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 23.05 per cent
Drying shrinkage
    Volume: 15.11 per cent
    Linear: 5.3 per cent
Dry modulus of rupture: 350 pounds per square inch
Time of slaking: 32.51 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	19.69	9.65	2.04	2.54	15.61	5.50	1,310	Very light gray
1	17.50	5.42	2.20	2.50	16.80	7.48	1,450	Light gray
4	15.60	7.00	2.06	2.41	16.44	5.80	1,530	Light gray
5	13.20	8.17	2.05	2.46	18.80	5.24	1,530	Gray
7	8.94	4.10	2.18	2.39	21.40	7.71	1,530	Gray
9	5.68	2.55	2.22	2.36	21.57	7.75	1,625	Gray
11	4.41	1.94	2.27	2.28	23.05	8.35	1,630	Dark gray
13	4.42	1.96	2.25	2.26	22.60	8.19	1,690	Dark gray
15	1.03	0.55	1.86	1.88	20.50	1.22	1,250	Dark gray

Porosity: The porosity drops steadily from 15.60 per cent at cone 4, where it becomes steel hard, to 1.03 per cent at cone 15.

Volume shrinkage: The volume shrinkage increases steadily from 16.44 per cent at cone 4, where it becomes steel hard, to 23.05 per cent at cone 11, and then drops to 20.50 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	5.3 per cent
Burning shrinkage at cone 7	7.71 per cent
Total shrinkage	13.01 per cent

Modulus of rupture: The strength of this clay increases steadily from 1,310 pounds per square inch at cone 03 to 1,690 pounds per square inch at cone 13.

Steel hardness: This clay is steel hard at cone 4.

Overburning temperature: This clay overburns at cone 15.

Best apparent burning range: From cone 4 to cone 15.

Softening point: Cone 28.

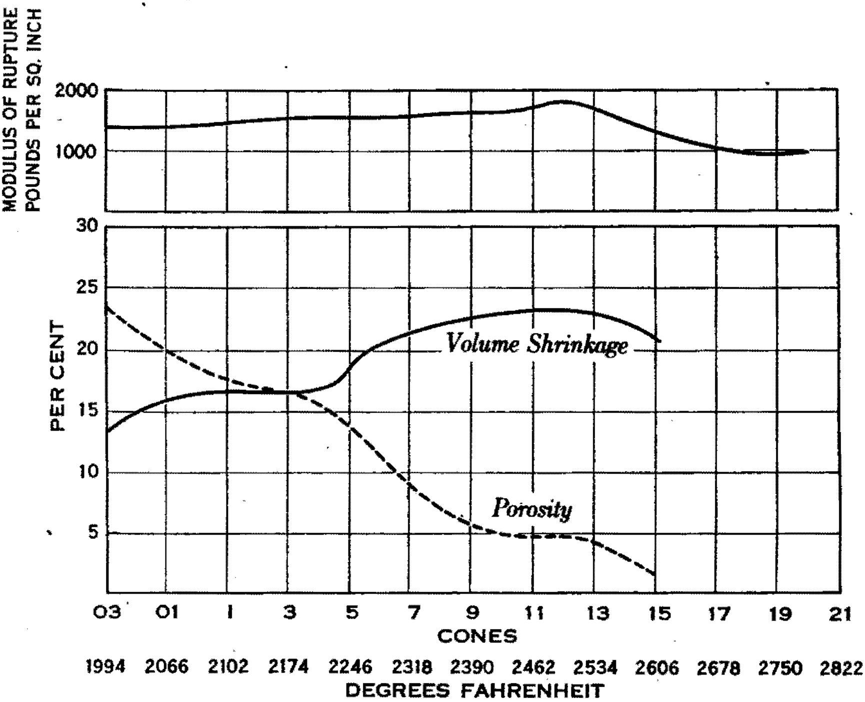


Figure 7—Sample No. 18a, John Silliman, Sperry Fork, bottom clay

In this vicinity the Lawrence member lies near the summits of the hills at an elevation of approximately 800 feet, and thus offers fine opportunities for stripping operations. Satisfactory plant sites are available to the north of the deposits on the Detroit, Toledo and Ironton Railroad, which traverses the valley of Little Pine Creek. The member here has excellent thickness and holds a high percentage of "cream" clay. The overlying Lower Kittanning clay is also of fair quality, being suitable for the manufacture of some of the heavy clay wares.

The total clay section is thus more than 12 feet. Along with the clays the recovery should also include the 3 feet 6 inches of Lower Kittanning coal, which is well fitted for ceramic uses as it is a free-burning, long flamed fuel with moderate sulphur and ash content.

The Lawrence clay maintains normal thickness and quality along the ridge summits south of Pine Creek in the southeastern part of Section 8 and in the southern part of Section 9. Outcrop exposures are present in many places along the old ore benches. The following measurements, approximately representative, were taken on the property of the W. M. Jefferys estate which is located in the west central part of Section 9:

Section No. 31		Ft.	In.
Coal, shaly, *Lawrence*			3
Clay, flinty, dark, good	*Lawrence*	1	5
Clay, plastic, light, excellent		4	8
Shale with ore nodules		3	2
Ore, *Ferriferous*			4
Limestone, *Vanport*		8	8

In this locality, the flint clay appears to be somewhat above the average in thickness, usually measuring more than 1 foot in thickness. The basal siliceous clay is thin or wanting. Along these ridges the covering of the clay is thin, less than 30 feet, which conditions are very satisfactory for strip mining. To the east and northeast the Lawrence member is replaced by sandstone.

On the ridge in the southeastern part of Section 8, on the property of John Silliman, near where the old road from Fox Hollow crosses the divide, the following measurements were taken in a prospect opening where the clay was well exposed:

Section No. 42		Ft.	In.
Sandstone, massive		10	0
Coal and partings, weathered, *Lower Kittanning*		3	0
Clay, part siliceous, *Lower Kittanning*		3	9
Coal, shaly, *Lawrence*			1
Clay, flint, good	*Lawrence*		8
Clay, plastic, light, good		1	6
Clay, plastic, light, excellent		5	9
Clay, plastic, light, siliceous		2	9
Shale, with ore balls		3	3
Limestone, *Vanport*, seen		2	0
Covered			

Along the ridge east of Fox Hollow in the northeastern part of Section 10, the Lawrence member is regularly present above the Vanport limestone. On the estate of W. M. Jefferys, the bed, properly faced by trenching, was sampled December 6, 1930, by W. R. Maxey and Wilber Stout. The separate units are shown below:

Section No. 30		Ft.	In.
Sandstone, massive		20	0
Coal, bony	*Lower Kittanning*		9
Coal, good		1	7
Coal, shaly			¾
Coal, good			8¾
Clay, impure			4
Coal, good			10½
Clay, plastic, *Lower Kittanning*		1	0
Clay, shale, and covered		7	2
Shale, drab, siliceous		2	0
Coal, shaly, *Lawrence*			2
Clay, dark, flinty, good, not sampled	*Lawrence*		9
Shale, coaly, not sampled			½
Clay, plastic, dark, sampled			10
Clay, plastic, light, excellent, sampled		4	10
Clay, plastic, siliceous, sampled		1	2
Clay, plastic, very siliceous, not sampled		1	0
Shale, drab, siliceous		2	0

Analysis of the Lawrence clay from the W. M. Jefferys estate at the head of Fox Hollow. Analyst, Downs Schaaf

Chemical analysis	
Water, hydroscopic, H_2O-	2.14
Water, combined, H_2O+	7.57
Silica, SiO_2	58.04
Alumina, Al_2O_3	25.02
Ferric oxide, Fe_2O_3	2.25
Ferrous oxide, FeO	.09
Lime, CaO	.31
Magnesia, MgO	.81
Titanic oxide, TiO_2	1.54
Phosphorous pentoxide, P_2O_5	.14
Sodium oxide, Na_2O	.27
Potassium oxide, K_2O	1.55
Manganous oxide, MnO	.01
Sulphur, S	.04
Zirconium oxide, ZrO_2	trace
Carbon, organic, C	.25
Carbon as CO_2 in carbonates, C	trace

Oxide ratio				
K_2O	.062	Al_2O_3 1.00		
Na_2O	.011		SiO_2	2.320
CaO	.012		TiO_2	.061
MgO	.032		P_2O_5	.006
FeO	.085			
MnO	.000			
RO	.202			

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 23.30 per cent
Drying shrinkage
  Volume: 14.07 per cent
  Linear: 4.94 per cent
Dry modulus of rupture: 470 pounds per square inch
Time of slaking: 56.16 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	21.98	11.15	1.97	2.53	13.94	4.90	2,825	Light gray
01	21.29	10.75	1.98	2.56	14.20	4.98	2,900	Light gray
1	20.23	10.25	1.97	2.48	14.50	5.10	1,950	Brownish gray
3	18.11	8.71	2.07	2.53	16.80	5.96	3,050	Darker brownish gray
5	14.64	6.86	2.13	2.50	20.26	7.28	3,150	Darker brownish gray
7	7.28	3.32	2.20	2.37	21.98	7.90	2,750	Darker brownish gray
9	3.80	1.70	2.21	2.29	22.04	7.95	3,075	Dark gray
11	4.75	2.30	2.20	2.30	22.60	8.19	2,825	Dark gray
13	6.30	3.10	2.19	2.30	22.10	7.99	1,525	Bluestone gray
16	8.55	4.51	1.90	2.07	21.02	7.56	1,560	Bluestone gray
20	9.80	3.68	1.71	1.82	19.50	6.98	1,400	Bluestone gray

Porosity: The porosity of this clay decreases steadily from 14.64 per cent at cone 5, where it becomes steel hard, to 3.80 per cent at cone 9, and then increases to 9.80 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 20.26 per cent at cone 5, where it becomes steel hard, to 22.60 per cent at cone 11, and then decreases to 19.50 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	4.94 per cent
Burning shrinkage at cone 7	7.90 per cent
Total shrinkage	12.84 per cent

Modulus of rupture: The strength of this clay increases steadily from 2,820 pounds per square inch at cone 03 to 3,075 pounds per square inch at cone 9, and then drops off to 1,400 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay overburns at cone 11.

Best apparent burning range: From cone 5 to cone 11.

Softening point: Cone 29.

Possibilities: This clay, representative of the average in the Lawrence field, is suitable for a wide variety of products ranging from face brick through fireproofing, sewer pipe, conduits, refractory ware, floor and wall tile, quarry tile, and terra cotta to cream-colored pottery. Its bonding strength is also good.

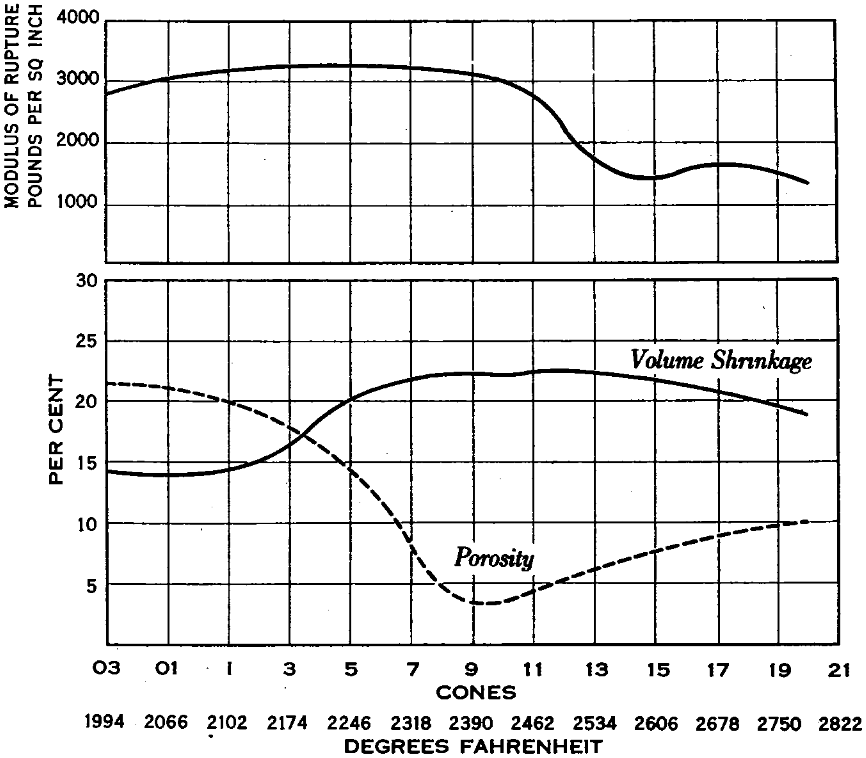


Figure 8—Sample No. 30, W. M. Jefferys estate, Fox Hollow

In the Fox Hollow area the Vanport limestone is only a few feet below the Lawrence clay, the two strata being separated by shale and a few inches of iron ore. From outcrop exposures the Lower Kittanning clay is not more than three feet in thickness and is of poor quality. Along this ridge most of the Lawrence clay is available by stripping and the quantity is sufficient for maintaining industries.

Along Little Pine Creek in Section 18 the clay resources are again important. In the west central part of the area the Lawrence and Lower Kittanning clays are mined and prepared for the general trade by the Lawrence Clay Company. On a good clean face of the pit a sample was taken for testing, September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The various strata in the section are shown below:

Section No. 10		Ft.	In.
Sandstone, soft		10	0
Shale, dark, siliceous			6
Coal, good	*Lower Kittanning*	2	10
Clay, dark, impure			2
Coal, good			10
Clay, dark, plastic	*Lower Kittanning*		4
Clay, light, plastic, good		4	2
Coal, shaly, *Lawrence*			3
Clay, dark, flinty, good, not sampled	*Lawrence*		10
Clay, plastic, light, excellent, sampled		4	9
Clay, plastic, light, slightly siliceous, good, sampled		3	7
Clay, dark, plastic, not sampled			6
Clay, light, plastic, siliceous, not sampled		2	4
Shale and covered		4	0
Ore, irregular, *Ferriferous*			6
Limestone, *Vanport*		6	0
Clay, dark, impure, coaly, *Clarion* coal horizon			4
Clay, plastic, siliceous, *Clarion*		6	8

In the present pit of this company the floor of the mine is the 6-inch layer of dark clay about 2 feet above the base of the deposit. This leaves 8 feet 2 inches of Lawrence clay of excellent quality and 4 feet 6 inches of Lower Kittanning clay somewhat above the average. Where the covering is thin along the ridge, weathering agencies have so mellowed both clays that their full plasticity is easily developed, a property of importance for bonding purposes. Associated strata of some value are the Lower Kittanning coal, the Ferriferous ore, the Vanport limestone, and the Clarion clay.

Analysis of Lawrence clay from the pit of the Lawrence Clay Company. Analyst, Downs Schaaf

Chemical analysis

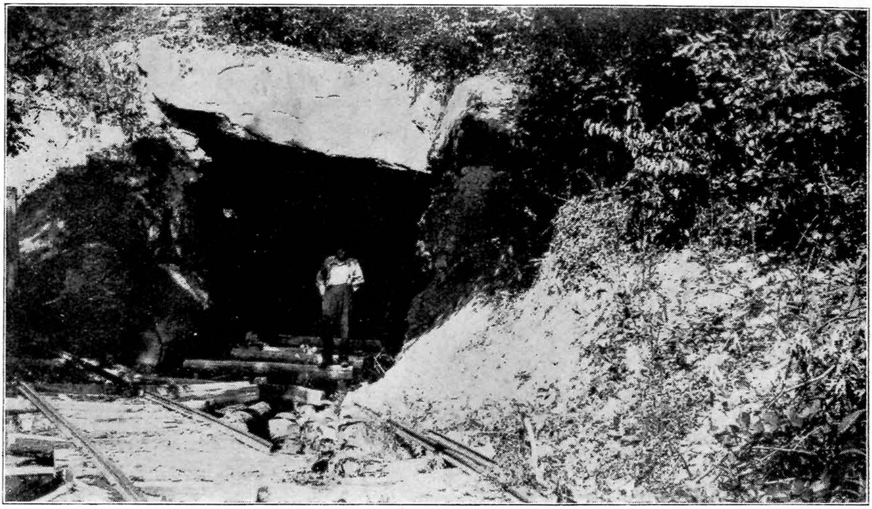
Water, hydroscopic, H_2O-	3.08
Water, combined, H_2O+	7.61
Silica, SiO_2	57.10
Alumina, Al_2O_3	25.47
Ferric oxide, Fe_2O_3	1.66*
Ferrous oxide, FeO	.30
Lime, CaO	.32
Magnesia, MgO	.88
Titanic oxide, TiO_2	1.55
Phosphorous pentoxide, P_2O_5	.26
Sodium oxide, Na_2O	.17
Potassium oxide, K_2O	1.11
Manganous oxide, MnO	.015
Sulphur, S	.43
Zirconium oxide, ZrO_2	trace*
Carbon, organic, C	.25
Carbon as CO_2 in carbonates, C	trace

Oxide ratio

K_2O	.044			
Na_2O	.[redacted] .007		SiO_2	2.242
CaO	.013	Al_2O_3 1.00	TiO_2	.061
MgO	.035		P_2O_5	.010
FeO	.070			
MnO	.001			
RO	.[redacted] .170			

---

*All the Fe, other than the ferrous oxide, FeO, is reported as ferric oxide, Fe_2O_3. This includes the Fe held in pyrite as FeS_2. The content of ZrO_2 is less than .01 per cent.



A.—Drift mine in Lawrence clay, Ceramic Clay Company, Pedro. (Photo by C. E. Bales.)

B.—Stripping mine of Lawrence Clay Company, Culbertson. (Photo by C. E. Bales.)

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 23.35 per cent
Drying shrinkage
  Volume: 19.36 per cent
  Linear: 6.10 per cent
Dry modulus of rupture: 434 pounds per square inch
Time of slaking: 49.7 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	20.11	10.07	2.00	2.50	12.87	4.47	3,132	Light cream
01	18.80	9.34	2.01	2.48	12.88	4.47	4,084	Pinkish cream
1	15.01	7.21	2.08	2.45	14.95	5.24	4,319	Pinkish cream
3	14.23	6.83	2.08	2.43	16.47	5.80	4,343	Pinkish cream
5	13.80	7.10	2.14	2.53	17.42	6.18	5,150	Grayish buff
7	12.50	5.60	2.24	2.27	19.89	7.13	5,668	Grayish buff
9	3.80	1.70	2.19	2.27	19.83	7.13	5,420	Dark grayish buff
11	1.00	0.44	2.24	2.27	20.01	7.17	4,454	Dark gray
13	2.84	1.31	2.16	2.22	19.95	7.52	3,101	Dark gray
16	10.03	5.38	1.71	2.04	18.40	6.55	2,512	Dark gray
20	16.01	1.47	1.80	1.85	17.40	6.17	2,353	Dark gray

Porosity: The porosity decreases steadily from 13.80 per cent at cone 5, where it becomes steel hard, to 1.00 per cent at cone 11, after which it increases rapidly to 16.01 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases slowly from 17.42 per cent at cone 5, where it becomes steel hard, to 20.01 per cent at cone 11, after which it drops slowly to 17.40 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	6.10 per cent
Burning shrinkage at cone 7	7.13 per cent
Total shrinkage	13.23 per cent

Modulus of rupture: The strength of this clay increases rapidly from 3,132 pounds per square inch at cone 03 to 5,668 pounds per square inch at cone 7, and then drops rapidly to 2,353 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 5 to cone 13.

Softening point: Cone 29.

Utilization: This clay is employed at present for terra cotta, faience pottery, yellowware, floor and wall tile, intermediate heat-duty refractories for cupolas, ladles, and general purposes, sagger clay, bonding clay for molding sands, fire brick, and grinding wheels, and mortars for blast, steel, electric, heating, and annealing furnaces.

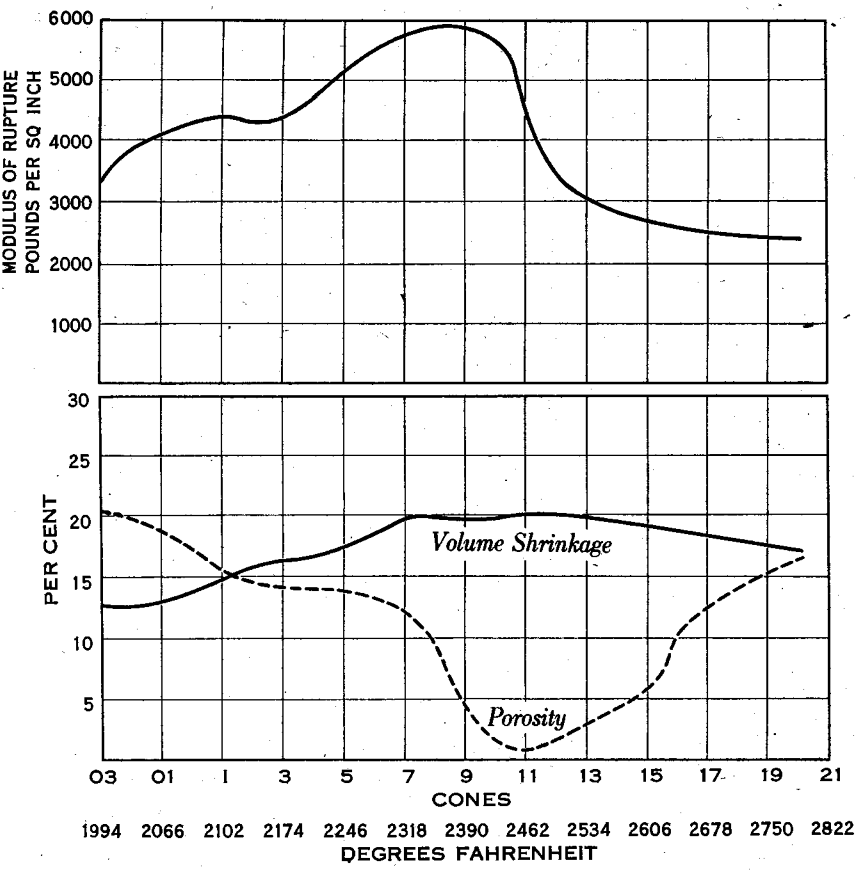


Figure 9—Sample No. 10, Lawrence Clay Company, Little Pine Creek

In 1922 the Lawrence clay was sampled by Wilber Stout on the William Maxey property (now owned by the Lawrence Clay Company) in the north central part of Section 18, Elizabeth Township.[1] Where sampled the clay was considerably weathered and therefore soft and plastic. The section as recorded is given below:

Section No. 35		Ft.	In.
Sandstone, massive		30	0
Coal, bony	*Lower Kittanning*		6
Coal, good		2	7
Clay, impure			1½
Coal, good			10
Clay, plastic, fair	*Lower Kittanning*	1	0
Clay, plastic, siliceous		3	0
Shale and shaly sandstone		2	0
Coal, shaly, *Lawrence*			4

---

[1] Geological Survey of Ohio, Bull. 26, pp. 276, 277, 278.

		Ft.	In.
Clay, dark, flinty, not sampled	*Lawrence*		9
Coal, shaly			2
Clay, plastic, light, excellent, sampled		5	6
Clay, plastic, light, siliceous, sampled		2	6
Shale and shaly sandstone with ore nodules		6	0
Limestone, *Vanport*		....	....

Tests of Lawrence clay from mine of William Maxey

Chemical analysis

Loss at 105° C	1.83
Ignition loss	6.97
Silica, SiO_2	59.90
Alumina, Al_2O_3	23.29
Ferric oxide, Fe_2O_3	2.49
Lime, CaO	.18
Magnesia, MgO	.51
Titanic oxide, TiO_2	1.75
Phosphorous pentoxide, P_2O_5	.20
Sodium oxide, Na_2O	.21
Potassium oxide, K_2O	2.49
Manganous oxide, MnO	trace
Sulphur, S	.12
Total carbon, C	.15
Inorganic carbon, C	.01

Oxide ratio

K_2O	.107	Al_2O_3	1.00	SiO_2	2.572
Na_2O	.009			TiO_2	.075
CaO	.008			P_2O_5	.009
MgO	.022				
FeO	.096				
MnO	.000				
RO	.242				

Physical tests

Working properties: Very plastic, smooth texture, good molding properties.

Tempering water	22.39 per cent
Drying linear shrinkage	6.39 per cent
Drying volume shrinkage	20.43 per cent

Burning behavior

Burning temperature	Per cent linear shrinkage	Per cent volume shrinkage	Per cent volume absorption	Color
Cone 08	3.39	9.83	23.04	Light cream
Cone 03	4.60	13.18	18.97	Light buff
Cone 2	5.76	16.30	14.41	Medium buff
Cone 5	7.80	21.63	0.46	Bluestone gray
Cone 8	8.32	22.93	0.35	Bluestone gray
Cone 11	5.33	15.15	0.21	Light gray
Cone 13	3.17	9.20	0.43	Light gray
Cone 15	1.67	4.94	0.29	Light gray

Overburning temperature: Cone 11 (1,350° C. or 2,462° F.).

Best apparent burning range: Cones 5 to 8 (1,230° C. to 1,290° C. or 2,246° F. to 2,354° F.).

Total linear shrinkage at cone 8: 14.71 per cent.

Deformation temperature: Cone 29 (1,650° C. or 3,002° F.).

Possibilities: Intermediate heat duty refractories, sewer pipe, face brick, fireproofing, stoneware.

Burns to a clear color comparatively free from iron spots. Changes from bluestone gray at cone 8 to light gray at cone 11. Shows signs of swelling at cone 11. Total linear shrinkage rather high.

Northwest of Lawrence Furnace the Lawrence clay is regularly present in the southern part of Section 17 and in the eastern part of Section 8. In an old limestone quarry on the Janet Walker McCune property and just north of the township road in the southeastern part of Section 8, the following measurements were secured where the beds were clearly exposed and were little affected by weathering. The record follows:

Section No. 9		Ft.	In.
Coal, very shaly, *Lawrence*			4
Clay, dark, good	*Lawrence*		5
Clay, plastic, light, excellent		5	1
Clay, plastic, light, siliceous		3	2
Clay, light, shaly		1	0
Shale, light gray, siliceous		4	0
Limestone, *Vanport*		7	10

From the evidence on the ore benches this body of clay extends northward along the main ridge for about three-quarters of a mile and offers opportunities for stripping except under small areas of heavy covering. North of this the bed appears to give way completely to a thick stratum of sandstone. Such a replacement of the Lawrence clay by sandstone is general in sections 7, 6, 5, 4, and 9.

The type locality for the Lawrence clay is just east of Lawrence Furnace in Section 16, where the Vanport-Lower Kittanning section was formerly very well exposed in the limestone quarries. Here the stratigraphic features of the clay are clearly defined as the associated Lawrence coal, although shaly in character, is from 6 inches to 1 foot in thickness and as shale and sandstone are regularly present between the Lawrence coal and the Lower Kittanning clay. Further, the general succession of beds shows conclusively that the Lower Kittanning coal belongs in one cycle and that the Lawrence coal belongs in another. The latter cycle, however, in some parts of the field is quite incomplete. The type section for the Lawrence members, which follows, was obtained near the divide and south of the road in the west central part of Section 16[1]:

---

[1] Geological Survey of Ohio, Bull. 26, p. 269.

