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HIGH-GRADE CLAYS OF THE EASTERN UNITED STATES

WITH NOTES ON SOME WESTERN CLAYS

BY

H. RIES, W. S. BAYLEY, AND OTHERS

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HIGH-GRADE CLAYS OF THE EASTERN UNITED STATES WITH NOTES ON SOME WESTERN CLAYS.

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INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

The field work required for the preparation of this report was done in the summer of 1918. Most of the worked deposits of the types of clay discussed in this report in Pennsylvania, Virginia, Florida, Alabama, Mississippi, Tennessee, Kentucky, Illinois, Arkansas, and parts of Missouri and Georgia were visited, but time was not available for detailed geologic mapping, much of which has already been done by the United States Geological Survey and State surveys.

In all the States visited the State geologists cooperated most cordially. Thanks are also due to the clay-mining companies for similar cooperation and for many courtesies.

The States of North Carolina and South Carolina were visited by W. S. Bayley, whose report is included in this bulletin, as are also some separate descriptions, by W. N. Logan, of the white clays of Indiana; by E. S. Moore, of the Cambrian residual clays of central Pennsylvania; by F. B. Peck, of the residual clays of the Oriskany of eastern Pennsylvania; by G. H. Brown, of the clays of New Jersey; by Wilbur Stout, of the glass-pot clays of Ohio; and by J. P. Buwalda, of some clays of Nevada. Thanks for assistance are also due to Dr. A. V. Bleininger, of the Bureau of Standards; Prof. C. W. Parmelee, of the University of Illinois; C. R. Schroyer, of the Illinois Geological Survey; M. E. Wilson, of the Missouri Geological Survey; Prof. E. S. Moore, of the Pennsylvania State College; Dr. R. R. Hice, then State geologist of Pennsylvania; and Prof. F. B. Peck, of Lafayette College. The petrographic work for the report was done by Dr. R. E. Somers.

IMPORTS OF CLAY.

STATISTICS.

Prior to the beginning of the war, in 1914, the United States had been a large importer of certain high-grade clays, which were used in the manufacture of white-ware pottery, floor and wall tile, electrical porcelain, paper, graphite crucibles, glass refractories, linoleum, paint, and other products. Some idea of the extensive use of these foreign clays in the domestic industry may be gained from the figures showing the imports for the years 1907–1920, published by the United States Geological Survey.

Clay imported and entered for consumption in the United States, 1907–1920.

Year.	Kaolin or china clay.			Common blue and Gross-Almerode glass-pot clay.		All other clays.				Total.	
						Unwrought.		Wrought.			
	Quantity (short tons).	Value.	Average price per ton.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.
1907..	239,923	$1,582,893	$6.60	12,378	$110,686	31,196	$145,698	2,520	$81,155	286,017	$1,920,432
1908..	176,895	1,129,847	6.39	4,872	37,053	27,730	129,411	1,372	22,990	219,869	1,319,301
1909..	246,381	1,505,779	6.11	12,346	104,401	30,147	134,978	1,906	50,632	290,780	1,795,790
1910..	257,902	1,593,472	6.18	21,176	181,334	27,890	113,352	1,496	26,205	308,464	1,914,363
1911..	255,107	1,461,068	5.73	17,193	124,278	26,086	100,540	1,032	10,436	299,418	1,696,322
1912..	278,276	1,629,105	5.85	23,112	184,018	32,473	127,004	794	12,109	334,655	1,952,236
1913..	268,666	1,623,993	6.04	24,986	204,911	42,582	155,693	1,889	22,178	338,123	2,006,775
1914..	328,038	1,927,425	5.88	16,761	122,325	50,069	195,956	3,232	41,712	398,100	2,287,418
1915..	209,132	1,152,778	5.51	8,864	62,569	23,718	90,367	1,343	12,433	243,057	1,318,147
1916..	253,707	1,326,684	5.22	2,501	12,134	42,478	163,421	180	1,994	298,866	1,504,233
1917..	241,029	1,315,769	5.46	88	709	26,581	123,439	338	2,142	268,036	1,442,059
1918..	168,100	1,153,240	6.86	114	983	26,984	163,484	137	1,087	195,335	1,318,794
1919..	180,592	1,965,393	10.88	4	133	23,759	187,550	498	4,262	204,853	2,157,338
1920..	361,800	3,568,677	9,86	6,837	157,201	34,252	272,524	691	10,267	403,580	4,008,669

This table shows that the chief foreign clay used in this country is English kaolin or china clay, which in 1920 represented nearly 90 per cent of the quantity and value of all the clay imported.

Until 1917 the strong movement of foreign clays to the United States continued, but with the entry of this country into the war the possibility increased that the importation of clay might be shut off, or at least reduced, owing to scarcity of ships, and so a real anxiety arose in the clay-using industries lest there should be a deficiency of clay for making those kinds of ware whose production had depended on a supply of foreign raw material. Not all the industries that used imported clays relied on them exclusively, but some did, and others relied on them to a large degree. Indeed, some manufacturers claimed that it was impossible to get along without a supply of imported raw material.

The following estimate, compiled by the United States Shipping Board, shows the quantity of English china clay required by the United States in 1918.

English china clay required by the clay-working industry of the United States in 1918.

	Long tons.
Porcelain and electrical	20,000
Paper filler	112,000
Paper coating	30,000
China	50,000
Oilcloth, cotton filler, and bleaching	12,000
Sanitary ware and tile	25,000
Ultramarine and paint	2,000

The quantities stated in the estimate for paper filler and for paper coating are probably too low.

When it became evident that shipments of clay from foreign countries might be curtailed, the problem was presented whether similar classes of clay now produced in the United States could be obtained in sufficient quantity to meet a considerably increased demand and whether those industries which had hitherto relied wholly or in part on foreign materials could not draw more largely on domestic sources of supply. Strictly speaking, therefore, this report deals with only those types of clay that had been imported; others are not considered unless they are closely associated with those that claim our particular attention.

On the whole, the facts concerning the domestic supply shown by this investigation, some of which have already been made public,[1] are most encouraging.

Though it is difficult and even unsafe to make any definite calculations of the quantity of clay in the domestic deposits, except where many test-hole records are available, it is nevertheless possible to form a reasonably safe estimate of the probable reserves of many deposits, or at least to state whether they are large or small.

SOURCES AND KINDS.

Most of the clays imported prior to 1914 were obtained from England and Germany. Those imported from England were chiefly kaolins and ball clays; indeed, England has supplied not only the United States but certain European countries that have not sufficient supplies of their own, such as Germany, France, Holland, Denmark, and Italy. The English kaolins were used not only by domestic manufacturers of vitrified and unvitrified clay wares but by makers of paper, paint, linoleum, ultramarine, and other products. The English ball clays were used in making the burned-clay wares mentioned above and also to some extent in making glass pots, crucibles, and abrasive wheels.

The type of clay that was most largely imported from Germany is that known as refractory bond clay, which is used in the manufacture of glass pots, crucibles, and abrasive wheels. According to the reports of the United States Bureau of Foreign and Domestic Commerce, the imports of German clays into the United States in 1914 amounted to 22,062 tons and in 1915 to 12,057 tons. The chief German clays included in these imports were the Gross Almerode clay, which was used extensively in making glass pots, and the

[1] Ries, H., The occurrence of high-grade American clays, and the possibility of their further development: Am. Ceramic Soc. Jour., vol. 1, No. 7, 1918.

Klingenberg clay, which was much employed by manufacturers of graphite crucibles. A third German clay that was widely used, though in smaller amounts, was the Vallendar clay, which was employed as an ingredient of enamels. A fourth German clay was the Scheppach refractory bond clay.

At the beginning of the war the exportation of the German clays had to stop, and that of the English clays was decreased. This decrease of imports at first caused considerable uneasiness among consumers, although some of them had rather large stocks of foreign clays, but it had the beneficial effect of increasing the consumption of domestic clays, and the increase might have been even greater had there been sufficient labor to mine the clay and cars to carry it to the points of consumption. Nevertheless, many manufacturers did use a larger quantity of domestic clays, and the clay-mining industry was thus stimulated. Then there arose a discussion as to the extent to which foreign clays were really needed in the domestic industries, and right at the beginning some strong differences of opinion were expressed.

In preparing this report the senior author has conferred with several clay technologists and corresponded with a large number of producers, and in addition he has ascertained as far as possible the regular purchasers of clay from every pit visited. From the data so obtained the conclusions given below have been drawn.

1. The industries that now use English clays but that in time may be able to dispense with them are those that manufacture vitrified tableware and sanitary ware, hard-fire porcelain, chemical porcelain, and linoleum. Some firms that make these products have already ceased to use the English clays, but the manufacturers of certain grades of vitreous ware at least have not yet found it possible to substitute American clays completely for imported ones. One objection that is made to some of the domestic clays is their lack of uniformity, and this is a fault that the domestic producers should strive to correct. Greater loss in firing is another objection made to American clays, but there seems to be a difference of opinion as to whether the trouble really lies in the clay or whether the manufacturers have not yet discovered the proper mixture of domestic materials and the best conditions of treatment.

Linoleum manufacturers claim that English china clay has greater uniformity of composition, better color, and more opacity than domestic clay.

Most paper manufacturers claim that English clay is necessary for coating because it has better color and spreads better, but that domestic clay to the extent of about 10 per cent can be mixed with it.

2. The industries that need only a small quantity of English clay are those that manufacture electrical porcelain and paper. The

makers of electrical porcelain could dispense with English ball clay and could cut out half of the English china clay they use. Some manufacturers of electrical porcelain use only domestic clays. One objection urged against American clays is that they are not uniform.

Many manufacturers of paper say that English clay is not needed for filler, but it seems to be needed for coating.

3. The industries that need no English clay are those that manufacture white earthenware and floor and wall tile.

The industries numbered 1 to 3 need no other foreign clay than that mentioned.

4. The industries that probably need no foreign clay whatever are those that manufacture glass pots, graphite crucibles, abrasive wheels, pencils, and paint (?).

All consumers and even all technologists may not agree concerning the requirements stated in the above grouping. The manufacturer naturally objects to changing a mixture that he has long been using.

For some years manufacturers of glass refractories have been using a considerable quantity of washed clay from the St. Louis district in their glass-pot mixtures and have also drawn upon the German pot clay, just as the crucible manufacturers have used the imported Klingenberg clay. When the supply of German clays was shut off domestic bond clays had to be sought, and they are now in use.

The makers of glass refractories seem to be successfully using domestic clays, but the makers of crucibles, or some of them, at least, complain that a mixture composed entirely of American clays does not stand as many heats as the old combination. This trouble, however, may be due to the fact that the proper combination has not yet been fully worked out.

