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SCOTT TURNER, DIRECTOR

**BENEFICIATION AND UTILIZATION OF
GEORGIA CLAYS**

BY

R. T. STULL and G. A. BOLE

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BENEFICIATION AND UTILIZATION OF GEORGIA CLAYS

By R. T. STULL and G. A. BOLE

INTRODUCTION

The Federal Government has done considerable work on the white-clay deposits of the lower Appalachian and Piedmont regions and has published the results.¹ All of this work, with one exception, had to do with the primary kaolins of the Piedmont Plateau. Bureau of Mines Bulletin 128 describes an investigation of the problem of refining the secondary (sedimentary) clays of the Dry Branch district of Georgia and the utilization of these clays in the manufacture of white ware. After the washing practice at the plant of the Georgia Kaolin Co. was modified to include the use of electrolytes to float the clay, preliminary tests of the washed clay were made. The washed clay was later tried in practice in dry-pressed ceramic bodies.

As the investigation indicated that when properly washed the sedimentary clays from a particular district could be used to advantage in a small field, it became evident that a study to cover a much wider range of raw materials and manufacturing processes should be made. A cooperative agreement between the Bureau of Mines and the Central of Georgia Railway, to which the latter contributed generously both in funds and personnel, made such an investigation possible.

The resources of ceramic raw materials of the coastal plain within Georgia were carefully examined by a field survey, and 30 samples of about 1 ton each of the various clays selected for test were taken. The survey was made and the samples collected by T. Poole Maynard, consulting geologist for the railway. The samples represented average clays from both operating mines and prospected but undeveloped deposits. At a few properties different samples were taken from different strata. The clays were sent in

¹ Watts, A. S., *Mining and Treatment of Feldspar and Kaolin in the Southern Appalachian Region*: Bull. 53, Bureau of Mines, 1913, 170 pp.; Sproat, I. E., *Refining and Utilization of Georgia Kaolins*: Bull. 128, Bureau of Mines, 1916, 59 pp.; Ries, H., Bayley, W. S., and others, *High-Grade Clays of the Eastern United States, with Notes on Some Western Clays*: Bull. 708, U. S. Geol. Survey, 1922, 314 pp.

bags, tagged inside and out, to the ceramic station of the Bureau of Mines at Columbus, Ohio, where the preliminary laboratory and washing tests were made.

After preliminary elutriation tests of the clays, an experimental washing plant, with approximately 3 to 5 tons daily capacity, was built at Columbus. Two men were employed continuously for two years on this work.

Physical tests and microscopic and chemical analyses of the clays were made in an endeavor to determine their field of usefulness. After this, information was gathered as to their proper utilization.

Commercial trials were made at plants of the Homer Laughlin China Co., American Encaustic Tile Co., Clean Tile Co., Canton Brick & Fireproofing Co., and Harbison-Walker Refractories Co. Tests were made at works of the General Electric Co., Hadfield-Penfield Steel Co., and Fisk & Co. Service tests of the refractories made from the tested clays were conducted at works of the Bonney Floyd Co., Ohio Malleable Iron Co., and American Bridge Co. The Bureau of Mines and the Central of Georgia Railway thank these companies for their interest and generous cooperation.

In addition to the 24 clays originally selected for the ceramic tests, 6 others were added in the washing tests. These latter were selected because of their apparent suitability for use as fillers. The filler tests were made at the Southern experiment station of the Bureau of Mines at Tuscaloosa, Ala., under the direction of W. M. Weigel, and the results have been reported.²

GENERAL SUMMARY OF FINDINGS

This report is divided into six parts as follows: (1) Occurrence of clays in Georgia and the source of the clays tested; (2) washing tests; (3) physical tests; (4) utilization of kaolins in white ware; (5) utilization of clays in refractories; and (6) utilization of clays in face brick. In brief, the conclusions are as follows:

1. The State of Georgia contains a large area of sedimentary kaolins and bauxites of industrial importance. Considerable development has taken place, and many undeveloped deposits are available.

2. Georgia clays can be washed free from material that causes dark specks in white ware; by proper blending a uniform product can be marketed, and the burning color of most of the clays can be improved.

² Weigel, W. M., *Size and Character of Grains of Nonmetallic Mineral Fillers*: Tech. Paper 296, Bureau of Mines, 1924, 44 pp.; *Georgia and Alabama Clays as Fillers*: Tech. Paper 343, Bureau of Mines, 1925, 34 pp.; "Georgia clays for paper fillers": Paper Trade Jour., Aug. 9, 1923; "Georgia clays for rubber fillers": Rubber Age, July 25, 1924,

3. The working properties and fire tests of the crude clays are mostly from fair to good. The color numbers range from 1 to 10, and average nearly 4. In the screen tests of the crude materials the range through 150 mesh was 46.15 to 99.89 per cent, but if the eight lowest results, which, except G-4, were bauxite or bauxitic clays, be eliminated the range was 82.11 to 99.89 per cent. The washed clays showed a range of recovery of 70.40 to 82.18 per cent in the filter presses. Chemical analyses showed the following part range of composition:

Range of composition of clays

	Crude clay	Washed clay
	<i>Per cent</i>	<i>Per cent</i>
Ignition loss.....	11.92-25.89	12.25-19.09
Silica.....	14.08-50.81	32.35-45.76
Alumina.....	33.61-56.23	35.13-46.06
Iron.....	.44- 1.92	.54- 1.56
Titanium.....	.77- 2.34	.88- 1.72
Sulphur.....	.01- .16	.01- .18

4. If Georgia clays are mined, refined, and blended with care, they can be used more in white ware than they are now. The high bisque loss and shrinkage can be overcome by proper body mixes and blending of clays. Georgia clays can be used to some extent in place of English china clay in floor and wall tile.

5. Georgia contains large deposits of refractory clays suitable for the manufacture of high-grade refractories. If enough of the clay is fired to a high temperature and used as a grog, the brick will go through the process of manufacture readily and will withstand every laboratory test for a high-grade refractory.

6. Furnace tests under actual working conditions have proved that the service rendered by fire brick made from Georgia sedimentary kaolins was at least equal to and in most tests superior to that rendered by fire clay and aluminous brick.

7. Light-cream and light-gray face brick can be made from a mixture of Georgia kaolin, aplite, and sand, and these brick compare favorably with the best face brick from the fire clays of the Freeport, Mercer, and Kittanning formations of Pennsylvania.

ACKNOWLEDGMENTS

In addition to acknowledging the assistance rendered by the companies already mentioned and to those who supplied the samples of clay, and mentioned later, acknowledgment must also be made to J. M. Mallory, general industrial agent, and T. Poole Maynard, consulting geologist for the Central of Georgia Railway; to D. J. Demorest for chemical analyses; to W. M. Weigel for the filler tests mentioned; to R. B. Gilmore, Albro Fessler, H. M.

Kraner, and Thomas Walker for the laboratory work, the major portion of which was done by the first two mentioned; and to C. B. Shearer and Davis Brown, of the Hadfield-Penfield Steel Co., Bucyrus, Ohio, for cooperation in the face-brick tests.

ECONOMIC GEOLOGY OF GEORGIA CLAYS³

The Georgia coastal plain, an area of approximately 35,000 square miles, lies to the south of the Piedmont Plateau. The contact between the two divisions, known as the Fall Line, follows an irregular line across the State from Augusta through Milledgeville and Macon to Columbus.

A strip along the northern border, 220 miles long and 40 to 50 miles wide, is known as the Fall Line Hills. This strip lies between the Fall Line to the north and the Dougherty Plain to the south and comprises an area of approximately 9,500 square miles. It is within the area of the Fall Line Hills that the sedimentary kaolins and bauxites of industrial importance are found. (See fig. 1.)

ORIGIN OF THE SEDIMENTARY KAOLINS

Evidence indicates that the Piedmont Plateau was a comparatively level area for a long period, during which vast beds of primary kaolin were formed through decomposition of the crystalline rocks. Prior to Cretaceous time, the Piedmont Plateau was tilted to the southeast, which produced a rearrangement of drainage and gave the streams a general southeast course.

The products of decomposition, which include kaolin, quartz sand, feldspar grains, and mica, and also other minerals in lesser quantities, were carried by the streams to the coastal plain. Their progress was accompanied by a sorting action and the coarser particles were dropped as the velocity of the streams lessened. The finest clay particles remaining in suspension were deposited in lagoons and quiet bodies of fresh water offshore, or were precipitated where fresh water met salt water, where flat-topped lenses of secondary kaolin were formed during long periods of continuous sedimentation.

These clay lenses range in extent from small areas a few inches in thickness to deposits 40 feet and more thick and covering areas of more than a square mile. Records of artesian wells bored in Wilkinson County show that these lenslike strata, alternating with white,

³ Notes have been abstracted from the following publications of the Geological Survey of Georgia:

Ladd, G. E., *Clays of Georgia*: Bull. 6, 1898, 204 pp.; Veatch, Otto, *Clay Deposits of Georgia*: Bull. 18, 1909, 453 pp.; Veatch, Otto, and Stephenson, L. W., *Geology of the Coastal Plain of Georgia*: Bull. 26, 1911, 466 pp.; Shearer, H. K., *Bauxite and Fuller's Earth of the Coast Plain of Georgia*: Bull. 31, 1917, 240 pp.; La Forge, L., Cooke, Wythe, Keith, Arthur, and Campbell, M. R., *Physical Geography of Georgia, with an introduction by S. W. McCallie*: Bull. 42, 1925, 189 pp., prepared jointly with U. S. Geol. Survey.

yellow, and brown sands, extend to great depths, in one place more than 500 feet. That these kaolins were probably fresh-water deposits is indicated by the fact that so far as known they contain no marine fossils, lime, gypsum, or manganese nodules.

The important white sedimentary clays of Georgia belong to the Middendorf formation of the Upper Cretaceous,⁴ and were evidently laid down contemporaneously with the fire clays of New Jersey, both showing the same relative position to the Fall Line, but differing in their physical properties. The Georgia sedimentary

FIGURE 1.—Topographic divisions of the coastal plain of Georgia

kaolins are comparatively white and are low in or lack fluxes, contain considerably less iron oxide, burn to a white to cream color, and are decidedly more refractory. The difference in the physical properties is due mainly to the difference in the composition of the parent rocks from which the clays originated.

Most of the Eocene and Tertiary clay deposits of Georgia are thinner, smaller in extent, and inferior in quality to the Cretaceous clays. The Upper Cretaceous sediments (Middendorf formation) rest unconformably upon ancient metamorphic and crystalline rocks corresponding to those of the Piedmont Plateau.

⁴ According to C. Wythe Cook, U. S. Geol. Survey, 1925.

The Eocene or later formations rest unconformably upon the Upper Cretaceous, and where the latter is absent they lie unconformably upon the crystalline rocks. The Upper Cretaceous deposits outcrop near the Fall Line in a belt extending entirely across the State. This belt is 2 to 30 miles wide.

Bordering this strip is an area 5 to 20 miles wide in which 4 to 40 feet of overburden lie above the kaolins and bauxites; in places the peaks of the hills rise to a height of 80 feet above the clays.

The Upper Cretaceous outcrop and the adjoining area covered with thin overburden form an area 20 to 30 miles wide, which extends across the State in a southwest direction from Augusta to Columbus. (Fig. 2.) Within this area the beds of kaolins and bauxites lie near the surface and mining can be done at low cost.

Since the deposition of the clays any lifting, tilting, or warping has not been of sufficient magnitude to disturb the clays appreciably. The clays are massive and apparently without laminated structure, which indicates a continuous deposition of material of the same nature.

No faulting or folding is to be observed and slickensides are rare. Where the surface has not been displaced by erosion the top of the clay lens lies on the same plane and dips to the southeast about 6 to 10 feet per mile, whereas the average dip of the coastal plain surface is 3 to 5 feet per mile.

FORMATION OF BAUXITE

Evidence indicates that the bauxites of the coastal plain are derived from the alteration of secondary kaolin. The process of alteration has been one of removal of silica, alkalies, and alkaline earths, with the resultant concentration of alumina, ferric oxide, and titania. In many places the deposits show gradations of material from kaolin on one hand to bauxite on the other.

Of the different theories advanced for the formation of bauxite, that of laterization⁵ seems the most rational for many deposits, though it does not offer a satisfactory explanation of the origin of some of the bauxites of the coastal plain.

The bauxites occur as lenses embedded in larger lenses of kaolin. Many bauxite lenses are completely enveloped in fine-grained, compact kaolin, which is generally massive and almost impervious to water. Those bauxite lenses at the top of the clay show indications of erosive displacement of the original top covering of kaolin. The

⁵ Swanson, C. O., "The origin, distribution, and composition of laterite": Jour. Am. Ceram. Soc., vol. 6, 1923, pp. 1248-1260.

kaolins are so "tight" grained and compact that the percolation of water seems difficult, if not impossible. The kaolin lenses, therefore,

FIGURE 2.—Central Georgia, showing clay belt

lack the loose or porous structure permitting free penetration of the water essential to the progress of laterization.

The Middendorf formation of the Upper Cretaceous in which the kaolins occur is practically devoid of plant remains; hence vegetal growth or vegetal decay seemingly was not an important factor in the alteration of the kaolins.

So resistant to the entrance of water are the kaolins that as freshly mined they contain scarcely enough moisture for molding into shape readily by dry pressing. Rain water that percolates through the overburden finds difficulty in penetrating the kaolin appreciably and issues along the slopes as numerous springs and seeps. Frequently, where no outcrops show, the top of a kaolin deposit can be traced a mile or more by following the line of springs.

Spring water flowing from the top of the kaolin invariably shows a "milky" or opalescence even in the driest season. If allowed to stand in a glass-stoppered bottle for months, the water fails to become clear or form a sediment. An "opalescent" spring is a good indication of a deposit of kaolin.

PROPOSED CLASSIFICATION OF CLAYS

The sedimentary clays from different localities in Georgia differ considerably in their physical properties. Their hardness ranges from that of flint clay to that of the very soft and friable clay. Their color in the natural state ranges from cream, light gray, and light blue to white; their color in the burned condition ranges from light buff to white, depending on the content of ferric oxide and titania. For convenience the clays may be classified as follows: (1) Flint clays; (2) hard clays; (3) semihard clays; (4) soft clays; (5) bauxitic clays; and (6) bauxites.

Inasmuch as the predominating evidence indicates that the bauxites were derived from the soft clays, the proposed classification has been made to include the bauxitic clays and bauxites.

FLINT CLAYS

The flint clays are represented by those found in Glascock County, near Gibson. Though they can not be classed as flint fire clays, many of their physical properties are similar. Like flint fire clays they are hard, break with a conchoidal fracture, do not slake, and are short or lacking in plasticity, but develop a weak plasticity when water-ground to a very fine condition. In color they are usually cream to light gray or drab. The silica content is comparatively high, as is indicated by the silica-alumina ratio, which ranges from 2.4 to 2.8. They show practically no fire shrinkage below cone 12 and deform at cones 31 to 33. (This and all other allusions to cone temperatures refer to temperatures obtained by the use of Orton standard cones.) The flint clays of Georgia are comparatively scarce

and have been found in only a few localities. Flint clay is mined at one point and shipped to Birmingham, Ala., where it is used in the manufacture of refractories.

HARD CLAYS

The hard clays are light cream to white. They are very fine grained, are comparatively free from grit, break with a conchoidal fracture, and when placed in water crumble to angular fragments one-eighth to one-fourth inch in diameter, but on standing do not slake to a slip condition. These fragments, however, soften in water so that they can be crushed between the thumb and finger. When kneaded or tempered with water, as for example in a wet pan, these clays are exceedingly plastic and moldable. When reduced to slips by long-continued agitation or grinding they settle with difficulty; the supernatant water remains strongly opalescent indefinitely and has an appearance suggesting the presence of silicic acid.

On filter-pressing the clays the water at first comes through milky, but soon clogs the filter sacks and makes the obtaining of firm cakes impossible. Objects molded from the thoroughly tempered clay dry safely though slowly, and show a high dry strength. Deformation temperatures range from cone 33 to cone 34. These hard clays evidently would be valuable for a considerable part of the bond clays in saggers and crucibles that require high temperatures. They are more widely distributed than the flint clays and are found in many places in Washington, Wilkinson, and northeastern Twiggs Counties.