Section No. 56		Ft.	In.
Coal, bony	*Lower Kittanning*	1	6
Coal, good		2	4
Clay, impure			4
Coal, good			10
Clay, lower part siliceous, *Lower Kittanning*		4	6
Sandstone, shaly		1	0
Shale, gray, siliceous		1	0
Coal, shaly, *Lawrence*			9
Clay, flint, dark	*Lawrence*	1	0
Clay, plastic, light, excellent		5	6
Clay, plastic, light, siliceous		2	9
Clay, shale, with ore nodules		4	0
Ore, *Ferriferous*			8
Limestone, *Vanport*		7	0

All the elements of the section from the Vanport limestone to the Lower Kittanning coal are here in their proper order and with normal thickness and properties. Although the section is comparatively short, only 33 feet in thickness, nevertheless it represents a long period of time as these great clay beds were built up very slowly and as the coal and limestone are gradual accumulations from organic life. Further, the depositional conditions were such that slight changes in the various factors gave rise to different kinds of sediments. Under such slow accumulation and under such close adjustment of sedimentation both laterally and vertically, changes out of the ordinary should be expected in different parts of the field. The most common of these are replacement of clay by sandstone, thinning of a coal bed to a mere soot streak, complete disappearance of shale and sandstone units, and erratic modifications as to thickness. These changes are all apparent in the Lawrence field and are responsible for the wide divergence from the type section as given above.

Near Lawrence Furnace in the northwestern part of Section 16 on the property of R. T. Lawson, the Lawrence clay, where it had been properly faced, was sampled September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The members exposed with their measurements are given below:

Section No. 21		Ft.	In.
Coal, rotten, *Lower Kittanning*		2	0
Clay, plastic, siliceous, weathered, *Lower Kittanning*		2	0
Sandstone, shaly, gray		8	4
Clay, shale, dark			7
Clay, flinty, dark, good, not sampled	*Lawrence*	1	0
Clay, plastic, light, excellent, sampled		5	11
Clay, plastic, light, slightly siliceous, sampled		1	10
Clay, plastic, siliceous, shaly, not sampled		1	3
Shale, with ore nodules		4	11
Limestone, *Vanport*		7	0

A.—Lawrence clay from exposure in old limestone quarry on property of R. T. Lawson, Lawrence Furnace. Location of type section. (Photo by C. E. Bales.)

B.—Mine of Lawrence clay at plant of the Plibrico Jointless Firebrick Company, Spencer Hollow. (Photo by C. E. Bales.)

Analysis of the Lawrence clay from the R. T. Lawson property near Lawrence Furnace. Analyst, Downs Schaaf

Chemical analysis		*Oxide ratio*					
Water, hydroscopic, H_2O-	2.55	K_2O	.053				
Water, combined, H_2O+	7.55	Na_2O	.010			SiO_2	2.252
Silica, SiO_2	57.28	CaO	.012	Al_2O_3	1.00	TiO_2	.059
Alumina, Al_2O_3	25.43	MgO	.032			P_2O_5	.009
Ferric oxide, Fe_2O_3	2.30	FeO	.112				
Ferrous oxide, FeO	.30	MnO	.001				
Lime, CaO	.30						
Magnesia, MgO	.81		——				
Titanic oxide, TiO_2	1.51	RO	.220				
Phosphorous pentoxide, P_2O_5	.22						
Sodium oxide, Na_2O	.25						
Potassium oxide, K_2O	1.35						
Manganous oxide, MnO	.025						
Sulphur, S	.08						
Zirconium oxide, ZrO_2	trace*						
Carbon, organic, C	.13						
Carbon as CO_2 in carbonates, C	trace						

---

*Less than .01 per cent.

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 23.47 per cent
Drying shrinkage
  Volume: 17.44 per cent
  Linear: 5.8 per cent
Dry modulus of rupture: 459 pounds per square inch
Time of slaking: 25.55 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	25.97	13.65	1.90	2.57	10.37	3.56	2,343	Very light buff
01	21.42	10.73	1.99	2.54	13.31	4.65	3,194	Very light buff
1	20.14	9.99	2.06	2.52	14.62	4.76	3,216	Light buff
3	20.11	10.01	2.10	2.52	16.06	5.65	3,518	Light buff
5	14.32	6.89	2.08	2.43	16.11	5.68	3,520	Grayish buff
7	8.82	4.02	2.19	2.41	20.00	7.20	3,632	Grayish buff
9	3.79	1.65	2.30	2.39	24.49	8.94	5,145	Grayish buff
11	2.43	1.11	2.19	2.25	25.19	9.18	4,297	Dark grayish buff
13	1.90	1.20	2.27	2.34	24.50	8.94	3,430	Dark grayish buff
16	1.08	0.53	1.94	1.97	22.86	8.27	2,667	Dark grayish buff
20	2.77	1.48	1.88	1.93	21.00	8.56	2,220	Dark gray

Porosity: The porosity drops steadily from 14.32 per cent at cone 5, where it becomes steel hard, to 1.08 per cent at cone 16, and then increases to 2.77 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 16.11 per cent at cone 5, where it becomes steel hard, to 25.19 per cent at cone 11, after which it decreases to 21.00 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.8	per cent
Burning shrinkage at cone 7	7.2	per cent
Total shrinkage	13.0	per cent

Modulus of rupture: The strength increases steadily from 2,343 pounds per square inch at cone 03 to 5,145 pounds per square inch at cone 9, after which it decreases to 2,220 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns above cone 16.

Best apparent burning range: From cone 5 to cone 16.

Softening point: Cone 28.

Possibilities: This clay, possessing excellent working properties and developing a strong body, is fitted for uses where plasticity, refractoriness, body structure, and color are factors. It may be recommended for faience, yellowware, and stoneware pottery; for terra cotta, sanitary ware, and glass pots; for floor, wall, decorative, quarry, and promenade tiling; for sewer pipe, flue lining, wall coping, conduits, and fireproofing; for face, salt-glazed, and terra cotta brick; and for bonding clay for a wide variety of uses.

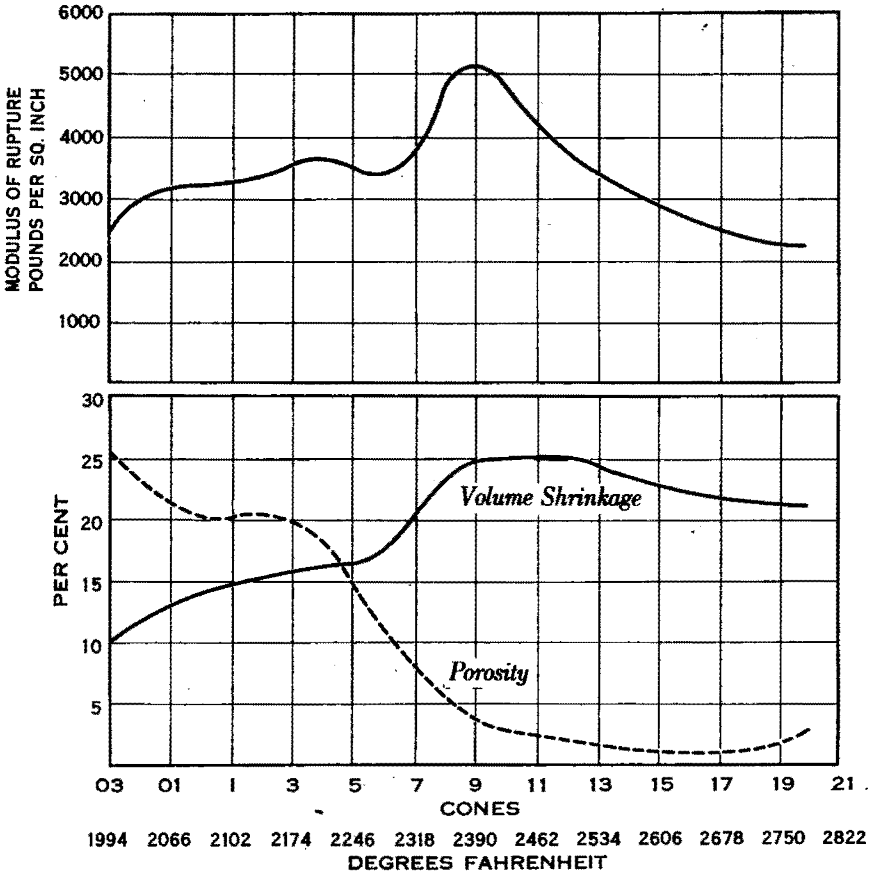


Figure 10—Sample No. 21, R. T. Lawson, Lawrence Furnace

Not far to the north and to the east of Lawrence Furnace the Lawrence member is replaced by sandstone but to the south along Cannons Creek it is regularly present. In the southeastern part of Section 16 this clay is mined in a large way by drifting by the Ceramic Clay Company with headquarters at Pedro. Some of the clay is shipped directly in the raw state, but most of it is prepared for the trade by grinding to a fine powder. The following section taken in their mines and pits shows the general stratigraphy of many beds in the Allegheny series in the southern Ohio field.:

Section No. 15		Ft.	In.
Sandstone, massive, soft		20	0
Coal, bony	*Lower Kittanning*		8
Coal, good		2	10
Clay, impure			3½
Coal, good			10
Clay, plastic, dark, *Lower Kittanning*		1	2

		Ft.	In.
Sandstone, argillaceous		3	6
Coal, bony, *Lawrence*			6
Clay, flinty, dark, good	*Lawrence*		9
Clay, plastic, light, excellent		6	8
Clay, plastic, light, siliceous		1	6
Shale, argillaceous, dark gray			8
Shale, with large ore nodules		2	0
Shale, argillaceous, dark gray		3	8
Ore, irregular, *Ferriferous*			4
Limestone, good, *Vanport*		7	0
Shale, green, impure			2
Clay, dark, good	*Clarion*		8
Coal, irregular			½
Clay, siliceous, good		5	1
Clay, very siliceous, good		4	1
Sandstone, clay-bonded		....	....

In the mine of the Ceramic Clay Company the lateral and vertical uniformity of the Lawrence clay is well shown. The variations are small as to thickness and as to quality. The member throughout the localitv contains a high percentage of "cream" clay.

GENERAL FEATURES OF THE LAWRENCE FIELD

The various rock sections secured in the Lawrence field are worthy of examination. The usual thickness of the Lawrence clay member is 9 feet 2 inches, which measurement should be approximated closely throughout the entire field. The separate units are regularly distinct and have the following thicknesses: flint clay 11 inches; "cream" clay 6 feet 1 inch; and siliceous bottom clay 2 feet 2 inches. The member thus contains 7 feet of refractory clay suitable for a wide range of uses. The associated Lawrence coal varies from a mere soot streak to 9 inches but averages about 4 inches. The appearance of shale and sandstone above the Lawrence coal is somewhat local, being present in only about one-half of the field. The true Lower Kittanning clay is much thinner than the Lawrence as the former averages only 3 feet 4 inches in thickness whereas the latter is 8 feet 2 inches. The sacrifice is not only in quantity but in quality. The Lower Kittanning coal found in this general interval is of economic importance as a fuel resource. The upper bench of coal is, on the average, 2 feet 9 inches in thickness and the lower bench 10 inches. Few intervals of equal thickness elsewhere in the State contain as great a wealth of useful materials, clay, coal, limestone, iron ore, and shale.

CHAPTER III

DEAN FIELD

INTRODUCTION

The Dean field is so named on account of the clay area centering around the old ore mining village of Dean. In parts of this field the boundaries are clearly defined, as sandstone rather abruptly replaces the Lawrence clay, whereas in other parts the limits are indefinite as the member gradually gives way in thickness and increases in silica at the expense of alumina. In the latter case the boundaries are placed where the clay ceases to maintain the standard for high grade purposes. As thus defined the southern boundary of the Dean field extends from the head of Buckhorn Hollow southeastward through Center Station to Cannons Creek in the central part of Section 11, Elizabeth Township, and the northern boundary from Mount Vernon Furnace southeastward through the Dean Forest in the northeastern part of Section 34, Decatur Township, to the central part of Section 1, Elizabeth Township. The southern limit of good clay is unknown as the member passes below drainage in the northeastern corner of Elizabeth Township. The northern extension of the clay into Buckhorn Hollow brings to view only a thin bed of very siliceous material. The field includes most of sections 21, 29, 28, 27, 33, and 34 and parts of 22, 32, and 35, Decatur Township, and most of sections 2 and 3 and parts of sections 4, 10, and 11, Elizabeth Township. The body of clay lies in a narrow belt about one and one-half miles in width and 5 miles in length. The combined known area of solid clay of standard quality is nearly 7 square miles.

In most of this field the Lower Kittanning coal is generally somewhat thin and impure. It is commonly directly overlain by a massive sandstone that makes an excellent roof for drift mining. The associated Lower Kittanning clay is also lacking in development but retains its usual quality. In most of the area the Lower Kittanning and Lawrence clays coalesce or are separated by only a thin stratum of Lawrence coal. The important Lawrence clay holds its normal thickness and shows but little variation in quality throughout the field. It is a great bed of excellent ceramic material. The underlying ore shales and Vanport limestone are regularly present with little diminution or change. Throughout the Dean field the Lawrence clay lies near the base of the hills, in most places being about good tipple height above the valley floors. The method of mining is almost entirely by drifting, the conditions being very good. The general geology of the field is next considered.

DETAILED SECTIONS

Southeast of Steece in Peter Cave Hollow the Lawrence clay is absent through replacement by sandstone. However, northeast of this in the south central part of Section 3 in Rider Hollow, the member appears in force, as is shown by the following section taken on land of Culbertson and Dickens on the west side of the valley just north of the reservoir. At this place a sample for testing was taken September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout.

Section No. 12		Ft.	In.
Sandstone, massive		15	0
Coal and parting, weathered, *Lower Kittanning*		2	0
Clay, plastic, fair, *Lower Kittanning*		2	10
Sandy shale and shaly sandstone		4	2
Shale, argillaceous		2	6
Coal, shaly, *Lawrence*			5
Clay, dark, flinty, sampled			8
Clay, plastic, light, excellent, sampled	*Lawrence*	7	3
Clay, plastic, light, siliceous, sampled			11
Clay, shale, not sampled		1	3

The shale and sandstone immediately overlying the Lawrence coal are sufficiently strong to allow drift mining of the Lawrence member alone. According to reports of miners the clay gives way to sandstone near the center of the ridge between Rider and Peter Cave hollows.

Analysis of Lawrence clay from the property of Culbertson and Dickens in Rider Hollow

Chemical analysis		*Oxide ratio*				
Water, hydroscopic, H_2O-	2.90	K_2O	.048			
Water, combined, H_2O+	7.53	Na_2O	.008		SiO_2	2.265
Silica, SiO_2	56.83	CaO	.011	Al_2O_3 1.00	TiO_2	.064
Alumina, Al_2O_3	25.09	MgO	.034		P_2O_5	.009
Ferric oxide, Fe_2O_3	2.22*	FeO	.093			
Ferrous oxide, FeO	.32	MnO	.000			
Lime, CaO	.28					
Magnesia, MgO	.86		——			
Titanic oxide, TiO_2	1.60	RO	.194			
Phosphorous pentoxide, P_2O_5	.22					
Sodium oxide, Na_2O	.21					
Potassium oxide, K_2O	1.20					
Manganous oxide, MnO	.01					
Sulphur, S	.49					
Zirconium oxide, ZrO_2	trace*					
Carbon, organic, C	.57					
Carbon as CO_2 in carbonates, C	trace					

---

*All the Fe, other than the ferrous oxide, FeO, is reported as ferric oxide, Fe_2O_3. This includes the Fe held in pyrite as FeS_2. The content of ZrO_2 is less than .01 per cent.

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 21.99 per cent
Drying shrinkage
  Volume: 15.20 per cent
  Linear: 5.5 per cent
Dry modulus of rupture: 447 pounds per square inch
Time of slaking: 37.7 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	20.40	10.07	2.02	2.53	13.41	4.68	2,480	Light cream
01	19.86	9.24	2.02	2.46	14.57	5.09	2,597	Pinkish cream
1	18.20	9.02	2.02	2.46	15.25	5.35	3,146	Pinkish cream
3	15.00	6.75	2.07	2.41	16.91	5.98	3,483	Pinkish cream
5	10.00	6.38	2.13	2.46	18.49	6.55	3,779	Grayish buff
7	5.10	2.33	2.19	2.31	19.60	7.01	4,100	Dark buff
9	5.05	2.36	2.14	2.25	19.22	6.70	3,225	Gray
11	2.31	1.30	2.13	2.20	18.18	6.44	2,828	Dark gray
13	2.53	1.19	2.13	2.18	18.11	6.44	2,775	Dark gray
16	9.25	5.32	1.74	1.99	17.09	6.06	2,493	Dark gray
20	15.00	7.25	1.68	1.73	14.80	5.20	2,000	Dark gray

Porosity: The porosity drops steadily from 10.00 per cent at cone 5, where it becomes steel hard, to 2.31 per cent at cone 11, after which it increases rapidly to 15.00 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 18.49 per cent at cone 5, where it becomes steel hard, to 19.60 per cent at cone 7, and then drops to 14.80 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.5 per cent
Burning shrinkage at cone 7	7.01 per cent
Total shrinkage	12.51 per cent

Modulus of rupture: The strength increases steadily from 2,480 pounds per square inch at cone 03 to 4,100 pounds per square inch at cone 7, and then drops steadily to 2,000 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 5 to cone 13.

Softening point: Cone 29.

Possibilities: This clay is standard in quality and may be utilized safely for terra cotta, sanitary and decorative tiling, quarry and promenade tile, refractory ware, sewer pipe, and related products, salt-glazed brick, and building brick. With careful preparation it may be employed also for sanitary ware, earthen pottery, and colored tableware. Its plastic properties fit it for a high grade bonding clay.

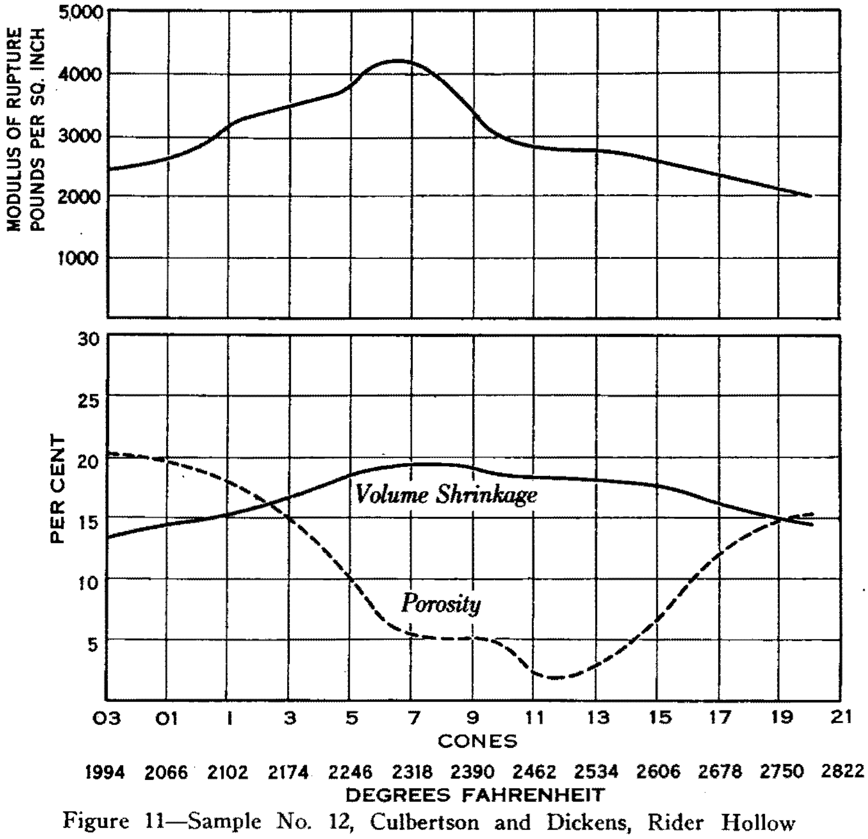


Figure 11—Sample No. 12, Culbertson and Dickens, Rider Hollow

Northeast of Rider Hollow in Little Texas Hollow, in the east central part of Section 3, Elizabeth Township, on the property of Culbertson and Dickens, the geological relations were secured in a well exposed prospect opening. The measurements are recorded below:

Section No. 13		Ft.	In.
Sandstone, massive		20	0
Coal blossom, *Lower Kittanning*		2	0
Clay, plastic, light to dark, fair quality, *Lower Kittanning*		6	9
Coal and coaly shale, *Lawrence*		1	0
Clay, plastic, light, excellent	*Lawrence*	5	8
Clay, plastic, light, siliceous, good		1	2
Covered			

The outstanding feature here is the exceptional thickness of Lower Kittanning clay, which is also above the average in quality. The total body of clay, over 14 feet in thickness, may conveniently be utilized for most wares of the heavy-clay type. The overlying sandstone forms a good roof for drift mining, thus allowing for the recovery of both clay and coal. The deposits lie about 700 feet above tide and at good tipple height above the valley floor. Just back of the old church at Dean, on land of the Lawrence County Clay and Coal Company, the following section was obtained in an old limestone quarry:

Section No. 7		Ft.	In.
Sandstone, massive		15	0
Coal, weathered to dust, *Lower Kittanning*		2	0
Clay, dark, plastic	*Lower Kittanning*		6
Clay, plastic, light, fair quality		3	6
Clay, shaly		1	5
Coal, very impure, *Lawrence*			3
Clay, dark, flinty, good	*Lawrence*		11
Clay, light, plastic, excellent		5	2
Clay, light, plastic, siliceous		1	0
Shale and covered		4	0
Limestone, part seen, *Vanport*		2	0

The above section is practically a duplication of that in Little Texas Hollow as to thickness, quality, and arrangement of the clay strata. The conditions are such that only drift mining is practical and this will necessarily include the removal of the overlying Lower Kittanning clay, hence operations in this locality should be designed to use both clays.

On the point at the forks of the hollow in the northeastern corner of Section 3, the following section was obtained in an old lime quarry on the property of the Dean State Forest Reserve:

Section No. 6		Ft.	In.
Sandstone, massive		20	0
Coal, good	*Lower Kittanning*	1	5
Clay, bluish, siliceous		1	3½
Coal, good			10½
Clay, plastic, light, part siliceous, fair quality, *Lower Kittanning*		2	6

		Ft.	In.
Coal, very impure, *Lawrence*			4
Clay, dark, plastic, good	*Lawrence*		8
Clay, light, plastic, excellent		7	0
Covered			

In the hollow north of this along the abandoned line of the Cincinnati, Hamilton, and Dayton Railroad, the Lawrence clay as an economic unit disappears in the northeastern corner of Section 34, Decatur Township, where it is replaced by sandstone. Such a condition is maintained also along the headwaters of Pine Creek in sections 23 and 26, where locally the entire section for more than 100 feet above the Vanport limestone gives way to sandstone.

Along Long Hollow in the Dean State Forest Reserve in the northern part of Section 2, Elizabeth Township, and in the southern part of Section 35, Decatur Township, the Lawrence member shows normal development as to thickness, structure, and quality. On the point at the forks of Long Hollow in the northwestern part of Section 2, Elizabeth Township, a sample was taken for testing where the clay had been well exposed in a prospect opening. The sampling was done September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The section of the strata exposed is given below:

Section No. 27

		Ft.	In.
Clay, plastic, weathered, *Lower Kittanning*		3	0
Coal, shaly, *Lawrence*			5
Clay, flinty, dark, sampled	*Lawrence*	1	4
Clay, plastic, light, excellent, sampled		5	10
Clay, plastic, siliceous, not sampled		1	0
Shales with ore nodules		6	0
Covered			

Analysis of the Lawrence clay at the forks of Long Hollow in the northern part of Section 2, Elizabeth Township. Analyst, Downs Schaaf

Chemical analysis

Water, hydroscopic, H_2O-	2.60
Water, combined, H_2O+	7.51
Silica, SiO_2	57.35
Alumina, Al_2O_3	25.29
Ferric oxide, Fe_2O_3	2.04
Ferrous oxide, FeO	.25
Lime, CaO	.30
Magnesia, MgO	.86
Titanic oxide, TiO_2	1.53
Phosphorous pentoxide, P_2O_5	.27
Sodium oxide, Na_2O	.21
Potassium oxide, K_2O	1.07
Manganous oxide, MnO	.01
Sulphur, S	.09
Zirconium oxide, ZrO_2	trace*
Carbon, organic, C	.68
Carbon as carbonates, C	trace

Oxide ratio

K_2O	.042				
Na_2O	.008			SiO_2	2.268
CaO	.012	Al_2O_3	1.00	TiO_2	.061
MgO	.034			P_2O_5	.010
FeO	.083				
MnO	.000				
	——				
RO	.179				

---

*Less than .01 per cent.

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 22.15 per cent
Drying shrinkage
  Volume: 14.13 per cent
  Linear: 5.3 per cent
Dry modulus of rupture: 207 pounds per square inch
Time of slaking: 38.50 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	25.26	13.05	1.94	2.59	10.71	3.7	2,407	Light gray
01	18.65	9.07	2.06	2.53	16.07	5.65	3,220	Light gray
1	17.63	8.71	2.07	2.49	16.79	5.95	3,285	Brownish gray
3	16.19	7.78	2.08	2.48	17.74	6.29	3,424	Dark buff
5	11.84	5.59	2.12	2.40	18.53	6.52	3,808	Dark buff
7	3.85	1.69	2.28	2.38	22.87	8.27	3,881	Dark gray, slightly buff
9	2.39	1.05	2.27	2.33	22.92	8.30	4,580	Dark gray
11	2.13	0.98	2.18	2.23	22.06	7.95	3,689	Dark gray
13	1.69	0.77	2.19	2.23	21.86	7.87	2,996	Dark gray
16	0.72	0.39	1.86	1.87	21.52	7.75	2,334	Dark gray
20	1.67	0.90	1.75	1.77	20.40	7.32	1,894	Dark gray

Porosity: The porosity steadily decreases from 11.84 per cent at cone 5, where it becomes steel hard, to 0.72 per cent at cone 16, and then increases to 1.67 per cent at cone 20.

Volume shrinkage: The shrinkage increases steadily from 18.53 per cent at cone 5, where it becomes steel hard, to 22.92 per cent at cone 9, and then drops to 20.40 per cent at cone 20.

Linear shrinkage:

Drying shrinkage	5.3 per cent
Burning shrinkage at cone 7	8.27 per cent
Total shrinkage	13.57 per cent

Modulus of rupture: The strength of this clay gradually increases from 2,407 pounds per square inch at cone 03 to 4,580 pounds per square inch at cone 9, after which it gradually drops to 1,894 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns above cone 20.

Best apparent burning range: From cone 5 to cone 20.

Softening point: Cone 28.