EXPORTS OF CLAY.

Although the United States has imported a considerable quantity of clay, it has, during the last few years at least, also exported a considerable quantity, as the following figures will show:

Clay exported from the United States, 1916–1920.

Year.	Fire clay.		All other.		Total.	
	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.
1916	45,752	$144,552	27,941	$145,970	73,693	$290,522
1917	54,023	268,093	29,194	178,764	83,217	446,857
1918	60,206	333,880	24,348	192,053	84,554	525,933
1919	37,486	262,501	30,983	249,571	68,469	512,072
1920	54,125	393,177	66,035	775,222	120,160	1,168,399

At least nine-tenths of the clay exported was sent to Canada, and the remainder was sent to Europe, South America, Central America, Asia, and Oceania.

STATISTICS OF PRODUCTION.

Some conception of the demands of the country for certain grades of domestic clay may be obtained from the following table. These quantities added to the imports less the exports give the total consumption. The classification in this table is not strictly exact, however, for it includes, under fire clay, grades that are not considered in this report. One prominent American potter says that the potters of the United States use in their mixtures from 35 to 40 per cent of American kaolin and from 25 to 50 per cent of domestic ball clay.

Domestic clay marketed in the United States, 1913–1920.

Year.	Kaolin.		Paper clay.		Slip clay.		Ball clay.		Fire clay.	
	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.
1913	28,834	$235,457	126,377	$567,977	10,902	$24,505	67,134	$237,672	1,820,379	$2,592,591
1914	34,191	284,817	116,328	558,334	8,237	17,731	67,927	255,767	1,409,467	2,147,277
1915	28,031	241,520	113,033	539,622	7,646	18,774	75,348	301,910	1,570,481	2,361,482
1916	47,723	306,819	153,434	768,911	14,064	47,939	89,761	391,152	2,057,814	3,708,009
1917	31,885	301,378	174,449	962,421	16,972	70,505	107,406	569,240	2,347,972	5,625,095
1918	37,969	391,109	141,725	1,068,420	13,552	49,898	89,896	590,631	2,305,033	5,664,064
1919 [a]	39,000	427,000	148,000	1,221,000	3,000	12,000	93,000	637,000	1,715,000	4,143,000
1920 [a]	[b]264,000	[b]2,385,000	([b])	([b])	10,009	49,000	145,000	1,340,000	2,400,000	7,720,000

Year.	Stoneware clay.		Brick clay.		Miscellaneous clay.		Total.	
	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.	Quantity (short tons).	Value.
1913	153,353	$143,587	158,890	$137,976	282,120	$240,694	2,647,989	$1,180,459
1914	130,383	116,610	199,154	161,852	244,173	214,180	2,209,860	3,756,568
1915	134,297	126,429	101,968	93,863	332,150	288,341	2,362,954	3,971,941
1916	135,958	137,779	97,164	76,854	336,672	314,311	2,932,590	5,751,774
1917	81,352	113,839	93,779	94,703	260,029	305,365	3,113,844	8,042,546
1918	86,800	147,098	([c])	([c])	301,386	421,421	2,976,361	8,332,641
1919 [a]	65,000	137,000	([c])	([c])	300,000	500,000	2,363,000	7,077,000
1920 [a]	90,000	250,000	([c])	([c])	250,000	350,000	3,159,000	12,094,000

[a] Estimated.
[b] Paper clay included under "Kaolin."
[c] Included under "Miscellaneous clay."

REQUISITE QUALITIES OF HIGH-GRADE CLAYS FOR DIFFERENT PURPOSES.

WHITE-WARE CLAYS.

The white-ware clays include the kaolins and ball clays and white-burning sedimentary clays which are used in white ware, including pottery, electrical goods, and floor and wall tile, whether vitrified or porous.

KAOLINS.

The kaolins include those white residual clays which burn white or nearly so and are of refractory nature and more or less porous after burning. Their plasticity is usually lower than that of the sedimentary clays, and they have to be washed before shipment to market. The necessity of washing this material with care can not be emphasized too strongly; the high reputation of English kaolins for uniformity is due to better preparation than that made in America.

Chemical analyses of kaolin, though not of much practical value, show that most of them contain a low percentage of impurities, that some approach rather closely to kaolinite in composition, and that they may have much the same composition whatever the nature of the parent rock. The influence of the parent rock is shown perhaps chiefly in differences in the content of silica.

Analyses of kaolins.

	1	2	3	4	5
Silica	45.78	46.50	72.30	48.26	43.31
Alumina	36.46	37.40	18.94	37.64	39.42
Ferric oxide	.28	.80	.40	.46	2.86
Ferrous oxide	1.08				
Lime	.50	Trace.	.68	.06	
Magnesia	.04		.39	Trace.	.04
Potash	.25	1.1	.42	1.56	.25
Soda					.30
Ignition loss	13.40	12.49	7.04	12.02	13.58
Water 110° C	2.05				
	99.84	98.29	99.57	100.00	99.76

1. Washed kaolin, Webster, N. C., derived from pegmatite. North Carolina Geol. Survey Bull. 12, p. 62, 1897.
2. Washed kaolin, West Cornwall, Conn., derived from feldspathic quartzite.
3. Crude kaolin, Glen Allen, Mo., derived from cherty dolomite. Missouri Geol. Survey, vol. 11, p. 562, 1896.
4. Washed kaolin, Cornwall, England, derived from granite. U. S. Geol. Survey Prof. Paper 11, p. 39, 1903.
5. Crude kaolin, Cold Spring, Va., derived from Cambrian shale. Analysis supplied by Virginia Geol. Survey.

Of the kaolins listed in the table only Nos. 1 and 4 are regularly used in the manufacture of white ware. No. 5 does not burn quite white enough, but a small amount of it can be used in a white body without seriously affecting the color.

The true kaolins used regularly in the manufacture of white ware come chiefly from North Carolina and Delaware.

WHITE-BURNING SEDIMENTARY CLAYS.

In the trade the white-burning sedimentary clays are known as kaolins, plastic kaolins, sedimentary kaolins, and secondary kaolins. Certain white sedimentary clays, like those found in Georgia and South Carolina, are also used in white wares. They are incorrectly spoken of as kaolins, and some potters seek to differentiate them from the white residual clays by calling them sedimentary kaolins.

Most of these clays are smooth, and some of them, like those of Georgia and South Carolina, may yield comparatively little residue on washing, but others, like those of Florida, carry a large proportion of sand. Few of them burn quite as white as the best true kaolins, and in plasticity they stand intermediate between the true kaolins and the ball clays. They closely resemble the residual kaolins in composition, but usually have higher shrinkage. According to the testimony of many manufacturers the one class can not be substituted, pound for pound, for the other.

The following tests and analyses give some of the characters of Georgia white sedimentary clay:

Analyses of white sedimentary clay from Georgia.

	1	2
Silica (SiO_2)	44.76	44.25
Alumina (Al_2O_3)	38.41	38.06
Ferric oxide (Fe_2O_3)	.63	1.03
Lime (CaO)	.20	.08
Magnesia (MgO)	.09	Trace.
Soda (Na_2O)	.09	.10
Potash (K_2O)	.35	.70
Titanic oxide (TiO_2)	1.37	1.29
Sulphur (S)	....	.06
Loss on ignition	13.46	13.63
Loss at 100° C	1.22	.38
	100.58	99.58

1. Dry Branch, Ga.
2. Gordon, Ga. Schurecht, H. G., Am. Ceramic Soc. Trans., vol. 19, p. 248, 1917.

Drying and shrinkage tests of white sedimentary clay.

	Drying shrinkage.	Fire shrinkage, cone 1.
English china clay	2.32	4.48
Washed Georgia clay	4.38	8.12

Tests of clay from Gordon, Ga., showing shrinkage and porosity in firing.[a]

Temperature (°C.).	Porosity (per cent).	Volume shrinkage (per cent).
1,210	29.45	36.01
1,250	28.33	33.05
1,290	31.02	32.88
1,330	34.15	31.10
1,370	28.53	36.05
1,410	22.78	40.40

[a] Schurecht, H. G., Am. Ceramic Soc. Trans., vol. 19, p. 248, 1917.

The white sedimentary clays of Georgia and South Carolina are being used more in pottery than formerly. However, as is pointed out by Watts,[2] they can not be indiscriminately substituted for other white-burning clays on account of differences in physical character. Results of tests of clays from South Carolina in porcelain bodies are given on pages 170–184.

BALL CLAYS.

The term ball clays is applied to clays of good plasticity, strong bonding power, and high refractoriness, which burn white or creamy white and are used in mixtures employed for making white ware to give the mixtures greater plasticity, to strengthen their bond, and to increase their density after firing. They are used chiefly in making white earthenware and porcelain but are also used in making floor and wall tile. Some of these clays are used in the manufacture of glass refractories and crucibles.

The supply of ball clay was formerly obtained from England, but large quantities are now obtained from western Kentucky and Tennessee. The total quantity reported by these two States in 1918 was 58,140 short tons, valued at $265,325.

The white-burning clay of Florida, which is called by some a ball clay, is really intermediate between the ball clays of Kentucky and Tennessee and the sedimentary clays of the belt that traverses Georgia and South Carolina.

The following results of chemical analyses of some ball clays are given for those who may be interested in their composition. The results of physical tests of ball clays are given on pages 13 and 281.

Analyses of ball clays.

	1	2	3
Silica (SiO_2)	46.85	48.99	46.87
Alumina (Al_2O_3)	33.15	32.11	36.58
Ferric oxide (Fe_2O_3)	2.04	....	1.14
Ferrous oxide (FeO)	....	2.34	....
Titanic oxide (TiO_2)	....	....	.43
Lime (CaO)	.35	.43	.50
Magnesia (MgO)	.40	.22	Trace.
Potash (K_2O)	.61	3.31 (potash and soda)	Trace.
Soda (Na_2O)	.10		1.60
Sulphur trioxide (SO_3)	.03	....	.06
Loss on ignition	16.45	9.63	11.52
Moisture at 100°C	....	....	1.60
	99.98	97.03	100.30

1. Whitlock, Tenn.
2. England.
3. Mayfield, Ky.

[2] Watts, A. S., Comparison of American china clays as porcelain ingredients: Am. Ceramic Soc. Jour., vol. 2, p. 151, 1919.

PAPER CLAYS.