SEMIHARD CLAYS

The semihard clays are most abundant. Raw they are cream to white and they burn light buff to white. They slake to a grain form about the size of flaxseed, and on long-continued agitation they blunge to a good slip. They settle slowly on standing and leave a light opalescence in the supernatant water. Under comparatively high pressure these clays filter-press slowly and form a comparatively soft cake, though one that can be handled. They are very fine grained and plastic and show good bonding strength. Their deformation temperatures range from cone 33 to cone 35. When used in combination with grog, sand, or other nonplastic material, with even as low as 30 per cent raw-clay content, the semihard clays mold readily and dry and burn safely.

These clays are in lenses, some of which are more than 650 acres in extent; thicknesses range from 10 to over 40 feet. A large lens near Gordon has a known maximum depth of 52 feet. Because of

their great abundance, ease of working, and refractory properties, they offer extremely favorable opportunities for the manufacture of refractories.

SOFT CLAYS

The soft clays in the natural state are cream and light blue to white; they burn cream to white. They slake and blunge readily to a slip condition and filter-press without difficulty. These clays are mined and washed extensively for the filler and ceramic trades. They are friable, fairly plastic, and show low bonding strength. They deform at cone 33 to cone 35. When used in quantities of more than 30 per cent in plastic bodies they are liable to crack in drying, but work satisfactorily in dry-press bodies, such as compositions for floor and wall tile and electrical insulators.

BAUXITIC CLAYS

The bauxitic clays are those with a silica-alumina ratio of 1.8 to 0.8 and are apparently mixtures of clay and bauxite. As the silica-alumina ratio decreases the ease of slacking, plasticity and dry strength also decrease. Usually a soft "oölitic" structure is visible, the "concretions" ranging from traces of pinhead size up to those about three-fourths inch in diameter. In color and hardness the bauxitic clays range from snow white and very soft to the gray-buff rock known locally as "chimney rock," which is soft enough to be quarried and cut readily, but hardens on exposure. Its name is derived from the fact that it has been used locally since pioneer days for the construction of chimneys. The deformation temperature of the bauxitic clays is between cones 35 and 38. These clays are abundant over large areas, associated with kaolin and bauxites. Their distribution, ease of mining, and refractory properties make the bauxitic clays ideal for the manufacture of high-grade refractories.

BAUXITES

The bauxites show an alumina content of 52 to 61 per cent. Those containing 52 to 56 per cent alumina are classed as "low grade" and those containing over 56 per cent as "high grade." Their deformation temperatures range from cone 37 to cone 40.

As there is no sharp line between bauxitic clays and bauxites, for one frequently grades into the other, some chimney rock falls within the low-grade bauxite class. Chimney rock, therefore, appears to lie on the indefinite line between bauxitic clays and bauxite.

OCCURRENCE OF AND DIFFERENCES BETWEEN CLAYS

As a rule, the high-grade bauxites lie near the bottom of a lens with low-grade bauxite above and bauxitic clay or kaolin below.

FIGURE 3.—Kaolin deposit, showing bauxite lens at top

(See fig. 3.) Chimney rock is frequently found above and in contact with the low-grade bauxite. The contact between the chimney rock and the low-grade bauxite and that between the low and high

grade bauxites is sharply defined as a rule. Both the high and low grade bauxites are valuable raw materials for the manufacture of high-grade refractories. The high-grade bauxites are used to a limited extent in the manufacture of alum, aluminum, and abrasives.

The difference between the flint and the hard clays is marked and apparently there is no well-defined gradation between the two. The most noticeable differences are those of plasticity and hardness. When crushed and moistened with water the flint clays are short and friable whereas the hard clays are very plastic and strong.

On the other hand, clays are found representing all gradations between the hard and soft clays. Examination of a large number of chemical analyses from different sources shows that the hard clays are a little higher in silica than the soft clays, and the silica decreases as the clays become softer. Empirically, the hard clays are near $1 \text{ Al}_2\text{O}_3$, 2.25 SiO_2 , which grades down to $1 \text{ Al}_2\text{O}_3$, 2.00 SiO_2 for the soft clays.

CAUSES OF HARDNESS

Evidently the hardness of these clays is due to free silicic acid. Its presence explains why spring waters flowing from the top of the clays are always opalescent and high in silica. The presence of silicic acid likewise accounts for the difficulty in slaking and filter-pressing the hard and semihard clays and for their high plasticity and bonding strength. The lack of free silicic acid in the soft clays also accounts for their ease of slaking and filter-pressing, the clearness of the water coming from the filter press, and their lower bonding strength.

Whether silicic acid was present when the clays were deposited or was formed or introduced long afterward is problematical. Evidence tends to show that the clays originally were hard and that the soft clays resulted through removal of free silicic acid. The flint clays may be secondary derivations from the hard clays because of their higher content of free silicic acid which underwent a hardening action by conversion to "set gels." Again it is possible that they were formed from the hard clays by the addition of silica.

DEPOSITION OF HARD AND SOFT CLAYS

Along the slopes of the hills where the clay has been beveled by erosion and later covered with a thin sandy overburden the edges of the clay deposits are usually soft. In mining back into the hill, however, where the clay and overburden have not been disturbed, the clay generally grades into the semihard and hard varieties.

In the large massive lenses that have been well protected by a heavy overburden of claylike fuller's earth, the hard and semihard clays extend in places from top to bottom of a lens. In other places the top 10 to 15 feet is hard or semihard clay and the bottom 10 to

20 feet is soft clay. The division between the two is abrupt and easily recognized when test borings are made in prospecting.

The two clays may have been laid down at different times separated by a time interval long enough for the lower clay to change from hard to soft before the top clay was deposited, or the entire lens may have been soft clay originally and the upper hard part

FIGURE 4.—Mining soft kaolin near McIntyre, Ga.

formed, although this is very doubtful, by infiltration of silicic acid from the gummy impure fuller's earth that usually overlies the hard clays. Where the gummy overburden is lacking or has been replaced by sand the underlying clay is usually the soft variety.

In some deposits the entire lens is soft clay. (See fig. 4.) When the overburden is stripped during mining these clays usually

show potholes and irregular surfaces which indicate erosion and long periods of exposure to weathering. Later these clays were covered with sand that in many places contains white-clay pellets or balls, some as large as a bushel basket, which were torn up from the clay beds by swift running waters and deposited with the sand. Under such conditions there would be opportunity for alteration from hard to soft clay, and under favorable conditions even to bauxite. Although there are isolated instances of hard and soft clay and bauxitic materials occurring in close proximity, the bauxites in general are associated with the soft clays. The hard clays are generally absent.

AREAS AND OPERATORS

No systematic field work covering the clay areas of the Georgia coastal plain has been done since the report⁶ of Veatch in 1909. Considerable development has taken place since then and numerous undeveloped properties have been located.

In 1909 only one clay mine was reported in Wilkinson County, and at that time it was inactive. Twiggs County during that year produced approximately 35 per cent of the kaolin of Georgia, nearly 25,000 tons. During the year 1924 Wilkinson County produced more than 65 per cent of the output of Georgia, which exceeded 85,000 tons.

The 24 counties named below lie wholly or partly in the coastal plain and are known to contain secondary kaolin or refractory clays of the "kaolinitic" variety:

Counties containing secondary kaolin or refractory clays

Baldwin.	Houston.	Quitman.	Talbot.
Bibb.	Jefferson.	Randolph.	Taylor.
Columbia.	Jones.	Richmond.	Twiggs.
Crawford.	Macon.	Schley.	Warren.
Glascok.	Marion.	Stewart.	Washington.
Hancock.	McDuffie.	Sumpter.	Wilkinson.

Space will not permit listing and describing all known kaolin, refractory clay, and bauxite properties in the Georgia coastal plain which offer commercial possibilities, but to show the development a list of the producing mines is given below, as of December, 1924:

TABLE 1.—*Operators producing kaolin, refractory clay, and bauxite*

Name	Place
Albion Kaolin Co.-----	Hephzibah, Richmond County.
Harbison-Walker Refractories Co.-----	Gibson, Glascock County.
Akron Pigment Co.-----	McIntyre, Wilkinson County.
Aluminum Flake Co. of Georgia-----	Do.

⁶ Veatch, Otto, Clay Deposits of Georgia: Geol. Survey of Georgia Bull. 18, 1909, 453 pp.

Name	Place
Kalbfleisch (Corp.)	McIntyre, Wilkinson County.
Edgar Bros. Co.	Edgar, Wilkinson County.
Do.	Dedrich, Wilkinson County.
Do.	Toddville, Wilkinson County.
Republic Mining Co.	Wiley, Wilkinson County.
Moore & Munger.	Claymont, Wilkinson County.
Savannah Kaolin Co.	Gordon, Wilkinson County.
Gordon Kaolin Co.	Do.
The Georgia White Brick Co.	Do.
Stevens (Inc.)	Nadine, Wilkinson County.
Do.	Stevens Pottery, Baldwin County.
American Clay Co.	Do.
Georgia Kaolin Co.	Dry Branch, Twiggs County.
John Sant & Sons Co.	Do.
Golding Sons Co.	Butler, Taylor County.

At present in Wilkinson County nine active mines are producing or utilizing kaolin, one is producing refractory clay, and two are mining high-grade bauxite. In the "Directory of Commercial Minerals in Georgia and Alabama along the Central of Georgia Railway," issued in 1924 by the industrial department of that railroad, 77 undeveloped properties and operating mines are listed in Wilkinson County alone, and since that publication was issued, 21 properties having commercial possibilities have been located.

SOURCE AND DESCRIPTION OF THE CLAY SAMPLES TESTED

The source and brief description of the samples of Georgia clays tested are as follows:

Sample G-1.—Run-of-mine sample from the upper strata of an operating mine of the Savannah Kaolin Co., at Gordon. It is a hard clay that is shipped to a limited extent to northern markets for refractories. The deposit ranges in thickness from 25 to 50 feet and the overburden from 20 to 25 feet.

Sample G-1b.—Sample from the same mine as G-1 but underlying it. This is a soft clay that is being mined and washed largely for the filler trade. It forms about two-thirds of the deposit and grades into sandy material near the bottom.

Sample G-2.—The clay was from the upper strata of a mine at Gordon, which at the time was idle but has since been put in operation by the Gordon Kaolin Co. Thickness of deposit, 20 to 48 feet. The sample was run of mine. Although generally resembling the soft kaolin, it contains many small oölites, which indicate a bauxitic nature, and the alumina content is above the kaolinite ratio common to the soft clays. The overburden is 1 to 20 feet thick.

Sample G-3.—Sample from a 40-foot pit, top to bottom, at an undeveloped property of Evans & Dedrich, of Gordon. The property has been prospected and the clay is known to be 25 to 42 feet

thick. The clay is hard and very plastic. The overburden is 10 to 30 feet thick.

Sample G-4.—Clay from the same mine as G-2, and immediately under it; constitutes about one-third of the total working face. It is a typical soft kaolin and when washed has been used in the filler trade. The sample was run of mine. The overburden averages about 20 feet.

Sample G-5.—A run-of-mine sample from an operating mine of Stevens (Inc.), of Stevens Pottery, which has a working face 15 to 28 feet high. The clay is soft, rather dense, and is used in the manufacture of refractories. The overburden averages 20 feet.

Sample G-6.—A run-of-mine sample from an operating mine of the Akron Pigment Co., at McIntyre. The deposit is 20 to 28 feet thick. It is a semihard clay that after washing is sold to the filler trade. The deposit is typically lenslike and has a uniform overburden of 20 feet.

Sample G-7.—The deposit of kaolin of Moore & Munger, at Claymont, ranges in thickness from 15 to 35 feet. It is a soft clay. An average sample was taken from a mine furnishing crude clay to the ceramic and filler trade. The overburden is 8 to 15 feet thick.

Sample G-8.—Clay G-8 occurs in a railroad cut and is 8 to 12 feet thick. The sample was run of mine, taken through the bed from top to bottom. It is a semihard clay and is undeveloped. It is owned by J. R. Van Buren, of Griswoldville.

Sample G-9.—Clay G-9 was from an undeveloped property of the W. R. Parker estate, at McIntyre, taken from top to bottom of a 15-foot pit. Prospecting has shown the deposit to be 15 to 21 feet thick; the overburden is a few inches to 25 feet thick.

Sample G-10.—An average sample of bauxite from an operating pit of the General Bauxite Co. at Toombsboro. Has the oölitic structure characteristic of a high-grade bauxite. The extent of the deposits is difficult to estimate because they occur as lenses embedded in the clay. The overburden is shallow.

Sample G-11.—A bauxitic refractory clay from the same pit as G-10, where it underlies the purer bauxite. It contains some quartz grains which lower the alumina-silica ratio nearly to that of kaolin. The oölitic bauxite structure is marked. The sample was an average of the bed.

Sample G-12.—This rather high-grade bauxite was a run-of-mine sample from a pit, the Cason Holder mine of the General Bauxite Co., at Toombsboro, with only a few feet of overburden. Virtually its entire structure is oölitic.

Sample G-13.—A low-grade bauxite, locally termed "chimney rock," used in the manufacture of refractories. It is a representa-

tive sample of the discard from bauxite mining, from the Nadine mine of the General Bauxite Co., now controlled by Stevens (Inc.).

Sample G-14.—A good grade of bauxite taken from an abandoned pit, the Garner Mine of G. Y. and A. L. Moore, of Cuthbert. In structure and chemical analysis it is very similar to G-12. The overburden averages about 10 feet.

Sample G-15.—This clay is locally called a "blue clay." Its blue color, which bleaches to a white, is evidently an organic stain. It should be classed between the semihard and soft clays. It represents the lower 15 to 20 feet of an operating mine with a 35 to 50 foot face. The sample was an average of the pit. The clay is being marketed crude by the Savannah Kaolin Co., of Gordon. The major part of the output of the mine goes to the white-ware trade. The overburden is 1 to 20 feet thick.

Sample G-16.—A soft kaolin from an operating mine of Golding Sons Co., at Butler, which has a working face 10 to 25 feet high. It is sold crude to the potters and to the filler trade. It is exceptionally free from grit. The overburden ranges from 10 to 25 feet.

Sample G-17.—A soft clay from the same general deposit as G-16 and similar to it excepting that it is not so good in color. It is sold as a sagger clay. The sample was taken mostly from the upper stained portion.

Sample G-18.—A low-grade bauxite high in iron. The sample was representative of the former workings in an abandoned pit of the Ledden mine of G. Y. & A. L. Moore, at Cuthbert.

Sample G-19.—Because of the presence of free grains of quartz, the chemical analysis resembles that of a kaolin, whereas the structure resembles that of low-grade bauxites. The sample was taken from a 5-foot exposure, top to bottom, on an undeveloped property of G. Y. & A. L. Moore, of Cuthbert. The overburden is light.

Sample G-20.—This material has been described as a refractory clay, but its structure is essentially bauxitic. The sample was run of mine from an operating pit of Easterlin Bros., at Andersonville.

Sample G-21.—This is a soft clay from a 20-foot pit on the property of C. T. Harden, of Oglethorpe. The clay is 6 to 10 feet thick; above it is 10 to 15 feet of sandy overburden.

Sample G-22.—A soft refractory clay from an abandoned mine of Mrs. Hamilton Yancey, of Perry. The color, both raw and fired, is excellent. The sample was taken, top to bottom, from a 15-foot face. The overburden is 5 to 30 feet thick.

Sample G-23.—This clay has a bauxitic structure, and contains much oölitic material. Its deformation temperature is exceptionally low for this type of clay. The sample was collected from an 8-foot outcrop in a ditch at an undeveloped property, the Fagan, near Fort Valley. The sample was given the preliminary tests only.

Sample G-24.—A sample from an undeveloped property, the Brs-well mine, at Nakomis. It was taken from an 8-foot pit, top to bottom. It has been erroneously described as a ball clay, but should be classed as a rather dense soft clay. The overburden is 15 to 20 feet thick.

Sample G-25.—Sample G-25 is a high-grade white silica sand that underlies G-16 and G-17 at Butler, and has been prospected to a depth of 25 feet.