Possibilities: A clear burning, refractory clay with good color and body structure suitable for a wide range of products in both the serviceable and ornamental fields. It is recommended for wares varying from building brick through hollow goods, refractory ware, terra cotta, and faience pottery to sanitary ware. Further, its green strength fits it for a high grade bonding clay. This clay appears to be ideal for stoneware as it bluestones rapidly and takes a good salt glaze at cone 5.

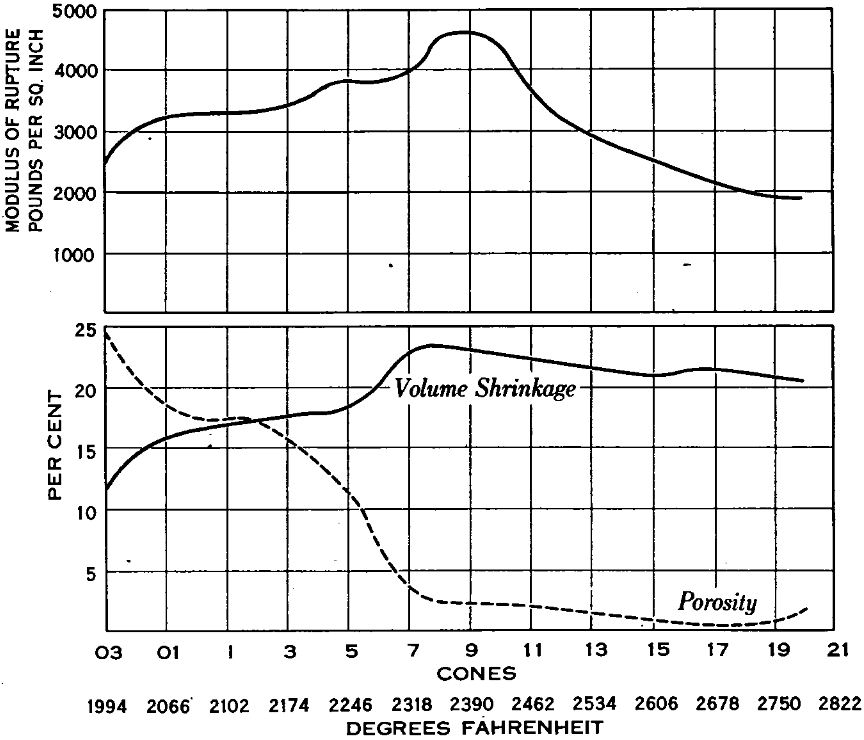


Figure 12—Sample No. 27, Dean State Forest Reserve, Long Hollow

At this place the flint clay is considerably above the average in thickness and is of good quality. In some respects it closely resembles the flint clay of the Strasburg field of Tuscarawas County with which it is directly correlative. The underlying plastic clay, 5 feet 10 inches in thickness, is exceptionally pure and smooth, having no apparent damaging qualities. Throughout this area the Lower Kittanning coal is generally thin, less than 2 feet 6 inches, and contains a thick parting of clay. The overlying massive sandstone offers good conditions for drift mining. Along this valley the Lawrence clay lies about 40 feet above drainage or at an elevation of approximately 730 feet.

In Munyon Hollow in the central part of Section 34, Decatur Township, the Lawrence clay lies well above drainage and shows normal development. The outcrop exposures on the old ore dumps indicate continuity and regularity. On the east side of the hollow about one-third mile north of Dean Church on the property of the Lawrence County Clay and Coal Company, the member was sampled May 22, 1931, by W. R. Maxey and Wilber Stout. The deposit had been well faced by trenching. Samples were taken of the top flint clay, of the "cream" clay, and of the more siliceous bottom clay.

Section No. 41		Ft.	In.
Sandstone, massive		30	0
Coal, good	*Lower Kittanning*	1	7
Clay and bony shale			3
Coal, good			9
Clay, light, plastic, fair, *Lower Kittanning*		4	0
Coal, shaly, *Lawrence*			3
Clay, dark, flint, Sample A	*Lawrence*		8
Clay, flinty, coaly, rejected			1
Clay, plastic, light, excellent, Sample B		4	9
Clay, plastic, light, siliceous, Sample C		2	4
Clay, plastic, light, very siliceous, not sampled		1	0
Shale, light, argillaceous		3	1
Limestone, *Vanport*		7	0

Analyses of the distinctive layers, that is, flint clay, "cream" clay, and siliceous clay, and also the averages as calculated from them, of the Lawrence member on the land of the Lawrence County Clay and Coal Company in Munyon Hollow. Analyst, Downs Schaaf

Chemical analyses

	Sample A Top of bed flint clay 8 in.	Sample B Middle of bed "cream" clay 4 ft. 9 in.	Sample C Bottom of bed, siliceous clay 2 ft. 4 in.	Average of A, B, and C 7 ft. 9 in.
Water, hydroscopic, H_2O-	2.53	1.45	1.47	1.55
Water, combined, H_2O+	12.04	7.31	6.80	7.56
Silica, SiO_2	47.84	58.22	63.02	58.77
Alumina, Al_2O_3	30.40	25.40	21.04	24.52
Ferric oxide, Fe_2O_3	2.10	2.05	2.36	2.15
Ferrous oxide, FeO	.20	.20	.22	.21
Lime, CaO	.40	.32	.30	.32
Magnesia, MgO	.14	.79	.14	.54
Titanic oxide, TiO_2	1.33	1.68	1.31	1.54
Phosphorous pentoxide, P_2O_5	.35	.11	.02	.10
Sodium oxide, Na_2O	.10	.29	.48	.33
Potassium oxide, K_2O	.49	1.42	2.13	1.55
Manganous oxide, MnO	trace	.01	.01	.01
Sulphur, S	.09	.02	.05	.04
Zirconium oxide, ZrO_2	trace	trace	trace	trace
Carbon, organic, C	1.90	.75	.60	.80
Carbon as CO_2 in carbonates, C	trace	trace	trace	trace

Oxide ratio

Sample A

$$\left.\begin{array}{ll} K_2O & .016 \\ Na_2O & .002 \\ CaO & .014 \\ MgO & .005 \\ FeO & .069 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 1.574 \\ TiO_2 & .044 \\ P_2O_5 & .011 \end{array}\right.$$

$$\begin{array}{ll} RO & .106 \end{array}$$

Sample B

$$\left.\begin{array}{ll} K_2O & .056 \\ Na_2O & .011 \\ CaO & .013 \\ MgO & .031 \\ FeO & .081 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 2.292 \\ TiO_2 & .066 \\ P_2O_5 & .004 \end{array}\right.$$

$$\begin{array}{ll} RO & .192 \end{array}$$

Sample C

$$\left.\begin{array}{ll} K_2O & .101 \\ Na_2O & .023 \\ CaO & .014 \\ MgO & .007 \\ FeO & .112 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 2.995 \\ TiO_2 & .062 \\ P_2O_5 & .001 \end{array}\right.$$

$$\begin{array}{ll} RO & .257 \end{array}$$

Average of A, B, C

$$\left.\begin{array}{ll} K_2O & .063 \\ Na_2O & .014 \\ CaO & .013 \\ MgO & .022 \\ FeO & .088 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 2.397 \\ TiO_2 & .063 \\ P_2O_5 & .004 \end{array}\right.$$

$$\begin{array}{ll} RO & .200 \end{array}$$

Physical properties of flint clay
by M. C. Shaw

Properties in green state

Workability: Fair plasticity
Water of plasticity: 15.71 per cent
Drying shrinkage
    Volume: 9.82 per cent
    Linear 3.38 per cent
Dry modulus of rupture: 450 pounds per square inch
Time of slaking: 38.25 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	30.60	15.71	1.95	2.81	17.6	6.25	436	Light gray
01	29.80	14.50	1.99	2.80	15.7	7.05	450	Light gray
1	29.20	15.30	1.92	2.71	14.8	5.20	710	Light gray
3	23.50	12.30	1.91	2.57	16.3	5.76	750	Gray, slightly buff
5	22.50	10.80	1.93	2.60	19.1	7.30	810	Gray, slightly buff
7	21.50	10.60	2.09	2.68	21.5	8.38	1,010	Gray, slightly buff
9	21.10	10.10	2.08	2.64	23.4	8.50	1,520	Dark gray
11	19.50	9.05	2.15	2.67	26.0	9.55	1,570	Dark gray
13	10.90	4.92	2.22	2.50	28.4	10.54	1,210	Dark gray
15	10.30	4.50	2.31	2.58	32.5	12.28	1,260	Dark gray

Porosity: The porosity drops steadily from 21.50 per cent at cone 7, where it becomes steel hard, to 10.30 per cent at cone 15.

Volume shrinkage: The volume shrinkage increases steadily from 21.5 per cent at cone 7, where it becomes steel hard, to 32.5 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	3.38 per cent
Burning shrinkage at cone 7	8.38 per cent
Total shrinkage	11.76 per cent

Modulus of rupture: The strength of this clay increases steadily from 436 pounds per square inch at cone 03 to 1,570 pounds per square inch at cone 11, after which it drops to 1,260 pounds per square inch at cone 15.

Steel hardness: Steel hard at cone 7.

Overburning temperature: This clay overburns above cone 15.

Best apparent burning range: From cone 7 to cone 15.

Softening point: Cone 30.

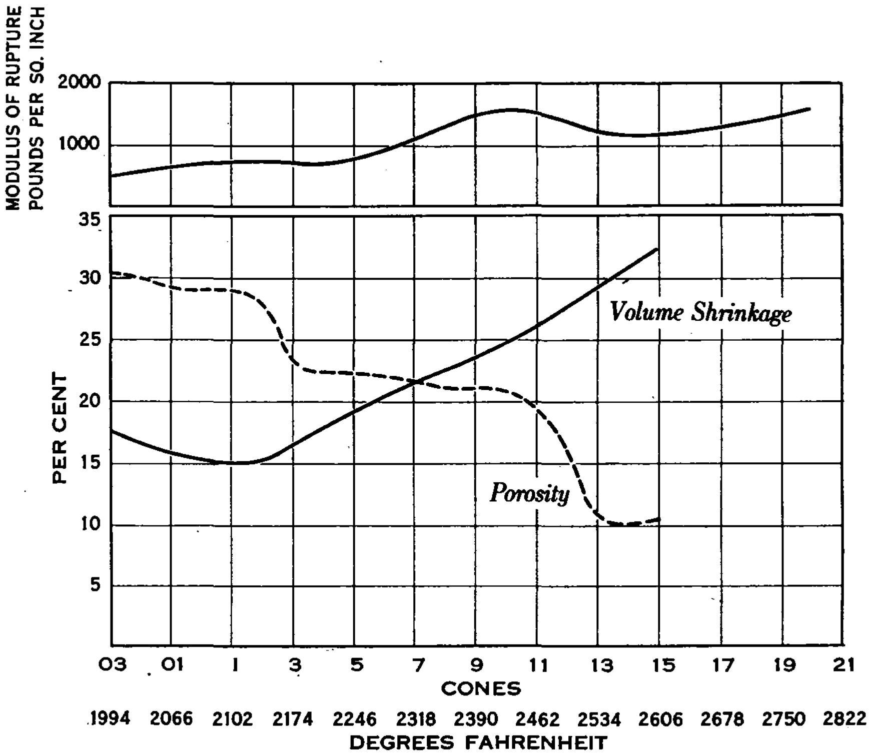


Figure 13—Sample No. 41, Lawrence County Clay and Coal Company, Munyon Hollow, flint clay

Physical properties of "cream" clay
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 21.21 per cent
Drying shrinkage
  Volume: 11.72 per cent
  Linear: 4.06 per cent
Dry modulus of rupture: 207 pounds per square inch
Time of slaking: 7.31 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	20.58	10.86	2.23	2.25	18.00	6.40	5,285	Light cream
01	19.01	9.05	2.12	2.62	20.09	7.52	5,115	Grayish cream
1	17.30	8.14	2.13	2.57	22.20	8.03	3,550	Light gray
3	15.80	7.70	2.06	2.45	22.30	8.04	1,800	Light gray
5	12.90	5.90	2.18	2.50	22.50	8.15	1,650	Light gray
7	13.20	6.07	2.18	2.52	24.00	8.74	2,350	Gray
9	3.30	1.42	2.30	2.38	25.50	9.35	2,110	Dark gray
13	2.14	1.07	2.10	2.14	19.10	6.82	1,210	Dark gray
16	6.66	3.43	1.94	2.08	14.60	5.13	2,660	Dark gray

Porosity: The porosity decreases steadily from 19.01 per cent at cone 01, where it becomes steel hard, to 2.14 per cent at cone 13, after which it increases to 6.66 per cent at cone 16.

Volume shrinkage: The volume shrinkage steadily increases from 20.09 per cent at cone 01, where it becomes steel hard, to 25.50 per cent at cone 9, after which it decreases to 14.60 per cent at cone 16.

Total linear shrinkage:

Drying shrinkage	4.06 per cent
Burning shrinkage at cone 7	8.75 per cent
Total shrinkage	12.81 per cent

Modulus of rupture: The strength of this clay is highest at the lower temperatures and decreases from 5,285 pounds per square inch at cone 03 to 2,660 pounds per square inch at cone 16.

Steel hardness: Steel hard at cone 01.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 01 to cone 13.

Softening point: Cone 29.

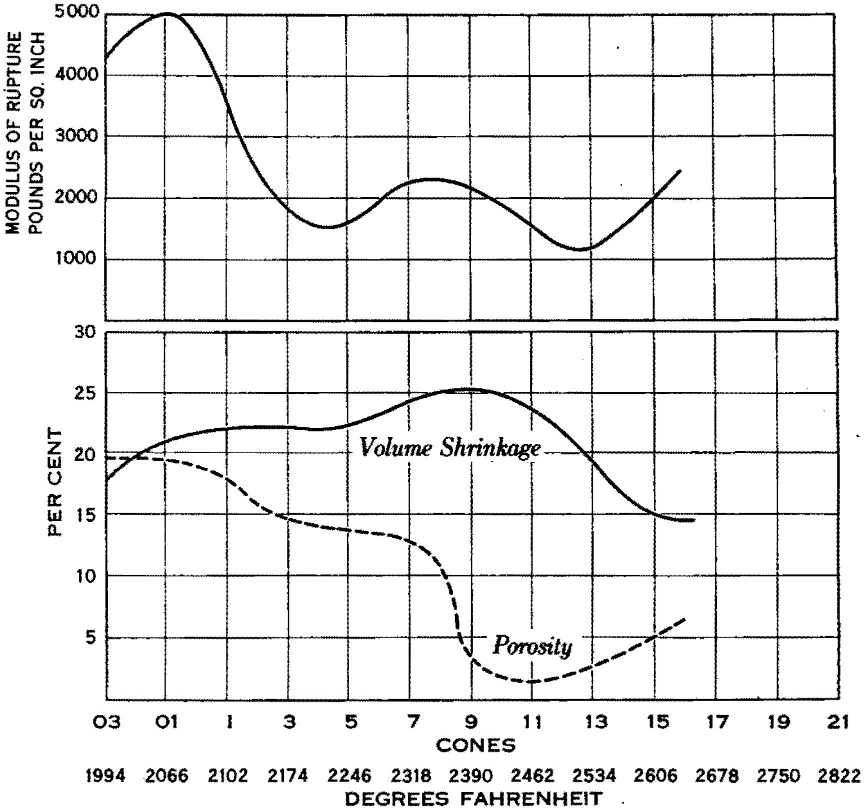


Figure 14—Sample No. 41, Lawrence County Clay and Coal Company, Munyon Hollow, "cream" clay

Physical properties of siliceous clay
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 27.58 per cent
Drying shrinkage
  Volume: 13.53 per cent
  Linear: 4.72 per cent
Dry modulus of rupture: 410 pounds per square inch
Time of slaking: 18.33 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	21.50	11.12	1.92	2.44	15.3	5.39	3,000	Light gray
01	22.00	11.35	1.94	2.49	16.9	5.98	5,115	Light gray
1	19.60	9.75	2.00	2.49	19.9	7.13	4,970	Light gray
3	17.20	8.17	2.11	2.55	24.1	8.78	4,360	Grayish buff
5	13.30	6.80	2.10	2.35	26.0	9.55	3,700	Grayish buff
7	9.00	4.10	2.11	2.29	25.9	9.50	3,210	Grayish buff
9	5.50	3.06	2.11	2.25	25.2	9.23	2,980	Brownish gray
11	1.39	0.65	2.15	2.17	24.2	8.82	3,600	Dark gray
13	2.97	1.55	1.92	1.97	15.1	5.31	2,800	Dark gray
15	4.98	2.66	1.87	1.97	14.8	5.20	2,725	Dark gray

Porosity: The porosity drops from 17.20 per cent at cone 3, where it becomes steel hard, to 1.39 per cent at cone 11, and then increases to 4.98 per cent at cone 15.

Volume shrinkage: The volume shrinkage increases from 24.1 per cent at cone 3, where it becomes steel hard, to 26.0 per cent at cone 5, after which it decreases to 14.8 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	4.72 per cent
Burning shrinkage at cone 7	9.50 per cent
Total shrinkage	14.22 per cent

Modulus of rupture: The strength of this clay increases from 3,000 pounds per square inch at cone 03 to 5,115 pounds per square inch at cone 01, and then gradually decreases to 2,725 pounds per square inch at cone 15.

Steel hardness: Steel hard at cone 3.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 3 to cone 13.

Softening point: Cone 28.

Possibilities of bed as a whole, that is flint, "cream," and siliceous clay: This clay is highly plastic and develops a dense, strong body which lends itself readily to the manufacture of glazed and unglazed structural materials as terra cotta, fireproofing, sewer pipe, wall coping, flue lining, and building brick; of tiling such as floor, wall, quarry, and promenade; of pottery such as faience, Rockingham, yellowware, and stoneware; and of refractories such as fire brick, ladle brick, hot top shapes, and high temperature cements. Its green strength is high, fitting it for use as the bonding ingredient in various molding sands, grinding wheels, and plastic refractories.

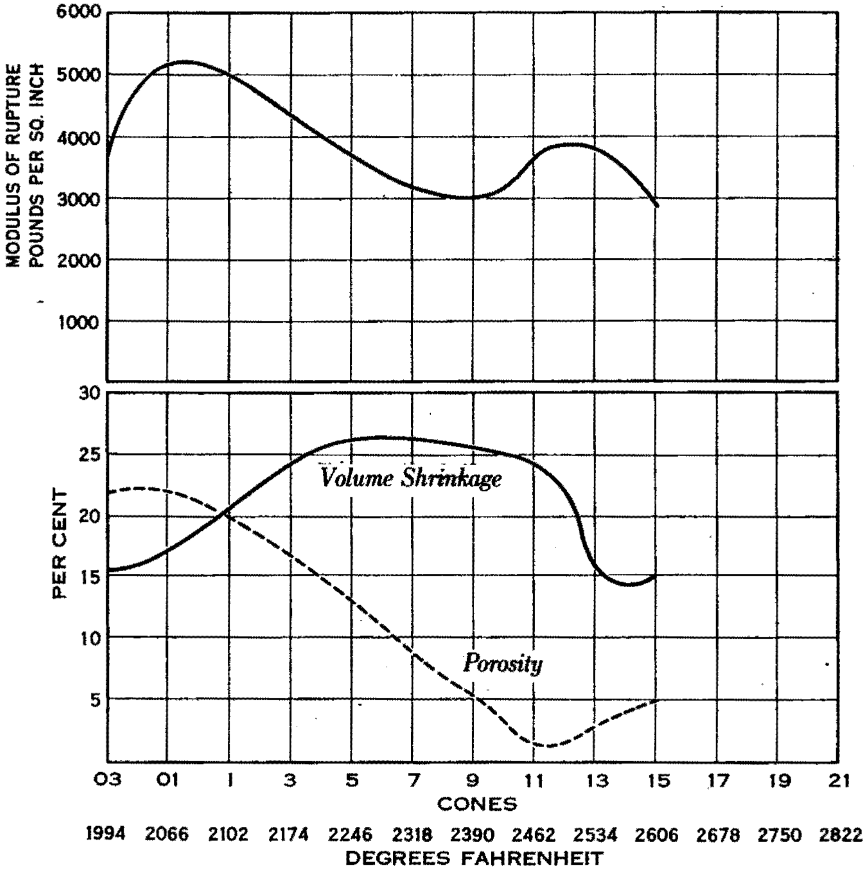


Figure 15—Sample No. 41, Lawrence County Clay and Coal Company, Munyon Hollow, siliceous clay

In the vicinity of Center Station, in all but the southwestern part of Section 33, and in the southern part of Section 28, Decatur Township, the Lawrence clay retains the general thickness and quality that it has at Dean. The area offers good facilities for mining and also a factory site. In an old limestone quarry on the property of the Lawrence County Clay and Coal Company and about one-third of a mile northeast of Center Station Y, the member was well exposed by a prospect opening.

A sample was taken here May 22, 1931, by W. R. Maxey and Wilber Stout. The measurements recorded are given below:

Section No. 39		Ft.	In.
Sandstone, massive		20	0
Shale, carbonaceous		1	2
Coal, good	*Lower Kittanning*	1	7
Clay and bony shale			5
Coal, good			9
Coal, bony			5
Clay, siliceous, *Lower Kittanning*		2	0
Coal, very shaly, *Lawrence*			3
Clay, flint, good, not sampled	*Lawrence*	1	1
Clay, plastic, light, excellent, sampled		5	10
Clay, plastic, light, siliceous, sampled		1	4
Shale, light, argillaceous		7	6
Limestone, *Vanport*		7	0

Chemical analysis of a sample of Lawrence clay from the property of the Lawrence County Clay and Coal Company near Center Station. Analyst, Downs Schaaf

Chemical analysis	
Water, hydroscopic, H_2O-	1.34
Water, combined, H_2O+	7.90
Silica, SiO_2	57.72
Alumina, Al_2O_3	26.28
Ferric oxide, Fe_2O_3	1.92
Ferrous oxide, FeO	.12
Lime, CaO	.49
Magnesia, MgO	.25
Titanic oxide, TiO_2	1.45
Phosphorous pentoxide, P_2O_5	.08
Sodium oxide, Na_2O	.22
Potassium oxide, K_2O	1.38
Manganous oxide, MnO	.01
Sulphur, S	.02
Zirconium oxide, ZrO_2	trace
Carbon, organic, C	.83
Carbon as CO_2 in carbonates, C	trace

Oxide ratio					
K_2O	.053				
Na_2O	.008			SiO_2	2.196
CaO	.019	Al_2O_3	1.00	TiO_2	.055
MgO	.009			P_2O_5	.003
FeO	.070				
MnO	.000				
	——				
RO	.159				

Physical properties
by M. C. Shaw

Properties in green state

Workability: Fair plasticity
Water of plasticity: 22.94 per cent
Drying shrinkage
  Volume: 14.67 per cent
  Linear: 5.14 per cent
Dry modulus of rupture: 400 pounds per square inch
Time of slaking: 26.50 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	22.60	11.50	1.96	2.53	12.20	4.25	1,210	Very light gray (nearly white)
01	22.90	10.00	1.98	2.48	16.60	5.87	2,150	Light gray
1	22.10	10.70	2.05	2.64	16.70	5.93	2,330	Light gray
3	17.50	8.11	2.14	2.59	20.00	7.17	2,160	Light gray
5	14.20	7.00	2.26	2.62	26.00	9.55	2,075	Gray
7	11.50	4.80	2.42	2.73	29.70	11.08	1,800	Dark gray, slightly brown
9	9.60	4.11	2.36	2.61	28.80	10.71	1,680	Dark gray, slightly brown
11	0.95	0.39	2.41	2.42	31.80	11.98	1,710	Very dark gray
13	1.89	0.78	2.43	2.48	28.80	10.66	1,790	Very dark gray
15	3.15	1.34	2.36	2.44	26.00	9.55	1,650	Very dark gray

Porosity: The porosity of this clay decreases steadily from 17.50 per cent at cone 3, where it becomes steel hard, to 0.95 per cent at cone 11, after which it gradually increases to 3.15 per cent at cone 15.

Volume shrinkage: The volume shrinkage of this clay steadily increases from 20.00 per cent at cone 3, where it becomes steel hard, to 29.70 per cent at cone 7, after which it drops to 26.00 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	5.14 per cent
Burning shrinkage at cone 7	11.08 per cent
Total shrinkage	16.22 per cent

Modulus of rupture: The strength of this clay increases from 1,200 pounds per square inch at cone 03 to 2,330 pounds per square inch at cone 1, and then gradually decreases to 1,650 pounds per square inch at cone 15.

Steel hardness: This clay is steel hard at cone 3.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 3 to cone 13.

Softening point: Cone 29.

Possibilities: The Lawrence clay from Center Station has all the desirable chemical and physical qualities for its utilization for several grades of pottery, for building materials as terra cotta, floor and wall tile, sewer pipe, fireproofing, conduits, and face brick, and for refractory products as fire brick, ladle brick, and cements.

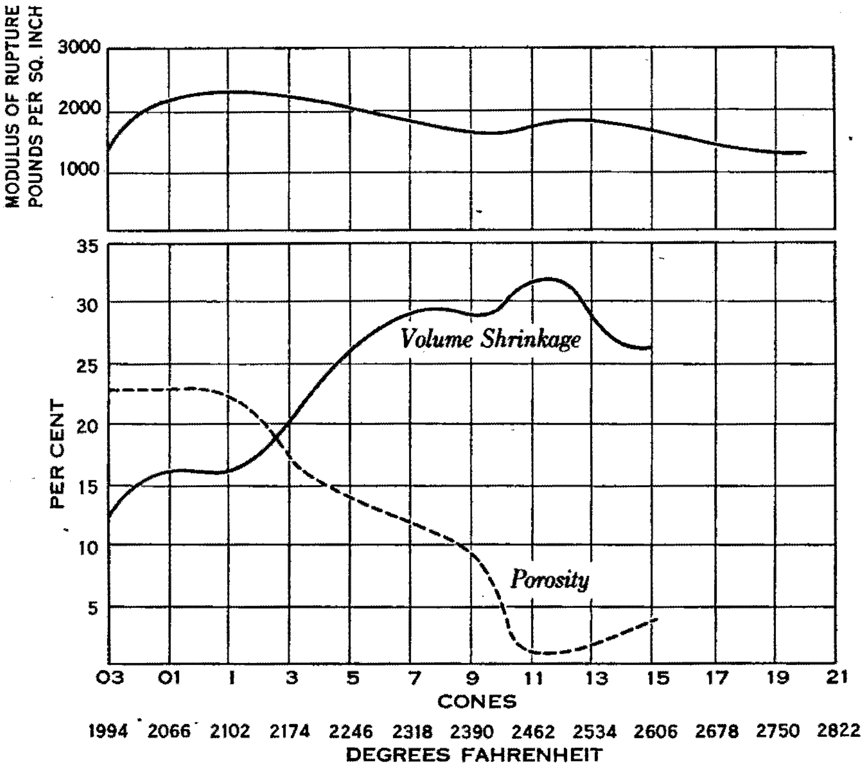


Figure 16—Sample No. 39, Lawrence County Clay and Coal Company, Center Station

The Lawrence member holds its thickness and quality in its extension northeastward along the valley above Center Station. The overlying Lower Kittanning clay is generally thin, not averaging more than 2 feet in thickness. The quality is fair. The associated coal stratum contains about 2 feet 6 inches of clean fuel of sufficient merit for factory purposes. This bed has not been mined except along the outcrop for local needs. In mining the Lawrence clay both the Lower Kittanning clay and coal would be removed, thus leaving the thick massive sandstone for the roof. The stratigraphic relations are shown in the following section taken on the property of the Lawrence County Clay and Coal Company east of the main highway, in the northeastern part of Section 33, Decatur Township.