Clay is used by the paper manufacturer as a filler, for coating, and in wall paper as a base for color applied to the surface. For all these purposes the clay must be free from grit, for grit cuts the wire of the screens and scratches the surface of the calendar rolls. It should also disintegrate readily. White clay is invariably selected, but the color may not have to be quite so carefully watched in clay for filler as in clay for coating. A third essential property is that the clay shall be retained by the pulp, a point that has to be determined by practical test. Whiteness and fineness, however, are of prime importance.

The domestic clays most used are the white sedimentary clays of Georgia and South Carolina, although the white residual clays of the Mount Holly Springs and the Saylorsburg district of Pennsylvania have been used to a lesser extent. More recently the white residual clay of Cold Spring, Va., has been employed for filler.

A canvass among the producers and consumers shows that most of the white clay from Georgia and South Carolina is sold for use in paper. Some manufacturers state, furthermore, that it is being used as a substitute for English clay; others state that it can not be so used. Curiously enough, some producers of the same class of paper express opposite opinions concerning the same clay.

According to Roe,[3] there has been a recent tendency to develop American clays for use in making paper. He writes:

> For many years there was a distinct prejudice in most quarters against local clays, it being claimed that the English article is of better color, contains less grit, and possesses to a higher degree those qualities which are peculiarly essential in a coating clay. As far as color is concerned, domestic clays tend to a yellow tone whereas the imported article is more of a blue white. It is a fact, however, that some of the higher grades of English clay are artificially colored with a blue coal-tar dye, which undoubtedly accounts for the superior color. In some cases ultramarine has been used for the purpose. This pigment is unstable under conditions which might easily obtain in paper making, in which cases the color imparted would fade. While the average English clay is better in color than the average American clay, some of the domestic clays now on the market are of good color and are admitted in most quarters to be quite satisfactory for filling purposes.

He further states that the domestic clays as formerly marketed carried too much grit, but that they have been geatly improved in this respect. For coating, however, the English clay is almost universally preferred.

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[3] Roe, R. B., Clays for use in paper making: Am. Ceramic Soc. Jour., vol. 2, p. 69, 1919.

PAINT CLAYS.

Manufacturers of paint demand in general a white gritless plastic clay, which is used to mix with the colors. In general the material required is similar to that demanded by the paper makers, although the requirements as to minute differences in shades of color and grit would seem not to be quite as severe, although one manufacturer states that the clay should pass a 300-mesh sieve. Low moisture content is also demanded. However, irregularity in product is seriously objected to, and clay miners should give heed to this fact. Domestic clays used in paints are obtained in general from the same districts as the paper clays.

LINOLEUM CLAYS.

White clays are used for making linoleum. In addition to whiteness, they must possess opacity, freedom from grit, and proper plasticity. The addition of talc to the clay is claimed by some to increase its opacity. Clays also differ in the quantity of linseed oil required to mix them with the color, and it is said that English clays take less oil than American clays. Absolute uniformity of standard is highly essential. The South Carolina white sedimentary clays and some of the domestic kaolins are employed to some extent in making linoleum.

REFRACTORY BOND CLAYS.

The refractory bond clays include those clays which have refractoriness and bonding power that makes them of value for glass refractories, for crucibles to melt steel and brass, and to a less extent for the bond of abrasive wheels.

In considering the properties of refractory bond clays, attention must be given both to the properties that exist in the clays in their raw condition and to the properties that are developed in the clay by burning.

The characteristic properties of the raw clays are their transverse strength, especially if mixed with an equal amount of sand, and the ratio of pore water to shrinkage water. Bleininger[4] suggests that clays may be divided into two classes—the first class including those whose modulus of rupture is 325 pounds to the square inch or more, and those whose modulus of rupture is between 225 and 325 pounds. The ratio of pore water to shrinkage water should not exceed 1.00

[4] Bleininger, A. V., and Loomis, G. A., The properties of some American bond clays: Am. Ceramic Soc. Trans., vol. 19, p. 601, 1917.

for clays of the first class. For strong, heavy, plastic clays, low in free silica, the ratio should not exceed 0.75, but siliceous bond clays, such as the Gross Almerode, can not meet this requirement.

The principal criteria of the value of the clay as determined by burning are the overfiring temperature and the softening point. For very severe service the clay should not develop a definite vesicular structure below 1,425° C. nor a softening point below cone 31 (1,750° C.); but, as Bleininger says, this specification may not be fair to some plastic clays that are of use in the manufacture of graphite crucibles, especially for brass melting, although even for this purpose the temperature of overfiring should not be much below 1,400° C. and the softening temperature not much below that of cone 30 (1,730° C.). Anything below these requirements should be ruled out as a bond clay.

To grade these clays, then, according to their uses, Bleininger suggests the following classification:

1. Clays particularly suited to manufacture of graphite crucibles used for melting brass. Should burn dense at 1,150° C. and show no evidence of overfiring at 1,400° C. and have other required physical properties.

2. Clays adapted for crucibles for steel melting. Should burn dense around 1,275° C. and not overfire at 1,400° C. or higher.

2a. Clays like those of class 2 but that do not overfire below 1,425° C. These clays are valuable in addition for making glass refractories.

3. Clays especially suited to glass industries. Should burn dense only at 1,425° C., or even higher, and not overfire below 1,450° C.

Clays that become dense between 1,150° and 1,300° C. and that overfire at or just above the temperature at which they become dense are of no value as refractory bond clays.

The following table by Bleininger and Loomis shows the characteristic physical properties of a number of good refractory bond clays, as well as some that are deficient in refractoriness:

Physical properties of some refractory bond clays.

Water in terms of dry weight.	Ratio of pore water to shrinkage water.	Shrinkage by volume in terms of dry volume.	Time of slaking (minutes).	Modulus of rupture of dried clay in pounds per square inch.	Modulus of rupture of dried mixture of 1 part clay to 1 part sand in pounds per square inch.	Temperature of vitrification (°C.).	Temperature of over-firing (°C.).	Remarks.
44.90	0.79	43.30	30	376	323	1,150	1,320	English ball clay; not satisfactory for steel-melting crucibles or glass refractories. Brass crucibles?
39.68	.57	42.58	78	345	381	1,125	1,425	Klingenberg, A. T. Cracks badly when used alone. Useful for graphite crucibles but not for glass refractories.
31.23	.69	35.01	12	475	255	1,200	1,230	New Jersey. No value as a high-grade bond clay.
31.14	.57	38.42	52	838	399	1,290	1,320	St. Louis. No value as a high-grade bond clay.
50.66	.56	55.05	108	230	363	1,100	1,400	Klingenberg, E. T. Good bond clay.
43.63	.72	43.63	33	328	351	1,200	1,430	St. Louis. Promising as a crucible material.
45.28	1.05	34.53	9	239	234	1,260	1,425	Kentucky. Not good when used alone. Could be mixed with a stronger clay for crucibles, possibly glass.
22.08	.80	24.46	8	479	281	1,350	1,350+	Southern Ohio. Not highest type of bond clay. Somewhat deficient in bonding power. Used in mixture.
40.33	.75	39.85	41	366	389	1,125	1,415	English ball clay. Useful for crucibles. Desirable ingredient of glass-pot mixture.
37.65	1.05	31.01	5½	187	199	1,260	1,425	Tennessee. Low bonding power. Good firing range. Useful in mixture for steel or brass crucibles.
45.16	.65	45.35	54	439	341	1,230	1,450	Southern Illinois. Excellent for glass refractories or crucibles.
50.85	.71	46.80	36½	359	362	1,290	1,400	Kentucky. Good bond clay, especially for steel-melting crucibles or glass refractories.
38.91	.67	40.61	113½	667	518	1,250	1,350	Maryland. Probably suitable for crucibles.
29.02	.72	32.32	128	817	466	1,450+	....	Arkansas. Excellent glass-pot clay. Not suitable for crucibles.
20.64	.99	20.57	49½	502	364	1,450+	....	Gross Almerode. Good for glass refractories.
31.39	.81	31.36	55	645	326	1,350	1,450	Mississippi. A good bond clay.

A number of interesting tests of crucible clays mixed with graphite have been made by M. C. Booze,[5] from which he concludes that no one clay satisfies to a high degree all the requirements for crucibles. Indeed, some of these requirements are so diametrically opposite that no one clay is entirely satisfactory. By selecting the clays that rank higher than the others in all or most of the requisite properties, using them as a base, and blending them with others, it is possible to get a mixture that gives better results than any one clay alone would yield.

The domestic clays used in the manufacture of glass pots and crucibles are obtained chiefly from the Wilcox group of northwestern Mississippi and the Lagrange formation of Tennessee, Kentucky, and Illinois, from the Carboniferous clays of the St. Louis district in Missouri, and from the Portsmouth district in Ohio. Some clay for glass pots has been obtained from deposists at Lowell, Ill.,[6] and in the Woodbridge district of New Jersey. The deposits near Lester, Ark., which occur in the Wilcox formation, have not been worked for at least two years, and there is no steady production from the locality near Contee, Md.

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[5] Booze, M. C., Some properties of bond clays for graphite crucibles: Am. Ceramic Soc. Jour., vol. 2, p. 461, 1919.

[6] Lines, E. H., Pennsylvanian fire clays of Illinois: Illinois Geol. Survey Bull. 80, p. 73, 1917.

DEPOSITS OF HIGH-GRADE CLAYS.

KAOLINS (WHITE RESIDUAL CLAYS).

DEFINITION.

The term kaolin is properly applied only to a white residual clay that is the product of weathering, though kaolinization may occasionally be caused by other processes,[7] but by many the term is somewhat loosely used to mean any clay that burns white or nearly white, including white clays of sedimentary origin. This practice is unfortunate, for the uses of these two classes of white clay are somewhat different.

GENERAL FEATURES.

Residual clays may be formed by the weathering of many different kinds of rock. The depth of the deposit depends on the extent to which weathering has penetrated the rock and the thickness of material that has been removed during the period of weathering or since the clay was formed. The depth to which weathering may penetrate the rock is determined by the permeability of the rock, the resistance of the minerals composing the rock, and by the depth to water level. We can not assume, therefore, that weathering will extend to the same depth in all kinds of rock or at all places. Even in the same formation weathering may reach to great depth at one locality but not at another. (See pp. 22–23.)

The shape of a deposit of residual clay will be governed largely by the shape of the parent rock—the rock from which it is derived. Thus a pegmatite dike will yield a deposit that is relatively long but narrow, whereas a horizontally bedded deposit or a mass of granite may yield a deposit that is of considerable horizontal extent as compared with its depth.