Sample G-26.—A run-of-mine sample from an operating mine of Edgar Bros. Co., near McIntyre. It is a soft clay. The working face of the pit is 20 to 40 feet high and the overburden is 10 to 20 feet deep.

WASHING TESTS

ENGLISH AND AMERICAN CLAYS

The amount of English china clay normally used in the United States prior to 1920 amounted approximately to one and one-half times the annual domestic production. The present ratio is somewhat more favorable to the domestic clays. The English clay is used mostly in the production of the better grades of pottery, paper, and oilcloth.

It was formerly considered that the English clays were more dependable than domestic clays on account of their better uniformity. This objection has been largely overcome by improved methods of working and preparation under technical control that have been adopted by the principal producers. The earlier objection to domestic clays on account of excessive grit or abrasive materials has also been removed by more careful preparation and selection.

The gritty material⁷ in kaolin may be composed of a number of different minerals, chief among which are quartz, mica, rutile, and partly weathered feldspar, besides the iron-bearing minerals detrimental to color.

Watts⁸ has described the washing methods in common use and Sproat⁹ has described an improved method in which electrolytes were employed. Sproat's method was adopted at a plant in the Dry Branch district of Georgia and successfully used for two years, but was discontinued during the World War when technical aid was not available. The only objection to the method from an operator's standpoint was the intelligent supervision necessary to its success.

⁷ Darby, G. M., "Determination of grit in clay": Chem. and Met. Eng., vol. 32, 1925, pp. 688-690.

⁸ Watts, A. S., Mining and Treatment of Feldspar and Kaolin in the Southern Appalachian Region: Bull. 53, Bureau of Mines, 1913, 170 pp.

⁹ Sproat, I. E., Refining and Utilization of Georgia Kaolins: Bull. 128, Bureau of Mines, 1916, 59 pp.

SEPARATION OF COARSE GRIT

Where grit is separated by flowing the clay slip in troughs or sluices, considerable fine granular material and many thin flakes of mica are carried over with the clay and a large part passes through the screens. The completeness of separation with respect to size of the particles depends on the force of gravity acting against the carrying power the water has by its velocity of flow. As gravity is constant, the degree of separation can be governed by regulating the velocity of flow. When it settles, the fine granular material carries down more or less clay substances, even though the clay has been deflocculated, and the quantity thus lost increases rapidly with the decrease in the velocity of flow and the size of the particles settling. To remove (through 120-mesh screen) the fine abrasive material that causes excessive wear on paper and oilcloth machinery, the flow would have to be reduced so much that the loss of clay carried down with the grit would be excessive.

Figures 5, 6, and 7 show the equipment at a typical plant.

SEPARATION OF THE FINER GRIT

Nearly everyone has noted when dissolving salts in a beaker of water by stirring with a glass rod that after the rod is taken out the grains of undissolved salt move rapidly in a spiral path toward the center of the beaker and form a flat cone on the beaker bottom. It was thought that this "center-seeking" principle might be adapted to the removal of fine grit and mica from clay. The cyclone dust separator employs a somewhat similar principle, and a clay-washing machine called the whirlpool classifier has been made to work on this principle.

THE WHIRLPOOL CLASSIFIER

The clay separator described below differs from the dust separator more particularly in that the conveying medium is water instead of air. The separation of the coarse from the fine and colloidal particles is effected by giving the clay slip a whirlpool motion while in a stationary cylindrical vessel. The separator has therefore been called the "whirlpool grit separator" or the "whirlpool classifier."

Figure 8, *A*, shows the elevation and *B* the plan of one of the first separators used in the preliminary experiments. The cylindrical part *a* was 12 inches in diameter and 8 inches high. The height of the collecting cone *b* at the bottom was 10 inches. Near the top of the cylindrical part was a tangential spout *c* for the inflow of the clay slip, which entering tangentially under a constant head sets up a whirlpool motion. The coarser particles are carried to the center

and downward, where they are collected at the bottom of the cone in a flask, *d*; the very fine particles of clay float over the top into a trough or launder, *e*, and out the spout *f*.

FIGURE 5.—Settling tanks and filter-press sheds at Gordon plant

BASIC PRINCIPLE OF WHIRLPOOL CLASSIFICATION

To trace the path of travel of a particle, consider the liquid in the separator *C* to be made up of an infinite number of concentric ele-

ments. The liquid flowing in tangentially through the spout at g causes these rings to rotate at different angular velocities, the highest being that of an element a short distance from the wall of the can.

FIGURE 6.—Mica troughs and pump shed at Gordon plant

(The liquid elements or rings actually in contact with the wall are retarded by friction.) Each element in succession toward the center of rotation has a lower velocity, due to the “slippage” or lag effect.

Let h be a granular particle large enough to be acted upon by the differential forces. Also let the arrows j and k of C represent the magnitude of the forces of two liquid elements, produced by the different angular velocities. The force j acting upon the outer edge of h , or the point farthest from the center of rotation, is greater than the force k acting on the inner edge of h , or the point nearest the center

FIGURE 7.—Mica troughs, whirlpool classifier, and pump shed at Gordon plant

of rotation. These unequal and parallel forces acting in the same direction on opposite sides of the particle h cause it to rotate in a horizontal plane.

The point about which the particle h rotates is not its center but a constantly changing point between its center and the center of rotation of the liquid elements. Because h has this off-center rotation

and a forward movement, it travels in a spiral path to the center of the cylinder. As h moves from the point of inflow to the center it is continuously passing from elements of higher to those of lower angular velocity, and therefore its rate of travel diminishes. While these unequal forces are crowding h toward the center of the cylinder. unequal and parallel forces, as well as gravity, are acting to force it downward.

FIGURE 8.—Whirlpool classifier used in preliminary experiments. For explanation, see text

The liquid with its suspended particles may be considered to consist not only of an infinite number of concentric elements, as described, but of an infinite number of horizontal disks or layers one above the other (see fig. 8, *D*). A disk of liquid opposite the inflow at g has the highest velocity and each successive layer below the velocity diminishes because of the lag effect.

As the disk of liquid on top of the particle h is rotating faster than the layer on its lower side, the force l acting on top of h is

greater than the force m acting on the lower side of h . These unequal and parallel forces therefore cause h to rotate vertically about a point below its center, and this rotation causes h to travel downward, assisted of course by gravity. At first h falls rapidly and then more slowly as it descends into layers of lower and lower speed of rotation.

Large particles travel to the center and downward more rapidly than small ones because the differential of forces acting upon their opposite sides is greater. As the size of a particle diminishes the difference between the magnitude of the forces acting upon it diminishes and as the diameter approaches zero the difference in magnitude of the forces approaches zero. However, before a particle attains the theoretical zero size its diameter becomes so small that the center-seeking force is overbalanced by the small centrifugal force, assisted by the carrying power of the liquid. Then the particle travels with the liquid and practically as a part of it, and ultimately flows over the top of the cylinder into the trough e and out of the spout f (fig. 8, A).

EXPERIMENTAL TEST OF WHIRLPOOL CLASSIFIER

Preliminary tests were made with 15-pound samples of Georgia kaolin previously washed at the mines. The clay was prepared in a slip consisting of 90 per cent water and 10 per cent clay by weight and was deflocculated with caustic soda.

First the separator was filled with clear water and the clay slip run in from a constant-level tank at an elevation of 15 feet. Inflow was regulated by a valve. After the clay slip had passed through, clear water was run through until the overflow became clear.

The grit collected in the flask was removed, dried, and weighed. The average grit removed from five tests was 6.09 per cent. It consisted mainly of silica grains and mica, with some coarse grains of kaolin and brown particles of rutile.

TESTS WITH A SEMICOMMERCIAL WASHING PLANT

A washing plant, using the same principle as that described above, was built to handle a 1,000-pound batch. (See figs. 9, 10, 11, and 12.) The blunger a was 4 feet in diameter and had a capacity of 600 gallons; the whirlpool separator f was 2 feet in diameter, and the two elutriators h and j , 3 and 5 feet, respectively; the settling tank k was 6 feet in diameter and had a capacity of approximately 1,000 gallons. The pump l could feed the slip to the filter presses m at a pressure of 65 pounds.

As the capacity of the blunger just about sufficed to take care of 500 pounds of clay when blunged to a slip of 15 per cent solids by

weight, the slip, after being thoroughly blunged with the appropriate amount of electrolyte, was passed through a nest of screens suspended in a gyratory riddle and stored in tank *d*, where it was agitated until an additional charge of 500 pounds was blunged and ready to be run through the washer. The valve leading from the agitator to the constant-level tank *e* was then opened and the charge run through the washer at the rate of about 2.5 gallons per

FIGURE 9.—Flow sheet of 1,000-pound clay-washing plant (not to scale). For explanation see text

minute. When the slip was run an attempt was made to get as much through the system as possible before starting the water for washing. The aim was to wash until the several cans were clear, but this was not always possible, as the capacity of the apparatus was not large enough. Much experimenting proved that the rate at which the clay was run through the washer could be varied considerably without materially changing either the quantity (per cent) or quality of the recovery in the settling tank.

FIGURE 11.—Elevation of clay-washing plant (see fig. 10)

FIGURE 13.—Suggested flow sheet for clay-washing plant. For explanation, see text

conveying by an endless belt or screw conveyor to a rotary drier; in this way the entire process becomes continuous and automatic.

As many whirlpool separators are provided as the capacity may demand. At one plant where the separator has been in use about a year a 6-foot cone handles daily about 500 tons of a 10 per cent slip.

FIGURE 14.—Details of whirlpool classifier with grit elevator. For explanation, see text

If an electrolyte is used to float the slip it is added in the blungers; the amount necessary is determined by laboratory tests. If an electrolyte has been added in the blungers the slip is flocculated in the settling tanks by the addition of acid. Such apparatus can be trusted to deliver to the presses approximately 70 per cent of the clay charged when Georgia sedimentary clays are being washed.

Details of the whirlpool classifier with grit elevator are shown in Figure 14, A, B, C, D. The design is the same as for details in Fig-

ure 8, *A*, *B*, *C*, *D*, excepting the use of a grit elevator for the glass bottle *d*. In Figure 8, *o*, is a metal tube whose length and diameter will vary with the capacity of the plant and the clay being washed.

A motor, *r*, drives a worm, *p*, at a speed that removes the grit from the cone of the classifier. By proper gears, *q*, the rate of removal can be controlled. At *s* water is admitted to wash the ascending column free from clay.

The capacity (in pounds per hour, calculated on a dry basis) of a classifier is governed by the density of the slip and the rate at which the slip is delivered. In Figure 15 the diameter of the inflow pipe has been plotted against the rate of flow. The figures are based on a slip containing 10 per cent of clay. A rough idea of the dimensions required for a classifier of desired capacity can be gained from the curves.

OPERATION OF 6-FOOT CLASSIFIER

In order to test the whirlpool principle under plant conditions, a 6-foot separator was installed between the mica troughs and the rotary screen at an old-style plant of the Gordon Kaolin Co. In order to add capacity two diametrically opposite tangential orifices, instead of the one used during the laboratory tests, were provided. The entire output of the plant, 50 tons daily, is put through the whirlpool, and the capacity probably could be doubled without crowding the separator unduly. Operation has been highly satisfactory even under these conditions, but under ideal conditions, such as those suggested by Figure 13, much more efficient operation could be expected.

Figures 9, 10, 11, 12, and 13 give a general idea of the layout of the plant and Figures 16 and 17 a near view of the whirlpool separator.

DEFLOCCULATION OF CLAY

The quantity of electrolyte necessary to add to the slip to deflocculate the clay and later to flocculate it, with distilled water, was determined by viscosity tests (Mariotte tube method) and settle tests. These methods have been described so often in the literature that further description¹⁰ is not considered necessary.

EFFECT OF ELECTROLYTES

Georgia sedimentary clays do not behave uniformly toward electrolytes, as is to be expected, because they differ greatly in colloidality. Some of the clays were not affected at all by small quantities of a base or acid, whereas some were very sensitive to electro-

¹⁰ Sproat, I. E., Refining and Utilization of Georgia Kaolins: Bull. 128, Bureau of Mines, 1916, 59 pp.

lytes of both classes. For some of the clays the settle tests were hardly so satisfactory as viscosity determinations, because a small proportion of a highly colloidal material stays in suspension much longer than the bulk of the material and thus renders the values misleading.

FIGURE 15.—Capacity of whirlpool classifier

A few of the clays are so highly deflocculated by blunging with distilled water that the addition of alkali distinctly raises the viscosity. One of the clays was especially difficult to handle, because neither acid nor alkali had the slightest effect upon it.

Sodium hydroxide was used as the deflocculant and acetic acid as the coagulant. Figure 18 compares the viscosity and the settle tests (distilled water used) of a few of the clays.

RESULTS OF WASHING

It was not always possible to tell from preliminary tests whether a clay would wash or burn to a good white, so all the clays that

FIGURE 16.—Top view of whirlpool classifier at Gordon plant

gave any promise of being satisfactory for either the filler or white-ware trade were run through the washer. A small sample of the overflow was dewatered in each case, and if the raw and fired clay proved not at all satisfactory in color, all but a small sample of the slip was discarded; if the color tests proved satisfactory, the entire charge was dewatered.

Eighteen samples, after washing, proved suitable for use as fillers. Three hundred-pound samples of each of these clays were sent to the Southern experiment station of the Bureau of Mines, at Tuscaloosa, for trial in the filler trade. Results have been published.¹¹

FIGURE 17.—Side view of whirlpool classifier

Fire tests showed that seven of the washed samples burned to a sufficiently good white to justify trial in the white-ware trade. (See "Utilization of Sedimentary Kaolins of Georgia in White Ware.")

Washing greatly improved the burned color of most of the clays, but two of them burned to a poorer white than the crude clay. The

¹¹ Weigel, W. M., *Georgia and Alabama Clays as Fillers*: Tech. Paper 343, Bureau of Mines, 1925, 35 pp.

degree to which any clay can be purified by this method of washing depends upon two factors: First, the dispersability of the clay, and, second, the specific gravity of the dispersed particles. If the impurity in a clay has a low specific gravity or is in a colloidal state of subdivision, or if it is both colloidal and of low specific gravity, it will pass into the settling tank.

The whirlpool classifier seems to separate mica flakes more efficiently than a simple process of flotation. The unbalanced forces acting on different parts of a flake cause what may be termed a

FIGURE 18.—Curves showing deflocculation and settling rates of clay tested

diving effect. As a result, the flakes concentrate at the bottom, whence they are removed with the grit.

DEWATERING

As the more finely divided clays filtered so slowly, methods other than filter pressing were tried. The thickened slip was run into large plaster of Paris troughs and dried. Heat was supplied and fans used in order to hasten the evaporation of the water. The method was slow at best, but gave better results with two of the more finely divided clays than did filter pressing.

A barrel of slip (clay G-26) containing 10 per cent solids was run through a Dorr laboratory-size thickener and brought to a solid content of 32 per cent; then it was dewatered in a continuous vacuum filter of the disk type. The cake contained 37 per cent moisture, as against 32 per cent in a pressure filter.

The efficacy of a vacuum filter varies greatly with different clays. The more finely divided the clay the slower the filtration. If a cake one-eighth inch thick can be built up without unduly slowing the operation, the system stands a chance of success. The results obtained with this particular clay seem to indicate that the method could be made an economic success.

Two barrels of slip were sent to the Sharples Co. and put through an experimental filter of the Gee type (centrifugal). Without canvas the filtration was fairly satisfactory, but after a trial had been made of various cloths a very efficient operation was obtained. If the segregation into graded-grain size is not undesirable, and if a price can be demanded for the product which will yield a return on the expensive installation required, the method would stand a chance of success.

During January, 1925, a very interesting process of clay washing was put into operation at one plant; it includes a unique system of dewatering, so far as the clay industry is concerned. The steps involved are: Crushing, wet tube-mill disintegration, cone classification with return of coarse to tube mill, screening, Dorr continuous thickening, rotary-drum (waste steam heat) dewatering, and rotary-kiln drying.

CHEMICAL AND MICROSCOPIC ANALYSES OF THE SEPARATES

CHEMICAL ANALYSES

In order to gain some idea of the efficiency of the washing, chemical and microscopic analyses were made of each of the separates of one of the clays, G-7, later selected for the white-ware tests. Table 2 gives the chemical analysis of the crude clay and of each separate.