Section No. 40		Ft.	In.
Sandstone, massive		30	0
Shale and covered		2	0
Coal, weathered	*Lower Kittanning*	1	6
Clay, impure			5
Coal, weathered			8
Coal, bony			3
Clay, plastic, fair, *Lower Kittanning*		1	10
Coal, very argillaceous, *Lawrence*			1
Clay, flint, good	*Lawrence*	1	2
Clay, coaly			1
Clay, dark, plastic, excellent		3	3
Clay, light, plastic, slightly siliceous		3	1
Clay, light, plastic, very siiceous		1	10
Shale, with ore nodules		6	10
Limestone, *Vanport*, seen		2	0

On the Ironton-Oak Hill highway, nearly one mile north of Center Station in the northeastern corner of Section 33, Decatur Township, many of the rocks are exposed from the Clarion clay to the Upper Freeport coal. A part of this section is given below:

Section No. 28		Ft.	In.
Sandstone, massive		20	0
Shale, gray		6	0
Coal smut, *Middle Kittanning*			1
Clay, plastic, gray, fair		5	6
Shale, gray, siliceous		1	2
Sandstone, massive		40	0
Shale, siliceous		2	0
Coal, weathered	*Lower Kittanning*	1	5
Clay, impure			7½
Shale, dark, hard			4
Coal, good			9
Coal, bony			1½
Clay, light to dark, *Lower Kittanning*		1	7
Coal, bony, *Lawrence*			4
Clay, dark, flinty, good	*Lawrence*		9
Clay, plastic, light, excellent		2	10
Clay, plastic, light, siliceous		1	9
Shale, with ore nodules		4	2
Ore, *Ferriferous*			4
Limestone, *Vanport*		5	6

Although the Lawrence clay is somewhat thin at this place, exposures near by indicate that such a condition is local. The material is of good quality. Both the overlying Lower Kittanning clay and the coal are thin, which condition is found generally in the Dean field. The main method of mining the clay would be by drifting.

The Dean field passes over the divide from the headwaters of Little Pine Creek to those of Pine Creek proper where the best development of Lawrence clay is found along the tributaries south of old Mount Vernon Furnace.

Just east of the main highway near the foot of the hill in the northwestern quarter of Section 27, Decatur Township, on the property of Manda Evans, the Lawrence clay was sufficiently well exposed for sectioning in an old limestone quarry. The following record shows the stratigraphic relations of the individual members:

Section No. 5		Ft.	In.
Sandstone, massive		20	0
Coal and covered, *Lower Kittanning*		3	0
Covered		10	8
Clay, dark, flinty, good	*Lawrence*		8
Clay, light, plastic, excellent		5	10
Clay, light, plastic, siliceous		1	0
Shale and covered		4	0
Limestone, *Vanport*, part seen		4	8

The evidence exhibited here indicates rather conclusively that the Lawrence clay carries northward under the main divide from the vicinity of Dean to that of Mount Vernon Furnace. Such being the case, the bodies of excellent material are large under this high ridge in sections 27, 28, 33, and 34, Decatur Township, and in Section 3, Elizabeth Township. Continuity, thickness, and quality may be expected.

On the Edward F. Roth property which lies east of the highway and one mile south of Mount Vernon Furnace and which is located in the south central part of Section 22, Decatur Township, the Lawrence clay had been well exposed by a prospect opening in an old ore bench. From this face a sample was cut by channelling, September 30, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout. The measurements are recorded below:

Section No. 29		Ft.	In.
Coal smut, *Lawrence*			4
Clay, flinty, dark, weathered, not sampled	*Lawrence*	1	1
Clay, plastic, light, excellent, sampled		2	8
Clay, plastic, light, siliceous, sampled		4	0
Clay, plastic, light, very siliceous, not sampled		1	2
Covered.			

Analysis of the Lawrence clay on the Edward F. Roth property about one mile south of Mount Vernon Furnace. Analyst, Downs Schaaf

Chemical analysis		*Oxide ratio*					
Water, hydroscopic, H_2O-	2.45	K_2O	.047				
Water, combined, H_2O+	6.90	Na_2O	.008			SiO_2	2.667
Silica, SiO_2	60.81	CaO	.013	Al_2O_3	1.00	TiO_2	.066
Alumina, Al_2O_3	22.80	MgO	.035			P_2O_5	.009
Ferric oxide, Fe_2O_3	2.49	FeO	.110				
Ferrous oxide, FeO	.27	MnO	.000				
Lime, CaO	.30						
Magnesia, MgO	.79		——				
Titanic oxide, TiO_2	1.50	RO	.213				
Phosphorous pentoxide, P_2O_5	.21						
Sodium oxide, Na_2O	.18						
Potassium oxide, K_2O	1.07						
Manganous oxide, MnO	.01						
Sulphur, S	.05						
Zirconium oxide, ZrO_2	trace*						
Carbon, organic	.22						
Carbon as CO_2 in carbonates, C	none						

---

* Less than .01 per cent.

Physical properties
by M. C. Shaw

Properties in green state

Workability: Fair plasticity
Water of plasticity: 20.83 per cent
Drying shrinkage
  Volume: 14.17 per cent
  Linear: 5.2 per cent
Dry modulus of rupture: 468 pounds per square inch
Time of slaking: 22.9 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	21.09	10.64	1.98	2.51	11.53	3.99	2,288	Light gray
01	19.56	9.75	2.01	2.51	12.51	4.35	3,303	Light gray
1	17.80	8.70	2.05	2.50	14.78	5.16	3,518	Light grayish buff
3	15.85	7.24	2.06	2.36	16.35	5.76	3,529	Light grayish buff
5	13.76	6.59	2.09	2.42	18.73	6.67	3,574	Brownish gray
7	8.72	4.23	2.21	2.27	20.69	7.41	4,047	Brownish gray
9	4.40	1.90	2.29	2.30	21.43	7.71	5,049	Dark brownish gray
11	0.45	0.25	1.79	1.80	22.36	8.07	4,687	Dark brownish gray
13	2.70	1.30	2.07	2.13	15.65	5.50	3,974	Dark gray
16	5.03	2,97	1.69	1.78	10.00	3.45	3,864	Dark gray
20	15.61	9.25	1.69	2.00	8.65	2.95	2,516	Dark gray

Porosity: The porosity of this clay decreases steadily from 13.76 per cent at cone 5, where it becomes steel hard, to 0.45 per cent at cone 11, after which it increases to 15.61 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 18.73 per cent at cone 5, where it becomes steel hard, to 22.36 per cent at cone 11, after which it drops to 8.65 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.2 per cent
Burning shrinkage at cone 7	7.41 per cent
Total shrinkage	12.61 per cent

Modulus of rupture: The strength of this clay steadily increases from 2,288 pounds per square inch at cone 03 to 5,049 pounds per square inch at cone 9, and then the strength of the clay decreases to 2,516 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns at cone 13.

Best apparent burning range: From cone 5 to cone 13.

Softening point: Cone 29.

Possibilities: A siliceous clay close to the standard in composition and in physical qualities for sewer pipe, flue lining, wall coping, fittings, fireproofing, conduits, liner plates, salt-glazed brick, and face brick.

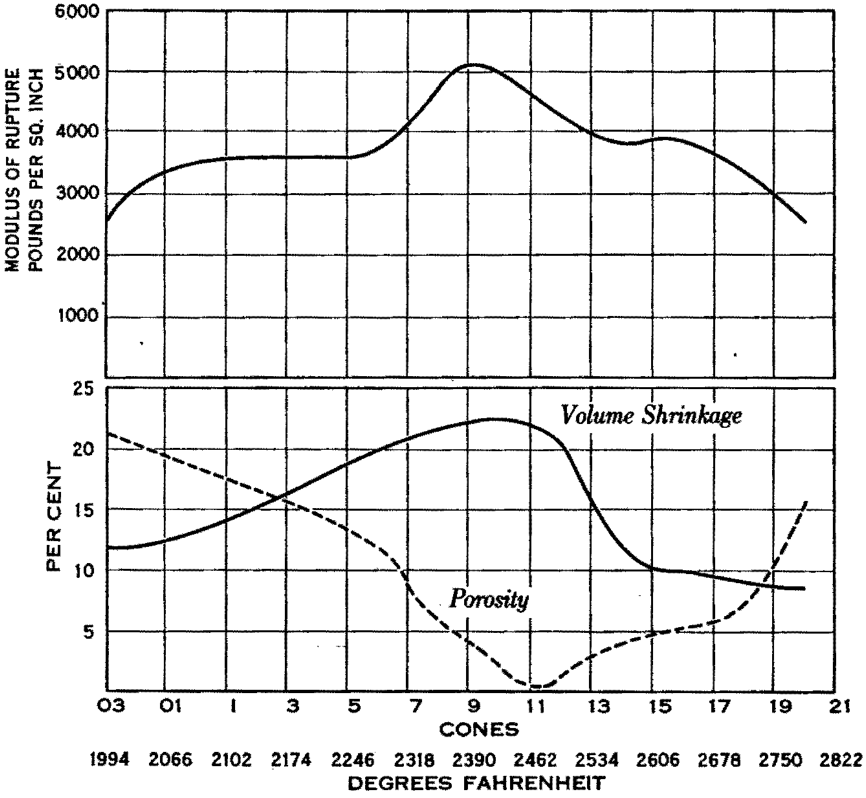


Figure 17—Sample No. 29, Edward F. Roth, Mount Vernon Furnace

Both to the north and to the west, from the head of the hollow south of Mount Vernon Furnace, the Lawrence clay appears to be changing from the aluminous to the more siliceous type, although retaining about its full thickness and structure. To the northeast it disappears as an economic unit before reaching the main headwater of Pine Creek along the abandoned line of the Cincinnati, Hamilton, and Dayton Railroad in northeast Section 22, southwest Section 23, northeast Section 34, and northern Section 35. To the west it retains much the same quality as shown above along its outcrop in the southern part of Section 21. Near Mount Vernon Furnace on land of William and Dora Triplett, the stratigraphic features are as shown in the record given below and taken in the northwestern corner of Section 22 just west of the cemetery and near the old fish pond.

Section No 14		Ft.	In.
Sandstone, soft, massive		20	0
Covered		3	0
Coal blossom, *Lower Kittanning*		1	0
Clay, plastic, shaly, *Lower Kittanning*		1	10
Coal, shaly, *Lawrence*			7
Clay, plastic, dark, good	*Lawrence*		8
Clay, plastic, light, siliceous		6	3
Sandstone, shaly		1	3
Limestone, flinty	*Vanport*	1	5
Limestone, good		4	0

To the north of Mount Vernon Furnace in sections 10, 11, 14, and 15, the Lawrence clay is either absent or thin and siliceous. Such an impoverishment is also apparent along Buckhorn Hollow in sections 9 and 16. Near its head, however, in the northeastern part of Section 20 and in the northwestern part of Section 21, the member is present but the outcrop evidence indicates that the clay is thin and decidedly siliceous. From such data the northern limit of the Dean field is approximately along a line east and west through Mount Vernon Furnace.

GENERAL FEATURES OF THE DEAN FIELD

The various sections throughout the area warrant the statement that the best of the Lawrence clay in the Dean field is in the vicinity of Dean along the valley of Little Pine Creek and along its tributaries in Rider, Little Texas, and Long Hollows. In its extension to Mount Vernon Furnace it loses quality in becoming decidedly more siliceous. North from this place the member becomes too impoverished to be attractive for ceramic utility. The clay near Dean is available to the Detroit, Toledo, and Ironton Railroad by building a switch some three miles in length along former grades, which will thus reduce the cost of construction.

Mining in the Dean field will be confined almost entirely to drifting. The conditions for such work, however, are good as the Lower Kittanning coal has not been disturbed and as the overlying sandstone is massive, thick, and strong. With such natural advantages, the yield of clay, and also coal, should at least approximate 60 per cent. In this field the Lower Kittanning coal is generally thin and locally much reduced through erosion following deposition. It is regularly divided into two benches with a thick parting of clay. From an average of a number of measurements the thickness of each unit is as follows: upper bench of coal, 1 foot 7 inches; clay parting, 6 inches; and lower bench of coal, 9 inches. This coal has sufficient quality for ceramic fuel.

In drift mining the Lawrence clay in this area, it will be necessary also to remove the Lower Kittanning clay, as such a material is in no way a satisfactory roof. From a number of measurements the thickness of the latter clay varies from 1 foot 7 inches to 6 feet 9 inches but averages 3 feet 5 inches. The quality is such that it may be used for the more common products such as building brick, building block, flue lining, etc. Where thin the Lower Kittanning clay may be "gobbed" with little expense and thus left in the mine. The Lawrence clay in the Dean field, as a whole, averages close to 7 feet 8 inches in thickness. It is made up of the usual different kinds, flint clay 9 inches, "cream" plastic clay 4 feet 8 inches, and siliceous plastic clay 2 feet 3 inches. In the Dean area proper the "cream" clay alone usually measures between 5 feet 6 inches and 7 feet. It is fine in texture, high in plasticity, and free from visible impurities. The overlying flint clay constitutes a good addition for refractory purposes. The Dean field thus offers a large volume of high grade clay for a wide range of ceramic products.

CHAPTER IV

FIREBRICK FIELD

INTRODUCTION

The Firebrick field of Lawrence clay lies in the northern part of Washington Township, embracing, in fact, about half of the township. With local modifications this field extends northward past Oak Hill in Jackson County, eastward into northwestern Greenfield Township, Gallia County, and westward into the northeastern corner of Bloom Township, Scioto County. In this report only the Lawrence County area will be considered. It embraces the clay bodies in sections 1, 2, 3, 9, 10, 11, 12, 13, 14, 15, 16, 21, 23, and 28, the combined area of clay being close to 6 square miles. Small scattered patches of good material are also present in the southern part of the township.

In the Firebrick field considerable irregularity and modification of the beds in the Vanport limestone-Lower Kittanning coal interval are apparent. The most outstanding of these is, locally, the absence or the thinning to a small thickness of the Lower Kittanning clay, thus allowing the Lawrence clay to be falsely placed just below the Lower Kittanning coal. In other localities both the Lower Kittanning and Lawrence clays are present in force, but are so coalesced as to appear as one unit. Under such conditions the Lawrence coal is reduced to a mere soot streak, and lies just above the dark flinty clay. Commonly the ore shales are replaced by several feet of shaly sandstone and sandy shale. Throughout this part of the field the Lower Kittanning coal is also unsteady, the thickness varying from only a few inches to 3 feet 6 inches.

DETAILED SECTIONS

At the mines of the Harbison-Walker Refractories Company on Bear Run in the central part of Section 16, Washington Township, the following record was obtained under deep covering and near the head of the main entry:

Section No. 25		Ft.	In.
Shale, arenaceous			
Clay, plastic, with some flint, *Oak Hill*		2	6
Coal, poor	*Lower Kittanning*		3
Clay, shale			2
Coal, poor			3½
Clay, dark	*Lawrence*		1
Clay, light, plastic, excellent		5	3
Clay, light, plastic, siliceous		2	0
Sandstone, argillaceous, floor of mine.			

The above section is unusual in that the Lower Kittanning clay and the Lawrence coal are absent, thus placing the Lawrence clay directly below the Lower Kittanning coal, which succession is false but only local. The associated Lower Kittanning coal is also abnormal in that it is unsteady, thin, and shaly. The "cream" clay of the Lawrence member is of fine quality and is reported to maintain good thickness throughout the locality. Clay is being mined both by drifting and by stripping for the Portsmouth and Pittsburgh works of the Harbison-Walker Refractories Company. The position of the clay deposit is near the summit of the ridge at an elevation of approximately 870 feet.

The mines of the Cambria Clay Products Company now extend to the northern part of Section 15, Washington Township, or into the main ridge west of Pioneer Furnace. A sample was taken for testing, December 5, 1930, by W. R. Maxey and Wilber Stout in the first room off the first west entry. The section follows:

Section No. 32		Ft.	In.
Shale, good roof.			
Coal, good	*Lower Kittanning*	2	1
Clay, impure			2
Coal, good			7¾
Clay, plastic, hard, carbonaceous, sampled	*Lawrence*		4
Clay, dark, flinty, sampled		1	1
Clay, plastic, light, excellent, sampled		4	3
Clay, plastic, siliceous, sampled		1	2
Clay, plastic, very siliceous, not sampled		1	0
Sandstone, clay-bonded.			

Here again the Lower Kittanning clay is absent, thus allowing the Lower Kittanning coal to rest directly on the Lawrence clay. The evidence for this interpretation is afforded by the high quality of the main clay stratum, by the thickness of the bed, and by the appearance locally of the more impure Lower Kittanning clay as irregular bodies in the upper part of the deposit. In this mine the flint unit of the Lawrence member lacks sharp differentiation from the underlying "cream" clay and is not especially flinty in nature. The quality of the material, however, is very good. The "cream" clay is uniformly fine in texture, high in plasticity, and free from silica and concretionary matter. The average thickness is between 4 and 5 feet. Locally the "cream" clay replaces most of the basal siliceous clay. In this part of the mine the mean thickness of the Lawrence clay is from 7 to 9 feet.

Analysis of the Lawrence clay from deep covering in the mine of the Cambria Clay Products Company. Analyst, Downs Schaaf

Chemical analysis

Water, hydroscopic, H_2O-	2.40
Water, combined, H_2O+	7.91
Silica, SiO_2	56.16
Alumina, Al_2O_3	25.92
Ferric oxide, Fe_2O_3	1.86
Ferrous oxide, FeO	.53
Lime, CaO	.30
Magnesia, MgO	.79
Titanic oxide, TiO_2	1.60
Phosphorous pentoxide, P_2O_5	.18
Sodium oxide, Na_2O	.25
Potassium oxide, K_2O	1.45
Manganous oxide, MnO	.02
Sulphur, S	.29
Zirconium oxide, ZrO_2	trace
Carbon, organic, C	.41
Carbon as CO_2 in carbonates, C	.03

Oxide ratio

K_2O	.056	Al_2O_3	1.00	SiO_2	2.167
Na_2O	.010			TiO_2	.061
CaO	.011			P_2O_5	.007
MgO	.030				
FeO	.085				
MnO	.001				
RO	.193				

Physical properties
by M. C. Shaw

Properties in green state

Workability: Fair plasticity
Water of plasticity: 16.34 per cent
Drying shrinkage
  Volume: 16.88 per cent
  Linear: 5.60 per cent
Dry modulus of rupture: 510 pounds per square inch
Time of slaking: 16.55 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	18.58	9.28	2.00	2.45	8.35	2.85	3,296	Light cream
01	17.98	8.48	2.12	2.58	12.52	4.35	3,200	Very light buff
1	17.44	8.15	2.13	2.58	13.02	4.54	3,110	Light buff
3	12.56	5.63	2.23	2.53	14.73	5.16	2,980	Buff
5	12.17	5.40	2.25	2.57	16.99	6.02	2,850	Buff
7	9.48	4.23	2.24	2.47	17.42	6.18	3,000	Dark buff
9	9.10	4.32	2.27	2.52	18.50	6.59	2,350	Brownish gray
11	8.80	4.00	2.20	2.31	19.80	7.09	1,820	Gray
13	8.00	3.99	2.14	2.25	20.40	7.32	1,300	Bluestone gray
16	7.81	3.97	1.97	2.14	21.10	7.60	1,250	Bluestone gray
20	2.12	1.14	1.86	1.90	20.80	7.48	1,100	Bluestone gray

Porosity: The porosity of this clay drops gradually from 12.17 per cent at cone 5, where it becomes steel hard, to 2.12 per cent at cone 20.

Volume shrinkage: The volume shrinkage gradually increases from 16.99 per cent at cone 5, where it becomes steel hard, to 21.10 per cent at cone 16, and then drops to 20.80 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.60 per cent
Burning shrinkage at cone 7	6.18 per cent
Total shrinkage	11.78 per cent

Modulus of rupture: The modulus of rupture is highest at lower temperatures. It decreases steadily from 3,296 pounds per square inch at cone 03 to 1,100 pounds per square inch at cone 20.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay does not overburn until after cone 20.

Best apparent burning range: From cone 5 to cone 20.

Softening point: Cone 30.

Utilization: This clay is now used for sewer pipe, wall coping, flue lining, fittings, intermediate heat duty fire brick, hot top shapes, radial stove brick, fireproofing, salt glazed brick, and face brick. It appears to be an ideal bonding clay for high grade refractory ware.

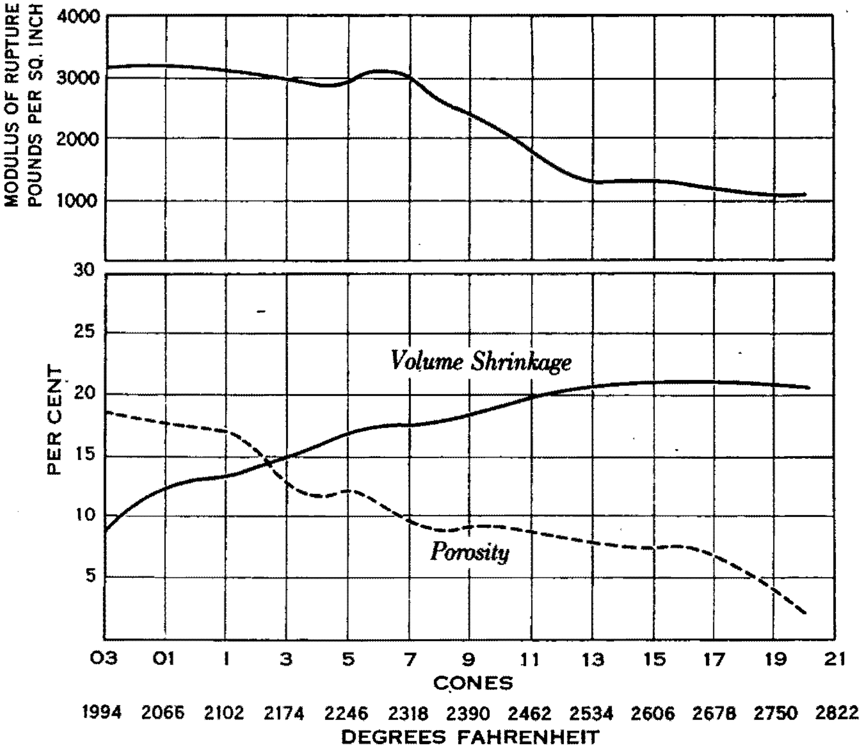


Figure 18—Sample No. 32, Cambria Clay Products Company, Pioneer Furnace

In the old part of the mine of the Cambria Clay Products Company a sample for testing was cut in 1921 by Wilber Stout. It was cut from the clay as there mined in Irish Hollow at the head of the first right entry in the central part of Section 10. The record is given below:[1]

Section No. 33		Ft.	In.
Shale		10	0
Coal, good	*Lower Kittanning*	2	2
Clay, impure			2
Coal, good			10
Clay, light, plastic, sampled, *Lawrence*		5	6
Sandstone, clay bonded.			

Tests of Lawrence clay from the mine of the Cambria Clay Products Company

Chemical analysis		*Oxide ratio*					
Loss at 105° C	1.83	K_2O	.049				
Ignition loss	8.56	Na_2O	.006			SiO_2	2.390
Silica, SiO_2	58.82	CaO	.019	Al_2O_3	1.00	TiO_2	.072
Alumina, Al_2O_3	24.60	MgO	.025			P_2O_5	.010
Ferric oxide, Fe_2O_3	2.11	FeO	.077				
Lime, CaO	.46	MnO	.000				
Magnesia, MgO	.62						
Titanic oxide, TiO_2	1.76						
Phosphorous pentoxide, P_2O_5	.24	RO	.176				
Sodium oxide, Na_2O	.14						
Potassium oxide, K_2O	1.21						
Manganous oxide, MnO	.01						
Sulphur, S	.31						
Total carbon, C	.25						
Inorganic carbon, C	.00						

Physical tests

Working properties: Plastic, fine-grained, good molding properties.

Tempering water	19.18 per cent
Drying linear shrinkage	7.01
Drying volume shrinkage	22.53

---

[1] Geological Survey of Ohio, Bull. 26, pp. 281, 282.

Burning behavior

Burning temperature	Per cent linear shrinkage	Per cent volume shrinkage	Per cent volume absorption	Color
Cone 08	2.18	6.40	23.50	Light cream
Cone 03	3.58	10.36	23.45	Light cream
Cone 01	3.57	10.33	19.91	Light cream
Cone 4	4.88	13.95	16.31	Light buff
Cone 7	5.71	16.18	12.47	Light buff speckled
Cone 8	5.70	16.15	12.54	Light buff speckled
Cone 12	6.39	17.96	5.57	Dark buff speckled
Cone 13	7.43	20.68	2.19	Brown buff
Cone 15	3.57	10.34	1.75	Bluestone

Overburning temperature: Cone 15 (1,410° C. or 2,570° F.)

Best apparent burning range: Cone 4 to cone 12 (1,165° C. to 1,310° C. or 2, 129° F. to 2,390° F.)

Total linear shrinkage at cone 12: 13.40 per cent.

Deformation temperature: Cone 28 (1,615° C. or 2,939° F.)

Possibilities: Intermediate heat duty refractories, sewer pipe, face brick, hollow block, fireproofing.

Shrinkage is rather high. The addition of grog to reduce shrinkage would be beneficial.

In Spencer Hollow the Lawrence clay has been utilized for many years for refractory products such as fire brick, bonding clay, and refractory cements. At the mines of the Plibrico Jointless Firebrick Company in the southwestern part of Section 3 and the northwestern part of Section 10, Washington Township, the bed is worked both in open cuts and in drifts. The member was sampled for testing May 22, 1931, by M. C. Shaw, W. R. Maxey, and Wilber Stout. The section follows:

Section No. 26		Ft.	In.
Sandstone, soft, shaly		20	0
Shale, dark gray, irregular		1	0
Clay, plastic, with some flint, *Oak Hill*		3	5
Coal, good	*Lower Kittanning*	1	4½
Clay, impure			1½
Coal, good			7¾
Clay, dark, plastic, not sampled, *Lower Kittanning*			9
Coal, smut, irregular, *Lawrence*			¼
Clay, plastic, light, excellent, Sample A	*Lawrence*	4	1
Clay, plastic, light, good, siliceous, Sample B.		3	2
Clay, very siliceous, floor of mine.			