The color is likewise dependent on features of the parent rock. If the parent rock contains few or no particles of iron-bearing minerals, which liberate iron oxides during the process of weathering, the residual clay is white, but if the parent rock contains many particles of iron-bearing silicates or ferruginous impurities the clay is likely to be more or less strongly colored. Residual clays may therefore range in color from snow white to an intense red or brown, caused by iron. Indeed, different parts of the same rock mass will

[7] Ries, H., Origin of kaolin: Am. Ceramic Soc. Trans., vol. 13, p. 51, 1911.

yield different-colored residual clays, which may lie side by side but be separated by sharp boundaries. In pits in residual limonite (brown iron ore) it is not uncommon to find lenses of white clay completely surrounded by brilliantly colored material.

TYPES OF ROCKS THAT FORM KAOLIN.

The true kaolins are not derived exclusively from feldspathic rocks. The deposits in the United States have been formed from syenite, granite, pegmatite, rhyolite, arkose, schists, shales, limestone, and feldspathic quartzite. The hydrous aluminum silicates in clay derived from the first six of these types of rock are produced chiefly by the decomposition of the feldspar; those in the shales, limestones, and quartzites are probably present in the parent rock.

NEED OF PURIFICATION FOR MARKET.

The parent rock of most kaolins contains considerable quartz, and some of it contains much mica, and as these minerals are regarded as undesirable impurities the kaolin is commonly washed in order to eliminate them as far as possible. Some kaolins present no special difficulty in washing, but others (such as the kaolin from Mount Holly Springs, Pa.) contain sand which is so finely divided that it tends to float off with the clay in the process of washing. By adding an electrolyte like sodium carbonate the clay is deflocculated and the silica settles out more completely. This method of treatment appears to work better with residual than with sedimentary clays. The quartz and mica are sometimes sold as by-products.

DISTRIBUTION OF KAOLINS IN THE UNITED STATES.

Kaolin deposits are rare in the glaciated area. Outside of this area they are somewhat widely distributed, at least in the eastern half of the United States, but the number of commercially valuable deposits is comparatively small. Moreover, the physical qualities of those already developed differ considerably, so that they are not all useful for the same purpose. Nor do they all occur in the same geologic formation.

KAOLIN-BEARING FORMATIONS.

All the kaolins found in the United States are probably of comparatively recent geologic age, but the age of the rocks from which they have been derived differs in different places.

Beginning in the northeast, there is an isolated deposit near West Cornwall, Conn., which is derived from a feldspathic quartzite. Small bodies of kaolin have been reported from western Vermont and yield a small output annually.

Next there are the kaolins derived from pegmatite in Delaware and Chester counties, Pa., which were extensively worked in former years, though their production has now fallen off greatly owing to the exhaustion of the deposits. Similar deposits are still worked in the State of Delaware.

Two other formations that yield kaolin in Pennsylvania are (1) the Devonian shales and cherty limestones, which are worked near Saylorsburg, Monroe County, and which supply residual clays farther west in the State, though all the material is not pure white, and (2) the Cambrian schists, which contain kaolin in the South Mountain district of Cumberland County, as well as farther west in Huntingdon County.

In Cecil County, Md., a small deposit of kaolin derived by decomposition from a granodiorite has been worked at different times.

In Hampshire County, W. Va., and adjoining portions of Virginia white and grayish-white residual clays occur in shales and sandstones of the Oriskany group.

Along the western slope of the Blue Ridge in Virginia the Cambrian shale yields white residual clays, but the known kaolins of the Piedmont area in that State have not proved to be valuable.

The western counties of North Carolina have long produced kaolins. The material was formed from pegmatite veins, but similar rocks in Georgia and Alabama have yielded little thus far.

In the Central States the only deposits of kaolin known are those derived from limestone in Missouri, and some of doubtful value in Wisconsin from schist and in Arkansas from syenite.

Some scattered deposits of unique character in Nevada and Idaho derived from limestone in Missouri, and some of doubtful value in California. One of doubtful origin and remote from the railway is known in Texas, as well as some small deposits in Colorado.

In the following descriptions the deposits are grouped according to the type of rock from which they are derived.

KAOLINS FROM PEGMATITES.

The purity of the crude clay depends on the mineral character of the parent rock. Where weathering has been complete all the feldspar is generally changed to clay. The impurities, which occur in varying amounts, are quartz and muscovite mica. Tourmaline in blocklike lumps or crystals and beryl are also found in some deposits. Garnet, if present in the original rock, is usually decayed to ferruginous spots. Other impurities may occur in small amounts. Rutile is almost invariably present, but the grains are so small that they can be seen only with the microscope. In the kaolins of North Carolina Bayley notes the occasional presence of lumps of iron or manganese oxide.

PENNSYLVANIA AND DELAWARE.

Kaolin derived from the weathering of pegmatite veins was formerly worked near Kaolin, Chester County, and Brandywine Summit, Delaware County, but the mines are no longer in operation.[8] Similar deposits were worked at Hockessin, Del., and are still being operated near Newark, Del.

MARYLAND.

Kaolin occurs in Cecil County,[9] but the production has not been very large nor steady. The clay has been used in china and in paper. According to tests made by the Bureau of Standards, the mixture of clays employed for making porcelain glass pots may contain about 24 per cent of this clay.

VIRGINIA.

The Piedmont province of Virginia contains a few deposits of kaolin, all derived from pegmatite by weathering, but none of them have proved to be of economic value, chiefly because their area, so far as known, is small, or because the quantity of washed product obtainable is small.

Some years ago attempts were made to work a deposit of kaolin near Roseland, in Nelson County, but the venture was unsuccessful, and the plant has been dismantled. Another deposit was formerly operated near Patrick, in Henry County.[10]

NORTH CAROLINA.

By W. S. Bayley.

DISTRIBUTION OF KAOLIN.

The kaolins of North Carolina occur west of the "fall line," which runs along the east side of Warren County and southwestward to the State line near Rockingham, Richmond County. (See Pl. I.) There are some white clays east of this line, but most of them are impure, and hence they can not be used for the same purposes as the kaolins so they are not discussed here.

The part of the State that lies west of the "fall line" is separable into two main physiographic divisions—the Piedmont Plateau to the east and the Appalachian Mountain area to the west. The line dividing these provinces (see Pl. I) is at the base of the Blue Ridge and passes diagonally through the State from the west side of Surry

[8] Hopkins, T. C., Clays of southeastern Pennsylvania (in part): Pennsylvania State Coll. Ann. Rept. for 1898–99, Appendix, p. 29, 1900.

[9] Ries, H., Report on the clays of Maryland: Maryland Geol. Survey, vol. 4, pt. 3, 1902. Cecil County report, Maryland Geol. Survey, p. 211, 1902.

[10] Ries, H., and Somers, R. E., Clays of the Piedmont province, Va.: Virginia Geol. Survey Bull. 13, 1917.

County, southwestward to the center of Polk County. A small area of the Coastal Plain covers parts of Richmond, Anson, and Montgomery counties, but this is somewhat broken by outliers of the Piedmont Plateau.

The mountain area is characterized by strong relief. It comprises mountain chains, broad plateaus, and deep, narrow valleys.

The plateaus were formed by long weathering and denudation, and it is at places on their surfaces where the weathering has been deepest that the best deposits of kaolin occur. The areas along the main streams have been reduced to nearly level plains, which have been cut into by the streams to depths of 100 to 300 feet. In these areas the rocks are deeply decomposed, and where they contained much feldspar deposits of kaolin have been formed. Unfortunately, however, most of these deposits are buried under surficial material and can not be found.

The Piedmont Plateau which lies east of the mountains is characterized by low, rounded hills, which are separated by broad, shallow valleys. Here all the rocks are deeply decayed, but the slope of the hills is so low that much of the product of decay has been left on the surface. Thus materials derived from different sources have been intermingled, and the entire surface is covered with a deep mantle of mixed detritus that obscures the underlying rocks, so that narrow belts of kaolin produced by the decomposition of pegmatite dikes are difficult to locate. Where feldspathic grainites or other feldspathic rocks occur over large areas, however, the deposits of kaolin may be so extensive that their presence may be revealed at the surface. Because of its striking appearance, the kaolin, even when much mixed with other materials, may easily be recognized. Indeed, the kaolin at the surface generally covers a much larger area than that beneath, and where kaolin outcrops on a slope, its creep or wash downhill may also tend to increase the apparent area of the deposit. Deposits of kaolin derived from pegmatites are generally more valuable than those derived from other feldspathic rocks, which usually contain much undesirable material. A few deposits of kaolin occur on the Piedmont Plateau in North Carolina, but the most promising ones are in the mountain area.

Deposits of clay are found also along the river valleys. Large quantities of the products of rock weathering have been transported from the upper courses of the streams and have been spread over the flood plains in the lower courses. Many of the rivers in North Carolina flow through districts where there is much kaolin, which they have brought down in large quantities and deposited, with other material, on their flood plains. Some of these deposits contain many minerals besides kaolinite; they consist of an impure clay which is not suited to the purposes for which the purer kaolin is employed, and they are therefore mentioned only incidentally in this report. Much of this clay may be used in making stoneware, but most of it is too impure even for this use.

The high-grade kaolins of North Carolina may, for convenience in classification, be separated into two groups—those of the mountainous district and those of the Piedmont Plateau. Only the clays of the mountains have been developed commercially.

ORIGIN.

The kaolins of North Carolina have without doubt been formed directly or indirectly by the weathering of feldspathic rocks. Those in the mountain regions, where the surface waters have had almost direct access to the material of the pegmatite dikes, have been formed directly by weathering. The kaolins around Bessemer City, Bostick's Mills, and Statesville may have been formed somewhat differently. There the areas underlain by the clay are wide rather than long and narrow, as in the mountain district, and possibly the feldspathic rocks from which the kaolin has been derived were formerly covered by swampy tracts, so that the surface water percolating through them to the bedrock became charged with carbonic and organic acids, which not only accelerated the process of weathering but may have caused the removal of some of the iron that was in the parent rock.

The data given below are based chiefly on studies of the deposits of the mountain region, which have been more extensively opened up, although the changes described might apply to the Piedmont area as well.

In the breaking down of the feldspar considerable silica is set free and must be removed in solution, for orthoclase on weathering gives only 52 per cent of its weight, or 61 per cent of its volume of kaolinite.

The residual clay, however, is generally very compact and contains as much as 90 per cent of kaolinite. This high content of kaolinite may be due either to the settling of the material or to enrichment of the kaolin by the migration into it of kaolinitic material from the higher-lying parts of the deposit.

Few deposits contain an average of more than 40 per cent of kaolin, even where all the feldspar has been entirely decomposed, and the rest of the material is made up of other minerals, chiefly quartz. Products of the decomposition of other constituents of the pegmatite may affect unfavorably the color or purity of the kaolin.