TABLE 2.—*Chemical analyses of separates*

	Crude	Grit	Can 1	Can 2	Can 3	Can 4
Ignition loss.....	13.55	11.42	13.06	13.30	13.55	13.47
Silica (SiO ₂).....	44.25	42.29	45.49	44.49	45.10	45.26
Alumina (Al ₂ O ₃).....	38.64	36.28	37.50	37.71	37.91	38.74
Ferric oxide (Fe ₂ O ₃).....	1.45	3.45	1.55	1.59	1.27	1.32
Titania (TiO ₂).....	1.62	5.79	1.86	2.15	1.75	.95
Phosphoric oxide (P ₂ O ₅).....	.05	.02	.07	.05	.05	.02
Lime (CaO).....	.17	.22	.05	.17	.16	.25
Magnesia (MgO).....	.10	.36	.11	.12	.08	.02
Potash (K ₂ O).....	.13	.31	.59	.41	.26	.09
Soda (Na ₂ O).....	.29	.33	.30	.20	.15	.25
Sulphur (S).....	.02	.02	.01	.01	.01	.01
TiO ₂ + Fe ₂ O ₃	100.27	100.49	100.19	100.45	100.29	100.38
Accessory minerals.....	3.07	9.24	3.21	3.54	3.02	2.27
	3.83	10.50	4.14	4.50	3.73	2.91

MICROSCOPIC ANALYSIS

The microscopic analysis of the separates gives a better idea of the efficiency of the washing than does the chemical analysis. A screen analysis of the separates is as follows:

<i>Screen analysis of separates</i>	
On screen No.:	Per cent
8-----	0.195
20-----	.310
65-----	.680
100-----	.242
150-----	.292
Grit separate (bottle)-----	1.072

The difference between the material on the screens was in size of grain rather than in minerals present. The material consisted largely of a fine-grained mineral having an index of refraction of 1.57 (probably bauxitic kaolinite). The accessory minerals included bauxite, quartz, zircon, and black iron oxide.

The most abundant mineral is iron-stained secondary kaolinite. A rather large amount of primary kaolinite is also present, and the following in large quantities: Quartz, zircon, rutile, biotite, and black iron oxide. Tourmaline was a rare constituent.

DESCRIPTION OF SEPARATES IN CANS (SEE TABLE 2)

Can No. 1, 2.043 (whirlpool).—The most abundant constituent is secondary kaolinite. A rather large amount of primary kaolinite is also present. The accessory minerals occur in rather large quantities in this separate; zircon and muscovite predominate. A rather large amount of a black mineral, probably iron oxide, is present. Rutile, quartz, and biotite occur in considerable quantities. A small amount of tourmaline is also found.

Can No. 2, 1.950.—This separate consists largely of iron-stained secondary kaolinite. A rather large amount of primary kaolinite is also present. Considerable zircon, muscovite, quartz, and rutile were found. Of these accessory minerals, muscovite predominated. A small amount of biotite and tourmaline was rarely found.

Can No. 3, 10.400.—This separate consists almost entirely of primary and secondary kaolinite. The secondary is iron stained and imparts a brown color to the clay. Only small amounts of fine-grained accessory minerals are present. Muscovite was found in the greatest quantity. Quartz, zircon, rutile, biotite, and iron oxide were found in smaller quantities.

Can No. 4, 81.816 (settle tank).—This separate consists almost entirely of primary and secondary kaolinite, much in excess of the

former. The secondary kaolinite is iron stained and imparts a slight brown color to the clay. Only very small quantities of fine-grained accessory minerals are present. Very small quantities of muscovite, quartz, zircon, rutile, and black iron oxide composed the accessory minerals that were present.

It is evident from the microscopic analyses that the washing process removes practically all of the accessory minerals and leaves in the clay only that portion which is extremely fine or which is present as a stain on the clay grains. Clay G-7 was chosen for special microscopic examination because it contained more of the accessory minerals and was more badly iron stained than any of the other clays which were washed.

The recovery of washed clay varied from 70.40 per cent in the case of G-4 to 82.18 per cent in the case of G-24. In order that an idea may be obtained of the percentage of the various separates as well as of the final recovery, the percentage removed at the various stages of the washing process is shown in Table 3 following:

TABLE 3.—*Mechanical separation of clay in washing process*

On screen No.—	G-2	G-4	G-15	G-16	G-24	G-26
8.....	0.20	-----	0.089	-----	0.387	-----
20.....	.50	-----	.039	-----	.268	-----
65.....	1.30	0.635	.429	0.20	1.362	0.07
100.....	.75	.185	.420	.20	1.100	.26
150.....	.55	.140	-----	-----	-----	-----
Grit separate (bottle).....	4.00	3.220	2.778	1.20	4.800	1.09
Can 1.....	5.00	2.190	1.857	1.50	-----	1.24
Can 2.....	7.00	5.300	5.034	4.20	1.000	1.46
Can 3.....	9.00	17.930	8.364	17.20	8.900	18.80
Can 4 (settle tank).....	71.70	70.400	80.990	75.50	82.183	77.08
	100.00	100.00	100.00	100.00	100.00	100.00

DESCRIPTION OF THE WASHED CLAYS

On account of the variation of kind and amount of electrolytes in the Columbus city water, which was used for the semicommercial tests, the results plotted in the graphs of Figure 10 were not a safe guide from which to calculate the amount of NaOH which should be added for deflocculation during the large batch washing, because the results there plotted were obtained when using distilled water. The viscosity of each clay is represented by a solid line and the amount remaining in suspension, termed "settle," by a dotted line.

Sample G-1.—Of this clay, 500 pounds was blunged and washed as described previously with 0.24 per cent NaOH. It was found necessary to carry on the blunging for 8 hours before the clay was completely disintegrated and ready to be put through the washer. The speed at which the washer was run was varied between 2 and 5 gallons per minute. Samples were collected during the several speeds, after which color pats were made up and burned. As there

was no variation in color apparent, it seemed safe to assume that the washer could be safely operated between these two limits. The color of the washed clay fired to cone 12 was a light gray, and it gave little promise for use in the white-ware industry. On account of the clay being finely divided some difficulty was experienced in filtering.

Sample G-2.—Of this clay 1,000 pounds was blunged with 0.24 per cent NaOH. The raw clay was a good white color but contained a considerable quantity of bauxite nodules. The clay blunged very readily after deflocculation. In many respects this is a very peculiar clay because the chemical analysis shows it to be bauxitic or diasporic in nature. In spite of this, however, it showed little more tendency to shrink during drying and burning than did the typical kaolins, and exhibited other excellent working properties. Sedimentation was rapid and left a sticky residue in the bottom of the blunger which was difficult to remove during subsequent washing. On the addition of acid the clay settled rapidly to a dense slip, from which the water could easily be decanted. This clay was especially easy to filter-press. The washed clay burned to a good white, as did also a porcelain body containing 30 per cent of the clay.

Sample G-4.—A 1,000-pound batch of this clay was blunged with 0.36 per cent NaOH. The color of the raw clay was a good white but contained considerable material in the form of black specks. It slaked with difficulty and blunged slowly, 10 hours being required for the operation. A number of pebbles settled at the bottom of the blunger. Upon the addition of acid the clay settled more slowly than did G-2 and formed a less dense slip. Filtering was therefore somewhat slower. The washed clay burned to a good white, and when made into a porcelain body the color was only slightly inferior to that of G-2.

Sample G-7.—A batch of 1,000 pounds was blunged with 0.25 per cent NaOH. The color in the raw state was only a fair white; microscopic examination showed it to be badly iron stained, and only a portion of the stain was removed during washing. It blunged and filtered easily. The fire tests showed the color to be inferior to that of G-2 and G-4.

Sample G-9.—One thousand pounds of this clay was blunged with 0.20 per cent NaOH. The color in the raw state was only a fair white; microscopic examination showed it to contain many black specks. The clay blunged easily but filtered slowly. A sticky sediment was deposited in the bottom of the blunger and was removed with difficulty. The fire tests of the washed clay were inferior in color to that of the raw clay, which may have been due to some form

of iron, either carbonate or colloidal hydrate. The color tests were so unsatisfactory that the clay was not tried in the white-ware industry.

Sample G-15.—One thousand pounds of this clay was blunged with 0.30 per cent of NaOH. The color of the clay in the raw state was a good white. It slaked readily and reduced the blunging time to 6 hours. No difficulty was encountered during the washing. On account of the finely divided condition of the clay the filtering was somewhat slower than that of G-2. The fire tests gave a good white color which was comparable to G-4.

Sample G-16.—One thousand pounds of this clay was also blunged. It contained a little grit but was of an exceptionally good white color. Color samples of the crude clay burned to a good white but showed some black specks. No residue remained on screens No. 8 or 20. As indicated by the viscosity tests this clay could be put into a high state of dispersion without the use of electrolyte. The clay blunged very easily and left little residue in the blunger. A predetermined quantity of acid was used to flocculate the clay. It settled rapidly and filtered easily. The washed clay and porcelain bodies made from it burned to an excellent white, free from specks.

Sample G-21.—The same amount, 1,000 pounds, of this clay was blunged. The color in the raw state was only fair. It blunged easily, was very finely divided, and fire tests showed the washed clay to be little improved in color by the operation. As the clay gave no promise for the white-ware industry only a small portion of it was filter-pressed.

Sample G-22.—One thousand pounds of this clay was blunged with 0.30 per cent of NaOH for deflocculation. The crude clay burned to a poor white; it slaked and blunged fairly easily but settled very slowly upon the addition of acid. As the fire tests on the washed clay were unsatisfactory only a portion of the batch was dewatered. On account of the extremely fine subdivision of the clay, filter pressing was exceedingly slow.

Sample G-24.—One thousand pounds of this clay was also blunged with 0.30 per cent of NaOH. This was the hardest clay of all to filter-press because of its very finely divided nature. It blunged rapidly and a very sticky sediment settled in the blunger. The fire tests showed it to be somewhat superior to G-22, but not sufficiently so to justify trying it in white-ware practice.

Sample G-26.—The same amount of this clay was blunged with 0.25 per cent of NaOH. The color in the raw state was a fair white and it burned to a good white. It slaked readily and no special difficulty was encountered during the washing. It filtered easily, comparing in this respect to G-2.

DISCUSSION OF RESULTS

All the clays excepting G-22 and G-24 gave a better color in fired ware after washing than did the crude clays. These two clays exhibited a phenomenon similar to "bluestoning" at cone 12. Many of the clays burned to a good white at cone 4 but developed a decided cream color at cone 12.

The color to which these clays will burn at cone 12 depends largely upon the ratio of the titanium and iron present. If the iron was low, 0.50 per cent Fe_2O_3 , and titanium high, 1.50 per cent TiO_2 , or vice versa, the clay in most cases burned to a fair white. If the same total of iron and titanium was present, but each to the extent of 1 per cent, the color was invariably poor. It is very probable that a titanate of iron is formed at the higher temperatures and causes the brownish tinge to which some of these clays burn above cone 8.

The washed clays containing more than 2 per cent of titanium plus iron oxides failed to give a good color when fired to cone 12. The one exception was G-16.

The percentage of iron oxide found by chemical analysis is not so important in producing a variation from white as the form in which it is present. One of the clays, which contained only 0.90 per cent of iron and low titanium, developed a creamish tinge at cone 4, due to the fact that the iron was present as a stain on the kaolinite grains and was not removed by washing.

CONCLUSIONS AS TO WASHING AND COLOR OF GEORGIA CLAYS

Based on data obtained during the investigation it would seem that:

1. The Georgia sedimentary clays can be washed free from dark-burning material that causes specks in white ware made from them.
2. With proper blending and adequate storage space a uniform product can be put on the market.
3. The burning color of the clays can be improved, excepting in the case of those clays that contain their impurities in the form of colloidal material or stain on the kaolinite grains. This was the case with only two of the white clays investigated.

LABORATORY TESTS OF GEORGIA CLAYS

SAMPLING OF CRUDE CLAYS

Each clay was carefully sampled by repeatedly quartering a ton sample down to 30 pounds. This was disintegrated to pass a 40-mesh sieve and again thoroughly mixed. These samples were used for the following laboratory tests.

PHYSICAL TESTS

These tests included the determination of the customary properties presented in Table 4. The data need no explanation excepting the column headed "color." These numbers represent the relative whiteness of the clays under test. No. 1 represents the best of the Georgia clays; the poorest color, No. 10, was a decided brown.

TABLE 4.—Working properties and fire tests of crude clays

Clay	Crude			Cone 01				Cone 11			
	H ₂ O plasticity	Volume shrinkage	Drying behavior	Volume shrinkage	Porosity	Burning behavior	Color No.	Volume shrinkage	Porosity	Color No.	Deformation cone
	<i>Per cent</i>	<i>Per cent</i>		<i>Per cent</i>	<i>Per cent</i>			<i>Per cent</i>	<i>Per cent</i>		
G-1.....	41.06	24.83	Good.....	20.54	35.75	Good.....	3	40.05	29.20	8	34
G-1b.....	31.20	20.60	...do.....	20.90	39.20	Fair.....	2	44.30	16.50	8	34
G-2.....	31.76	11.56	Poor.....	13.83	50.71	Poor.....	1	25.40	41.25	2	34
G-3.....	35.76	17.05	Fair.....	19.98	38.39	Fair.....	3	42.64	14.07	7	34
G-4.....	33.60	15.40	...do.....	11.76	42.81	...do.....	1	35.04	24.41	2	34
G-5.....	38.50	22.68	Good.....	13.01	41.37	Good.....	2	38.01	22.82	3	34½
G-6.....	44.50	24.97	Fair.....	14.34	43.47	Poor.....	2	47.27	12.65	3	34
G-7.....	35.20	18.71	Good.....	18.10	40.81	Fair.....	2	41.88	13.62	5	35
G-8.....	42.33	28.19	...do.....	14.46	40.14	Good.....	3	35.59	16.37	6	34
G-9.....	38.06	27.40	...do.....	14.68	42.79	...do.....	2	69.07	24.48	5	34
G-10.....	28.60	11.03	Poor.....	12.06	54.15	Fair.....	2	44.77	27.77	6	38
G-11.....	39.66	20.38	...do.....	18.36	42.52	Good.....	3	43.09	24.30	8	35
G-12.....	29.68	14.49	...do.....	13.52	56.24	...do.....	3	47.10	29.56	7	39
G-13.....	32.80	7.53	Bad.....	16.80	49.10	...do.....	3	45.15	27.05	7	37½
G-14.....	33.83	12.90	Poor.....	12.80	36.60	Poor.....	2	47.87	29.46	4	39
G-15.....	38.73	15.83	Fair.....	14.68	44.20	Good.....	1	37.32	25.72	2	34½
G-16.....	43.30	20.90	...do.....	12.69	46.20	...do.....	1	36.43	26.96	3	34
G-17.....	41.90	17.04	Good.....	12.17	46.44	Fair.....	2	34.40	28.55	4	33
G-18.....	28.96	14.21	Poor.....	16.96	50.20	Poor.....	7	55.32	24.00	10	34
G-19.....	42.40	13.34	Bad, bars cracked.			Bad.....	3	52.17	15.51	7	34½
G-20.....	30.13	11.32	Good.....	15.20	48.60	Poor.....	3	44.86	15.93	6	36
G-21.....	49.50	36.46	Poor.....	25.09	40.83	Bad.....	3	44.57	13.94	9	34
G-22.....	38.33	16.55	Fair, bars cracked.			...do.....	2	36.65	11.94	6	34
G-23.....	38.10	26.66	Fair.....	12.61	38.83	Good.....	2	32.09	15.03	7	33
G-24.....	38.23	20.66	Good.....	15.58	42.00	...do.....	1	45.04	14.92	2	34
G-26.....	28.60	16.80	...do.....	14.60	45.80	...do.....	1	35.80	23.80	3	34

All porosity determinations were made in the air expansion volumeter, and are, therefore, slightly higher than porosities determined by the saturation method.

SCREEN ANALYSES

Wet-screen analyses (see Table 5) were made of all of the crude clays. The screens used were Tyler standard No. 65, 100, and 150. Samples from the material on all screens were saved for microscopic examination.