Chemical analyses of the samples of Lawrence clay from the mine of the Plibrico Jointless Firebrick Company. Analyst, Downs Schaaf

	Sample A Top part 4 ft. 1 in.	Sample B Bottom part 3 ft. 2 in.	Average of A and B
Water, hydroscopic, H_2O-	1.77	2.30	2.00
Water, combined, H_2O+	8.30	9.11	8.65
Silica, SiO_2	53.86	52.04	53.07
Alumina, Al_2O_3	27.30	29.92	28.44
Ferric oxide, Fe_2O_3	3.29	1.86	2.67
Ferrous oxide, FeO	.24	.22	.23
Lime, CaO	.48	.21	.36
Magnesia, MgO	.40	.56	.47
Titanic oxide, TiO_2	2.10	1.96	2.04
Phosphorous pentoxide, P_2O_5	.07	.07	.07
Sodium oxide, Na_2O	.15	.18	.16
Potassium oxide, K_2O	.74	.89	.81
Manganous oxide, MnO	.01	.01	.01
Sulphur, S	.44	.02	.26
Zirconium oxide, ZrO_2	trace	trace	trace
Carbon, organic, C	1.04	.70	.89
Carbon, as CO_2 in carbonates, C	trace	trace	trace

Oxide ratio

Sample A

$$\left.\begin{array}{ll} K_2O & .027 \\ Na_2O & .005 \\ CaO & .018 \\ MgO & .015 \\ FeO & .117 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 1.973 \\ TiO_2 & .077 \\ P_2O_5 & .002 \end{array}\right.$$

$$RO\quad .182$$

Sample B

$$\left.\begin{array}{ll} K_2O & .030 \\ Na_2O & .006 \\ CaO & .007 \\ MgO & .019 \\ FeO & .063 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 1.739 \\ TiO_2 & .066 \\ P_2O_5 & .002 \end{array}\right.$$

$$RO\quad .125$$

Average sample

$$\left.\begin{array}{ll} K_2O & .028 \\ Na_2O & .006 \\ CaO & .013 \\ MgO & .017 \\ FeO & .092 \\ MnO & .000 \end{array}\right\} Al_2O_3\ 1.00 \left\{\begin{array}{ll} SiO_2 & 1.866 \\ TiO_2 & .072 \\ P_2O_5 & .002 \end{array}\right.$$

$$RO\quad .156$$

Physical properties of top clay
by M. C. Shaw

Properties in green state

Workability: Very plastic
Water of plasticity: 25.58 per cent
Drying shrinkage
  Volume: 24.02 per cent
  Linear: 8.74 per cent
Dry modulus of rupture: 320 pounds per square inch
Time of slaking: 42.65 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
01	16.66	7.96	2.08	2.51	17.78	6.29	1,700	Light grayish buff
1	16.90	7.79	2.09	2.33	17.30	6.14	1,700	Light grayish buff
4	15.76	6.40	2.31	2.34	18.80	7.04	1,624	Grayish buff
5	10.28	4.60	2.17	2.61	20.22	7.25	1,750	Grayish buff
7	7.54	3.45	2.78	2.36	20.00	7.17	1,820	Grayish buff
9	4.80	0.41	2.24	2.26	19.78	7.08	1,900	Grayish buff
11	2.86	1.32	2.17	2.23	18.92	6.75	1,910	Dark buff
13	1.04	0.43	2.45	2.48	24.87	9.50	1,880	Dark buff
15	2.75	1.26	2.21	2.27	19.30	6.90	1,625	Dark buff
16	3.60	1.70	2.18	2.30	20.30	7.28	1,500	Darker buff

Porosity: The porosity drops gradually from 10.28 per cent at cone 5, where it becomes steel hard, to 1.04 per cent at cone 13, and then increases to 3.60 per cent at cone 16.

Volume shrinkage: The volume shrinkage increases steadily from 20.22 per cent at cone 5, where it becomes steel hard. to 24.87 per cent at cone 13, and then drops to 20.30 per cent at cone 16.

Total linear shrinkage:

Drying shrinkage	8.74 per cent
Burning shrinkage at cone 7	7.17 per cent
Total shrinkage	15.91 per cent

Modulus of rupture: The modulus of rupture increases steadily from 1,700 pounds per square inch at cone 01 to 1,910 pounds per square inch at cone 11, after which it decreases to 1,500 pounds per square inch at cone 16.

Steel hardness: This clay is steel hard at cone 5.

Overburning temperature: This clay overburns at cone 15.

Best apparent burning range: From cone 5 to cone 15.

Softening point: Cone 28.

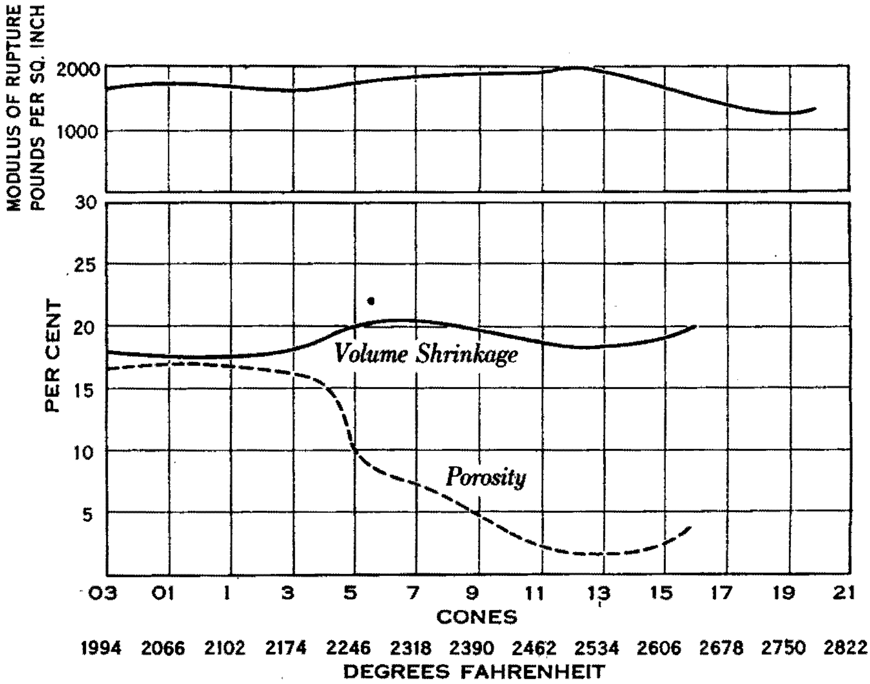


Figure 19—Sample No. 26, Plibrico Jointless Firebrick Company, Spencer Hollow, top clay

Physical properties of bottom clay
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 24.92 per cent
Drying shrinkage
  Volume: 19.82 per cent
  Linear: 7.09 per cent
Dry modulus of rupture: 420 pounds per square inch
Time of slaking: 35 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
01	14.75	6.81	2.17	2.69	20.22	7.25	1,800	Light gray
1	14.10	6.33	2.19	2.36	20.94	7.51	1,870	Light gray
4	12.67	5.98	2.12	2.42	19.90	6.21	1,870	Grayish buff
5	9.80	5.25	2.15	2.55	20.44	7.32	1,890	Grayish buff
7	6.90	4.22	2.21	2.24	20.45	7.33	1,825	Grayish buff
9	4.19	1.94	2.16	2.25	21.53	7.75	1,825	Dark grayish buff
11	1.47	0.63	2.33	2.37	27.50	10.16	1,910	Dark grayish buff
13	2.36	1.04	2.27	2.32	22.06	7.95	1,870	Dark grayish buff
15	2.25	1.01	2.23	2.28	16.23	5.72	1,800	Very dark grayish buff

Porosity: The porosity steadily decreases from 9.80 per cent at cone 5, where it becomes steel hard, to 1.47 per cent at cone 11, and then increases to 2.25 per cent at cone 15.

Volume shrinkage: The volume shrinkage remains very constant from cone 01 to cone 9, staying around 21 per cent, after which it increases rapidly to 27.50 per cent at cone 11, and then gradually decreases to 16.23 per cent at cone 15.

Total linear shrinkage:

Drying shrinkage	7.09 per cent
Burning shrinkage at cone 7	7.33 per cent
Total shrinkage	14.42 per cent

Modulus of rupture: The strength of this clay remains very constant over the entire firing range, having a modulus of rupture of 1,800 pounds per square inch at cone 01 and increasing steadily to 1,910 pounds per square inch at cone 11.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns above cone 15.

Best apparent burning range: From cone 3 to cone 11.

Softening point: Cone 28.

Utilization of bed as a whole: Used chiefly in the production of jointless or monolithic fire brick; finds a market also for refractory mortars, for intermediate heat duty fire brick, for bonding clay for molding sands and grinding wheels, and for the plastic ingredient of many ceramic bodies.

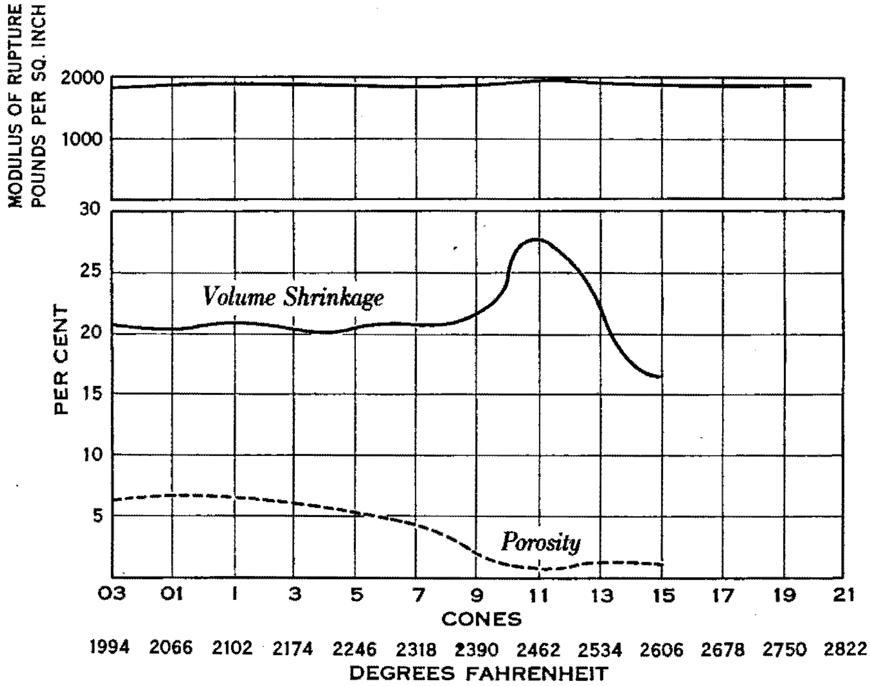


Figure 20—Sample No. 26, Plibrico Jointless Firebrick Company, Spencer Hollow, bottom clay

In 1921 a sample for testing was taken by Wilber Stout in a mine of the Portsmouth Refractories Company, now owned by the Plibrico Jointless Firebrick Company, on the ridge in the central part of Section 3, in Spencer Hollow, Washington Township. The measurements and tests as recorded follow:[1]

Section No. 34		Ft.	In.
Sandstone, shaly		5	0
Clay, flint and plastic, *Oak Hill*		5	0
Coal, good	*Lower Kittanning*	2	7
Clay, impure			3
Coal, good			8
Clay, dark, flinty, excluded	*Lawrence*		3
Clay, light, plastic, sampled		6	0
Sandstone, clay bonded.			

Chemical analysis of the Lawrence clay from mines of the Portsmouth Refractories Company, now Plibrico Jointless Firebrick Company

Chemical analysis		*Oxide ratio*				
Loss at 105° C	1.93	K_2O	.058			
Ignition loss	8.48	Na_2O	.007		SiO_2	2.382
Silica, SiO_2	58.14	CaO	.017	Al_2O_3 1.00	TiO_2	.079
Alumina, Al_2O_3	24.41	MgO	.029		P_2O_5	.011
Ferric oxide, Fe_2O_3	2.35	FeO	.087			
Lime, CaO	.42	MnO	.001			
Magnesia, MgO	.71					
Titanic oxide, TiO_2	1.92		——			
Phosphorous pentoxide, P_2O_5	.28	RO	.199			
Sodium oxide, Na_2O	.17					
Potassium oxide, K_2O	1.42					
Manganous oxide, MnO	.01					
Sulphur, S	.45					
Total carbon, C	.18					
Inorganic carbon, C	.00					

Mineralogical examination

The sand separate consists essentially of clay-quartz-sericite aggregates and of free quartz in both large and small grains. Muscovite and pyrite are fairly plentiful. The pyrite occurs as broken fragments, and as small octahedral crystals in only a few cases imbedded in the clay. The larger fragments are more common and probably were formed subsequently to deposition of clay. Zircon, tourmaline, and rutile occur frequently as accessory minerals in sands.

The clay separate carries some impurities, mostly quartz and sericite. Pyrite occasionally is found as small crystals. Rutile and iron oxide are present as very fine grains and imbedded in the clay matrix.

The outstanding characteristic of sample is presence of coarse pyrite, which probably could be removed by concentration methods, and presence of abundant quartz sand.

---

[1] Geological Survey of Ohio, Bull. 26, pp. 278, 279, 280.

Physical tests

Working properties: Very plastic, smooth texture, fine-grained, molds well.

Tempering water	23.15 per cent
Drying linear shrinkage	8.80
Drying volume shrinkage	28.80

Burning behavior

Burning temperature	Per cent linear shrinkage	Per cent volume shrinkage	Per cent volume absorption	Color
Cone 08	2.79	8.13	22.58	Cream
Cone 03	5.44	15.46	17.74	Cream
Cone 01	6.03	17.01	15.76	Light buff
Cone 4	7.29	20.32	6.10	Gray
Cone 8	8.24	22.75	0.91	Gray
Cone 12	8.17	22.57	0.70	Brown gray
Cone 14	6.38	17.93	2.56	Brown gray
Cone 15	2.13	6.25	1.66	Brown gray

Overburning temperature: Cone 14 (1,390° C. or 2,534° F.).

Best apparent burning range: Cones 4 to 12 (1,165° C. to 1,310° C. or 2,129° F. to 2,390° F.).

Total linear shrinkage at cone 12: 16.97 per cent.

Deformation temperature: Cone 26 (1,595° C. or 2,903° F.).

Possibilities: Moderate heat duty refractories, sewer pipe, face brick, hollow block, fireproofing.

Its drying shrinkage is rather high and could be reduced by the addition of non-plastic material, preferably grog.

In this field the true relation of the Lawrence member with the reappearance of the Lower Kittanning clay is shown in the following section taken near Eifort in 1913 at the mines of Morgan and Horton Clay Company in Section 5, Bloom Township, Scioto County:[1]

Section No. 37		Ft.	In.
Shale and soil		10	0
Coal, rotten	*Lower Kittanning*	1	0
Clay, impure			1
Coal, good			9
Clay, dark, plastic	*Lower Kittanning*	1	0
Clay, light, plastic		5	6
Clay, light to dark, flint	*Lawrence*		8
Clay, plastic, light		7	4
Sandstone, clay bonded.			

---

[1] Geological Survey of Ohio, Bull. 26, p. 283.

In the above section the Lawrence clay is in its true position below the Lower Kittanning coal. The section is similar to that of the Lawrence Clay Company in the Lawrence field and to that at the Dean Church in the Dean field. A change in the swamp conditions during deposition thus produced various results as to the development and relations of the Lawrence and Lower Kittanning members.

In the pit now (1931) being worked by the Morgan and Horton Clay Company the strata have changed somewhat from what they were in the old mine. The total thickness of clay is less, the decrease being caused mainly by a contraction of the Lawrence clay. The section taken by W. R. Maxey and F. F. Dickman with notations on the parts sampled is given below:

Section No. 37a

		Ft.	In.
Shale, gray, argillaceous		12	6
Clay, plastic, with ore nodules, *Oak Hill*		3	0
Coal, soft, weathered, *Lower Kittanning*		1	6
Clay, shaly, rejected	*Lower Kittanning*		6
Clay, plastic, light to dark, excellent, sampled		4	6
Clay, flinty, dark, sampled	*Lawrence*		5
Clay, light, plastic, good, sampled		1	10
Clay, light, plastic, very siliceous, sampled		2	0

Analysis of the sample of Lower Kittanning and Lawrence clays from the pit of Morgan and Horton Clay Company. Analyst, Downs Schaaf

Chemical analysis		*Oxide ratio*					
Water, hydroscopic, H_2O-	2.85	K_2O	.078				
Water, combined, H_2O+	7.05	Na_2O	.013			SiO_2	2.129
Silica, SiO_2	56.10	CaO	.017	Al_2O_3	1.00	TiO_2	.053
Alumina, Al_2O_3	26.35	MgO	.010			P_2O_5	.003
Ferric oxide, Fe_2O_3	2.14	FeO	.084				
Ferrous oxide, FeO	.28	MnO	.000				
Lime, CaO	.44						
Magnesia, MgO	.27		——				
Titanic oxide, TiO_2	1.40	RO	.202				
Phosphorous pentoxide, P_2O_5	.07						
Sodium oxide, Na_2O	.35						
Potassium oxide, K_2O	2.04						
Manganous oxide, MnO	.01						
Sulphur, S	.23*						
Zirconium oxide, ZrO_2	trace						
Carbon, organic, C	.61						
Carbon as CO_2 in carbonates, C	trace						

---

*It should be noted that some of the Fe reported as Fe_2O_3 is really combined as FeS_2, since qualitative tests show that most of the S is in the form of pyrite, FeS_2.

Physical properties
by M. C. Shaw

Properties in green state

Workability: Good plasticity
Water of plasticity: 18.52 per cent
Drying shrinkage
  Volume: 15.75 per cent
  Linear: 5.55 per cent
Dry modulus of rupture: 380 pounds per square inch
Time of slaking: 27.9 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	17.30	8.15	2.12	2.56	16.80	5.95	2,460	Light gray
01	17.70	8.20	2.15	2.62	18.20	6.48	4,220	Light gray
1	16.90	7.70	2.18	2.62	19.70	7.05	4,280	Medium gray
3	14.50	6.60	2.23	2.61	20.10	7.21	4,800	Gray
5	5.74	2.50	2.29	2.43	23.30	8.46	5,050	Gray
7	3.11	1.38	2.26	2.33	23.50	7.56	4,200	Gray
9	1.33	0.59	2.27	2.31	22.70	8.23	4,280	Dark gray
13	7.23	3.52	2.05	2.22	15.60	5.50	3,220	Dark gray
16	16.60	9.40	1.77	2.13	0.68	0.23	2,220	Dark gray

Porosity: The porosity steadily decreases from 5.74 per cent at cone 5, where it becomes steel hard, to 1.33 per cent at cone 9, and then increases rapidly to 16.6 per cent at cone 16.

Volume shrinkage: The volume shrinkage increases steadily from 23.3 per cent at cone 5, where it becomes steel hard, to 23.5 per cent at cone 7, and then decreases rapidly to 0.68 per cent at cone 16.

Total linear shrinkage:

Drying shrinkage	5.55 per cent
Burning shrinkage at cone 7	7.56 per cent
Total shrinkage	13.11 per cent

Modulus of rupture: The strength of this clay gradually increases from 2,460 pounds per square inch at cone 03 to 5,050 pounds per square inch at cone 5, and then gradually decreases to 2,220 pounds per square inch at cone 16.

Steel hardness: Steel hard at cone 5.

Overburning temperature: This clay overburns above cone 16.

Best apparent burning range: From cone 5 to cone 11.

Softening point: Cone 30.

Utilization: Widely used for bonding molding sands, sagger bodies, flint clays and grogs, for part of mixture in decorative, sanitary, quarry, and promenade tiling, for intermediate heat duty refractory ware, for high temperature cements, and for mortar and wad clays at blast, open hearth, electric, tempering, heat treating, annealing, forging, and melting furnaces.

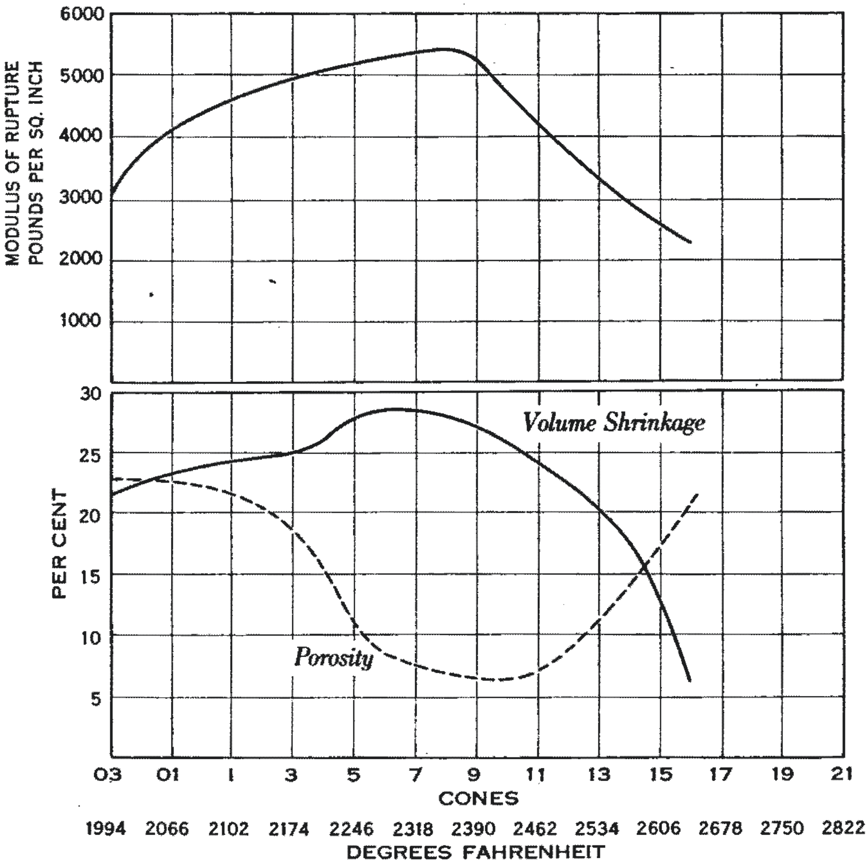


Figure 21—Sample No. 37a, Morgan and Horton Clay Company, Eifort

At the brick plant of the Cambria Clay Products Company near Black Fork, in Section 1, Washington Township, Lawrence County, the Lawrence and Lower Kittanning clays are also present in the coalesced form. The record taken under deep covering at the head of the main entry is given below:

Section No. 38		Ft.	In.
Shale		10	0
Coal, good	*Lower Kittanning*	2	0
Clay, fair		1	6
Coal, good			6
Clay, light, plastic	*Lower Kittanning*	2	1
Clay, dark, plastic			4
Clay, light, plastic		2	0
Clay, dark, flinty	*Lawrence*		4
Clay, light, plastic, good		6	2
Sandstone, clay bonded.			

The Lawrence clay has normal development to the east of the above section in the heads of Kokeene and Pokepatch hollows in northwestern Greenfield Township, Gallia County, but farther east in the vicinity of Gallia Furnace it is largely wanting due to replacement by sandstone. The deposits consist principally of Lawrence clay and in places entirely of this material. The overlying Lower Kittanning coal is generally thin and is troubled with a thick clay parting.

In the vicinity of Oak Hill the main clay stratum is the Lawrence lying directly below or not far under the Lower Kittanning coal. The changes in the succession of the beds are well shown in the strip mine of the Chapman Clay Company where the Lower Kittanning clay appears only as local lenses, some scarcely 10 feet across and less than 1 foot in thickness. A section there shows the following stratigraphic units:

Section No. 36		Ft.	In.
Shale and shaly sandstone		10	0
Clay, plastic, dark	*Oak Hill*		8
Clay, flint, light gray, good		1	3
Clay, shaly, dark			5
Coal, good	*Lower Kittanning*	1	8½
Clay, light, plastic			6½
Coal, good			6
Clay, light, flaky, micaceous, only locally present, thickness 1 inch to 2 feet 6 inches, *Lower Kittanning*		1	0
Clay, plastic, dark, excellent	*Lawrence*	4	5
Clay, plastic, light, excellent		1	1
Clay, plastic, soft, light, fair		2	4

At the mines of the Aetna Fire Brick Company and at those of the Cedar Heights Clay Company northwest of Oak Hill the section is much the same as that shown above except that the Lower Kittanning clay has a more regular development. However, the bed is generally thin, less than 2 feet in thickness. The section changes little in the extension of the field on westward to the ridges in the vicinity of Jefferson Furnace.

GENERAL FEATURES OF THE FIREBRICK FIELD

As previously stated, the outstanding feature in the Firebrick field is the absence over most of the area of the Lower Kittanning clay, thus falsely placing the Lawrence clay directly below the Lower Kittanning coal. The normal succession, however, occurs with sufficient frequency as to prevent confusion in the identification of the several clay units. In this field the Lawrence clay varies from 5 to 15 feet in thickness but averages close to 7 feet. The upper unit or the flint clay stratum is not always present. Where observed the thickness of this material ranges from 3 inches to 1 foot 3 inches and the quality appears to be uniformly good. The middle unit of the Lawrence member is the "cream" clay with high plasticity and purity, which qualities make it the outstanding plastic clay of the State. The thickness remains rather steadily between 4 and 6 feet. The siliceous clay in the basal part of the deposit gradates downward into clay-bonded sandstone. It is very free from damaging impurities such as shot or masses of limonite, siderite, pyrite, and gypsum.

Throughout the Firebrick field the conditions are such that the Lower Kittanning coal may be saved in mining the Lawrence clay. Its recovery is a fuel asset of considerable importance. From a number of determinations scattered throughout this area the mean measurements of the Lower Kittanning coal are as follows: upper bench of coal, 1 foot 9 inches; clay parting, 5 inches; and lower bench of coal, 7 inches. Along the western margin of the Firebrick field large quantities of clay may be won by stripping as the member lies along the summits of the ridges and as the covering is largely shale. In the eastern part, however, drift mining must be practiced. The conditions for such a procedure are satisfactory as the roof is either a tough shale or a massive sandstone. The recovery should be at least 60 per cent of both clay and coal. The Firebrick field now supports several successful operations and yet contains ample clay for a few additional plants.

CHAPTER V

OUTLYING AREAS

INTRODUCTION

Outside the main fields—Lawrence, Dean, and Firebrick—the Lawrence clay and also the Lower Kittanning bed are erratic as to thickness and quality and uncertain as to position and extent. The sections thus change from place to place and, along with this, necessarily the conditions for utilization are undergoing modifications. Locally some of the deposits have good properties, offering conducive opportunities for the ceramic worker. In large areas, however, the clays are so thin and poor that any attempted utilization will surely be met with failure. As the conditions in the scattered deposits are so much less satisfactory than they are in the larger more stable fields, utilization should first begin where the elements of success are most favored. Sections showing the geological features in the best of the outlying deposits and also in the more impoverished areas will be given in order that a knowledge of the clay situation throughout Lawrence County may be obtained.