Even quartz, which is one of the most resistant constituents of the pegmatite, may sometimes show the effects of attack by the percolating waters, as in the rounding of the edges of the grains, or the pitting of their surface by solution. Indeed, it is probable that they have invariably undergone solution to some extent, though perhaps only exceptionally is the solution marked. The quartz then has a pebbly appearance, and the crude kaolin may look very much like a mass of water-worn pebbles in a fine-grained sediment. The solution may be due to the action of the alkaline carbonates produced during the weathering of the feldspar, for it is well known that quartz is appreciably dissolved by alkalies. If the quartz in the original rock was in fine grains some of it may be completely dissolved, but much of it may nevertheless remain as grit or sand in the kaolin.

Beryl alters to mica or kaolinite and in altering to mica is apt to yield fine scales, which are difficult to separate from the flakes of kaolinite, and may injure the refined product if the beryl was originally present in any quantity.

Tourmaline, though probably strongly resistant to weathering, appears in some deposits to have been decomposed to a mixture of clay and iron oxide.

Muscovite loses its elasticity and luster and alters to a hydrated mica, but generally it changes so slowly that it may be picked by hand from the kaolin, provided the plates are large enough, and much of it may be so slightly altered that it can be sold as sheet, ground, or punch mica, depending on its size.

Biotite, hornblende, and any other ferriferous minerals may be altered to a number of compounds, among which may be limonite or other iron hydroxides, and even ferrous carbonate. In the presence of abundant oxygen the hydroxides are apt to form; and these stain the kaolin brown or yellow. In the absence of oxygen ferrous carbonates are produced, and as these are soluble in carbonated water they may be carried away in solution. Thus, near the surface, where the percolating waters carry abundant oxygen, staining by iron salts is rather common, whereas with increase of depth the stains decrease, except where crevices furnish channels along which the water may flow freely, and at ground water level the kaolin is practically free from them.

The most objectionable components of the kaolin are the products of the decomposition of garnet. When the crystals are decomposed they give rise to chlorite and other micaceous products that are commonly colored reddish brown by iron hydroxides or other iron compounds. The heaviest particles may be separated from the kaolin by washing, but some of the lightest material floats over with the slip and is distributed through the refined kaolin, even seriously impairing its value. In the clay bank the decomposed crystals of garnet appear as little circular brown spots. If the spots are few the clay containing them may be removed by hand sorting before the crude material is sent to the washer, but if abundant there is no recourse but to abandon that part of the mine in which they occur.

VARIATION IN COMPLETENESS OF KAOLINIZATION.

Most pegmatite dikes contain a large proportion of quartz, so that the average quantity of kaolinite in their decomposed parts is generally much less than 40 per cent, so low that the deposits are not profitably workable throughout. However, richer pockets are scattered through the dike mass, and upon these the miner depends for his commercial success. He therefore passes by the poorer material and removes the richer.

As kaolinization progresses downward from the exposed surface the completeness of the process becomes less and less as depth from the surface increases until the proportion of undecomposed material becomes so great that deeper mining is impracticable. Although even at great depth, the feldspar is partly kaolinized, the quantity of undecomposed feldspar is so great that a crowbar can not be forced into a mass of it without hammering. The quantity of kaolin in the mass is there so small that the increased cost of preparing it for market makes its mining unprofitable.

The depth at which mining becomes unprofitable differs in different dikes, but in deposits well up on slopes it is generally at about 95 feet from the exposed surface. The purer kaolin lies near water level, and above this plane kaolinization is practically complete. When the miners reach water level the kaolin becomes so plastic that it is difficult to maintain the shafts, and for this and other reasons the mining operations become so expensive that the shaft has to be abandoned unless it can be drained. Consequently deposits high up on slopes are generally minable at greater depths than those at the bases of slopes or on plains, where the water level is nearer the surface. Usually the best kaolin in any deposit lies near the level of the ground water. Below this level the completeness of kaolinization rapidly diminishes with depth, and in many deposits the dike material a few feet below the water level has been protected from alteration to such an extent that it might be used as a source of feldspar. In general, a dike is richer in kaolin near its footwall than near its hanging wall. The hanging wall, especially if it is composed of schists, protects the material to some extent against downward-flowing water, but near the footwall the water accumulates.

Though the statements just made are correct as to the completeness of kaolinization of the feldspar in the different parts of a dike, yet the present relation of a pegmatite to the surface features of the vicinity is not the only condition that determines the thoroughness of its alteration. Fresh feldspar and completely kaolinized feldspar occur at the same elevation and near each other in neighboring dikes. Watts[11] calls attention to the fact that a few years ago, at Penland,

[11] Watts, A. S., Mining and treatment of feldspar and kaolin: Bur. Mines Bull. 53, p. 17, 1913.

N. C., a dike in an advanced stage of kaolinization was being worked for kaolin, and that another dike 50 yards distant which was also being worked contained fresh feldspar. He adds, however: "The kaolin deposit is not well defined and appears to have been disturbed by a slide; whereas the fresh feldspar is in a well-defined dike."

It is not apparent to the writer why the kaolin at Penland is regarded as a slide. A sketch map of the occurrence is given in figure 4 (p. 49). However, in one of the shafts from which kaolin was taken a distinct dike of pegmatite about 2 feet wide cut diagonally through the kaolin, and the material of this dike is practically unchanged. The feldspar of the small dike is microcline and not orthoclase. Evidently the microcline resisted decomposition more successfully than the orthoclase and is therefore nearly intact. Some of the contrasts in the degree of alteration of neighboring dikes are probably due to differences in the character of the feldspar.

REFINING AND BY-PRODUCTS.

A thorough system of washing should remove many of the objectionable constituents from the crude kaolin and yield a refined product of nearly constant composition. Constancy of composition is more easily attained than freedom from impurities. At one mine the product was maintained at a constant standard during at least five years, as indicated by the table below, which shows the limits of variation in the refined kaolin shipped between the years 1890 and 1895. The analyses were made by N. P. Pratt on material dried at 100° C.

Analyses of washed kaolins from Dillsboro, N. C.

[Furnished by Harris Clay Co.]

	1	2
Silica (SiO_2)	46.47	46.47
Alumina (Al_2O_3)	38.82	38.14
Ferric and ferrous oxides (Fe_2O_3+FeO)	.89	.36
Lime (CaO)	.28	.50
Magnesia (MgO)	.25	.09
Alkalies (K_2O+Na_2O)	.75	.64
Water (H_2O)	13.34	13.61

1. Analysis of kaolin high in iron and alkalies.
2. Analysis of kaolin low in iron and alkalies.

Some of the objectionable constituents are not so readily removed. Nearly all refined kaolin contains some quartz and feldspar, and some of it contains a large proportion of more objectionable components. Washing alone, no matter how carefully and thoroughly done, will probably not remove all the iron hydroxides, for some of them are colloidal, but unquestionably many of the heavy iron-stained particles and much of the quartz that now finds its way into the refined product can be removed by more careful washing.

Analyses of the crude and washed kaolins from the Springer pit, near Webster,[12] give some idea of the improvement made by washing an unusually good crude clay.

Analyses of crude and washed kaolin from the Springer pit near Webster, N. C.

	1	2
Silica (SiO_2)	62.40	45.78
Alumina (Al_2O_3)	26.51	36.46
Ferric oxide (Fe_2O_3)	1.14	.28
Ferrous oxide (FeO)	....	1.08
Lime (CaO)	.57	.50
Magnesia (MgO)	.01	.04
Alkalies (Na_2O+K_2O)	.98	.25
Water (H_2O above 100° C.)	8.80	13.40
Moisture (H_2O below 100° C.)	.25	2.05
	100.66	99.84

1. Crude material.
2. Washed material.

The crude material contained 15.61 per cent of quartz and 18.91 per cent of feldspar and the washed material contained 6.60 per cent of these two components.

In some of the deposits a great deal of the quartz occurs in grains so fine that it passes the sand wheels used to remove the coarse components from the crude kaolin. This quartz may pass into the mica troughs and settle, and if not mixed with much mica it may be used in scouring soaps and other cleansers. It is not sharp enough for sandpaper and rarely pure enough for use in making glass. Occasionally the coarser quartz, when fairly uniform in size, has been used in roofing but with what success is not known.

Much of the mica that was in the original pegmatites has remained unaltered during the kaolinization of the feldspar and is now embedded in the crude clay. That which is in large flakes or aggregates of flakes may generally be easily separated from the kaolin by hand, and if it is clean and uniform in structure may be put on the market as "sheet mica" or if in smaller flakes as "punch mica." Indeed, some of the mines are now producing mica of this kind. As the mica must be removed from the mine and separated from the kaolin, the small additional expense required to save and sort it is warranted by the price at which it can be sold. In some pegmatites, however, the mica occurs in very fine scales. Moreover, the coarser mica found in most dikes is so severely pounded and torn in the processes of refining the crude clay that much of it is shredded into fine particles. The quantity of fine mica that passes the sand wheels may be very great. Much of it drops to the bottom in the mica troughs, but the fine scales float out in the slip that goes to the settling tanks. By placing screens of the proper mesh in the sluice

[12] Ries, H., Clay deposits and clay industry in North Carolina: North Carolina Geol. Survey Bull. 13, p. 62, 1897.

carrying the slip most of this mica might be saved and sold as "ground mica." At the Sprucepine mine an excellent grade of ground mica is now being saved at very little cost.

COMPOSITION.

A number of analyses of both crude and washed kaolins from North Carolina have been published. The crude kaolin usually has a high content of silica, whereas the washed kaolin commonly shows a ratio of silica to alumina, which closely approaches that of kaolinite, although occasionally the content of silica falls below that of kaolinite, thus indicating that hydrous aluminum oxide or some hydrous aluminum silicate other than kaolinite may be present. A few illustrative analyses are given below.

Analyses of kaolins from North Carolina.