TABLE 5.—Wet-screen analyses of crude clays

Clay	On 65	On 100	On 150	Through 150
G-1.....	8.58	6.32	1.07	84.00
G-1b.....	.007	.003	.008	99.082
G-2.....	7.26	2.27	2.17	88.25
G-3.....	9.54	2.66	5.68	82.11
G-4.....	20.02	2.31	1.77	75.94
G-5.....	1.89	.90	1.01	98.29
G-6.....	5.26	2.49	6.08	86.15
G-7.....	4.46	2.33	2.17	91.02
G-8.....	1.59	1.03	1.12	96.23

TABLE 5.—*Wet-screen analyses of crude clays*—Continued

Clay	On 65	On 100	On 150	Through 150
G-9.....	1.96	1.86	2.45	92.11
G-10.....	25.96	4.22	2.39	66.42
G-11.....	44.10	5.07	4.66	46.15
G-12.....	39.62	4.52	5.73	50.09
G-13.....	39.89	3.06	4.36	52.67
G-14.....	19.37	3.12	4.09	73.41
G-15.....	.22	.33	.62	98.83
G-16.....	.25	.21	.16	99.37
G-17.....	.64	1.42	3.05	94.94
G-18.....	32.50	4.18	6.96	56.34
G-19.....	8.08	3.74	2.55	85.44
G-20.....	10.38	3.07	3.02	73.51
G-21.....	.20	.14	.43	99.23
G-22.....	.45	.34	.13	99.07
G-23.....	1.88	1.41	2.43	94.76
G-24.....	1.12	1.29	.61	96.96
G-26.....	.006	.01	.04	99.89

CHEMICAL ANALYSES

Analyses were made of the 11 washed clays and all of the crude clays excepting G-23 and G-25. These are given in Table 6 following:

TABLE 6.—*Chemical analyses of crude and washed clays*

Clay	Moisture at 105°C.	Ignition loss	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	P ₂ O ₅	CaO	MgO	K ₂ O	Na ₂ O	S
G-1: Crude.....	<i>P. ct.</i> 2.05	<i>P. ct.</i> 12.67	<i>P. ct.</i> 45.61	<i>P. ct.</i> 36.15	<i>P. ct.</i> 1.47	<i>P. ct.</i> 0.77	<i>P. ct.</i> 0.05	<i>P. ct.</i> 0.80	<i>P. ct.</i> 0.30	<i>P. ct.</i> 0.43	<i>P. ct.</i> 0.00	<i>P. ct.</i> 0.02
Washed.....	2.19	12.83	45.76	36.04	1.44	1.36	.06	.15	.36	.19	.00	.02
G-1b: Crude.....	.26	13.73	45.08	38.80	.44	1.60	.03	.13	.06	.07	.10	-----
G-2: Crude.....	.59	19.62	31.79	45.46	.66	1.68	.07	.11	.17	.00	.00	.04
Washed.....	.46	19.09	32.35	46.06	.54	1.40	.04	.14	.02	.00	.11	.04
G-3: Crude.....	1.15	13.53	46.56	35.51	1.59	1.29	.05	.39	.25	.00	.00	.03
G-4: Crude.....	-----	13.25	45.10	38.52	.82	1.55	.03	.02	.10	.00	.00	.04
Washed.....	.69	13.81	45.11	38.59	.60	1.36	.03	.02	.12	.00	.00	.02
G-5: Crude.....	.98	12.73	45.78	37.01	1.11	1.32	.06	.35	.18	.75	.03	.06
G-6: Crude.....	1.09	13.27	45.74	37.05	1.41	1.32	.08	.15	.10	.00	.04	.05
G-7: Crude.....	.99	13.42	43.82	38.26	1.44	1.60	.05	.17	.10	.13	.29	.02
Washed.....	9.15	12.25	41.10	35.13	1.29	.88	.02	.23	.02	.09	.23	.01
G-8: Crude.....	1.33	12.40	97.07	35.52	1.26	1.28	.04	.25	.37	.16	.04	.08
G-9: Crude.....	.69	11.92	50.81	33.61	1.35	1.16	.09	.30	.05	.18	.12	.10
Washed.....	.84	13.43	44.86	38.01	1.20	1.44	.09	.04	.13	.17	.00	.02
G-10: Crude.....	.35	24.07	16.09	55.48	1.77	2.04	.06	.16	.08	.00	.00	.02
G-11: Crude.....	.52	14.13	42.59	38.04	1.59	2.34	.08	.88	.12	.00	.00	.05
G-12: Crude.....	.89	25.89	14.08	55.34	1.65	1.98	.07	.14	.06	.04	.06	.05
G-13: Crude.....	.57	21.97	24.80	47.99	1.92	1.88	.04	.95	.21	.00	.00	.03
G-14: Crude.....	.46	25.41	14.42	56.23	.96	2.34	.01	.31	.12	.00	.00	.06
G-15: Crude.....	.74	13.79	43.25	39.45	.96	1.17	.04	.24	.11	.16	.38	.15
Washed.....	.40	13.67	44.97	38.79	.72	1.20	.03	.11	.02	.25	.00	.03
G-16: Crude.....	.75	13.18	44.86	38.55	1.02	1.03	.07	.21	.10	.51	.08	.02
Washed.....	.73	13.18	45.60	37.63	.87	1.52	.06	.05	.26	.34	.04	.04
G-17: Crude.....	.42	12.29	48.93	35.33	.90	1.44	.08	.30	.21	.34	.14	.01
G-18: Crude.....	.86	23.19	18.10	47.85	7.60	2.08	.05	.26	.29	.00	.00	.02
G-19: Crude.....	.60	13.23	45.56	36.57	.99	1.48	.01	.35	.24	.00	.00	.01
G-20: Crude.....	.53	17.17	35.93	43.32	1.35	1.60	.06	.14	.11	.00	.12	.03
G-21: Crude.....	2.62	11.45	42.66	37.34	1.47	1.04	.04	.25	.07	.17	.13	.16
Washed.....	2.54	14.15	42.68	37.52	1.56	1.32	.06	.02	.08	.22	.19	.18
G-22: Crude.....	.64	13.99	44.14	39.09	.60	1.64	.07	.16	.04	.00	.02	.06
Washed.....	.72	13.92	44.30	38.75	.54	1.72	.07	.08	.10	.00	.00	.03
G-24: Crude.....	.83	13.24	47.83	35.31	1.29	1.60	.02	.07	.05	.00	.04	.01
Washed.....	.82	13.79	44.98	36.93	1.50	1.56	.02	.16	.07	.14	.14	.07
G-26: Crude.....	4.08	12.68	43.50	37.26	.81	1.16	.14	.13	.07	.02	.49	.01
Washed.....	.50	13.69	44.77	38.43	.75	1.52	.13	.07	.17	.18	.13	.07

FIRE TESTS

Tests of working properties and fire tests of a body containing the various washed clays were made. Table 7 shows the results of these tests.

In order to accentuate the effect the clay under test had on the various properties, a body high in test clay was used. The test body used in the tests of the washed clays was made up as follows: Feldspar, 25 per cent; flint, 25 per cent; ball clay, 5 per cent; test clay, 45 per cent.

TABLE 7.—Working properties and fire tests of bodies containing washed clays

	Green				Cone 5½			Cone 12		
	Water of plasticity	Drying shrinkage (vol.)	Casting weight of cup (grams)	Modulus of rupture (pounds per square inch)	Porosity	Shrinkage (vol.)	Color	Porosity	Shrinkage (vol.)	Color
G-1b.....	25.2	13.2	65.2	60	16.3	22.1	3	2.30	28.8	3
G-2.....	25.8	7.17	70.1	55	20.4	24.0	2	6.39	30.9	3
G-4.....	24.8	12.16	60.1	85	14.5	21.3	2	2.80	31.6	2
G-7.....	26.3	15.37	63.5	81	15.4	23.8	4	.32	28.0	4
G-15.....	28.5	21.55	64.2	76	16.7	21.3	2	2.33	28.9	3
G-16.....	28.4	18.20	63.1	70	20.5	20.6	3	3.68	28.6	3
G-24.....	27.2	17.82	65.2	117	14.2	23.2	4	.11	30.9	4
G-26.....	26.0	14.80	68.1	90	16.4	22.4	3	2.12	29.4	3
E.....			62.5	66						
F.....			46.9	177						

The casting tests were carried out by making the bodies up to the same specific gravity and using the amount of electrolyte necessary to bring the slip to minimum viscosity. The slip was allowed to remain in dried cup molds for 10 minutes. The recorded weights are the weight of the cast cup after drying at 100° C.

The modulus of rupture was determined on cast bars, 1 by 1 by 6 inches, over a span of 5 inches.

The color numbers are those of standard bodies used as reference by a large white-ware manufacturer. Standard No. 1 is the whitest body obtainable by the use of specially prepared North Carolina kaolin. No. 2 in the scale is prepared by using a high-grade English china clay as delivered at the plant. No. 3 contains the best Georgia clay as ordinarily delivered. No. 4 is inferior in color to standard No. 3.

The letters E and F refer, respectively, to English china clay and Florida kaolin, which were used for comparison with the Georgia clays.

DISCUSSION AND CONCLUSIONS

1. The best of the Georgia clays are low in fluxes, especially of the R_2O class.

2. Iron and titanium oxides are the most abundant of the metal oxides occurring as impurities in the kaolins, and form the basis for the objectionable color developed in these clays at high temperatures. Due to the high degree of division of these impurities, it is often impossible to remove them by a washing process. This is illustrated in Table 6, in which some of the washed clays show a greater iron and titanium content than the crude.

3. The deformation point of the kaolins is uniformly from cones 34 to 35; the impure bauxites tested ran as high as cone 39; and the bauxitic clays were between these values.

4. The drying and firing shrinkage of the kaolins is uniformly high.

5. The shrinkage of the bauxitic clays is extremely high, amounting at cone 11 to more than 50 per cent by volume in some cases. When used as a grog for refractory brick the clay must be calcined to a much higher temperature than cone 11 and for a long period of time.

6. The kaolins are very fine grained when free of oölites—in several instances more than 99 per cent passed a 150-mesh screen.

UTILIZATION OF SEDIMENTARY KAOLINS OF GEORGIA IN WHITE WARE

GENERAL WARE

Tests were run on two of the clays, G-2 and G-15, after washing at a pottery in the East Liverpool district, Ohio. They were incorporated in semiporcelain bodies, and the body mix was as follows:

Constituent:	Body mix used	Per cent
Georgia kaolin		20.8
English china clay		3.5
North Carolina kaolin		8.5
English ball clay		14.6
Feldspar		14.8
Flint		37.8
		100.0

The bodies were made up into several hundred pieces of ware by ordinary plant procedure. Some were cast, others jiggered, and all were dried, fired, glazed, and decorated in the regular way. The ware included plates, cups, saucers, and creamers.

The ware was bisque-fired to cone 8 in a tunnel kiln in 70 hours. The glost fire was to cone 5 in 30 hours.

No trouble developed during any stage of the process, and the ware was in every way as good as that ordinarily produced.

WALL AND FLOOR TILE

Several of the clays were run through plant practice in floor and wall tile bodies at Zanesville, Ohio, and Olean, N. Y. Clays G-2, G-4, G-7, G-15, and G-16 were used in floor tile, and G-2, G-7, and G-16 were tried in wall-tile bodies.

WALL TILE—FIRST TESTS

As a preliminary survey the body compositions first tried in wall tile were as follows:

	<i>Body mix used</i>	
Mix:	1	2
Cornwall stone.....	12.0	-----
Tennessee ball clay No. 7.....	12.0	8.0
Cooley ball clay.....	12.0	8.0
Clay (experimental).....	30.0	36.0
Flint.....	34.0	36.0
Feldspar.....	-----	12.0
	100.0	100.0

Seventy-five-pound batches of these bodies were blunged for 4 hours and put through a No. 140 screen. The slip was continuously agitated until it was run into the presses, where it was subjected to a pressure of 90 pounds. All bodies filtered easily and formed good firm cakes, which were dried and pulverized to pass 40 mesh.

The tile were made in two sizes, 6 by 6 by $\frac{15}{16}$ inch and 6 by 3 by $\frac{3}{8}$ inch, under a pressure of 50 pounds per square inch in a steam press. The bodies containing G-7 and G-16 pressed well and no loss occurred in the handling and trimming, but the body containing G-2 was weak and broke easily in the "green" state. The moisture content for all the bodies was approximately 9 per cent.

The tile were air-dried and fired in updraft kilns to cones 11 to 12, which were placed inside the saggers.

The 6 by 6 inch tiles received a temperature treatment corresponding to the deformation of cone 11, while the 3 by 6 inch tiles were fired to cone 12. The bisque was then dipped in a clear glaze and fired to cone 1.

The small tile fired satisfactorily but the 6 by 6 inch size cracked badly during the bisque fire. No additional cracks developed, however, during the glost burn. The large shapes made from the body containing G-2 behaved particularly badly in the bisque burn. This

is a peculiar clay which seems to have the working properties of a kaolin, but is above the kaolinite ratio in alumina.

When the data had been examined it was found that these clays varied widely in degree of vitrification and consequently in shrinkage and porosity at cone 11. It was therefore decided to blend the clays in an endeavor to get a body with approximately the shrinkage and porosity desired in the industry, that is, 13 per cent absorption and not more than 5 per cent shrinkage at cone 11.

The percentage of ball clay was decreased in the second set of tests, as the Georgia clays are themselves quite plastic. In three instances the flint was raised somewhat in an endeavor to open up the body. Furthermore, the second set of trial bodies was more thoroughly blunged than was the first set. In no test, however, was sufficient time allowed for the moisture thoroughly to permeate the dried powder prior to pressing.

WALL TILE—SECOND TESTS

The bodies used for the second set of tests were as follows:

Composition of bodies in second test

Constituent	1	2	3	4	5	6
Feldspar.....	12.0	12.0	12.0	12.0	12.0	12.0
Tennessee ball clay No. 7.....	8.0	8.0	8.0	7.0	7.0	7.0
Cooley ball clay.....	8.0	8.0	8.0	7.0	7.0	7.0
Clay G-7.....	36.0	18.0	27.0	36.0	18.0	27.0
Clay G-16.....		18.0			18.0	
Clay G-2.....			9.0			9.0
Flint.....	36.0	36.0	36.0	38.0	38.0	38.0
	100.0	100.0	100.0	100.0	100.0	100.0

PHYSICAL PROPERTIES

Shrinkage (linear).....	7.0	5.6	5.0	6.8	5.5	4.8
Absorption.....	11.7	9.2	13.0	11.7	10.5	15.8
Color.....	C	A	B	C	A	A

The bodies used in the second set of tests were prepared and pressed in the same way as in the first with the exceptions already noted.

The bodies worked equally as well as in the first tests and developed no cracks during drying. When the ware had been drawn from the bisque kiln it was found that the cracking had been decreased, but not eliminated, especially in the larger pieces.

As the dies used were made with allowance of 4 per cent shrinkage, the tiles made from the Georgia clay were all under size. The commercial ware was fired (cone 11) to 13 per cent absorption,

hence body No. 3 had approximately the desired absorption and not an excessive shrinkage. The 6 by 3 inch tile of this composition passed the plant test 80 per cent perfect; while there was a 60 per cent loss in the 6 by 6 size, the 6 by 6 inch went through 40 per cent perfect.

The plant tests of wall tile were then discontinued. Later tests at the Ceramic station of the Bureau of Mines indicated that good results can be expected by blending the clays in the proper ratio and using the blend in amounts of less than 20 per cent kaolin in a body already containing 15 per cent of a primary kaolin.

CONCLUSIONS ON WALL-TILE TESTS

The tile in none of the tests showed a tendency to warp. There were no specks visible in any of the specimens except those introduced by tramp iron. This indicates that the whirlpool washing was effective in eliminating a serious objection raised against Georgia kaolins.

The color of the glazed ware made from the different clays was, in order of whiteness, G-2, G-16, and G-7. While not as chalk white as one or two of the commercial makes, which may have contained blue stain, the color of the tile made from G-2 and G-16 is nevertheless good white ware. The tile made from G-7 had a slight ivory tinge but was as good a white as several of the commercial wares. No blue stain was used in the trial bodies.