DETAILED SECTIONS

In the vicinity of Coalgrove and along the lower course of Ice Creek, the main stratigraphic units and their general succession are shown in the following record secured at the mines of the Alpha Portland Cement Company in Section 26, Upper Township:

Section No. 24

		Ft.	In.
Sandstone, massive		30	0
Disconformity, small			
Coal, bony, very irregular, *Middle Kittanning*			4
Clay, plastic, light, siliceous, with some ore nodules	*Middle Kittanning*	4	0
Clay, very siliceous, with ore nodules		1	1

		Ft.	In.
Shale, argillaceous		7	9
Sandstone, massive		23	0
Disconformity, small		....	....
Coal, good	*Lower Kittanning*	1	5
Coal, bony, with pyrite			¾
Coal, good		1	½
Clay, impure			5
Coal, good			9
Coal, bony			1
Clay, plastic, light, lower part very siliceous with ore nodules near base, *Lower Kittanning*		8	7
Sandstone, shaly		10	8
Clay, flint, dark	*Lawrence*		1
Clay, light, plastic, good		3	9
Clay, light, plastic, part siliceous, some ore nodules near base		5	7
Ore, irregular, *Ferriferous*			8
Limestone, good, *Vanport*		6	0
Shale, green, impure			4
Clay, dark, flinty	*Clarion*		5
Coal, bony			1
Clay, light, plastic		2	2
Clay, light, plastic, very siliceous		5	7
Sandstone, clay-bonded.			

In this vicinity the Lawrence clay has normal thickness but the basal portion contains many ore balls and much fine shot which restricts its utilization to the manufacture of the commoner types of heavy clay products. Such a contamination usually occurs when the clay body lies directly on the Ferriferous ore and Vanport limestone or when it is not protected by the intervention of the few feet of ore shales. The overlying Lower Kittanning clay is not attractive for ceramic work on account of its highly siliceous nature and its content of damaging impurities. The underlying Clarion clay, although decidedly siliceous, has good properties. The above section is also representative of the members in the vicinity of Coalgrove. The Lawrence member, however, appears locally with good thickness and without damaging impurities at the plant of the Carlyle-Labold Company at Coalgrove and also along the river hills east of Ironton and south of the highway tunnel. Farther east on Ice Creek and Little Ice Creek, considerable modification takes place both as to the arrangement of beds and as to the quality of the materials.

On Hog Run, a branch of Ice Creek, the Lawrence clay appears to be divided into two parts with a thin layer of shale as the separating medium. This condition is shown in the following record taken on the Hecla property in the southeastern part of Section 22, Upper Township, where the strata were well exposed in a prospect opening. At this place the Lawrence member was sampled for testing, October 1, 1930, by G. A. Bole, Lonnis Denison, W. R. Maxey, and Wilber Stout.

Section No. 22		Ft.	In.
Sandstone, massive		20	0
Coal, weathered	*Lower Kittanning*	1	11
Clay, siliceous		1	0
Coal, weathered			11
Clay, plastic, gray, fair, *Lower Kittanning*		4	10
Coal, shaly, *Lawrence*			1
Clay, flinty, dark, not sampled	*Lawrence*	1	0
Coal, shaly, not sampled			½
Clay, plastic, light, good, sampled			11
Clay, plastic, dark, excellent, sampled		2	2
Clay, plastic, light, siliceous, sampled		2	1
Clay, plastic, slightly shaly, not sampled			8
Shale, light gray, argillaceous		1	4
Clay, plastic, dark, good			2
Clay, plastic, light, good		5	10
Ore, *Ferriferous*			7
Limestone, *Vanport*, part seen		2	0

At this place the quality of the Lawrence clay and also that of the "lower" clay are very good and that of the Lower Kittanning clay is better than usual. For products such as sewer pipe, fireproofing, building brick, etc., all the materials between the Ferriferous ore and the Lower Kittanning coal, measuring more than 18 feet, may be used. Such a mix should have good working properties and burn to a strong body with a buff color. The overlying coal is very satisfactory for ceramic fuel as it burns freely and with a long flame. The coal may be mined as an adjunct with clay. The sandstone overlying these strata is sufficiently massive and thick to form a strong desirable roof for drift mining.

Analysis of the Lawrence clay on the Hecla property on Hog Run, Section 22, Upper Township. Analyst, Downs Schaaf

Chemical analysis				*Oxide ratio*			
Water, hydroscopic, H_2O-	2.63	K_2O	.059				
Water, combined, H_2O+	6.90	Na_2O	.010	Al_2O_3	1.00	SiO_2	2.236
Silica, SiO_2	56.56	CaO	.013			TiO_2	.063
Alumina, Al_2O_3	25.29	MgO	.038			P_2O_5	.010
Ferric oxide, Fe_2O_3	2.48	FeO	.100				
Ferrous oxide, FeO	.30	MnO	.001				
Lime, CaO	.33						
Magnesia, MgO	.96						
Titanic oxide, TiO_2	1.60	RO	.221				
Phosphorous pentoxide, P_2O_5	.24						
Sodium oxide, Na_2O	.25						
Potassium oxide, K_2O	1.50						
Manganous oxide, MnO	.02						
Sulphur, S	.14						
Zirconium oxide, ZrO_2	trace						
Carbon, organic, C	.71						
Carbon as CO_2 in carbonates, C	.04						

Physical properties
by M. C. Shaw

Properties in green slate

Workability: Fair plasticity
Water of plasticity: 26.23 per cent
Drying shrinkage
  Volume: 14.20 per cent
  Linear: 5.20 per cent
Dry modulus of rupture: 360 pounds per square inch
Time of slaking: 12.60 minutes

Burning behavior

At cone	Porosity in per cent	Absorption in per cent	Bulk specific gravity	Apparent specific gravity	Volume shrinkage in per cent	Linear shrinkage in per cent	Modulus of rupture in pounds per square inch	Color
03	27.64	14.78	1.87	2.58	12.58	4.35	2,115	Light buff
01	20.32	10.14	2.01	2.52	18.13	6.40	3,062	Buff
1	19.52	9.71	2.01	2.50	19.02	6.78	3,126	Dark buff
3	15.03	7.20	2.09	2.46	20.96	7.52	3,157	Dark buff
5	13.70	6.53	2.10	2.43	21.67	7.80	3,376	Dark buff
7	5.99	2.72	2.20	2.34	23.69	8.62	3,668	Dark buff
9	4.41	2.12	2.08	2.18	22.60	7.14	3,436	Dark buff
11	1.48	0.69	2.03	2.06	21.01	7.56	2,554	Dark brownish gray
13	3.88	1.90	2.04	2.13	19.93	7.14	2,418	Dark brownish gray
16	7.30	4.15	1.76	1.90	17.30	6.14	1,890	Dark brownish gray
20	10.72	5.75	1.83	1.88	13.60	4.76	1,353	Dark brownish gray

Porosity: The porosity decreases steadily from 19.52 per cent at cone 1, where it becomes steel hard, to 1.48 per cent at cone 11, after which it increases to 10.72 per cent at cone 20.

Volume shrinkage: The volume shrinkage increases steadily from 19.02 per cent at cone 1, where it becomes steel hard, to 23.69 per cent at cone 7, after which it decreases slowly to 13.60 per cent at cone 20.

Total linear shrinkage:

Drying shrinkage	5.20 per cent
Burning shrinkage at cone 7	8.62 per cent
Total shrinkage	13.82 per cent

Modulus of rupture: The strength of this clay increases slowly from 2,115 pounds per square inch at cone 03 to 3,668 pounds per square inch at cone 7, after which it slowly decreases to 1,353 pounds per square inch at cone 20.

Steel hardness: Steel hard at cone 1.

Overburning temperature: This clay overburns at cone 9.

Best apparent burning range: From cone 1 to cone 9.

Softening point: Cone 20.

Possibilities: The chief field for this clay, as determined by the tests, is for heavy clay products such as sewer pipe, wall coping, flue lining, fittings, fireproofing, and face brick.

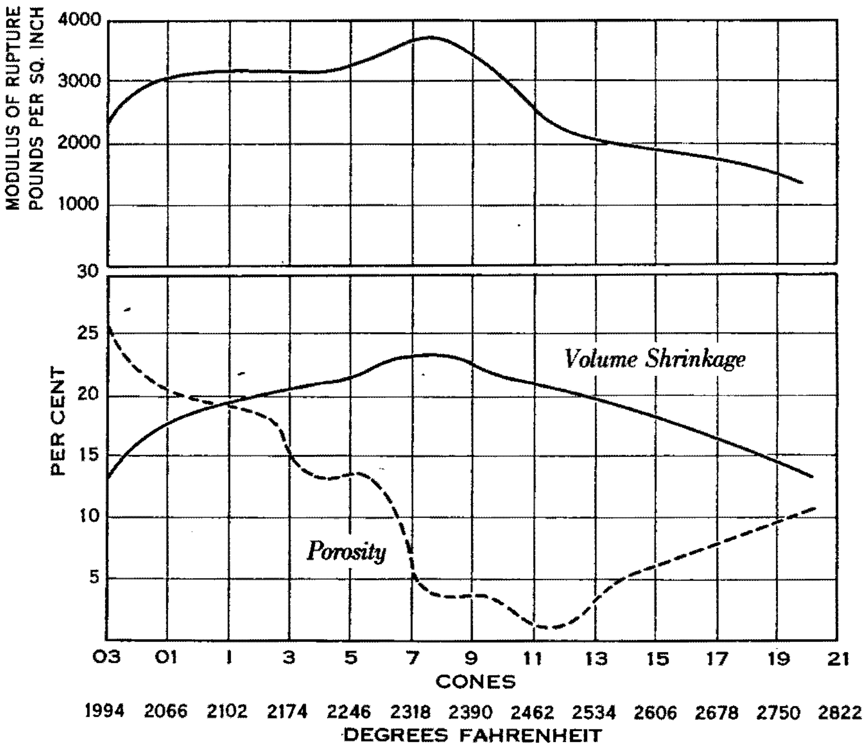


Figure 22—Sample No. 22, Hecla property, Hog Run

The Lawrence and Lower Kittanning members with some modifications appear to extend northeastward along Sugar Creek in Section 13, Upper Township, and in Section 23, Perry Township. Along Ice Creek in the north central part of Perry Township flint clay appears on the horizon usually occupied by the Lawrence member. Such deposits are local in extent, being found only in this vicinity and along Little Ice Creek. They are also variable as to the quality of the flint clay and as to its association with plastic clay and with shale. This flint clay is not correlative with that in the upper part of the Lawrence member, which is best developed in the Strasburg field of Tuscarawas County. The following section was taken where the flint clay was well exposed in a prospect opening in the south central part of Section 30, Perry Township. The mineral rights are held by the Hecla Company and the surface by James Walters.

Section No. 23	Ft.	In.
Clay, weathered, *Lower Kittanning*	2	0
Clay, dark, coaly, *Lawrence* coal horizon		2
Clay, plastic, good, *Lawrence*	3	9
Shale with ore balls and nodules of flint clay	7	6
Flint clay with plastic clay, sandstone, and ore balls	5	2

This flint clay is the hard siliceous type with moderate refractory qualities. Formerly it was utilized for the manufacture of fire brick. The supply was secured as a secondary product in drifting for iron ore.

Formerly the Lower Kittanning coal and clay were worked by the Orchard Knob Brick Company in Section 16, Upper Township. The clay was mined by drifting and averaged about 6 feet in thickness. In the vicinity of LaGrange Furnace the Lawrence clay is generally absent and the Lower Kittanning stratum thin and impure. Similar conditions exist along the ridges between Osburn Run and Norman Run in Hamilton Township and in the southern tier of sections in Elizabeth Township.

In the area between the Lawrence and Dean fields in northern Elizabeth Township, the impoverishment of clay is conspicuous and general. The Lawrence member is nearly everywhere completely replaced by sandstone or shale and the Lower Kittanning stratum is so thinned and modified as to be unattractive for ceramic purposes. In general, wherever sandstone forms the roof of the Vanport limestone, no clays of value are present. A few sections in this area will suffice to show the stratigraphic features.

Along the road on the divide from Center Station to Center Furnace in the southwestern corner of Section 33, Decatur Township, the beds are well exposed and have the following measurements:

Section No. 79		Ft.	In.
Coal blossom, *Middle Kittanning*		1	0
Clay, siliceous, impure		1	0
Sandstone, nodular		1	0
Shales, gray		8	0
Coal blossom, *Strasburg*			2
Clay, dark, plastic	*Oak Hill*	5	0
Clay, light, plastic		4	4
Coal, shaly, "*Lost Seam*"		2	0
Shales, dark, siliceous		1	10
Coal, good	*Lower Kittanning*	1	2
Clay, impure			3
Coal, good			5
Clay, plastic, siliceous, poor, *Lower Kittanning*		3	0
Shale, part very siliceous		16	0
Shale and covered		8	0
Ore, *Ferriferous*			4
Flint, ferruginous	*Vanport*	1	0
Limestone, good		6	0
Clay, light, plastic, part siliceous, *Clarion*		6	0

In this locality the Lawrence clay is absent through replacement by shale and sandstone and the Lower Kittanning clay is thin and impure. On the ridge across the hollow to the north of this, however, the Lawrence member appears with normal thickness and excellent quality. The change from wants to good clay thus takes place rather sharply. Such a replacement of the Lawrence clay by sandstone and shale extends on southeastward from Center Station past Bartles and across the upper course of Cannons Creek to Storms Creek where the beds disappear below drainage. On Bear Run and its tributaries, or in the area around Center Furnace, only the Lower Kittanning clay is present, the Lawrence being replaced by the sandstone that forms the roof of the Vanport limestone. The following record taken at the mines of the Superior Portland Cement Company in the southwestern part of Section 32, Decatur Township, illustrates well the replacement of clay by sandstone:

Section No. 63		Ft.	In.
Sandstone, massive		30	0
Coal, good	*Lower Kittanning*	1	10
Clay, impure			2
Coal, good			8
Clay, plastic, light, fair	*Lower Kittanning*	5	8
Clay, shaly, siliceous		1	6
Sandstone, massive		16	6
Shale, argillaceous		1	8
Ore, *Ferriferous*			7
Limestone, *Vanport*		7	0

Similar conditions are found north of the main divide on the ridges between Howard Run and Youngs Branch and between Youngs Branch and Buckhorn Hollow. In this area neither the Lawrence nor the Lower

ANALYTICAL TABLE OF LAWRENCE CLAYS

Sample No.	PROPERTY	LOCATION				Thickness of bed	Thickness of sample	Kind of clay sampled
		Place	Section	Township	County	Ft. In.	Ft. In.	
17	Ceramic Clay Co.	Ellisonville	27	Elizabeth	Lawrence	11 2	8 0	"Cream" and siliceous
16	Ceramic Clay Co.	Frecka Ice Pond	20	Elizabeth	Lawrence	8 10	7 4	"Cream" and siliceous
20	John Silliman	Sand Cut	19	Elizabeth	Lawrence	8 7	7 9	"Cream" and siliceous
18	John Silliman	Sperry Fork	16 west	Elizabeth	Lawrence	8 9	7 3	"Cream" and siliceous
18a	John Silliman	Sperry Fork	16 west	Elizabeth	Lawrence		1 3	Flint
18a	John Silliman	Sperry Fork	16 west	Elizabeth	Lawrence		3 7	"Cream"
18a	John Silliman	Sperry Fork	16 west	Elizabeth	Lawrence		2 7	Siliceous
30	W. M. Jefferys Estate	Fox Hollow	10	Elizabeth	Lawrence	8 7	6 10	"Cream" and siliceous
10	Lawrence Clay Co.	Little Pine Creek	18	Elizabeth	Lawrence	11 8	8 4	"Cream" and siliceous
21	R. T. Lawson	Lawrence Furnace	16	Elizabeth	Lawrence	10 0	7 9	"Cream" and siliceous
12	Culbertson & Dickens	Rider Hollow	3	Elizabeth	Lawrence	8 10	8 10	Flint, "cream," and siliceous
27	Dean State Forest	Long Hollow	2	Elizabeth	Lawrence	8 2	7 2	Flint, "cream," and siliceous
41	Lawrence County Clay and Coal Co.	Munyon Hollow	34	Decatur	Lawrence	8 10	7 9	Flint, "cream," and siliceous
41	Lawrence County Clay and Coal Co.	Munyon Hollow	34	Decatur	Lawrence		0 8	Flint
41	Lawrence County Clay and Coal Co.	Munyon Hollow	34	Decatur	Lawrence		4 9	"Cream"
41	Lawrence County Clay and Coal Co.	Munyon Hollow	34	Decatur	Lawrence		2 4	Siliceous
39	Lawrence County Clay and Coal Co.	Center Station	33	Decatur	Lawrence	8 3	7 2	"Cream" and siliceous
29	Edward F. Roth	Mt.Vernon Furnace	22	Decatur	Lawrence	8 11	6 8	"Cream" and siliceous
32	Cambria Clay Products Co.	Pioneer Furnace	15	Washington	Lawrence	7 10	6 10	Flint, "cream," and siliceous
26	Plibrico Jointless Firebrick Co.	Spencer Hollow	15	Washington	Lawrence	7 3	7 3	"Cream"
26	Plibrico Jointless Firebrick Co.	Spencer Hollow	15	Washington	Lawrence		4 1	"Cream"
26	Plibrico Jointless Firebrick Co.	Spencer Hollow	15	Washington	Lawrence		3 2	"Cream"
37	Morgan and Horton Clay Co.	Eifort	5	Bloom	Scioto	9 3	8 9	"Cream" and siliceous
22	Hecla Property	Hog Run	22	Upper	Lawrence	6 10	5 2	"Cream" and siliceous
	Average of samples of entire bed					8 10	7 5	

Sample No.	PROPERTY	CHEMICAL COMPOSITION																	OXIDE RATIO		
		Water, hydroscopic H_2O-	Water combined H_2O+	Silica, SiO_2	Alumina, Al_2O_3	Ferric oxide, Fe_2O_3	Ferrous oxide, FeO	Lime, CaO	Magnesia, MgO	Titanic oxide, TiO_2	Phosphorous pentoxide, P_2O_5	Sodium oxide, Na_2O	Potassium oxide, K_2O	Manganous oxide, MnO	Sulphur, S	Zirconium oxide, ZrO_2	Carbon, organic, C	Carbon as CO_2 in carbonates, C	Sum of K_2O, Na_2O, CaO, MgO, FeO, MnO.	Al_2O_3	Sum of SiO_2, TiO_2, P_2O_5
17	Ceramic Clay Co.	2.50	7.10	57.79	25.40	1.72	0.25	0.31	0.88	1.57	0.21	0.27	1.51	0.01	0.05	Trace	0.44	0.02	0.188	1.00	2.345
16	Ceramic Clay Co.	2.41	7.12	58.69	25.25	1.16	0.24	0.34	0.92	1.55	0.24	0.25	1.49	0.01	0.04	Trace	0.25	0.05	0.170	1.00	2.395
20	John Silliman	3.00	7.22	58.21	25.13	1.70	0.28	0.32	0.86	1.59	0.14	0.21	1.15	0.01	0.05	Trace	0.17	None	0.173	1.00	2.385
18	John Silliman	2.57	7.27	59.90	25.04	0.54	0.22	0.32	0.80	1.60	0.18	0.22	1.10	0.01	0.04	Trace	0.30	Trace	0.126	1.00	2.463
18a	John Silliman	3.07	8.04	55.96	26.40	1.58	0.20	0.36	0.20	1.73	0.18	0.20	1.10	0.01	0.04	Trace	0.88	Trace	0.132	1.00	2.192
18a	John Silliman	2.50	7.28	59.62	25.14	0.72	0.20	0.32	0.79	1.61	0.11	0.22	1.20	0.01	0.02	Trace	0.34	Trace	0.135	1.00	2.440
18a	John Silliman	2.50	6.48	62.40	21.11	2.15	0.21	0.30	0.75	1.35	0.11	0.46	2.04	0.01	0.04	Trace	0.32	Trace	0.270	1.00	3.025
30	W. M. Jefferys Estate	2.14	7.57	58.04	25.02	2.25	0.09	0.31	0.81	1.54	0.14	0.27	1.55	0.01	0.04	Trace	0.25	Trace	0.202	1.00	2.387
10	Lawrence Clay Co.	3.08	7.61	57.10	25.47	1.66	0.30	0.32	0.88	1.55	0.26	0.17	1.11	0.015	0.43	Trace	0.25	Trace	[illegible] 0.170	1.00	2.313
21	R. T. Lawson	2.55	7.55	57.28	25.43	2.30	0.30	0.30	0.81	1.51	0.22	0.25	1.35	0.025	0.08	Trace	0.13	Trace	0.220	1.00	2.320
12	Culbertson & Dickens	2.90	7.53	56.83	25.09	2.22	0.32	0.28	0.86	1.60	0.22	0.21	1.20	0.01	0.49	Trace	0.57	Trace	0.194	1.00	2.338
27	Dean State Forest	2.60	7.51	57.35	25.29	2.04	0.25	0.30	0.86	1.53	0.27	0.21	1.07	0.01	0.09	Trace	0.68	Trace	0.179	1.00	2.339
41	Lawrence County Clay and Coal Co.	1.55	7.56	58.77	24.52	2.15	0.21	0.32	0.54	1.54	0.10	0.33	1.55	0.01	0.04	Trace	0.80	Trace	0.200	1.00	2.464
41	Lawrence County Clay and Coal Co.	2.53	12.02	47.84	30.40	2.10	0.20	0.40	0.14	1.33	0.35	0.10	0.49	Trace	0.09	Trace	1.90	Trace	0.106	1.00	1.629
41	Lawrence County Clay and Coal Co.	1.45	7.31	58.22	25.40	2.05	0.20	0.32	0.79	1.68	0.11	0.29	1.42	0.01	0.02	Trace	0.75	Trace	0.192	1.00	2.362
41	Lawrence County Clay and Coal Co.	1.47	6.80	63.02	21.04	2.36	0.22	0.30	0.14	1.31	0.02	0.48	2.13	0.01	0.05	Trace	0.60	Trace	0.257	1.00	3.058
39	Lawrence County Clay and Coal Co.	1.34	7.90	57.72	26.28	1.92	0.12	0.49	0.25	1.45	0.08	0.22	1.38	0.01	0.02	Trace	0.83	Trace	0.159	1.00	2.254
29	Edward F. Roth	2.45	6.90	60.81	22.80	2.49	0.27	0.30	0.79	1.50	0.21	0.18	1.07	0.01	0.05	Trace	0.22	None	0.213	1.00	2.742
32	Cambria Clay Products Co.	2.40	7.91	56.16	25.92	1.86	0.53	0.30	0.79	1.60	0.18	0.25	1.45	0.02	0.29	Trace	0.41	0.03	0.193	1.00	2.235
26	Plibrico Jointless Firebrick Co.	2.00	8.65	53.07	28.44	2.67	0.23	0.36	0.47	2.04	0.07	0.16	0.81	0.01	0.26	Trace	0.89	Trace	0.156	1.00	1.940
26	Plibrico Jointless Firebrick Co.	1.77	8.30	53.86	27.30	3.29	0.24	0.48	0.40	2.10	0.07	0.15	0.74	0.01	0.44	Trace	1.04	Trace	0.182	1.00	2.052
26	Plibrico Jointless Firebrick Co.	2.30	9.11	52.04	29.92	1.86	0.22	0.21	0.56	1.96	0.07	0.18	0.89	0.01	0.02	Trace	0.70	Trace	0.125	1.00	1.807
37	Morgan and Horton Clay Co.	2.85	7.05	56.10	26.35	2.14	0.28	0.44	0.27	1.40	0.07	0.35	2.04	0.01	0.23	Trace	0.61	Trace	0.202	1.00	2.185
22	Hecla Property	2.63	6.90	56.56	25.29	2.48	0.30	0.33	0.96	1.60	0.24	0.25	1.50	0.02	0.14	Trace	0.71	0.04	0.221	1.00	2.309
	Average of samples of entire bed	2.44	7.46	57.52	25.42	1.96	0.26	0.33	0.73	1.57	0.18	0.24	1.33	0.01	0.15	Trace	0.47	0.01	0.185	1.00	2.338