	1	2	3	4	5	6
Silica (SiO_2)	62.40	45.78	46.95	45.70	46.41	46.30
Alumina (Al_2O_3)	26.51	36.46	37.73	40.61	38.46	39.06
Ferric oxide (Fe_2O_3)	1.14	.28	.15	1.39	.07	.20
Ferrous oxide (FeO)	....	1.08	....	....	....	....
Lime (CaO)	.57	.50	Trace.	.09	....	Trace.
Magnesia (MgO)	.01	.04	Trace.	.45	.07	Trace.
Potash (K_2O)	} .98	.25	.60	} 2.82	.42	.60
Soda (Na_2O)	}		.18	}	.17	.11
Titanic oxide (TiO_2)	....	....	.05	....	....	.04
Water (HO_2 above 100° C.)	8.80	13.40	13.99	8.98	14.40	13.77
Moisture (H_2O below 100° C.)	.25	2.05	....	.35	....	....
	100.88	99.84	99.65	100.39	100.00	100.08

	7	8	9	10	11	12
Silica (SiO_2)	45.56	45 61	46.51	49.56	46.95	44.00
Alumina (Al_2O_3)	38.65	38.63	39.91	37.53	37.24	40.79
Ferric oxide (Fe_2O_3)	.41	.46	.11	.02	.40	.11
Lime (CaO)	.05	.08	.00	.00	Trace.	Trace.
Magnesia (MgO)	.08	.08	.00	.06	Trace.	Trace.
Potash (K_2O)	.80	.90	Trace.	.05	.49	.55
Soda (Na_2O)	.55	.66	.00	.05	.24	.07
Titanic oxide (TiO_2)	.10	....	....	....	.05	Trace.
Water (H_2O above 100° C.)	13.90	13.57	13.38	12.65	14.10	14.72
	100.10	99.99	100.01	99.96	99.47	100.24

1. Crude kaolin from Springer pit, Webster. North Carolina Geol. Survey Bull. 13, p. 62, 1897.
2. Commercially washed sample of kaolin from Springer pit, Webster. North Carolina Geol. Survey Bull. 13, p. 62, 1897.
3. Sample of kaolin from Hog Rock mine, Webster. Washed in laboratory. Bur. Mines Bull. 53, p. 131, 1913.
4. Washed kaolin from Hog Rock mine, Webster. Idem, p. 61.
5. Commercially washed sample of kaolin from Roda mine, Sylva. Analysis furnished by Harris Kaolin Co.
6. Sample of kaolin from Buchanan property, Sylva. Washed in laboratory. Bur. Mines Bull. 53, p. 154, 1913. (Probably same as Ross property. See p. 55.)
7. Commercially washed sample of kaolin from Old Sprucepine mine, Sprucepine. Analysis furnished by Harris Kaolin Co.
8. Commercially washed sample of kaolin from Harris mine, Penland. Analysis furnished by Harris Kaolin Co.
9. Commercially washed sample of kaolin from Wilson mine, Micaville. Analysis furnished by Harris Kaolin Co. Calculated to 100 per cent dry material.
10. Commercially washed sample of kaolin from Hand mine, Woodrow. Analysis furnished by Harris Kaolin Co. Calculated to 100 per cent dry material.
11. Sample of kaolin from mine of Harris Clay Co. near Bryson. Washed in laboratory. Bur. Mines Bull. 53, p. 126, 1913.
12. Sample of kaolin from mine of Gurney Clay Co. near Franklin. Washed in laboratory. Idem, p. 135.

KAOLINS IN THE MOUNTAIN REGION.

OCCURRENCE.

The kaolins of the mountain districts are all, so far as known, residual products resulting from the decay of pegmatite dikes that cut the schistose rocks and granites. These dikes are not continuous for long distances and consequently form very narrow lenses. Many of them are parallel to the plains of schistosity of the rocks with which they are associated, and the strike of these rocks in turn is parallel to the trend of the mountain ridges in their vicinity. As most of the ridges have a general northeasterly trend most of the dikes also have a northeasterly trend. A few of the dikes cut across the planes of schistosity, but most of these crosscutting dikes are offshoots of main dikes that follow those planes. As a rule the largest deposits of kaolin have been produced by the decomposition of the larger dikes and therefore have a northeast trend. The crosscutting dikes are smaller than those that run parallel to the structure of the schists and have given rise to smaller deposits of kaolin.

CHARACTER OF THE PEGMATITES.

The relations of the pegmatites to the neighboring rocks have been so well described by Sterrett[13] that his statements concerning them may be quoted almost without modification. After stating that the pegmatites of North Carolina occur mainly in the Roan gneiss, which is a series of hornblendic gneisses and schists, and in the Carolina gneiss, which is nonhornblendic, he says:

> Pegmatites occur in irregular masses, streaks, lenses, augen, or balls, some of them having no visible connection with other pegmatite bodies. They range from a fraction of an inch up to many yards in thickness. * * *
>
> Horses, or inclusions of wall rock, are common in pegmatite. Some of them are in the form of bands or sheets parallel to the walls, and the schistosity of these bands is also parallel to the walls. They range from an inch or two up to several feet in thickness, and their length may be many times their width. Elsewhere they occur as irregularly shaped masses, from a few inches up to several feet thick. * * * In some places the horses are partly pegmatized by streaks of pegmatite ramifying through them and by the development of considerable feldspar and quartz through their mass. In such places no sharp line can be drawn between the pegmatite and the original horse.
>
> Pegmatite is closely allied to granite in composition. As in granite, the essential constituents are feldspar and quartz, with more or less mica and other accessory minerals. Though hornblende is rather a common mineral in granite, it is less so in pegmatite. Orthoclase and microcline are the most common varieties of feldspar found in pegmatite. In many places, however, a variety of plagioclase, either albite or oligoclase, makes up part or all of the feldspar component. The feldspar occurs in masses and rough crystals, some of them with a diameter of several feet.

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[13] Sterrett, D. B., Mica deposits of North Carolina: North Carolina Geol. and Econ. Survey Economic Paper 23, p. 37, 1911, and U. S. Geol. Survey Bull. 430, pp. 601–604, 1910.

Quartz assumes various forms and positions in the pegmatite. In many places it bears much the same relation to the feldspar and mica as in granite, the three minerals being thoroughly mixed with one another; but the individual grains are many times larger than in ordinary granite. Not uncommonly the quartz and feldspar assume a graphic-granite texture in a portion of the pegmatite. Another common feature is the occurrence of large separate masses of quartz occupying various positions in the pegmatite. Such quartz masses may be irregular in form and but little influenced by the shape of the pegmatite or inclosing wall. Many of them, however, lie in bands or sheets parallel to the walls. There may be one or more of these quartz bands constituting varying proportions of the pegmatite. Their thickness ranges from a fraction of an inch up to 6 or more feet. Many of them are lenticular in shape, the length varying from four or five to twenty or more times the thickness. In numerous places these quartz streaks or veins are persistent through the whole length of the pegmatite exposed. Some inclose feldspar or mica bodies; others do not. The quartz of these segregations is massive and generally granular, though locally crystallized. If crystallized it may be translucent or clear and of a dark, smoky, or light color. It is generally rather pure and does not contain feldspar or mica in appreciable quantity.

Muscovite is the common mica of pegmatite. * * * Biotite occurs in moderate quantity in a few deposits and in smaller amount in many others. * * * The mica occupies various positions in the pegmatite. Where the rock has a typical granitic texture the mica may be found evenly distributed through it. More commonly the larger crystals will be found either in clusters at intervals through the "vein" in places connected by streaks of small crystals, or collected along one or both walls of the pegmatite, with some of the crystals partly embedded in the wall rock. Where there is a quartz streak within the pegmatite the mica occurs on either or both sides of it. The mica may be partly embedded in the quartz or be scattered through the remaining portion of the pegmatite, which generally is composed largely of feldspar.

The dike rocks in places contain garnet, beryl, tourmaline, and other rarer compounds. During kaolinization these minerals may be changed partly to kaolin and partly to a mixture of iron and manganese oxides and hydroxides, which are likely to stain the kaolin in streaks and to produce in it little nodules of limonite. The biotite breaks down into limonite and perhaps chlorite or some other hydrated micaceous mineral and produces soft black masses in the midst of the clay. These constituents are particularly objectionable because of the difficulty of separating them from the kaolin, for their fine scales are apt to float and be carried into the settling vats when the kaolin is collected.

Beryl and tourmaline occur chiefly in the feldspathic portions of the dikes. As the beryl readily alters to kaolin it is not found in the kaolinized product, but the tourmaline changes to limonitic masses which color the clay brownish black.

KAOLIN MINES.

All the deposits of kaolin now being worked in North Carolina occur in the mountain district, and all of them are residual deposits from pegmatites. In addition there are many other similar deposits which are not being worked. Some of them are too small for profitable exploitation; others, though large, are not near the railroads; others are owned by people who lack financial means to develop them; and others are being held in reserve by the owners of the present active plants. Other deposits include some that are promising but have not been brought to the attention of the public and many which have never been explored.

In this paper only active deposits, those that have recently been active, promising deposits near transportation lines, and deposits held in reserve are described. On the accompanying map (Pl. I) the locations of these deposits are indicated and also the locations of known deposits which are not described in the text, but which will be referred to in a forthcoming report of the North Carolina Geological and Economic Survey.

The eight active mines of the State are in Haywood, Jackson, Mitchell, and Yancey counties. Three others, now inactive but partly equipped for operation, have been opened in Swain, Haywood, and Mitchell counties, and a score or more promising deposits might possibly be developed into producing properties under favorable conditions. The deposits are described in general from southwest to northeast.

DILLSBORO, JACKSON COUNTY.

Hog Rock mine.—The Hog Rock mine of the Harris Kaolin Co. is about 4 miles southeast of Dillsboro, near Harris, on Little Savannah Creek, Jackson County. It is the oldest mine in the State and has been operated continuously for 30 years.

The deposit is well up on the slope of a hill which has been reduced by open-cut work to three terraces above the valley level. The present workings are on the two higher terraces. The deposit consists of pockets of rich kaolin separated by narrow lenses and streaks of quartz and by layers of gneiss. In the aggregate, so far as it has been developed, it is 900 feet long and 250 feet wide at its broadest part, but its width diminishes at one place to 100 feet and again increases to 200 feet. It is cut diagonally by a spur of quartz-mica rock 400 feet long and 30 feet wide. West of this rock there are other deposits 15 to 20 feet wide, which are separated from the larger deposit by several hundred feet of gneiss. Still farther west a new deposit about 300 feet long and 100 feet wide has recently been opened. It is separated from the deposits to the east by 750 to 900 feet of gneiss and is apparently entirely independent of them.

The depth to which kaolinization has progressed differs markedly in different parts of the mine. The maximum depth to which mining has gone is 125 feet from the original surface. This depth has been reached partly by open cuts and partly by shaft. Because of the pockety character of the deposit a reliable estimate of the reserve can not be made.

The walls of the deposit are not well exposed. They appear to be formed of decomposed Carolina gneiss. The quartz-mica rock that penetrates the large deposit is mainly quartz streaked with little tongues of pegmatites. It contains pockets of decomposed feldspar, clumps of mica, small masses of limonitic material that may have come from hornblende or tourmaline and nodules of soft brown and black flaky limonite, as well as others of manganese oxides.