About 20 per cent of properly blended mix of the Georgia sedimentary kaolins can doubtless be used in wall-tile bodies, but inasmuch as these kaolins are almost lacking in free silica the flint should be increased accordingly.

The sedimentary kaolin as prepared by Sproat¹² was tested under plant practice in the wall and floor tile industries where they are reported to have given satisfactory results.

FLOOR-TILE TESTS

Two floor-tile bodies were tested under regular plant practice. Body A was prepared in the same manner as were the first wall-tile bodies, and body B was weighed and ground wet in a test mill, after which it was filter-pressed. From this point on the process was identical with regular plant practice.

Five clays were tested: Three in body A, G-2, G-7, G-16, and two in body B, G-4 and G-15.

¹² Sproat, I. E., *Refining and Utilization of Georgia Kaolins*; Bull. 128, Bureau of Mines, 1916, 59 pp.

Compositions of the vitreous floor-tile bodies were as follows:

Composition of floor-tile bodies

Body A:		Body B:	
Erwin feldspar	45	Feldspar	40
Flint	15	Flint	20
Clay (experimental)	30	Clay (experimental)	30
Kentucky ball clay No. 4	10	Tennessee ball clay	10
		Heavy MgO	1

Body A was molded in two sizes—1 inch hexagons and $2\frac{1}{6}$ by $2\frac{1}{8}$ by $\frac{1}{2}$ inch shapes. The dust was pressed in hydraulic presses under a pressure of 2,000 and 1,600 pounds, respectively. No loss occurred through handling or trimming. Body B was pressed into shapes $\frac{1}{2}$ by 1 by $\frac{1}{2}$ inch.

The tile made from body A was air-dried and burned in saggers to cone 12 in an updraft kiln. The ware came from the kiln in perfect condition. There were no losses from warping or cracking. The tiles with G-7 and G-16 showed greater vitrification than did the regular body, and the color with these was not quite so good as that of the regular ware. G-2 body was very white and compared favorably with the regular product. All tile made from the different bodies showed zero absorption.

G-4 and G-15 made into body B after the same practice as that used in the manufacture of body A from the point where the dust was pressed gave even better results, as they were burned to cone 10 to 11 instead of cone 12. The color was somewhat better than that of tile made from G-7 and G-16. They were also whiter than the regular commercial ware made at the plant, but the finish was not so good, due, no doubt, to the fact that the body was prepared in small batches and not as well granulated as the regular body prepared mechanically in large batches. Some of the commercial body was also prepared in the same manner and put through the process in exactly similar manner to the bodies under test. This lacked the gloss which it has when prepared in the regular way. Both the floor-tile bodies made from Georgia clay were whiter than the commercial bodies so made.

There was no loss in the floor-tile bodies made from the Georgia clays through drying or burning at either plant. All five clays are well suited for use in manufacture of vitrified tile.

CONCLUSIONS REGARDING UTILIZATION OF GEORGIA KAOLINS IN WHITE WARE

1. The use of Georgia (sedimentary) kaolins in the several white-ware industries is no novelty. They have been used in virtually every type of pottery body, both dry press and plastic, where a china

clay is required. In some cases they have been used successfully, while in others their use has been discontinued because of various reasons more or less warranted.

2. Their use has been abandoned by some chinaware manufacturers principally because of lack of uniformity. Many of the clays burn to a good white, while many others which burn to a cream color could be produced white enough to meet requirements if the proper care were taken in their mining and refining. However, some of the clays are so stained with colloidal iron oxide that their color can not be improved by washing. Bleininger states that the slight variation from white shown by these clays can be corrected by the use of cobalt stain. Most of the Georgia clays are produced for the filler trade where whiteness in the raw state is all important and the burning color is of no consequence. A more serious effort should be put forth by the producers to cater primarily to the pottery trade by producing in quantities, uniform as to color and working properties.

3. These clays have been used extensively in the sanitary tile and electrical porcelain industries. Some manufacturers have not used Georgia sedimentary kaolins in these wares because black specks developed during the firing in the trials. The tests completed on clays washed at the Ceramic station of the Bureau of Mines prove that the latter difficulty can be overcome by proper washing.

4. A serious problem in connection with the use of sedimentary clays in white ware is the high bisque loss and excessive shrinkage. These difficulties can, it seems, be largely overcome by proper body mixes and by the blending of the clays. These clays analyze close to theoretical kaolinite in alumina and silica, and therefore contain almost no free silica, and bodies containing them require a higher flint content than bodies containing primary kaolins. A higher flint content improves whiteness.

5. Georgia clays, as pointed out many times, are very different from English clays in physical structure and to a less extent in mineralogical constitution, hence they can not be expected simply to displace the English clay in a ceramic body. It is a peculiar fact that no one ever suggests substituting entirely Florida for English clay, but to the author's knowledge Georgia clays have been condemned in many cases because they will not substitute pound for pound in a plastic body for the imported clay. Florida clays have been used judiciously and have gained a reputation for possessing two very desirable qualities, namely, workability and strength. On the other hand, they do not cast so rapidly as do the best Georgia or English clays. The more desirable Georgia clays cast as rapidly as do the English china clays and improve the workability of the mix nearly as well as do the Florida kaolins.

CONCLUSIONS REGARDING GEORGIA AND ENGLISH CLAYS

1. As indicated by tests made in two plants, washed Georgia clays can be used to advantage to displace all of the English china clay in a vitrified dry-press body of small size, such as floor tile.
2. The washed clay can be used to displace a portion of the china clay in a porous dry-press body such as wall tile up to about 20 per cent of the batch. However, the extent to which the displacement may safely be carried depends largely upon the shape and size of the ware.
3. The amount of the sedimentary clays that can be used in plastic bodies is much less than in a dry-press body and should probably not exceed 10 to 15 per cent of the batch. The amount will vary with the ware being manufactured.
4. The proper blending of the clays, together with judicious body mixes, will render the Georgia clays much more available for white-ware purposes. An increase in flint in bodies containing Georgia clays is essential to obviate crazing of the glaze, reduce shrinkage, and incidentally to improve whiteness.
5. The color of ware made from a properly washed clay is about equal to that of ware from the usual grade of china clay, and it is only slightly inferior to that of ware from the highest grade of English clay and domestic primary kaolins.

UTILIZATION OF GEORGIA CLAYS IN REFRACTORIES**IMPORTANCE AND SUPPLY OF CLAY**

Of the different raw materials used in the manufacture of refractories, clay must be relied upon in the future, as in the past, to supply the bulk, because of its abundance, wide distribution, and broad application.

It has been stated that supplies of the best fire clays of Pennsylvania, Maryland, Ohio, and Kentucky within reach of the railroads are decreasing, and the average quality of the fire-clay refractories classed as No. 1 has fallen off within the last 15 to 20 years. It must, of course, be recognized that there are fire-clay refractories on the market at the present time as good as any in the past, but the bulk of such, as a class, has evidently decreased in refractoriness.

Several plants have experienced difficulty in finding sufficient flint clay of good quality to supply their needs, while others have exhausted their No. 1 plastic clay and have been compelled to use bond clays of lower refractory value. Some plants are bonding their high-grade flint clays with plastic clays deforming at cone 29 and lower. Bleiningger and Brown¹³ have pointed out that a fire brick under load at furnace temperatures is no better than its bond.

¹³ Bleiningger, A. V., and Brown, G. H., "The behavior of fire bricks under load conditions at a temperature of 1,300° C.": Trans. Am. Ceram. Soc., vol. 12, 1910, p. 341.

The broader application of the electric furnace to metallurgical and chemical industries, the development of new processes, automatic stoker-fired boilers, and the extended use of forced draft to furnaces have created a demand for a more serviceable fire brick of higher refractory value. Such a brick can be made from kaolins and highly aluminous clays.

GEORGIA KAOLINS

The kaolins are plastic and mold readily, and many of them show a fairly good dry tensile strength. As the alumina content of the clays increases above the kaolinite ratio their plasticity and tendency to slake decrease and, with rare exceptions, their iron content increases with the alumina. Kaolins and bauxitic clays, which may not be suitable for fillers or pottery, fuse at a very high temperature and therefore are valuable for the manufacture of refractories.

Bleininger and Brown also point out the advantages of using the same clay for grog and bond, as follows:

As to fire brick made from a clay material which is sufficiently plastic so as to be used alone, it is clear that its ability to carry loads depends simply upon its composition. Some of the very best tests have been obtained on materials of this kind. * * *. Such a clay will stand up or fall by virtue of its own quality. A pure clay of moderate plasticity would be the ideal material for the manufacturing of fire brick.

In the fire-brick industry most of the flint and plastic fire clays are obtained by underground mining, which is comparatively expensive. Often it is necessary to move considerable inferior clay to obtain the desirable refractory clay, and a ton of inferior clay must be moved to get a ton of No. 1 clay. The cost of clay delivered at the plant may vary from \$1 to \$2 per ton and in some cases it amounts to even more.

The kaolins and bauxites of Georgia are essentially surface deposits which have been covered with an overburden that varies from 3 to 40 feet in depth. Several deposits of substantial thickness have comparatively thin cover. One deposit in particular is 28 to 40 feet in thickness and has a cover ranging from 1 foot, along a ravine, up to 14 feet and averaging about 8 feet over an area of probably a square mile. Such a clay can be mined by stripping and delivered to the plant at a cost of approximately 20 to 30 cents per ton.

LABORATORY TESTS

Thirteen clays were tested for refractory purposes, as follows: G-1, G-3, G-5, G-7, G-10, G-11, G-12, G-13, G-14, G-15, G-19, G-20, and G-23. The chemical analyses and deformation cones have already been given (p. 42). In Figure 19 are plotted the $\text{RO-Al}_2\text{O}_3\text{-SiO}_2$ ratios of the several clays. The iron is figured as FeO . TiO_2 , P_2O_5 , and S are omitted from the calculations shown in the

diagram. These clays seem to owe their high refractoriness in most part to their low RO in general, and in particular to low alkali content. RO is here used to represent oxides, either monovalent or divalent.

Besides the ordinary laboratory tests to determine the physical properties of these clays, full-size brick were made and tested under load at furnace temperatures, spalling tests were run, and porosity determinations made. The brick were made from a mixture of 60 per cent 10-mesh grog calcined to cone 13, and 40 per cent of the same raw materials as bond. The brick were molded dry press and fired to cone 14. The physical characteristics of the clays are shown in Table 5 and the physical characteristics of the brick made from the several clays and bauxites and burned to cone 14 are shown in Table 8.

TABLE 8.—*Result of tests of dry-press brick*

Sample No.	Deformation temperature cone No.	Porosity at cone 14	Spalling loss after 10 immersions	Load test, 50 lbs. per square inch at 1,420° C.
	<i>Per cent</i>	<i>Per cent</i>		
G-1-----	34	28.28	0.50	Without failure.
G-3-----	34	28.78	.00	Do.
G-5-----	34½	33.55	.17	Do.
G-7-----	35	27.79	.34	Do.
G-10-----	38	44.20	13.15	Not tested.
G-11-----	35	39.32	16.95	Do.
G-12-----	38+	42.65	22.40	Do.
G-13-----	38	43.75	25.15	Do.
G-14-----	39+	42.81	18.30	Do.
G-15-----	34+	35.83	.58	Without failure.
G-19-----	34+	41.45	14.15	Do.
G-20-----	35+	36.87	.52	Do.
G-23-----	33	35.48	9.25	Do.

Samples G-10 to G-14, inclusive, and samples G-19, G-20, and G-23 are bauxitic and should have been calcined at a much higher temperature. The bricks made from these materials were friable and of a weak structure, and should be burned considerably above cone 16 in order to give them the mechanical strength to withstand spalling and load. They are comparatively low in plasticity, and hence do not mold as readily as a kaolin-bonded brick.

A second lot of brick was made from bauxites, G-10 to G-14, inclusive, and tested for spalling and load capacity at furnace temperatures. These brick were made dry press from a mixture of 70 per cent of the bauxite calcined to cone 14 and bonded with 30 per cent of kaolin G-3 and the brick fired to cone 16. Results of the tests are shown in Table 9.

TABLE 9.—*Result of tests for spalling and load capacity*

Sample No.	Porosity	Spalling loss	Load test, 1,350° C.
	<i>Per cent</i>	<i>Per cent</i>	
G-10-----	36.80	5.62	Failed at 691 lbs. per square inch.
G-11-----	16.05	...	Cracked in burning. Not tested.
G-12-----	31.60	.39	Failed at 847 lbs. per square inch.
G-13-----	35.40	1.68	Failed at 870 lbs. per square inch.
G-14-----	39.20	5.14	Failed at 640 lbs. per square inch.

Even though bonded with kaolin and fired to cone 16 these brick were not burned hard enough to give them best strength and lowest spalling loss. Their appearance indicated that they would have been improved if burned at cone 18. In spite of this the brick made from G-12 and G-13 gave good results in both the spalling and load tests.

LARGE-SCALE TESTS OF SAMPLE G-3

As kaolin G-3 is a hard clay and typical of a number of deposits of the Georgia coastal plain it was selected for the large-scale tests. A carload was shipped to a large fire-brick plant and made into standard-size fire brick by the slush-mold re-press process in the regular manner. These brick were made from 60 per cent of the clay calcined, in "dobies," to cone 14 and 40 per cent of the raw

FIGURE 19.—Relation of RO-SiO₂ content refractoriness

clay as bond. The calcined and raw clays were ground together and tempered without screening, according to regular plant practice. In spite of the high grog content the brick dried very slowly. They remained on the dry floor twice as long a period as was plant practice before they were in proper shape for re-pressing. After re-pressing (hand) they remained on the dry floor twice as long as the low-grog flint fire-clay bricks being made at the plant. The fine-grained highly plastic nature of the clay accounts for the slow drying. The brick were burned in a new castle kiln in three benches to cones 10, 11, and 14. The total linear shrinkage of the cone 14 brick, calculated on the burned length as basis, was 5.67 per cent. Approximately 50 per cent of this was drying shrinkage and 50 per cent burning shrinkage.

The average weight of several standard-size kaolin fire brick was $6\frac{1}{2}$ pounds, compared to an average of 7 pounds of standard-size fire-clay fire brick. The difference of one-half pound per brick therefore means a saving of 500 pounds per 1,000 brick, an item which comparatively reduces freight cost materially. Every ton saved in the refractories for boiler settings in naval craft and ocean-going liners means a ton increase in displacement for ammunition, fuel, or freight.

Spalling or load tests at furnace temperatures were made of brick burned at cone 14 in comparison with a well-known Pennsylvania flint fire-clay brick of excellent qualities. Results of these tests are given in Table 10.

TABLE 10.—*Comparison of clay G-3 and Pennsylvania flint fire-clay brick*

Brick	Deformation temperature, cone No.	Porosity	Spalling	Load at 1,350° C.
G-3-----	34	<i>Per cent</i> 34.0	<i>Per cent</i> 2.22	Withstood 733 pounds per square inch without failing (maximum capacity of machine). Failed at 485 pounds per square inch.
Pennsylvania-----	31	20.8	1.52	

SERVICE TESTS OF SAMPLE G-3

IN MALLEABLE IRON FURNACE

A bung of 40 G-3 brick burned at cone 10 was tested in a malleable iron furnace. The bung was tested in the most severe position in the furnace, which is directly above the bridge wall where the fire gases leave the furnace and start their passage over the hearth and burden of metal to be melted. When operating at one heat per day the furnace is heated and cooled slowly so that the conditions are not severe on the brick, but when operated at two heats per day the heating and cooling are done rapidly, thus imposing more severe treatment upon the brick and their life is thereby materially shortened.

Two brands of fire-clay brick, one from Pennsylvania and one from Missouri, had been found by the steel plant where the tests were made to give maximum service. When the furnace was operated at 1 heat per day these brick would last for 18 or 19 heats, but when the furnace was operated at 2 heats per day their life averaged only 11 heats.

The G-3 brick withstood 11 heats, with the furnace operating at 2 heats per day. The brick showed no evidence of failure through corrosion, as was the case in the two commercial brands, but they

failed through spalling. The brick (cone 10) used showed an average porosity of 32.8 per cent and a spalling loss of 7.98 per cent, compared to 32 per cent and 2.22 per cent, respectively, for the brick burned to cone 14. Even though these brick were not burned hard enough to withstand spalling, they gave as good service as the best bung brick the plant has been able to obtain. A bung of 40 brick burned to cone 14 was later tested and lasted through 11 heats. The brick were in much better condition at the end of the test than were the cone 10 brick, but they were replaced at the end of the week's run, as they would not have lasted more than a heat or two longer.