Sample No.	PROPERTY	GREEN PROPERTIES						FIRED PROPERTIES																				
		Workability	Water of plasticity in per cent	Drying shrinkage		Modulus of rupture in pounds per square inch	Time of slaking in minutes	Minimum porosity		Per cent porosity at cone 7	Maximum volume shrinkage		Per cent volume shrinkage at cone 7	Maximum linear shrinkage		Per cent linear shrinkage at cone 7	Total maximum linear shrinkage		Total linear shrinkage at cone 7	Maximum modulus of rupture		Overburning temperature		Best apparent burning range	Softening point		Color at cone 7
				Volume shrinkage in per cent	Linear shrinkage in per cent			At cone	Per cent		At cone	Per cent		At cone	Per cent		At cone	Per cent		At cone	Pounds per square inch	Cone	°F.		PCE	°F.	
17	Ceramic Clay Co.	Good plasticity	21.93	16.19	5.70	502	63.30	11	0.79	3.87	9	22.50	21.71	9	8.15	7.83	9	13.85	13.53	9	5,272	13	2,462	Cone 3 to cone 13	29	2,984	Brownish gray
16	Ceramic Clay Co.	Good plasticity	21.40	16.92	6.10	465	39.26	11	3.76	6.08	7	22.31	22.31	7	8.07	8.07	7	14.17	14.17	7	4,397	13	2,462	Cone 5 to cone 13	28	2,939	Medium buff
20	John Silliman	Good plasticity	22.35	15.30	5.30	458	60.87	16	1.17	8.71	9	24.41	22.00	9	8.90	8.23	9	14.20	13.53	9	5,202	16	2,642	Cone 5 to cone 16	27	2,921	Medium buff
18	John Silliman	Good plasticity	23.22	16.54	6.08	458	23.75	13	1.66	9.69	13	24.50	21.93	13	8.94	7.91	13	15.04	14.01	9	5,376	16	2,642	Cone 5 to cone 16	29	2,984	Medium buff
18a	John Silliman	Very good plasticity	26.77	21.48	7.75	340	38.00	15	1.42	7.21	15	35.38	26.76	15	13.55	9.84	15	21.30	17.59	11	1,850	15	2,570	Cone 4 to cone 15	30	3,002	Gray
18a	John Silliman	Very good plasticity	28.03	21.64	7.79	410	29.76	15	3.27	15.28	13	25.45	23.70	13	9.31	7.71	13	17.10	15.50	13	1,910	15	2,570	Cone 4 to cone 15	29	2,984	Gray
18a	John Silliman	Good plasticity	23.05	15.11	5.30	350	32.51	15	1.03	8.94	11	23.05	21.40	11	8.35	7.71	11	13.65	13.01	13	1,690	15	2,570	Cone 4 to cone 15	28	2,939	Gray
30	W. M. Jefferys Estate	Good plasticity	23.30	14.07	4.94	470	56.16	9	3.80	7.28	11	22.60	21.98	11	8.19	7.90	11	13.13	12.84	5	3,150	11	2,345	Cone 5 to cone 11	29	2,984	Brownish gray
10	Lawrence Clay Co.	Good plasticity	23.35	19.36	6.70	434	49.70	11	1.00	12.50	11	20.01	19.89	11	7.17	7.13	11	13.27	13.23	7	5,668	13	2,462	Cone 5 to cone 13	29	2,984	Grayish buff
21	R. T. Lawson	Good plasticity	23.47	17.44	5.80	459	25.55	16	1.08	8.82	11	25.19	20.00	11	9.18	7.20	11	14.98	13.00	9	5,145	16	2,642	Cone 5 to cone 16	28	2,939	Grayish buff
12	Culbertson & Dickens	Good plasticity	21.99	15.20	5.50	447	37.70	11	2.31	5.10	7	19.60	19.60	7	7.01	7.01	7	12.51	12.51	7	4,100	13	2,462	Cone 5 to cone 13	29	2,984	Dark buff
27	Dean State Forest	Good plasticity	22.15	14.13	5.30	207	38.50	16	0.72	3.85	9	22.92	22.87	9	8.30	8.27	9	13.60	13.57	9	4,580	above 20	2,570	Cone 5 to cone 20	28	2,939	Dark gray, slightly buff
41	Lawrence County Clay and Coal Co.		22.65	12.10	4.19	487	13.01	13	2.62	12.65	9	26.24	24.35	9	9.66	8.94	9	13.86	13.14	5	5,021	14	2,534	Cone 3 to cone 14	28	2,939	
41	Lawrence County Clay and Coal Co.	Fair plasticity	15.71	9.82	3.38	450	38.25	15	10.30	21.50	15	32.50	21.50	15	12.28	8.38	15	15.66	11.76	11	1,570	15	2,570	Cone 7 to cone 15	30	3,002	Gray, slightly buff
41	Lawrence County Clay and Coal Co.	Good plasticity	21.21	11.72	4.06	207	7.31	13	2.14	13.20	9	25.50	24.00	9	9.35	8.75	9	13.41	12.81	03	5,285	13	2,462	Cone 01 to cone 13	29	2,984	Gray
41	Lawrence County Clay and Coal Co.	Good plasticity	27.58	13.53	4.72	410	18.33	11	1.39	9.00	5	26.00	25.90	5	9.55	9.50	5	14.27	14.22	01	5,115	13	2,462	Cone 3 to cone 13	28	2,939	Grayish buff
39	Lawrence County Clay and Coal Co.	Fair plasticity	22.94	14.67	5.14	400	26.50	11	0.95	11.50	11	31.80	29.70	11	11.98	11.08	11	17.12	16.22	1	2,330	13	2,462	Cone 3 to cone 13	29	2,984	Dark gray
29	Edward F. Roth	Fair plasticity	20.83	14.17	5.20	468	22.90	11	0.45	8.72	11	22.36	20.69	11	8.07	7.41	11	13.27	12.61	9	5,049	13	2,462	Cone 5 to cone 13	29	2,984	Brownish gray
32	Cambria Clay Products Co.	Fair plasticity	16.34	16.88	5.60	510	16.55	20	2.12	9.48	16	21.10	17.42	16	7.60	6.18	16	13.20	11.78	03	3,296	20	2,768	Cone 5 to cone 20	30	3,002	Dark buff
26	Plibrico Jointless Firebrick Co.		25.23	21.92	7.92	370	38.83	12	1.25	7.22	12	26.19	20.23	12	9.83	7.25	12	17.74	14.92	11	1,910	15	2,570	Cone 4 to cone 13	28	2,939	
26	Plibrico Jointless Firebrick Co.	Very good plasticity	25.58	24.02	8.74	320	42.65	13	1.04	7.54	13	24.87	20.00	13	9.50	7.17	13	18.24	15.91	11	1,910	15	2,570	Cone 5 to cone 15	28	2,939	Grayish buff
26	Plibrico Jointless Firebrick Co.	Good plasticity	24.92	19.82	7.09	420	35.00	11	1.47	6.90	11	27.50	20.45	11	10.16	7.33	11	17.25	14.42	11	1,910	15	2,570	Cone 3 to cone 11	28	2,939	Grayish buff
37	Morgan and Horton Clay Co.	Good plasticity	18.52	15.75	5.55	380	27.90	9	1.33	3.11	7	23.50	23.50	7	7.56	7.56	7	13.11	13.11	5	5,050	16	2,642	Cone 5 to cone 11	30	3,002	Gray
22	Hecla Property	Fair plasticity	26.23	14.20	5.20	360	12.60	11	1.48	5.99	7	23.69	23.69	7	8.62	8.62	7	13.82	13.82	7	3,668	9	2,282	Cone 1 to cone 9	20	2,768	Dark buff
	Average of samples of entire bed		22.24	15.30	5.43	430	33.32	13	1.65	7.78	10	23.68	21.99	10	8.58	7.91	10	13.97	13.29	7	4,327	14	2,534	Cone 4 to cone 14	28	2,939	

Geological Survey of Ohio. Fourth Series, Bulletin 36.

Kittanning clay is an asset of value. Near the head of Buckhorn Hollow the Lawrence clay appears locally, but it is thin and decidedly siliceous. The impoverishment of the clays is also evident on the headwaters of Pine Creek, southeast of Moulton, on Painters Creek, and on Nigger Creek. Aside from the Dean field, Decatur Township has no large body of Lawrence clay.

East of Olive Furnace in the southeastern part of Washington Township, the Lawrence clay again appears in local areas and with good properties. The following record taken in the southeastern part of Section 35, or along the road that leads from Olive Station to Indian Creek, shows the stratigraphic features in this locality:

Section No. 206	Ft.	In.
Shale, gray, siliceous	12	0
Coal blossom, *Lower Kittanning*	2	0
Clay, plastic, light, fair, *Lower Kittanning*	4	0
Clay, shale, upper part siliceous	3	0
Coal blossom, *Lawrence*		6
Clay, plastic, light, good, *Lawrence*	5	6
Sandstone, clay bonded	5	0
Shale and covered	6	0
Limestone, good, *Vanport*	5	0

This body of Lawrence clay appears to be small, being confined to the headwaters of Olive Creek. The quality of the material, however, is very good as it is a smooth plastic clay of high purity. On the ridges north of Olive Furnace and on those south of the headwaters of Brushy Fork, no clays of value are present in the Vanport-Lower Kittanning interval. They also show lack of development on the headwaters of Brady Creek. The southern part of Washington Township is lacking in the kind of deposits necessary for successful clay enterprises.

CHAPTER VI

UTILIZATION AND POSSIBILITIES OF THE LAWRENCE CLAY

INTRODUCTION

The Lawrence clay has a wide application for ceramic products because of its composition, which is close to the center of the field of general utility, and of its physical properties, which are well developed and beneficially balanced. Only small adjustments from the proportions 57.50 per cent SiO_2, 25.40 per cent Al_2O_3, and 4.60 per cent RO bases, which are the average amounts of these components in the Lawrence clay as mined, fit the material for use in many kinds of ware ranging from face brick to high grade pottery. The utilization and possibilities of the Lawrence clay are considered more specifically.

TERRA COTTA

The Lawrence clay, mined near Pine Grove Furnace and shipped by boat to Cincinnati, appears to have been used at that place for the manufacture of terra cotta as early as 1859. Trial kilns of such ware were also burned in 1908 by the Orchard Knob Brick Company at its plant which was located on the Detroit, Toledo, and Ironton Railroad about one mile north of Ironton. However, the true merits of the Lawrence clay for this purpose were not recognized until recently when two of the leading firms in the United States began using it as the basis for their products. The Lawrence clay is ideal for terra cotta as it has excellent drying and burning properties and at maturity develops a clean buff color. The composition is also satisfactory. The average content of silica in the natural clay is 56.52 per cent, alumina 25.42 per cent, and fluxing bases 4.66 per cent, thus approximating closely the standard composition for such ware. This clay, with its long burning range, reaches its best maturity at cone 7. Further, the character of the deposit should not be overlooked. This constancy of the Lawrence clay in both texture and composition over the three fields assures uniformity of conditions in factory practice throughout the years of utilization.

The clays commonly used in the production of terra cotta are buff burning as a body of this type is cheap, as it takes a glaze well, and as its color is easily hidden by the glaze coating. The physical and chemical qualities demanded in such a clay by the manufacturers of architectural terra cotta are not only many, but severe, because the ware is made in a great variety of sizes and shapes. Some of these pieces are large in dimensions and some are complex in design. On this account the terra cotta body should have excellent drying and burning qualities. The clay should complete its drying shrinkage fairly early as then the strains produced in drying may be absorbed while the clay is still somewhat mobile. Further, its burning shrinkage should be low and uniform to assure good shape to the product. As the custom, which is presumably necessary, is to use a considerable proportion of grog in the body, the bonding clay must have sufficient plastic and binding powers to give workability to the mass and fair dry strength to the body. The burning range of the clay should be long in order to secure a high yield of first class ware from the kiln.

Terra cotta is made by a one-fire process in both glazed and unglazed finishes and in a great variety of colors and textures. Any component that damages the surface of the ware is undesirable. Hence clays for such work should be low in crystals of pyrite and gypsum, in soluble salts of the sulphate and bicarbonate types, in concretions either large or small of calcareous and ferruginous matter, and in incidental impurities from the roof and floor of the mines. In order that the pieces of terra cotta shall have good resistance to cracking in cooling and to spalling in service, the free silica content of the clay must not be excessive. In addition to these requirements, the grogged body should mature to a fairly dense texture at what may be termed moderate ceramic practice, which is about cone 2 for fritted glazes and close to cone 7 for Bristol glazes. Low absorption is now demanded by the trade in order that the ware may withstand the strains produced by freezing and thawing, by sudden heating or cooling, by moisture, and by building load. The importance of using only such clays as may be relied upon to fulfill best all these requirements, without even occasional failures, may be appreciated when it is considered that terra cotta is almost always made to order in new sizes and in special shapes for each job and for delivery according to a definite schedule. Clays suitable for terra cotta bodies are therefore not common and with few exceptions they require careful selection for satisfactory results. The Lawrence clay of southern Ohio meets these rigid specifications exceptionally well as is demonstrated by its service in the industry.

BOND CLAYS

GENERAL PURPOSES

Bond clays are used in a variety of fields, but at last analysis for the same purpose—namely, the bonding into a unit and the giving of strength to body mixes of various sorts. Bond clays are used to add strength and workability to molding sands, sagger bodies, plastic refractories, high temperature cements, and fired refractories. Good bond clay should be highly refractory and should have low drying and firing shrinkages, a long burning range, and very particularly a high green strength. Excellent grade bond clays are required for plastic and glass house refractories. The clays used in glass house refractories are usually prepared clays. They are highly weathered and are generally washed to rid them of incidental minerals, particularly the iron-bearing minerals. Weathering ordinarily adds considerable strength and workability to bond clays.

An examination of the tables of physical tests shows that some of the Lawrence clays possess the above-mentioned properties to a very marked degree. An important item which makes these clays particularly well suited for bond clays is their exceptional uniformity. The Lawrence clays, as they are extremely fine grained, slake readily, and are strong and highly plastic, are peculiarly well suited for use in high temperature cements, for laying up first quality fire brick, and when mixed with grog or ganister for making a plastic refractory of exceptional strength and low shrinkage. A desirable property of a bond clay is that it retain its strength on repeated heatings. Some of the best of the Lawrence clays possess this essential.

The Lawrence clays are at present being used commercially as a bond for molding sands, plastic refractories, saggers, crucibles, and fired refractories. Few fire clays have more of the desirable bond clay properties and have them so well developed as, for example, samples Nos. 31b, 17, and 32. Sample No. 32, for instance, is highly refractory, cone 30, has an exceptionally low drying shrinkage, 2.36 per cent, and firing shrinkage, 7.6 per cent, and has a high dry strength, 510 pounds per square inch. Its fired modulus of 3,296 pounds is not high but ample. Samples Nos. 17 and 31b are remarkable for their fired strength, over 5,000 pounds, are refractory, cone 29, and have very low shrinkages, but slake more slowly than sample No. 32. Any clay having a dry strength in excess of 400 pounds may be classed as a good bond clay, especially if its shrinkage is low, its P. C. E. in excess of cone 29, and its burning range long.

FOUNDRY USES

The Lawrence clay has its widest use as a bond for molding sands. It is employed in foundries throughout the central and the eastern states and also in southern Canada. Shipments are made by one company alone to more than 80 foundries. The use of fire clay in molding sand is largely for the preparation of synthetic sands for both iron and steel foundries. Sufficient clay is mixed with "sharp" (more or less free from clay) quartz sand to form a plastic refractory mixture, suitable for molding purposes. A properly mixed sand requires that each individual grain be covered with a thin coating of clay. To accomplish this with a minimum of time and energy requires that the clay be plastic and workable and be ground to a fairly fine mesh size. The clay should slake rather rapidly to a smooth slip. It should adhere to the sand particles tenaciously and at the same time should have sufficient cohesion in itself to give a high strength. The clay need not be extremely refractory, although it must not vitrify at the temperature at which the metal is poured. A clay with a fusion point of 2,900°F. is usually sufficiently refractory.

Since it is advantageous to reuse the sand as often as possible, a sand which will retain its bonding properties upon repeated use in the mold is highly desirable. Fire clay is now employed to a considerable extent, for "reviving" or "reclaiming" naturally bonded "spent" sands. This process consists in mixing a small quantity of very fine ground clay, 100 mesh or finer, with the sand in order to replace the bond that had been lost through the foundry practice. A sand should not be of such density as to interfere unduly with the proper venting of a mold. This means that so much clay must not be used as to close the pores to the escape of gases when the metal is poured. The availability and uniformity of the Lawrence clays, coupled with their physical properties which render them particularly suited as bonds for molding sands, account for the wide use of these clays in the foundry field. Clays Nos. 37, 31, 12, 10, and 17 are now being used in this work. It is doubtful if there is another clay as widely used by the foundries of the country as No. 37.

A so-called foundry clay is usually a moderately siliceous, weathered bond clay. It is used to patch and daub cupolas and malleable furnaces. The shrinkage should be low in order that it will not tear away from the underlying brick. It should become dense at the service temperature so as to resist slag. The less refractory of the Lawrence clays and especially those with low shrinkage and a long burning range are suited for this purpose.

SAGGERS

The Lawrence clay was introduced over thirty years ago as an ingredient in sagger bodies in the East Liverpool district and has been used increasingly during the past few years by the potters of Ohio. In the manufacture of saggers a portion of the material employed is calcined clay, commonly broken saggers, and the rest is raw clay. The reason for using the calcine is to reduce the excessive shrinkage which is usually characteristic of the raw plastic clays, and to open up the body so it will better resist thermal shock. Saggers, like terra cotta, are seldom made from one clay in addition to the grog used. A single bond clay seldom possesses all the properties desired in a sagger body, so blended clays have come to be used almost entirely. When such bodies are fired they produce a strong sagger (box) which is used to hold the finer ceramic products, to protect them from the impingement of the flame, and to keep the gases of combustion from coming in contact with the ware. For such work a clay is required which has good plasticity, low shrinkage, high strength, and fair refractoriness. Sagger clays should not vitrify excessively at the range over which they are to be used, which is not usually over cone 9 or 11. A clay which will retain its strength and not become increasingly susceptible to heat shock on repeated heatings is highly desirable.

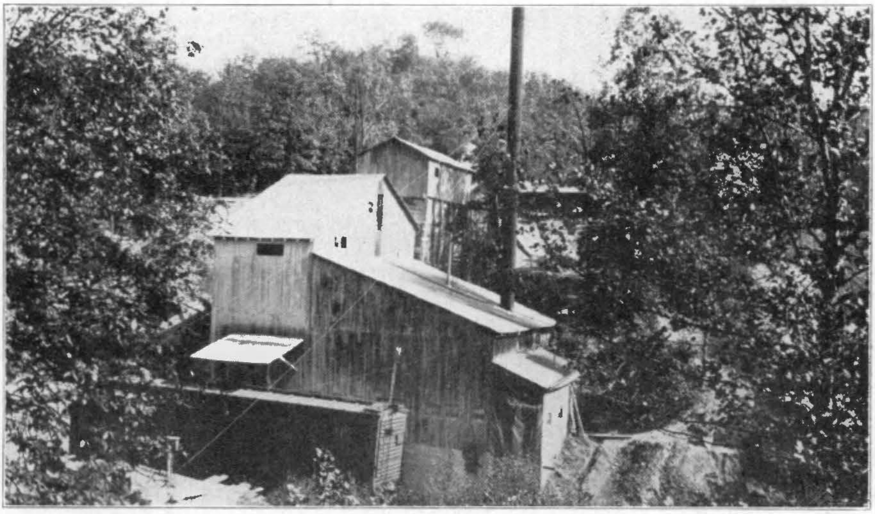
Several of the clays of the Lawrence district are well suited for saggers because they have all the necessary fired requirements, are easily worked, and are strong in the green state. Most of these clays have their highest strength over the range at which saggers are ordinarily used. Many of the potteries in the Zanesville and several of those in the East Liverpool district are using and approve Lawrence clay as an ingredient in their sagger bodies. Clays from sections Nos. 10, 15, 25, 32, 26, 37, and 36 are now being supplied to the potteries as a raw ingredient for saggers. If weathered and washed they would probably be even more widely marketed.

PLASTIC REFRACTORIES

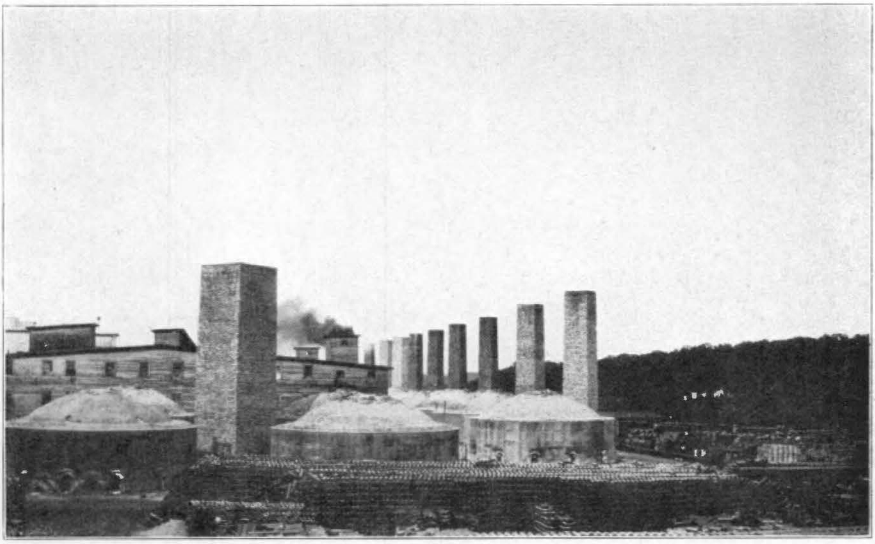
Plastic refractories, sometimes referred to as ramming mixes, are becoming more popular as their quality is improved. Formerly very inferior materials were used for this type of lining, but recently the most refractory nonplastics are being combined with high grade bond clays to produce a body in some cases more heat resistant than the best fire clay refractories. For patching, for packing around burners, and for substituting for costly special shapes, these high grade plastic refractories are being used extensively. Prepared sagger mixes are now supplied to the potteries by several companies. Due to their uniformity and high quality, these plastics are giving improved sagger life at a decreased cost to the plant. The properties particularly desired in clays used to bond the nonplastic in this type of refractory are low drying and firing shrinkage, reasonable strength, and high refractoriness. A clay which will close up early and still not vitrify under prolonged service is ideal. Clays Nos. 26a, 26b, and 26c from the Firebrick field are marketed for this purpose. Sample No. 32 also would appear to be very satisfactory.

FIRE CLAY MORTARS AND HIGH TEMPERATURE CEMENTS

Fire clay mortars and high temperature cements are used to bond fired refractories into a unit structure. Such mortars should be easily



A.—Clay mill of the Ceramic Clay Company, Pedro. (Photo by C. E. Bales.)



B.—Sewer pipe works of Cambria Clay Products Company, Black Fork. (Photo by C. E. Bales.)

workable if the ware is laid with a buttered joint, and the clay should form a smooth slurry if the brick are dipped and hammered into place, as all high temperature masonry should be constructed.

Finely ground plastic fire clay was used formerly almost exclusively as a mortar for laying up fire brick, but, due to high shrinkage and to a very poor low temperature set, it has been largely supplanted by the prepared mortars commonly referred to as "high temperature cements." These cements are usually composed of a fire clay base as the plastic and refractory ingredient, coupled with a cold set ingredient which acts as a mild flux when the cements are exposed to a high temperature. Brick structures laid up with the best of these cements have remarkable strength at all temperatures. The cement gives a joint impervious to slags and to corrosive gases. The Lawrence clays offer promise in this field and are so used. They are sufficiently refractory, they readily slake down to a smooth, strong bonding paste, and in some cases they have a remarkably low shrinkage, both green and fired.

REFRACTORIES

The refractory industries require clays which are capable of withstanding a high degree of heat. Because of a wide range of service conditions which they must meet, refractories are usually divided into three main classes—high, intermediate, and low heat duty—depending upon the utilization for which they are intended. High heat duty refractories contain a large amount of so-called "nonplastic" which is commonly flint clay or a mixture of flint clay and fire clay grog. The plastic clay employed is usually small in amount, as it is used only as a bond for the more refractory flint clays. It must, therefore, be of very high grade. On the other hand, low heat duty brick, sometimes called "back up" brick, are made entirely of plastic clays. Intermediate heat duty brick vary widely in plastic clay content, as they usually contain a considerable amount of nonplastic. Low heat duty refractories are ordinarily made from clays which are capable of withstanding temperatures ranging from cones 18 to 26. Intermediate heat duty brick are manufactured from plastic clays ranging in P. C. E. value from cone 26 to cone 31, or they are composed of flint clays bonded with such plastic materials. In the production of high heat duty brick the bond clay should have a P. C. E. value in excess of cone 30. In many cases, however, where exceptionally refractory nonplastics are employed, a plastic clay with a P. C. E. value of cone 28 or 29 may be satisfactory. The very best prepared bond clays have a P. C. E. value of cone 32-33.

In a good refractory clay the total percentage of fluxes, such as ferric oxide, ferrous oxide, lime, magnesia, potassium oxide, and sodium oxide, is small. This impoverishment in bases is necessary as these ingredients largely influence the softening point of the clay. Good refractory clays contain from 4 to 7 per cent of fluxes. The alumina-silica ratio bears an important relation to refractoriness, as the higher the alumina the more resistant the clay. The Lawrence clays of the southern Ohio field are now used commercially by several refractories manufacturers as a bond in both high and intermediate heat duty wares.

SEWER PIPE AND ALLIED PRODUCTS

A sewer pipe body must be fairly well vitrified and still remain tough. Service specifications are definite and require that sewer pipe resist a high crushing load, that it have a smooth glaze, and that it be impervious to water under a given pressure. A body vitrification which will give an absorption of from 4 to 6 per cent seems to be ideal. The clays used in this industry should therefore be of such a nature that they will produce this type of body at the proper temperature. They must be sufficiently plastic to extrude from a pipe press, must dry and burn without warping or cracking, and must have good dry strength to facilitate setting the pipe in the kiln for firing. A long firing range over a high fired strength range is highly desirable. The composition of the body must be acidic enough to take a good salt glaze. Schurecht states that a silica content of around 60 per cent, based on fired clay, is ideal for producing a good salt glaze. This figure will vary with the physical condition of the clay, the fluxes present, and the firing temperature. Nearly all sewer pipe plants make flue liners and wall coping, which require the same type of clay and are made in the same way, except that the flue liners are not glazed and are usually fired to a lower temperature in order to produce a more open body less susceptible to thermal shock.

Several of the Lawrence County clays have properties which indicate that they would make good sewer pipe. They are very plastic, strong in both the green and dried state, and become dense on firing to the proper temperature. Most of these clays also take a salt glaze very well. Sample No. 32 has been used successfully for this purpose since 1914. It is a little more refractory than it need be for the purpose, but gives a fine ware when fired to cone 9. Other deposits in this field appear to give just as much promise and several clays, having a higher fired strength, Nos. 37, 29, and 20, might be even more desirable, although the total shrinkage in each case is in excess of that in sample No. 32.

SANITARY AND DECORATIVE TILING

As the trade is being attracted more and more by the softer natural shades of tiling than by the old line of bright, shiny glazed ware, the native clays that give pleasing colors are now being used to a much greater extent than formerly. Tile are made by both the dry press and the stiff mud process, but largely by the former. To achieve satisfactory results the clay should have uniformity of composition, good green strength, moderate shrinkage, long burning range, dense body structure, and a clear, pleasing color. The Lawrence clay meets all these requirements very well and is now being used for tile manufacture by several of the large firms in the central part of the United States.

QUARRY AND PROMENADE TILE

Quarry and promenade tile, the square and diamond shape ware designed by the English for paving courts, promenades, terraces, porches, halls, etc., are again in favor. Their field has also been extended as to color, size, shape, and use. Such ware is now replacing floor and wall tile for many purposes. Quarry or promenade tile are made from natural clays singly or from simple mixtures of such substances. They are burned to hard maturity in order to withstand intensive weathering agencies and severe usage. The Lawrence clay of southern Ohio is well fitted for the manufacture of quarry tile, either alone or with the addition of other clays. Along with other desirable qualities, it develops at moderate maturity a durable body of a warm buff color and at higher temperatures a dense vitrified body of a bluestone gray color, usually exhibiting some shade of buff. The more siliceous part of the Lawrence member with the addition of manganese dioxide produces bodies with attractive gray tones. Iron-mottled shades, varying in range and intensity, are produced by mixtures of Lawrence and Huckleberry clays. With Pink Eye clay it yields colors ranging from light pink to nearly black, depending on the quantity of pigment present and on the state of reduction. Further, the buff tones of the Lawrence clay may be made warmer and more golden by the addition of a plastic clay from the horizon of the Lower Mercer limestone.

FACE BRICK

The face brick industry requires a clay which will produce a strong product and also have a pleasing appearance. Formerly face brick could be divided into buffs, grays, and reds. Further, mechanical textures were then popular. At present no definite or set ruling on what a good face brick is or what properties such ware must have is effective, as practically every architect requires a different color, texture, shape, or size. The general feeling among architects at present is that the brick unit must interpret the type of architecture into which it is built, rather than have any preconceived quality as an individual unit. In general, face brick should be uniform in texture and size, but they may vary considerably in color. At present blending or mingling of tones is most acceptable to the trade. The clay should burn dense at a relatively low temperature and should show no warping or bulging. However, one or all of these requirements, with the possible exception that the brick must be sufficiently strong to carry the load required, have been set aside by architects and builders.