The deposits at this place evidently represent a large dike and several smaller parallel dikes, which in general have a northeastward trend and a nearly vertical dip. The dikes were irregular in width, and the feldspar and quartz, in the main dike at least, were irregularly distributed.

The crude clay is distinctly cream-colored when first mined, but it becomes darker after it has been dried out and exposed to the air. This darkening is apparently due to the oxidation of some iron compound. The kaolin contains a great deal of fine white mica and fine sand, a little decomposed feldspar, a few reddish-yellow stains, and a few concretionary nodules of mixtures of limonite and psilomelane or wad. Most of these nodules are small, but some of them are about an inch in diameter. They are readily separable from the kaolin in the refining process, and consequently manganese is rarely reported in analyses of the commercial product. The material from different pockets differs in chemical composition, but a uniform product is maintained by careful mixing.

The crude kaolin passes through agitators, sand wheels, the usual tanks, and screens, and after being pressed and dried it is hauled by horse tram 4 miles on a narrow-gage road to a siding at Dillsboro, on the Murphy branch of the Southern Railway.

The output of the mine and plant is about 2,400 tons annually. Its capacity is about double this quantity, provided sufficient labor is obtainable.

The kaolin from the Hog Rock mine is well known to nearly all the white-ware potters of the Middle West. It has been used by them in the manufacture of china and porcelain. It has also been employed in making floor and wall tile and is now being tested for use in glass-melting pots. For some years it has constituted a part of the mix for making the binder for vitrified carborundum wheels.

The following tests of the crude kaolin were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of kaolin from Hog Rock mine, Dillsboro, N. C.

Workability	Short, sandy; corners tear; dries well.	
Color of unfired clay		White.
Water of plasticity, in terms of dry clay	per cent	44.78
Air shrinkage by volume, in terms of dry clay	do	20.92
Air shrinkage, linear	do	7.6
Moisture factor on dry basis	do	1.10
Fineness test:		
Residue, 20-mesh sieve	do	38.60
Residue, 65-mesh sieve	do	7.08
Residue, 100-mesh sieve	do	.65
Residue, 200-mesh sieve	do	5.80
Amount passing 200-mesh sieve	do	47.87

Fire tests of kaolin from Hog Rock mine, Dillsboro, N. C.

Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).	Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).
1,190	37.1	16.0	1,370	30.9	24.1
1,250	41.9	18.6	1,410	24.9	30.7
1,310	36.8	17.9			

Roda mine.—The Roda mine, which is operated by the Harris Kaolin Co., is in Jackson County, about 7½ miles southeast of Dillsboro and 5 miles southeast of Webster on the south side of Tuckasegee River, opposite the mouth of Cany Fork. The plant in which the clay is filtered and pressed is on the south side of the river, 1 mile east of Webster. The washer is near the mine.

In his report on this mine Watts[14] says that the dike which gave rise to the kaolin

> cuts diagonally a low ridge and has a northeasterly strike. A broad band of sugar quartz follows the south wall which is very crooked. The extent of the dike has been proved more or less by test pits, but the chief exposure is by a long tunnel driven from the west slope of the hill. This tunnel passes through a broad band of low-grade pegmatite material into a band having a low quartz content.

An average sample from a shaft sunk into this band contained 26 per cent of kaolin. Since Mr. Watts's visit the mine has been sufficiently developed to show two dikes, one 20 feet and the other 40 feet in width, separated by 40 feet of rock. The deposit is pockety, and the clay in the different pockets differs somewhat in character.

In 1918 there were five active shafts, the material from which was mingled in the flume leading to the washer, so that the washed kaolin formed an average product of the whole mine. The crude kaolin yields about 25 per cent of refined product. The depth of the work-

[14] Watts, A. S., Bur. Mines Bull. 53, p. 156, 1913.

able clay is about 50 feet on the lower slopes of the ridge and more than 100 feet on its upper slopes. The estimated reserve is about 10,000 tons in that portion of the deposit that has been developed, but it is plain that its entire extent has not yet been explored.

The crude kaolin is white and somewhat sandy. It contains some fine mica, some sand, a few tiny black specks, large fragments of quartz and partly decomposed feldspar, and a few large flakes of silvery muscovite. Black streaks of a decomposed mineral are abundant near the wall of the western vein, and near the surface streaks of red clay and bunches and streaks of soft black compounds of manganese spoil the kaolin, but the main mass of the clay is free from stain and dark streaks. Veins of mica, however, embedded in red clay, occur throughout the mass. Much of the mica is stained and therefore useless, but 7 or 8 tons of rough material are separated monthly and put on the market as cut and scrap mica. It is noticeable that the better mica and the better clay are found together, and that where the mica is poor the kaolin also is apt to be inferior.

Under the microscope the kaolinite is seen to occur mainly in plates and flakes, but many of them are radially arranged, forming bundles and globular masses. The dark specks are composed of iron-stained clumps of kaolinite, pieces of stained feldspar, and here and there plates of chloritic material and shreds of greenish-yellow mica that are fragments of decomposed muscovite.

An analysis of the washed kaolin, furnished in 1917, is given in the table on page 25.

The crude clay is carried to the washer by a flume. The slip is pumped to a pipe which carries it to a flume, through which it flows by gravity to a tank on the top of a hill, then by a gravity siphon to the top of another hill 1½ miles distant, and finally by another flume 3 miles to the settling tanks at the plant on the river. After being pressed it is carried by motor truck 3 miles to a siding of the Southern Railway at Sylva. The normal capacity of the plant is about 2,500 tons of refined clay annually.

The uses of the kaolin from the Roda mine are the same as those of the kaolin from the Hog Rock mine. Indeed the kaolin of either mine is often substituted for that of the other.

WOODROW, HAYWOOD COUNTY.

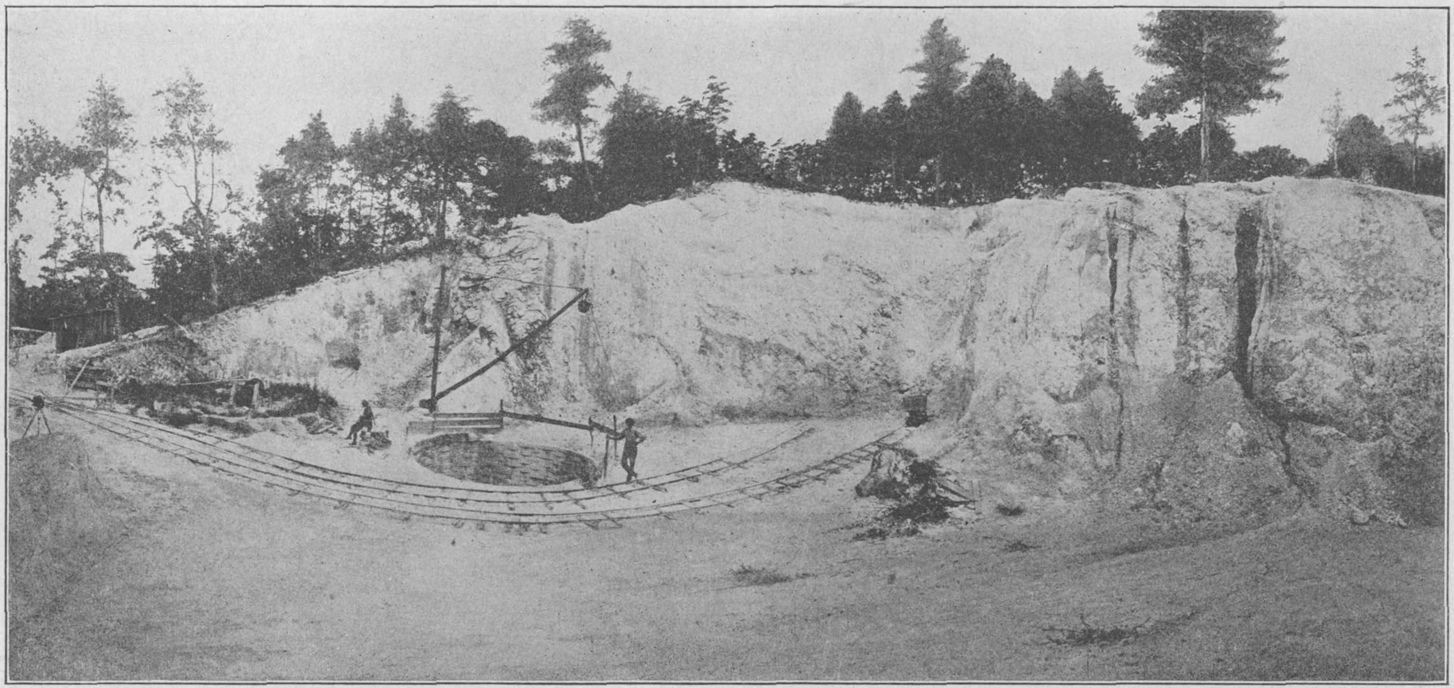
Mine of the Hand Clay Co. (Inc.).—The Hand Clay Co.'s mine (Pl. I) is about 1 mile southeast of Woodrow on the Pigeon River division of the Tennessee & North Carolina Railroad, a short branch that makes a connection with the Murphy branch of the Southern Railway system. Woodrow is 6 miles south of West Canton (its post office), and the plant is connected with the railroad at Woodrow by a narrow-gage tram that uses cars drawn by mules. This deposit may be the same as the Sonoma prospect mentioned by Keith[15] in 1907.

The deposit is well up on a hill slope that affords a convenient grade for sluicing the crude material to the refining and compressing plant in the valley. It is worked by an open cut 40 feet deep and 90 feet wide and by 2 shafts, of which one in August, 1918, was 72 feet deep and still in workable clay. Thirty-nine borings, distributed over an area 450 feet long and 120 feet wide, indicate a workable deposit at least 450 feet long by 90 feet wide and covered by an overburden not more than 5 feet thick. The deposit strikes about N. 20° E. and dips nearly vertically. Two tunnels, 55 feet and 125 feet long, which cut across the deposit, show a fairly uniform bed of clay, broken here and there by streaks of quartz. The thickness of the deposit is not known, for the augers penetrated to depths of only 30 feet, but most of the holes were stopped in hard clay. As the present workings show a thickness of at least 90 feet of workable material, it is safe to assume the average thickness over the whole area to be 60 feet. On this assumption the quantity of crude clay available is about 135,000 tons. If 20 per cent is saved as refined kaolin the reserve is about 27,000 tons. If the average depth of the workable clay is assumed to be 90 feet the calculated reserve rises to 40,000 tons. In making this estimate no allowance has been made for the presence of a horse of flint that shows in the pit. This horse may disappear at a greater depth or it may expand; at present its underground extension is unknown, though recent shaft work indicates that it is "playing out."