FIGURE 20.—Brick removed from bung after 11 heats; left, kaolin; right, fire clay

The condition of the cone 14 brick, as compared to the Pennsylvania brick at the end of the test, is shown in Figure 20.

IN ELECTRIC FURNACE DOORS

Tests were made of the G-3 fire brick placed in a door of a 3-ton Ludlum electric steel-melting furnace. After a long series of experiments on different types and brands of brick the plant has adopted a silica brick as the one giving maximum service.

The furnace is provided with two doors, one at each side. One door was lined with silica brick and the other with G-3 kaolin brick. Brick in these doors, in addition to being subject to a high temperature, must withstand the cutting action of slag and metal which is continually thrown against them by the furnace arc.

The silica brick failed after 48 heats as compared to 62 heats for the G-3 brick, an increase of 14 heats, or almost 30 per cent. When the two doors were removed their appearance was substantially the same. Records of tests at the plant show that fire-clay fire brick fail on the average after about 35 heats.

The kaolin brick showed no tendency to spall. Failure was finally due to corrosion of the door at the bottom until it was too thin for safety.

There was almost no penetration of the slag, as is clearly shown in Figure 21, which is a photograph of the brick removed from the badly corroded portion of the door.

IN ELECTRIC FURNACE ROOF

The third span from the door in the silica-brick crown of the Ludlum electric furnace was laid up with the kaolin brick in order

FIGURE 21.—Kaolin brick removed from electric furnace door at end of sixty-second heat

to compare their service with the silica brick. Practice at this plant was to operate a roof for two weeks and put in a new one over the week end. At the end of the two weeks the brick would often be good enough to last much longer, but as only one furnace was in operation no chances were taken of having a roof fail during the week. As the roof with which the test was being run was in good shape at the end of two weeks it was decided to use it for another week in order to make the test more severe.

The entire crown was in fairly good shape at the end of the third week. The kaolin brick were in as good shape as the silica brick on either side of them. Figures 22 and 23 show brick removed from the crown at the end of the test. The silica and kaolin brick were side by side in the setting. It will be noted on the portion broken

from the brick that there has been less penetration of the kaolin than of the silica brick.

IN LADLE LINING

Tests were run to determine the behavior of these brick in ladle linings. Fifteen of the brick were placed in the bottom of an open-hearth ladle, where difficulty is experienced in getting ordinary fire brick to "hold up" against the temperature of molten steel and the water-cooling between heats. Under this treatment ordinary fire brick fail after two or three weeks through spalling and disintegration. The brick were placed in the bottom of a 20-ton steel foundry ladle and gave a service of 15 weeks without showing signs of spall-

FIGURE 22.—Silica brick removed from roof of electric furnace after three weeks' service

ing or crumbling. As the ladle was completely rebuilt at the end of this period, the test was incomplete.

IN BOILER SETTING

Trouble was being experienced in obtaining proper refractories for the side walls in a stoker-fired fire box at the heating plant at Ohio State University, Columbus. Carborundum brick are used along the clinker line and give good service, but through local heating produced by faulty operation of the stoker the fire-clay brick immediately above the fuel bed were dripping badly. One hundred of the kaolin brick fired to cone 14, which were placed in a side wall immediately over the carborundum, stood up well, while a Kentucky

fire brick, recommended for the service by a local dealer, was cut away badly on both sides of the kaolin brick. The lower brick in the panel, which were subjected to a rather severe slag action, showed less superiority to the flint-clay brick than did the brick in the upper part where the slag action was less severe.

IN KILN DOOR

An outstanding feature of this refractory has been brought out in use in the wicket of a high-temperature, cone 30, experimental kiln in which they can be used over and over again without shrinking or becoming brittle, while any other type of clay brick, including the high aluminous, will serve for only a few heats.

FIGURE 23.—Kaolin brick removed from roof of electric furnace after three weeks' service

IN OIL-FIRED FURNACES

Two hundred of the G-3 brick fired to cone 14 were laid up in a checker baffle in the combustion chamber of an oil-fired Wickes vertical tube boiler. The flame was supposed to impinge on a target before coming in contact with the baffle, although at times the flame licked the wall. A temperature of 2,800° to 3,000° F. was said to exist at the baffle. The best grades of fire brick had a life of 48 to 96 hours, depending upon the length of the oil flame. The kaolin brick held up fairly well for about 8 days, although they began to pull away from the walls after 48 hours, evidently through shrinkage. Highly aluminous brick held up somewhat better than the kaolin brick under the same circumstances. The failure

in all cases was due to the intense heat and the corrosive action of the oil flame.

The test was not very satisfactory, as the failure was so gradual that no end point could be determined. The life of the different refractories tried varied greatly among themselves, depending on whether the flames actually impinged upon the brick being tested.

CONCLUSIONS REGARDING REFRACTORINESS OF GEORGIA CLAYS

1. The Georgia sedimentary kaolins, bauxitic clays, and bauxites tested show deformation values from cones 34 to 39, superior load-carrying capacity, and good resistance to spalling. The resistance to slag is not very different from a high-grade clay fire brick.

2. Enough work has been done to demonstrate that these refractory materials can be made into brick in a practical way, both by the dry-press and slush-mold processes.

3. Furnace tests under actual working conditions have shown that the service rendered by fire brick made from Georgia sedimentary kaolins was at least equal to and in the majority of cases superior to that of fire clay and silica brick.

4. Inasmuch as the high-grade accessible fire clays are waning, the average quality of the fire brick decreasing, and the demand for better fire brick increasing, it would appear that the future of the fire-brick industry lies in the utilization of the sedimentary kaolins, bauxitic clays, and bauxites of the coastal plain. Vast areas are underlaid by deposits of such substantial thickness that there is enough high-grade material to meet the needs of the refractory industry for years to come.

UTILIZATION OF GEORGIA CLAYS IN FACE BRICK

OCCURRENCE, QUANTITY, AND QUALITY

Throughout the southeast, and more especially in the coastal plain States, no clays have been found from which face brick, light cream to clear buff and light gray in color, can be made. Large quantities of such brick are used in this territory for building purposes and substantially all are shipped in from north of the Ohio and Potomac Rivers.

These desirable light-colored brick carry a freight charge of \$18 to \$20 per 1,000, which makes their delivery cost up to about \$48 to \$50 per 1,000, as of December, 1924.

Clays in Georgia suitable for the manufacture of face brick of red through brown to gun-metal hues are comparatively scarce. These are confined mostly to the variable clays derived from the

decomposed granites, to alluvial clays more or less sandy and irregular, and to shales in a small area in the northwestern corner of the State.

The bulk of the cream, buff, and gray brick which find their way into the southern market are made from No. 2 fire clays, generally obtained by underground mining. The coal-measure clays of the South, and more especially those of Georgia and Alabama, are high in iron and burn to a dark color not at all comparable to the light-colored brick made from the fire clays of the Freeport, Mercer, and Kittanning formations of Ohio and Pennsylvania. For several years brick manufacturers have been searching the South for clays from which buff and lighter shades of brick could be made, but so far their efforts have not been rewarded.

The geology of the country indicates that no clays are likely to be found which in themselves will produce brick equal to those made from the No. 2 fire clays of Ohio and Pennsylvania. The best possibility of producing such brick would seem to be to utilize the sedimentary kaolins of the coastal plain in a synthetic mixture by adding the necessary fluxes they lack.

The refractoriness of the Georgia clays is due mainly to their low content of fluxing impurities. It would, therefore, be impractical to make face brick from these kaolins alone, because the temperature required to burn them dense to vitrified would be too high to attain economically. Even when burned to a vitrified condition the shrinkage is so great that warping and cracking are excessive.

In the Piedmont Plateau to the north (see fig. 1), and bordering the kaolin beds of the coastal plain, are comparatively large bodies of aplite, a granite consisting chiefly of quartz and feldspar, which range from a few feet to over 1,000 feet in width. Microscopic examination of several specimens indicates that the component minerals are principally orthoclase, albite, microcline, and quartz. The iron content, expressed as Fe_2O_3 , ranges from 0.5 to about 2.0 per cent, and the combined alkali and alkaline-earth content from 6 to 14 per cent.

Chemical analyses of samples of aplite from different localities show considerable variation in composition. The rock does not burn to a sufficiently good white to be useful for high-grade ceramic products. No important use has been found for it except locally where the partly weathered outcrop is used as road material.

These aplites contain the fluxes lacking in the kaolins, and by mixing the two in proportions that give the desired fluxing action and adding enough quartz sand (usually found below the clays) to control the shrinkage, it would seem that they could be used for face brick ranging in color from a light cream or light buff to light gray.

The color would depend on the iron content in the raw materials and the heat treatment.

SMALL-SCALE TESTS

The first tests were made with small trial pieces and were followed by large-scale tests in which full-size brick were made under the conditions of practice.

APLITE USED

Preliminary experiments were made to determine the fluxing effects of different aplite samples on the kaolin. Four different samples of aplite, designated M-1, M-2, M-3, and M-4, were taken from different exposures occurring in a railway cut near Milledgeville, Ga. Sample M-1 was from an exposure where the weathered part has been removed for road dressing. It was hard, unweathered, and dull pink in color. It softened at cone 12 and formed a light-gray porcelainlike glass. The chemical analyses and empirical formula of M-1 are as follows:

Chemical analyses of aplite M-1

Constituent:	Per cent	Constituent:	Per cent
Moisture at 105° C-----	0.02	Lime (CaO)-----	0.54
Ignition loss-----	.44	Magnesia (MgO)-----	.11
Silica (SiO ₂)-----	84.00	Potash (K ₂ O)-----	3.13
Alumina (Al ₂ O ₃)-----	8.93	Soda (Na ₂ O)-----	2.66
Ferric oxide (Fe ₂ O ₃)-----	.50		
Titania (TiO ₂)-----	.02	Total-----	100.37
Phosphoric oxide (P ₂ O ₅)---	.02		

FORMULA

0.376 K ₂ O	}	{	0.988 Al ₂ O ₃	}	15.6 SiO ₂
0.484 Na ₂ O					
0.109 CaO					
0.031 MgO					

Calculation from the formula indicates that the aplite is composed of the equivalent of approximately 16.82 per cent orthoclase, 22.83 per cent albite, 6.49 per cent anorthite,¹⁴ and 51.86 per cent quartz. No chemical analyses were made of samples M-2, M-3, and M-4, which were partly weathered and somewhat iron stained along the seams. Their deformation temperatures were cone 12 for M-2 and M-3 and cone 9 plus for M-4. M-2 and M-3 when fused were light brown; M-4 was apparently more iron stained and fused to a darker color.

¹⁴ For convenience the alkaline earths are calculated as anorthite although they probably do not occur in that form. The Fe₂O₃, TiO₂, and P₂O₅ are evidently impurities.

CLAYS USED

For the preliminary tests, kaolins G-3, G-8, and G-15 were selected, and for the large-scale tests, kaolins G-8 and G-35. The chemical analyses and deformation temperature of these kaolins are as given in Table 11.

TABLE 11.—*Chemical analyses and deformation temperatures of kaolins used in face-brick tests*

	G-3	G-8	G-15	G-35
Moisture (105° C.)	1.15	1.33	0.74	-----
Ignition loss	13.33	12.40	13.79	13.85
Silica (SiO ₂)	46.56	47.67	43.25	44.26
Alumina (Al ₂ O ₃)	35.51	35.52	39.45	40.11
Ferric oxide (Fe ₂ O ₃)	1.59	1.26	.96	.71
Titanium (TiO ₂)	1.29	1.28	1.17	.90
Phosphoric oxide (P ₂ O ₅)	.05	.04	.04	-----
Lime (CaO)	.39	.25	.24	-----
Magnesia (MgO)	.25	.37	.11	-----
Potash (K ₂ O)	.00	.16	.16	.43
Soda (Na ₂ O)	.00	.04	.38	-----
Sulphur (S)	.03	.08	.15	-----
Cone No.	34	34	34	34

PRELIMINARY TESTS

For the preliminary tests, G-15 was used in combination with the four different aplites ground to 65 mesh and with potter's flint in the mixtures given in Table 12.

TABLE 12.—*Group 1. Mixtures for preliminary tests*

No.	G-15	Aplite	Flint
1.	55	45	0
2.	50	50	0
3.	45	55	0
4.	50	40	10
5.	50	35	15
6.	50	30	20

The mixtures were kneaded to a good plastic condition. The trial pieces were molded by hand in the form of 2-inch cubes which were dried and then fired to cone 6.

There was comparatively little difference in the appearance of the trials made from the same aplite. Trials containing M-1 were a cream color; those containing M-2, M-3, and M-4 were light buff. All showed a few fine black specks. The structure of the trials appeared to be good, even though their porosities were comparatively high. Trials containing 50 to 55 parts aplite and 45 to 50 parts clay showed lowest porosity, the average being 19.3 per cent. At cone 6 trials containing M-4 did not differ much from the others in porosity, even though the deformation temperature of M-4 was three cones lower.

RESULTS OF BURN TO CONE 12

To produce a vitrified condition and to observe its influence upon the color and general appearance, a duplicate set of Group I was burned to cone 12. Trial pieces were also placed in the kiln in order to note the behavior of kaolins G-3 and G-8 in combination with the four different aplites. These mixtures were composed of 50 per cent kaolin and 50 per cent aprite and were designated as Group II.

At cone 12, the colors ranged from a gray white in trials containing M-1 aprite and G-15 kaolin to a medium gray in trials containing M-4 aprite and G-3 kaolin. The fine black specks were developed more prominently and gave the trials an appearance not unlike light-colored, fine-grained granite. To the eye, the structure of the trials was dense and well vitrified, although the average porosities of the different mixtures ranged from about 4 to 14. The porosity is evidently due in part, at least, to the grinding being coarser and to the structure being coarser than for true porcelain. Table 13 compares average porosities of trial pieces containing different aprites and fired to cone 12.

TABLE 13.—*Comparison of average porosities*

Aprite sample	Average porosity, Group I	Average porosity, Group II	Average porosity, Groups I and II
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
M-3.....	4.61	5.12	4.74
M-1.....	5.69	5.14	5.55
M-2.....	7.52	9.37	7.98
M-4.....	11.35	14.20	12.06

The fluxing values of the four different aprites, as indicated by the porosity determinations, were quite different, as Table 13 shows. Compositions containing M-3 showed the lowest porosities and those containing M-4 the highest. No satisfactory reason why M-4 had the lower fluxing value is evident in view of its having the lower deformation temperature.

FILL-SIZE TRIALS OF BRICK

For making standard-size brick, clays G-3 and G-8 were selected, mainly because neither was considered good enough for white ware and because both represented properties that were undeveloped. Any of the clays of similar character would probably have given similar results. Inasmuch as there was not enough of any one sample of aprite left for full-size brick tests, the residue of the four aprites from the preceding tests was mixed and ground to pass 65 mesh.

The proportion of M-4 much exceeded that of the others; in fact, it formed about 75 per cent of the mixture.

Mixtures of each kaolin, G-3 and G-8, and aplite were made, consisting of 50 parts kaolin and 50 parts aplite. Part of the mixes was molded dry press on a small hydraulic machine while the remainder was tempered to a plastic condition, molded by hand, and re-pressed.

The brick were dried and burned to cone 10 and shrinkage and porosity determinations made, as shown in Table 14.

TABLE 14.—*Total linear shrinkage and porosity of brick made from kaolins G-3 and G-8 with aplite*

Clay and process	Shrinkage	Porosity
	<i>Per cent</i>	<i>Per cent</i>
G-3 (dry press).....	5.00	22.50
G-3 (re-press).....	7.86	21.70
G-8 (dry press).....	4.29	16.40
G-8 (re-press).....	8.57	16.45

No serious difficulties occurred in drying or burning. The brick seemed to be of good color and sound structure. The re-pressed brick were cream gray; the dry-press brick were gray. Brick containing kaolin G-8 were lighter colored than those containing G-3. All showed a few fine black specks.