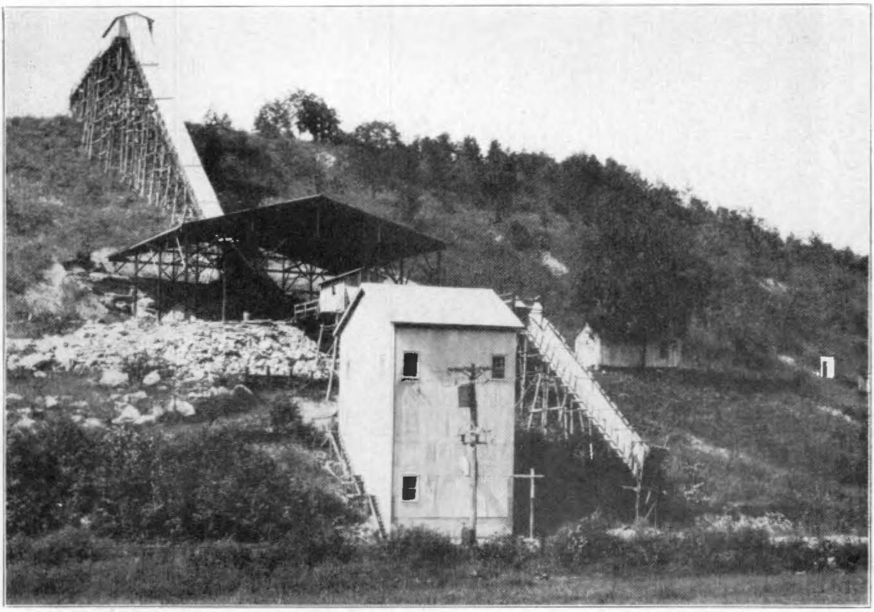
The clays from the Lawrence district are suitable for use in the face brick industry. The ware produced may be classed as to color as buff, light gray, bluestone gray, and iron mottled, and as to texture as smooth, mat, and rough. Above cone 10 all these clays fire to a good gray.

SALT-GLAZED AND ENAMELED BRICK

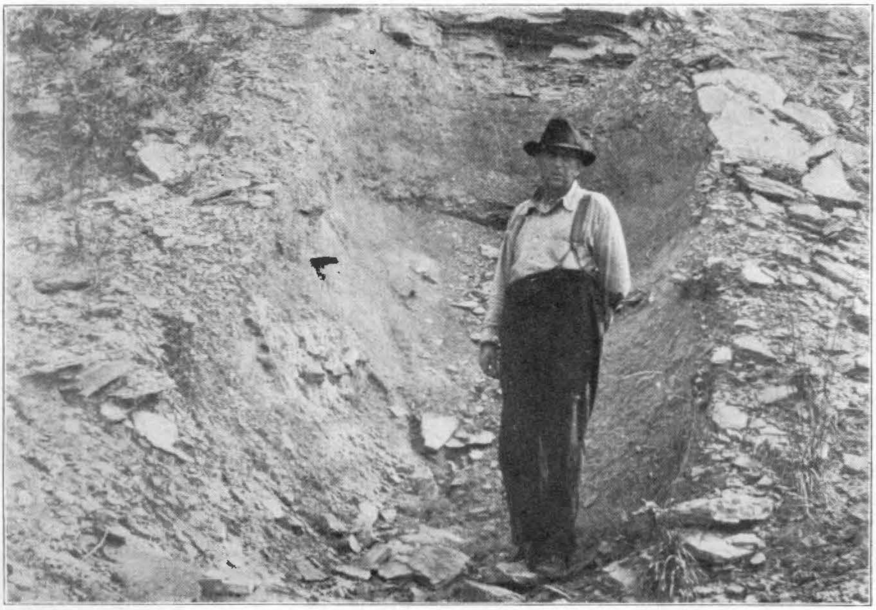
Out of the confusion of a great variety of building brick demanded by the architects and builders there has emerged one very definite trend, which is an increasing demand for glazed brick. These glazes are affixed either as a prepared glaze before the ware is set in the kiln or as a coating developed in the kiln by adding salt at the fire boxes. In the latter case, the clay should have the necessary chemical and physical qualities to take a good vapor glaze and also to develop a pleasing color. In the case of applied glazes and enamels, the clay should unite firmly with the enamel or glaze and should hold it without shivering, crawling, or crazing. Brick of this character should be true and uniform in size and shape and should be without distortions of bulging, dishing, or warping. Clays low in iron and fairly high in silica are the most satisfactory. All the clays from the Lawrence district take a good salt glaze and several of them show a very attractive yellow or buff body under the surface coating. The tests indicate also that enameled or terra cotta brick may be successfully produced.

YELLOWWARE AND RELATED PRODUCTS

Yellowware and its related forms, Majolica and Rockingham, have been a part of the regular ceramic output of Ohio for over 70 years. The potters began, in 1799, with an earthen body prepared from alluvium found along the streams, soon turned to the denser structure of the stoneware type produced from coal formation clays, and then, in 1840, introduced yellowware made by more improved methods than the stoneware, but with little change in the body components. Cincinnati for years drew a part of its supply of yellowware clay from Lawrence County. Some of this appears to have been Mercer clay from near Newcastle on Osburn Run, but most of it was Lawrence clay from the ridges northeast of Pine Grove Furnace. As the Lawrence is nearly an ideal yellowware clay, it needs no further discussion here.



A.—Clay mill of Lawrence Clay Company, Culbertson. (Photo by C. E. Bales.)



B.—Exposure of Lawrence clay on Hecla property, Hog Run. (Photo by C. E. Bales.)

STONEWARE

Lawrence clay for many years was shipped to Cincinnati for the manufacture of stoneware at the Findlay Street, Vine Street, and Hamilton Road potteries. Most of the supply came from the vicinity of Pine Grove Furnace. Stoneware is usually made from semi-refractory clays and is glazed with a prepared glaze or with a slip clay. Stoneware clays must be dense burning at comparatively low temperatures and must have sufficient plasticity and toughness to permit their being worked on a potter's wheel. Other requirements are good strength, rather long firing range, low shrinkage, and sufficient refractoriness to withstand a fire which will produce a dense hard body without warping. Stoneware is commonly made from a mixture of clays in order that the right properties may be attained in the body. A few of the Lawrence clays appear to have the necessary qualifications for this industrial application, in that they are very plastic, have a high strength, and fire over a long range to a hard, dense body. The more siliceous clays, such as are found near the bottom of the Lawrence stratum, are best suited for stoneware as they work well, shrink less on drying, bluestone readily, and can be glazed successfully. The Lawrence clay from the Dean State Forest property in Long Hollow is one which seems to be especially suited for such use. Others, when only the lower part of the bed is utilized, also give promise of satisfactory results.

SANITARY WARE

The composition of the Lawrence clay is such that with washing and with only small changes it is readily adaptable for the manufacture of sanitary ware. Its high plasticity would probably make necessary the addition of little if any ball clay; its bases, averaging about 4.6 per cent in the raw clay, need augmenting with only small quantities of feldspar; and its content of fine-grained silica, close to 27 per cent, naturally lessens decidedly the requirement of potter's flint. The qualities that recommend the Lawrence clay for this purpose are uniformity of composition, ratio of bases to alumina to silica, excellent plasticity, long burning range, ability to hold a glaze, and good maturity at glaze temperatures. Tests made so far indicate that this clay has sufficient plasticity and suspensibility to cast either small or large pieces. The one objection to the material, that of the buff color at maturity, is not so vitally serious where opaque white or colored glazes are employed. The Lawrence clay of southern Ohio certainly has sufficient merit to warrant thorough factory testing for sanitary ware.

TABLEWARE

In Ohio native clays have been used to some extent for over 130 years in the fabrication of ware for the dining-room and kitchen. The substitution of kaolin for the coal formation clays gave the whiteness of color that for many years the trade desired in tableware. With the present shift in taste to colored bodies, our native clays for some shades of ware may be used for a large part of the clay ingredient of the batch. A very attractive line of tableware in which coal formation clays form a part of the body mixture has recently been placed on the market. The ware is of the ivory type. The composition of the Lawrence clay is not far different from that of the average whiteware body. The components in each are in close agreement as to kind and quality, although some differences are apparent. The Lawrence clays tend to bluestone at the temperature at which semi-porcelain is ordinarily fired, cone 9, but they will give little or no trouble from discoloration if the temperature of maturity is reduced to cone 7. If such adjustments are made, a good color can be obtained with as much as 30 or 40 per cent of Lawrence clay.

The plasticity of this clay is such as to require little or no ball clay in the batch, the content of fine-grained free silica substitutes for potter's flint, and the basic fluxes, K_2O, Na_2O, CaO, and MgO, held in the sericite scales, are effective in promoting vitrification. The small quantity of iron oxide shot and pyrite crystals in the Lawrence clay is objectionable as such minerals produce specks in the ware. Weathering will remove the pyrite and thorough washing will remove the concretionary matter. The Lawrence clay has all the desirable working, drying, and burning qualities and deserves careful consideration for use in the manufacture of tableware and related products.

COOKING AND SERVING WARES

Cooking and serving wares are usually made from plastic refractory clays. Such ware is dense and strong and is capable of withstanding sudden temperature changes without rupture. Clay used in this type of ware should be plastic, so that it can be worked on a potter's wheel, should be strong enough in the green state to withstand the rough handling incident to drying and setting, and should be of such a nature that it can be burned to a very low porosity at the desired temperature. Usually this ware is covered with either a colorless glaze or a brown Albany slip clay, which adds to the appearance of the product and also to the ability of the dishes to hold liquids. Several of the Lawrence clays could very easily be used in making this type of ware by virtue of their plastic and refractory properties and of their ability to mature to a low porosity or high density at a relatively low temperature.

CONDUITS

The physical and chemical properties of the Lawrence clay would seem to recommend its employment for the manufacture of conduits with simple or with complex web structure. For this purpose the more siliceous part, or the lower two-thirds of the bed, is best fitted. Such clay contains the free silica necessary to correct shrinkage and warpage, to vitrify the body to the required density, and to produce the acidity indispensable in salt glazing. Further, in some locations the material is very free from crystals of pyrite and gypsum and shot of the iron minerals which are deleterious, causing such defects as pimples, blisters, hair cracks, and pits in the face of the ware. The matured body has good strength and, when salt glazed, a pleasing buff color. The region offers not only the clay for the production of conduits, but also such advantages as cheap fuel, satisfactory labor, and diversified shipment by railroad and river.

FIREPROOFING

The Lawrence member of southern Ohio has been utilized to some extent since 1808 for the manufacture of fireproofing. The chemical composition and the working, drying, and burning properties of the clay are very satisfactory for such work. The only undesirable quality of these clays is the rather high maturing temperature. Some of them, however, develop a satisfactory body at cone 4 to cone 6. The best results are obtained when the full thickness of the bed is mined. The additional silica provided by the siliceous clay in the basal portion of the deposits tends to decrease body defects of fabrication and treatment and to lower the maturing temperature with a saving of fuel. The Lawrence clay is well fitted for the production of fireproofing and related wares.

CRUCIBLES

The Lawrence member of southern Ohio has contributed bonding clay for the crucible industry for many years. Only carefully selected cream clay is employed. It is then weathered for several months to remove the oxidized pyrite and the other soluble matter and to develop its full plasticity and strength. In the regular procedure the soft mellow clay is pugged to a stiff mud consistency, machined into blocks, and stored in enclosed bins for protracted aging. Thus processed, the clay is smooth and very plastic and has exceptional bonding power, moderate shrinkage, and high green strength. These qualities combined with its refractoriness make the Lawrence one of the leading crucible clays of the United States.

CHAPTER VII

METHODS OF TESTING

SAMPLING

Most of the samples were taken along the outcrop of the Lawrence member, where, during the days of the charcoal furnaces, the quarrying of the Vanport limestone or the stripping of the Ferriferous ore had penetrated the rocks to a depth sufficient to expose a face of clay with only slight alteration by weathering agencies. Preparatory to sampling, the clay bed was further exposed by trenching to such a depth that the strata showed uniformity of structure and the clay appeared natural and representative. The face of the clay was then reduced to a uniform slope, either vertical or at a high angle. From the Lawrence clay thus exposed a sample averaging about 200 pounds in weight was taken by uniformly channelling the bed from top to bottom. Also, samples of each kind of clay in the deposits, such as flint, "cream," and siliceous, were taken in each field. These procedures were followed by measuring a detailed section of all the exposed strata with special attention to the layers of clay sampled. A few samples were taken in drift or open cut mines, which exposures thus simplified the work by removing the preliminary steps. On the whole, the samples are considered representative of the Lawrence clay in the area under consideration and give a close approximation to the merits of the material.

GRINDING

The grinding and testing of these clays were done at the Clay Products Plant of The Ohio State University Engineering Experiment Station, located at Roseville, Ohio. Following a preliminary air drying, the clays were first given a primary crushing in a jaw crusher which reduced the size of all lumps to one-half inch or less. After this they were sent through a roll crusher and then screened until the entire samples passed a 20-mesh sieve. At this stage the clay was ready to be made up into the various test pieces. By the process of quartering, samples were taken for chemical analyses, which were run by the Geological Survey of Ohio.

PREPARATION OF TEST SPECIMENS

All of the specimens were prepared by pugging the material with water to a stiff mud consistency. The tempered clay was then fed into a small brick machine and extruded through a die 1 inch square. One hundred clay bars 2 inches long were made to be used in determining the firing range of the clay and its suitability for salt glazing. Fifty bars 6 inches long were cut to be used in determining the modulus of rupture, both dry and fired, and also to give the linear shrinkage at various temperatures. Twelve bars were made 1 inch long, thus giving a cube 1 inch on a side for the slaking test. In addition to these bars, standard test cones were pressed for the determination of the pyrometric cone equivalent or P. C. E. of each clay.

TESTS

This investigation includes all the tests which were thought necessary to determine the possible utility of each of these clays. In each case the specifications and test methods of the American Society for Testing Materials were closely adhered to, in order that comparative results might be obtained.

WORKABILITY

Workability is by far the most important property of clay, because when this is lacking it is of comparatively little value for the manufacture of most clay products. This property is determined by "feel" and by the effect of die extrusion upon the clay column. The coal measure clays are usually workable but not always highly plastic. They vary widely in plasticity from formation to formation and in the same rock section from top to bottom of the deposit. Plastic clays when thoroughly mixed with the correct proportion of water can usually be worked and formed into any desired shape, and will maintain this shape through the drying period, due to the fact that they bond into strong, dense bodies. On the other hand, clays of low plasticity are more difficult to knead and shape and do not generally form such a dense body. Workability is not necessarily directly proportional to plasticity: many clays are too plastic to work well in the stiff mud process. Such clays may, however, be valuable in other processes such as in slip casting. Ball clays are of this type. All the clays studied in this investigation had good workability, as was determined both by the "feel" and by their actions in the auger machine.

WATER OF PLASTICITY

The water of plasticity is the amount of water necessary to add to a dry clay in order to obtain the "best moldable" condition. This term should not be confused with "pug water" which is the water required to bring a clay as received to the point of maximum workability. In general, the more plastic the clay the more water will be necessary to place it in the most favorable condition for molding and the greater will be the drying shrinkage.

With the clay in its most workable state, 100 briquettes approximately 1 by 1 by 2 inches were made by extrusion from the die, the column being cut into the required lengths with a spatula. These briquettes were accurately weighed to 0.01 gram. Their volumes also were accurately determined in an overflow volumeter by using kerosene oil. All of the briquettes were then dried to constant weight at 110° C., cooled to room temperature in a desiccator, and again weighed. Water of plasticity was calculated, using the following formula:

$$\text{Per cent water of plasticity} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$$

DRYING SHRINKAGE

Clays of high drying shrinkage and good mechanical strength may dry without cracking, but are usually susceptible to warping. On the other hand, if the mechanical strength is poor, they may warp and also crack in drying, due to stresses set up while shrinking. Clays of moderate plasticity with good molding properties and with a low drying shrinkage are most desirable for the manufacture of clay products, because the ware will hold its shape better during the drying and because the losses due to cracking and warping will be reduced to a minimum.

After weighing, the cool bars were placed in kerosene oil and soaked for 24 hours, when the volumes were again taken in oil, being careful that each piece was wiped dry of any oil on the surface before it was placed in the volumeter. After the dry volume of each briquette had been obtained, the drying shrinkage was calculated from the following formula:

$$\text{Per cent drying shrinkage} = \frac{\text{wet volume} - \text{dry volume}}{\text{dry volume}} \times 100$$

After determining the volume shrinkage the linear shrinkage was obtained, both by formula and by linear measurement. In obtaining the values from the formula the previously calculated volume shrinkage was substituted in the following equation:

$$\text{Per cent linear shrinkage} = 100 \times \left[\sqrt[3]{1 + \frac{b}{100}} - 1 \right]$$

A check on this value was obtained by measuring directly with a steel scale the difference in length of a shrinkage line which was marked on the bar while in a plastic stage. The results of these two methods checked very closely.

SLAKING

When a lump of raw clay is immersed in water it falls to pieces or slakes, the process ceasing only when the clay has broken down to a fine powdery mass. The time required varies from a few minutes in the case of soft, porous clays to several days for tough, strongly bonded, plastic clays.

The slaking property is one of some practical importance. Clays which slake easily temper more rapidly, or if the material is to be washed, it disintegrates more rapidly in the washer. It is also a rough test for distinguishing between clays of high and those of low strengths.

The slaking test, as followed in this investigation, was run on 1-inch cubical blocks of pure clay. These samples were cut from the clay column, air dried, and then dried to a constant weight in a drier at 110° C. After this process they were placed in a desiccator and allowed to cool. When cooled the blocks were placed on a 2-mesh screen and inserted in a water bath to a depth of about 2 inches. The time required in minutes for the whole test piece to slake and settle through the screen is the figure reported. A fire clay slaking under 10 minutes is considered a rapid slaking clay, and one requiring over 30 minutes is slow slaking under the test conditions.

MODULUS OF RUPTURE

The transverse breaking strength, otherwise known as the modulus of rupture, is almost universally used for general strength testing. This gives more uniform results than either the crushing or tensile tests and can be conducted more easily than the former. Strength determinations readily indicate over-firing when it is caused by the development of a vesicular (blebed or bloated) structure.

The mechanical strength of clay or clay bodies in the dry or burned condition is a very important property, as it not only influences the usefulness of the product, but also the convenience of manufacture. Weak objects are exceedingly difficult to handle and fire, due to their fragile nature.

In this investigation the strength tests were run on both dried and fired samples of each clay. The tests were run at the Roseville Station on the cross breaking machine,[1] which allows a 5-inch span to be loaded

---

[1] MacGee, A. E., Journal of American Ceramic Society, Vol. X, p. 571, 1927.

by small increments at the center of the span. After determining the load necessary to rupture the bar, the following formula was used to obtain the value of the modulus of rupture:

$$\text{Modulus of rupture} = \frac{3\,\text{WL}}{2\,\text{B}\,\text{D}^2}$$

W equals the load necessary to break the bar, L equals the length of the span, B equals the breadth, and D equals the depth of the bar.

FIRED PROPERTIES

When clays are subjected to a rising temperature a number of changes of a physical and chemical nature may take place. These include loss of volatile constituents, vitrification, and changes in volume, color, porosity, hardness, and specific gravity. Upon these factors depend to a large extent the value and utility of the clay.

BURNING RANGE AND FIRING RANGE

Two ranges which should be considered in maturing clay bodies are the burning range and the firing range. These terms, though commonly used interchangeably, should be distinguished, as each concerns a different phase of maturity. The burning range refers to that period in the maturing of clay products which extends from the temperature at which it becomes steel hard to the temperature at which it becomes worthless through structural weakness. The firing range covers the interval from the temperature at which it first develops the physical properties which are desirable in the ware to the temperature at which the properties are no longer suitable for the ware under consideration. For instance, in a dense, hard product the range will include the period of complete vitrification, whereas in a porous body, such as is necessary for flower pots and the like, the range will include the period just after a hard body has been produced, but before very much, if any, vitrification has taken place.

In the determination of the burning behavior, each of the clays was fired at several different temperatures ranging from cone 03 (1,994° F.) to cone 20 (2,786° F.). The firing was carried on in gas-fired kilns at a rate sufficiently slow to permit complete oxidation of the clay and to produce a good body at that particular temperature within the firing range of the clay. In order to determine the best firing range of the clay, determinations were made of porosity, absorption, shrinkage, and specific gravity.

To procure these data the following procedure was pursued: The fired pieces were drawn from the kiln and placed in a desiccator where they remained until they were sufficiently cool to be handled. They were then weighed to the same degree of accuracy as the plastic bodies, that is, 0.01 of a gram, and then they were placed in distilled water and boiled for two hours. After boiling, the pieces were wiped clean of the excess water on the surface and again weighed and the volumes taken in an overflow volumeter using water as the liquid. From this data the following properties were obtained.

POROSITY AND ABSORPTION

The degree of porosity in fired ceramic ware bears a very close relationship to strength, bulk density, permeability, thermal and electrical conductivity, and resistance to weathering, thermal shock, abrasion, erosion, slagging, and chemical attack by gases.

The porosity of a clay, which may be defined as the volume of the pore space between the clay particles, is expressed in percentages of the total volume of the clay, and depends on the shape and size of the particles making up the mass.

The porosity-temperature strength relation in the burning of a clay serves as an important criterion for determining the commercial use of the clay and indicates to what temperature the clay should be fired when used for particular wares. It is evident that a decrease in porosity shows the progress of hardening and vitrification in the material during firing. Clays showing a sharp drop in porosity, due to sudden fluxing action, vitrify rapidly, and, where a rise in the porosity curves quickly succeeds the drop in porosity, it indicates a short firing range. Porosity may be expressed in two ways:

(1) *Per cent porosity* or the weight of water absorbed by the open pores in terms of the exterior volume. It is calculated by the following formula:

$$\text{Per cent porosity} = \frac{\text{saturated fired weight} - \text{fired weight}}{\text{fired volume}} \times 100$$

(2) *Per cent absorption* or the weight of water absorbed by the open pores in terms of the dried weight. It is calculated by the following formula:

$$\text{Per cent absorption} = \frac{\text{saturated fired weight} - \text{fired weight}}{\text{fired weight}} \times 100$$

SPECIFIC GRAVITY

Specific gravity is the weight per unit volume expressed in terms of the density of water. It is of value in determining the weight of raw clay per unit volume, and also serves as an index of the process of vitrification taking place during firing. In this investigation the specific gravity was expressed in two ways:

(1) Apparent specific gravity. This value represents the ratio of the volume of the solid plus the volume of the closed pores to an equal volume of water.

(2) Bulk specific gravity. This represents the ratio of the entire volume of the material, including solids, closed pores, and open pores, to an equal volume of water.

Both the apparent and bulk specific gravity are affected by the following factors: (1) inversion of silica, (2) fusion, (3) chemical reaction, (4) crystallization, (5) porosity, (6) the formation of "blebs" on firing.

The following formulae are used in determining the specific gravities:

$$\text{Bulk specific gravity} = \frac{\text{fired weight}}{\text{fired volume}}$$

$$\text{Apparent specific gravity} = \frac{\text{fired weight}}{\text{fired volume} - (\text{sat. wt.} - \text{fired wt.})}$$

SALT GLAZING

Salt glazing is the process of coating a clay product with an impervious glaze by adding salt, NaCl, to the fuel in the fire box and by allowing the salt fumes and the gases of combustion to pass around the hot ware in the kiln. The Lawrence clays were submitted to this test to determine their suitability for taking such a glaze. In this investigation the procedure was as follows: The green clay bars were placed in a gas-fired, direct-fire kiln so that all of the faces except one were exposed to the gases of combustion. The kiln was then slowly heated to 2,150° F., at which temperature salt glazing was done. The dampers were closed nearly tight and the fire box closed except for a small opening which was left to admit the salt. Six handfuls of salt were then thrown into the fire box and the entire kiln was shut up for 4 minutes, after which the damper was opened and the fire started again, as during this period the temperature drops slightly. The furnace was again heated to 2,150° F. and the same procedure followed. This was done five times before the salt glazing was considered complete.

PYROMETRIC CONE EQUIVALENT (P. C. E.)

In ceramic work the common method employed to determine the fusion or softening point of a clay is that of forming the clay into a pyramidal piece, similar in shape and proportions to the standard pyrometric cones, then placing it under firing conditions with standard cones and noting the point of softening. The P. C. E. is (considered to have been) reached when the cone has bent over until the tip touches the base. The temperature at which clays soften shows a wide range. the P. C. E. being affected by the amount and chemical constitution of the fluxing impurities present, the texture, such as size of grain of refractory and non-refractory particles, the homogeneity of the mass, the conditions of the fire, whether oxidizing or reducing, and the mineral constitution of the clay.

Pyrometric cone equivalent (generally known as the P. C. E. value) determinations were made on all of the samples. The plastic clay as it came from the pug mill was pressed into cones in a 1-inch mold. These were thoroughly dried and then placed on a refractory plaque approximately 1½ inches in diameter with Standard Orton cones placed between the test clay cones. This plaque was then placed in the gas-fired furnace of the tangential burner type and fired at the rate prescribed by the American Society for Testing Materials. Triplicate tests were run in every instance.

CONVERSION TABLE[1]
CONES TO TEMPERATURES

Cone No.	When fired slowly, 20° C. per hour		When fired rapidly, 150° C. per hour	
	° C.	° F.	° C.	° F.
010	890	1,634	895	1,643
09	930	1,706	930	1,706
08	945	1,733	950	1,742
07	975	1,787	990	1,814
06	1,005	1,841	1,015	1,859
05	1,030	1,886	1,040	1,904
04	1,050	1,922	1,060	1,940
03	1,080	1,976	1,115	2,039
02	1,095	2,003	1,125	2,057
01	1,110	2,030	1,145	2,093
1	1,125	2,057	1,160	2,120
2	1,135	2,075	1,165	2,129
3	1,145	2,093	1,170	2,138
4	1,165	2,129	1,190	2,174
5	1,180	2,156	1,205	2,201
6	1,190	2,174	1,230	2,246
7	1,210	2,210	1,250	2,282
8	1,225	2,237	1,260	2,300
9	1,250	2,282	1,285	2,345
10	1,260	2,300	1,305	2,381
11	1,285	2,345	1,325	2,417
12	1,310	2,390	1,335	2,435
13	1,350	2,462	1,350	2,462
14	1,390	2,534	1,400	2,552
15	1,410	2,570	1,435	2,615
16	1,450	2,642	1,465	2,669
17	1,465	2,669	1,475	2,687
18	1,485	2,705	1,490	2,714
19	1,515	2,759	1,520	2,768
20	1,520	2,768	1,530	2,786

Cone No.	When heated at 100° C. per hour		Cone No.	When heated at 100° C. per hour	
	° C.	° F.		° C.	° F.
23	1,580	2,876	32	1,700	3,092
26	1,595	2,903	33	1,745	3,173
27	1,605	2,921	34	1,760	3,200
28	1,615	2,939	35	1,785	3,245
29	1,640	2,984	36	1,810	3,290
30	1,650	3,002	37	1,820	3,308
31	1,680	3,056	38	1,835	3,335

---

[1] The properties and uses of pyrometric cones: The Standard Pyrometric Cone Company, Columbus, Ohio.