LARGE-SCALE TESTS

The small-scale tests indicated the possibility of making face brick from kaolin and aplite rock containing sufficient alkalies and alkaline earths to produce the desired fluxing action. The next step in the investigation was to determine the working properties of such mixtures when molded in regular dry-press and stiff-mud machines and to determine the behavior of the brick in drying and burning. For the large-scale tests 8 tons of material was shipped to the testing department of the Hadfield-Penfield Steel Co., at Bucyrus, Ohio, where the tests were made under the direct supervision of the authors.

CLAYS USED

Two tons of each kaolin, G-8 and G-35, were taken from the deposits in such manner as to give fair average samples. Both kaolins are very plastic, but differ considerably in other properties. As previously mentioned, G-8 belongs to the semihard class. It does not burn to a good white and is not used for pottery or filler purposes, but it has good bonding strength; G-35 is a soft kaolin; it burns to a good white and is sold to both the pottery and filler

trades, but it has low bonding strength. It is one of the extra clays tested for filler use and is described in more detail in Bureau of Mines Technical Paper 343. It came from McIntyre, Ga.

APLITE USED

Four tons of aplite was quarried from the same dike from which sample M-3 was previously taken for the small-scale tests. The railroad cuts the dike at about right angles giving an exposure approximately 12 feet deep and about 400 yards wide.

The 4-ton sample was taken about 3 feet in from the face and 6 to 7 feet down from the top. The sample was light pink to cream color; although hard it was partly weathered and iron stains and thin films of clay showed in the seams.

As no fine-grinding equipment of sufficient size was available, the sample was first shipped to a plant where it was ground to pass 60 mesh, then reshipped to Bucyrus for the tests.

Analysis of an average sample of the ground aplite, the empirical formula, and the calculated mineral constitution follow. The deformation temperature was cone 10.

Chemical analysis of ground aplite

Constituent:	Per cent	Constituent:	Per cent
Moisture (at 105° C.)-----	0.40	Phosphoric oxide (P_2O_5)-----	0.01
Ignition loss-----	1.62	Lime (CaO)-----	.82
Silica (SiO_2)-----	73.30	Magnesia (MgO)-----	.05
Alumina (Al_2O_3)-----	15.00	Potash (K_2O)-----	4.13
Ferric oxide (Fe_2O_3)-----	1.51	Soda (Na_2O)-----	3.37
Titania (TiO_2)-----	.17		
		Total-----	100.38

MOLECULAR PROPORTIONS

0.3842 K_2O	}	{	1.2862 Al_2O_3	{	10.684 SiO_2
0.4768 Na_2O			0.0825 Fe_2O_3		0.787 H_2O
0.1281 CaO					
0.0109 MgO					

APPROXIMATE MINERAL CONSTITUENTS

	Per cent
Orthoclase-----	24.96
Albite-----	29.19
Anorthite. (See ref. 14, p. 61)-----	8.39
Quartz-----	28.83
Kaolinite-----	8.63

MIXTURES MADE

For the large-scale tests, 11 different compositions were made consisting of 800 to 1,000 pounds each. The materials were weighed on platform scales in batches of 200 pounds, and tempered in a

6-foot wet pan. When enough clay had been tempered with enough water for molding by the dry-press method, the remainder was tempered for molding by the stiff-mud method. About 200 bricks were made from each mixture; 50 to 60 of these were formed in a two-mold power-driven dry press, and the remainder formed in a water-lubricated side-cut die attached to a stiff-mud auger machine. This brick machine has a rated capacity of 4,000 to 7,500 building brick per hour. The brick were cut on a hand-cutter set to cut fire-brick size, or about five-sixteenths inch wider than for standard face brick.

When a mix had been expressed, the auger machine was cleaned before the next mix was introduced. The "left overs" from cleaning the machine were thoroughly mixed and tested for molding properties in a "two-hole" conduit die.

After the bricks were formed, they were dried in the open air to a leather-hard condition, then wrapped in paper, packed in excelsior, and hauled by automobile to Columbus, Ohio, where the drying was completed and the brick burned at the Ceramic station of the Bureau of Mines. The first lot of brick made in the large-scale tests comprised five different mixtures, as shown in Table 15.

TABLE 15.—*Mixtures for trials with full-size brick*

Number	Kaolin		Aplite
	G-35	G-8	
A-60.....	40	-----	60
A-50.....	50	-----	50
A-40.....	60	-----	40
B-60.....	-----	40	60
B-50.....	-----	50	50

RESULTS OF LARGE-SCALE TESTS

1. All five compositions molded perfectly in both the dry-press and stiff-mud machines.

2. The stiff-mud brick containing G-35 kaolin cracked somewhat in drying, brick containing 40 per cent of the kaolin considerably less than those containing 60 per cent. None of the brick containing G-8 kaolin cracked in drying.

3. The brick were bone dry when set in a round down-draft gas-fired kiln with a setting chamber 39 inches diameter and 39 inches high. They were burned to cone 9 in 35½ hours. The kiln was cooled and brick removed 36 hours after the fires were shut off.

4. All brick containing kaolin G-35 showed small cracks which were evidently drying cracks that were not visible when the brick

were set but opened in the burning. None of the brick containing G-8 cracked in the burning.

5. The brick appeared to be well vitrified and were light gray in color; those containing G-35 were considerably lighter. The shrinkage was very high as the brick came from the kiln with a decided "hollow face" or "dish."

6. In Table 16 is given the shrinkage of the brick made from those mixtures which came from the kiln in a sound condition. These shrinkages, as well as all others that follow, are calculated on "die length" as basis.

TABLE 16.—*Linear shrinkage of sound brick from kiln*

Brick number and process	Drying	Burning	Total
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
B-60 (dry press).....	0.00	8.70	8.70
B-60 (stiff mud).....	2.94	8.33	11.27
B-50 (dry press).....	.00	7.73	7.73
B-50 (stiff mud).....	2.94	7.84	10.78

EFFECT OF THE ADDITION OF SALT

To a second lot of brick made of both kaolins with aplite, common salt was added to determine how it affected shrinkage and overcame cracking. A little less than 0.2 per cent NaCl was added dry to the charge. The compositions of these two mixtures were as follows: No. A-55—clay, G-35, 45 pounds; aplite, 55 pounds; salt, 3 ounces. No. B-55—clay, G-8, 45 pounds; aplite, 55 pounds; and salt, 3 ounces.

Both mixtures worked perfectly in both the dry-press and stiff-mud machines. Several lengths of two-hole conduits were expressed without showing signs of cracking or tearing.

All pieces dried safely. They showed that the salt had overcome the cracking entirely, but seemed to have no appreciable effect in reducing the drying shrinkage. A thin greenish yellow scum with a salty taste showed on the surface.

The brick were burned to cone 9 in 52 hours and cooled in 36 hours. None of the stiff-mud brick of either mixture were cracked. The dry-press brick of B-55 were also sound but about 10 per cent of the A-55 dry-press brick showed minor cracks. The scum that formed during the drying had made brown stains on the dry-press brick and a brown glaze on the stiff-mud brick. The glaze was thicker, more glossy, and darker on brick containing G-8 kaolin than on those containing kaolin G-35. The brick were well vitrified and showed a high shrinkage. Following are the total shrinkages.

Total linear shrinkage

No. and process:	Per cent
A-55, stiff mud-----	11.27
B-55, stiff mud-----	11.76
B-55, dry press-----	7.25
A-55, dry press-----	(Not determined)

EFFECT OF THE ADDITION OF SAND

Because of its volume changes quartz sand is instrumental in reducing shrinkage. A mixture of 85 per cent quartz sand and 15 per cent ball clay expands approximately one-half inch in 12 inches when burned to cone 9. Therefore, burning shrinkage can be controlled within limits that depend on three factors: (1) Minimum clay content necessary for bonding strength and molding properties; (2) minimum flux content necessary to control the degree of vitrification; and (3) maximum sand content permissible without danger of "checking" or "cracking" during burning.

The next lot of brick was made from a mixture containing 35 per cent of kaolin G-8, 52½ per cent of aplite, and 12½ per cent of quartz sand. Part of the brick were made dry press and the remainder were molded in the auger machine. Even with such a low kaolin content the column issued from both the brick and the conduit dies as near perfect as could be desired, thus indicating the remarkable molding properties of the kaolins.

The dry-press and part of the stiff-mud brick were thoroughly dry when set, but part of the latter still contained some moisture after 24 hours' drying in a gas-fired drier. No cracking occurred during drying. The brick were burned in 54 hours to cone 9 and cooled in 36 hours. No cracked brick resulted from the burning or the rapid cooling. The addition of sand reduced the shrinkage appreciably, inasmuch as the brick were three-sixteenths inch longer than those previously made without sand. The total shrinkage of the stiff-mud brick was 9.76 per cent, a reduction of 2 per cent over brick to which no sand was added. The total shrinkage of the dry-press brick was 6.28 per cent, a reduction in shrinkage of 1.97 per cent. Brick which were bone dry when set were light gray in color, but those which were damp when set were "pink gray." There was some indication that this color may have been due partly to scumming.

Six of the dry-press brick and 12 of the stiff-mud brick in the leather-hard condition were shipped to Fisk & Co.'s plant at Darlington, Pa., where they were dried and set in the top of a round down-draft kiln fired with natural gas and burned to cone 10 in 6 days. The bricks were well vitrified and were light gray in color. The total shrinkage was 9.8 per cent.

EFFECT OF ADDING MORE SAND AND SOME BARIUM CARBONATE

In the final lot of brick made the sand content was increased to 18 per cent and 2 ounces of barium carbonate was added to 100 pounds of the mixture. Mixtures containing both kaolins separately and also the two mixed in equal parts were made. The compositions were as in Table 17.

TABLE 17.—*Mixtures with sand and barium carbonate*

No.	Kaolin		Aplite	Sand	BaCO ₂
	G-35	G-8			
	Pounds	Pounds	Pounds	Pounds	Ounces
A-18.....	38		44	18	2
B-18.....		38	44	18	2
AB-18.....	19	19	44	18	2

The foregoing work demonstrated that such mixtures worked successfully in both the dry-press and the stiff-mud process. As the latter appeared in every way satisfactory for these kaolins, and is preferable from the standpoint of the producer, no dry-press brick were made from the three mixtures named above.

All three mixtures worked perfectly in both the brick and conduit dies. No cracking was observed during drying. The brick were set bone dry. They were burned to cone 8½ in 50 hours and cooled in 40 hours. A few of the A-18 brick cracked slightly during burning, though this was not serious. None of the B-18 or AB-18 brick were cracked. The A-18 brick were light cream gray, whereas the B-18 brick were a little darker. The brick from all three mixtures were lighter in color than those previously made during these experiments. Evidently the improvement in color was due partly to the lower burning temperature and partly to the influence of the barium carbonate. The structure of the brick seemed dense though not thoroughly vitrified. The linear shrinkage and porosity of the three compositions were as in Table 18.

TABLE 18.—*Linear shrinkage and porosity of three mixtures*

Number.	Drying shrinkage	Burning shrinkage	Total shrinkage	Porosity
	Per cent	Per cent	Per cent	Per cent
A-18.....	2.10	5.74	7.84	7.20
B-18.....	2.39	5.45	7.84	6.60
AB-18.....	2.25	5.61	7.86	6.90

The addition of sand made no appreciable difference in the drying shrinkage but reduced the burning shrinkage materially; the latter was nearly 4 per cent less than that of brick made without sand.

Several brick of the B-18 mix were fired to cone 4 in 36 hours. They showed a total shrinkage of 7.2 per cent and a porosity of 23 per cent.

RESULTS OF A COMMERCIAL BURN

In order to prove conclusively that kaolin-aplite face brick can be made from the available material, interested parties turned over a plant for a half day for the experiment. A carload of kaolin and a carload of aplite and sand were shipped to the plant for the tests. Two mixes were made. One mix consisted of 40 parts kaolin, 40 rock, and 20 sand; the other was 50 kaolin and 50 rock. Both mixtures were ground in a dry pan and put through a 10-mesh screen. Part of the clay was G-3 and part from the adjoining property. The aplite was from the same dike as that used in the semicommercial tests. About one-third of the materials was used; from this 6,000 brick were made during the run. The rock, clay and sand were ground separately, then mixed and pugged in a 12-foot horizontal pug mill. The ground rock was much coarser than that used in the former tests. The coarseness of the rock proved both a desirable and an undesirable factor. The full fluxing value was not made available but the coarseness aided the drying.

The mix came through the process of fabrication perfectly; no trouble was experienced after a proper pugging consistence had been established.

The bricks were run through a waste-heat drier in 24 hours without loss. Except a few that were to be burned elsewhere, the entire lot was set in various parts of a 35-foot round down-draft kiln and fired to cone 4.

The firing temperature was not high enough to give the brick the desired vitrification, but the test proved conclusively that a higher burning temperature and finer grinding are the only changes in plant practice needed to produce a satisfactory ware. The brick had a total shrinkage over die size of 3.5 per cent and a porosity of 22 per cent. A few of the brick were placed in three different tunnel kilns run on different time-temperature schedules. A burn to cone 5 in 30 hours and a burn to cone 8 in 70 hours failed to produce a vitrified brick. A burn to cone 12 in 74 hours produced an excellent ware. The texture of all the brick was good. The color developed at cone 12 was a light gray. The total shrinkage at cone 12 was 6.25 per cent for the aplite-clay brick and 5.82 per cent for the aplite-clay-sand mix. A more finely ground aplite would have caused the ware to mature at a considerably lower temperature.

CONCLUSIONS REGARDING VALUE OF GEORGIA KAOLIN FOR FACE BRICK

1. The foregoing results indicate that light-cream and light-gray face brick can be made from Georgia kaolin, aplite, and sand. These brick compare favorably with the best face brick made from the fire clays of the Freeport, Mercer, and Kittanning formations of Pennsylvania.

2. These kaolins are so plastic that mixtures containing as low as 35 per cent kaolin to 65 per cent nonplastic material mold readily by the stiff-mud process, which is entirely satisfactory for such mixtures and is therefore preferable to the dry-press process.

3. The so-called "soft" kaolins are friable, have low dry strength, and are liable to crack in drying and burning.

4. The so-called "hard" kaolins are the most desirable for brick-making purposes. They have good bonding power and dry strength and will dry and burn without cracking.

5. Cracking during drying and burning of the soft kaolins can be eliminated by the addition of salt. If too much salt is added it causes an efflorescence and brings soluble iron salts to the surface which develop into a brown discoloration or even a glaze on burning. The cracking caused by the soft clay can be overcome best by the addition of hard clay, as was demonstrated in mix AB-18.

6. It has been demonstrated that such brick can be burned safely to cone 8 to 9 in 36 to 54 hours in a test kiln holding 200 brick.

7. Brick containing 50 per cent or less of kaolin when set bone dry do not present a serious problem because of water. They contain no carbon, pyrite, or other oxidizable matter; therefore they have no oxidation period and the burning can be carried on rapidly.

8. Ware made commercially from kaolin-aplite mixes, with less than 50 per cent clay, dry safely, have enough strength to be set in a kiln in the regular way, and at cone 12 or less will develop a good texture and the desired porosity without excessive shrinkage.

9. It is safe to say that a down-draft kiln of 70,000 to 80,000 brick can be burned practically and economically in 3 or 4 days and cooled in a like period.

RAW MATERIALS AVAILABLE

The area along the lower edge of the Piedmont Plateau contains aplite low in iron and high in fluxes; it lies close to the vast deposits of kaolin and white sand along the northern border of the coastal plain. The supply of raw materials for the manufacture of high-grade face brick is enough to support a large industry indefinitely.

Quarrying, transportation, and grinding of the aplite rock will, of course, add to the cost of production. In comparison with face

brick made from fire clays obtained by underground mining, the added cost of the flux is compensated by the lower cost at which the kaolin and sand can be mined by steam shovel.

Several known areas 100 to over 600 acres in extent are underlaid with kaolins 15 feet to more than 40 feet thick. The overburden is comparatively light.

Fuel costs are higher in the kaolin districts than in the fire-clay areas, but the extra cost of fuel is overbalanced by cheaper labor and the shorter time of burning permissible with the kaolin mixtures.