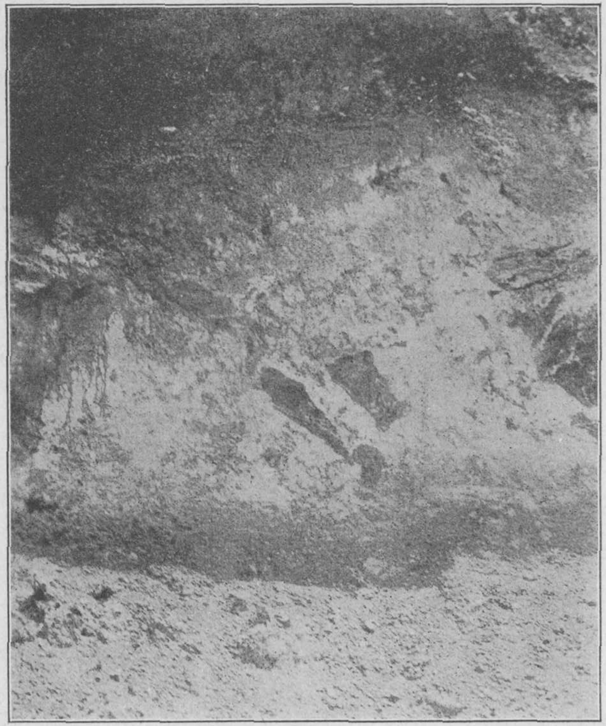
The walls of the deposit are not clearly defined, because the rock has been so much broken down by weathering that its original character is not now recognizable. Keith[16] maps the country rock as Carolina gneiss, which is in accord with the abundance of weathered micaceous material in the overburden. The clay deposit was evidently a pegmatite dike striking about N. 20° E. and dipping about 85° SE. In general it was uniform in composition, but in one place at least it was crossed by a mass of quartz which now appears as a horse in the kaolin. (See Pl. II.)

The crude clay is white, finely granular, and free from coarse quartz. It contains an abundance of quartz and is discolored here and there by small brownish-yellow stains similar to those seen on the sides of cleavage cracks in semikaolinized feldspar. In addition the clay contains numerous very small flakes of white mica and small

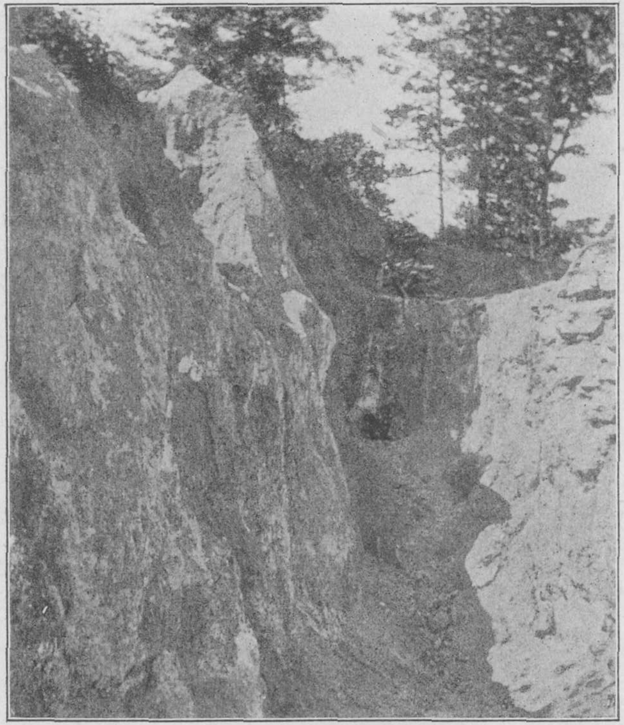
[15] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Pisgah folio (No. 147), p. 7, 1907.
[16] Keith, Arthur, op. cit.



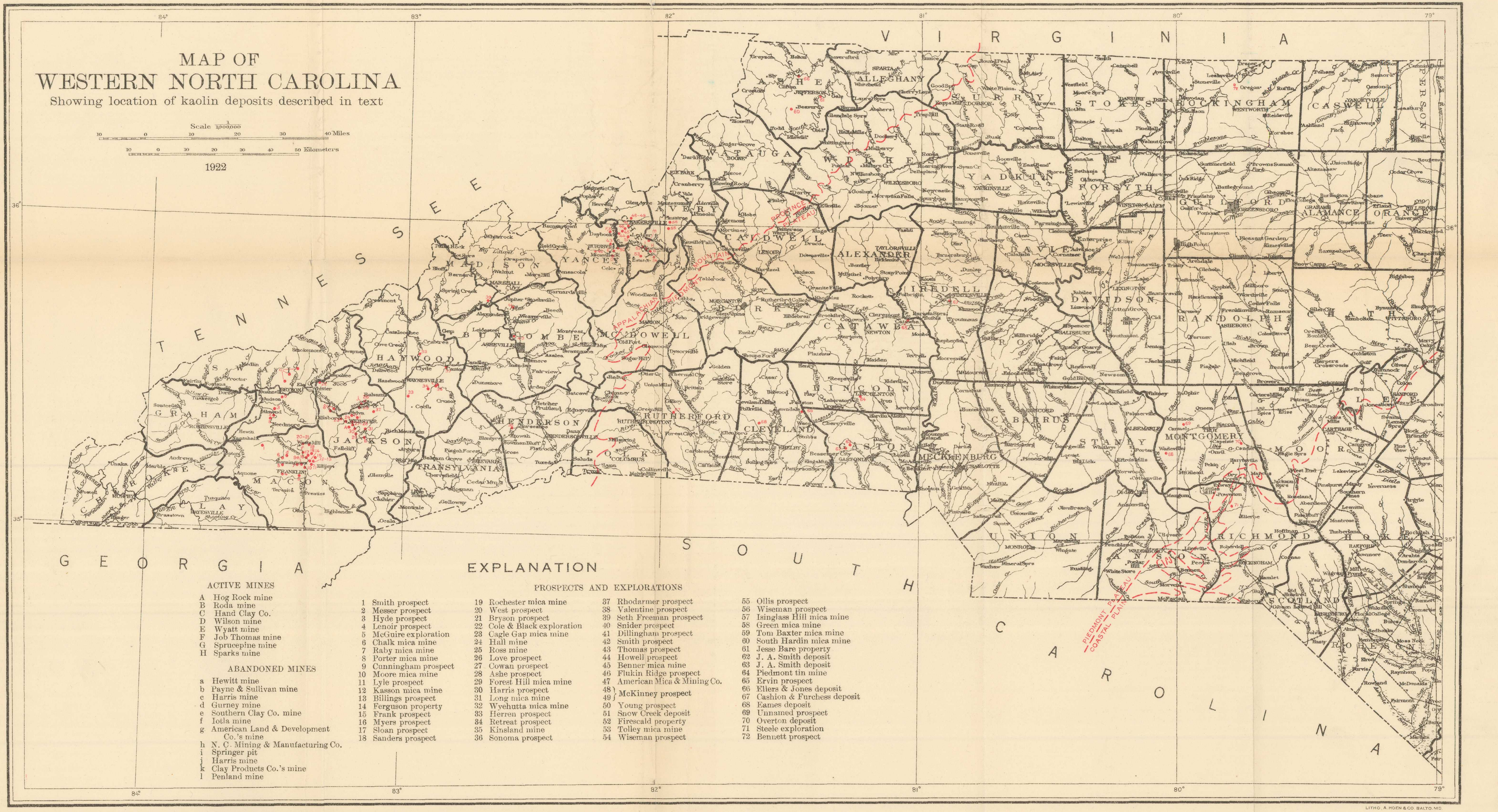
PANORAMIC VIEW OF HAND MINE, WOODROW, N. C.



A. WALL OF PIT OF GURNEY CLAY CO., NEAR FRANKLIN, N. C.
Showing inclusfons of country rock in the kaolin.



B. PIT No. 1 OF PAYNE & SULLIVAN MINE, BRYSON, N. C.
View looking southwest.


MAP OF
WESTERN NORTH CAROLINA
Showing location of kaolin deposits described in text
Scale 1/1,000,000
40 Miles
50 Kilometers
1922
EXPLANATION
ACTIVE MINES
A Hog Rock mine
B Roda mine
C Hand Clay Co.
D Wilson mine
E Wyatt mine
F Job Thomas mine
G Sprucepine mine
H Sparks mine
ABANDONED MINES
a Hewitt mine
b Payne & Sullivan mine
c Harris mine
d Gurney mine
e Southern Clay Co. mine
f Iotla mine
g American Land & Development Co.'s mine
h N. C. Mining & Manufacturing Co.
i Springer pit
j Harris mine
k Clay Products Co.'s mine
l Penland mine
PROSPECTS AND EXPLORATIONS
1 Smith prospect
2 Messer prospect
3 Hyde prospect
4 Lenoir prospect
5 McGuire exploration
6 Chalk mica mine
7 Raby mica mine
8 Porter mica mine
9 Cunningham prospect
10 Moore mica mine
11 Lyle prospect
12 Kasson mica mine
13 Billings prospect
14 Ferguson property
15 Frank prospect
16 Myers prospect
17 Sloan prospect
18 Sanders prospect
19 Rochester mica mine
20 West prospect
21 Bryson prospect
22 Cole & Black exploration
23 Cagle Gap mica mine
24 Hall mine
25 Ross mine
26 Love prospect
27 Cowan prospect
28 Ashe prospect
29 Forest Hill mica mine
30 Harris prospect
31 Long mica mine
32 Wyehutta mica mine
33 Herren prospect
34 Retreat prospect
35 Kinsland mine
36 Sonoma prospect
37 Rhodarmer prospect
38 Valentine prospect
39 Seth Freeman prospect
40 Snider prospect
41 Dillingham prospect
42 Smith prospect
43 Thomas prospect
44 Howell prospect
45 Benner mica mine
46 Flukin Ridge prospect
47 American Mica & Mining Co.
48, 49 McKinney prospect
50 Young prospect
51 Snow Creek deposit
52 Firescald property
53 Tolley mica mine
54 Wiseman prospect
55 Ollis prospect
56 Wiseman prospect
57 Isinglass Hill mica mine
58 Green mica mine
59 Tom Baxter mica mine
60 South Hardin mica mine
61 Jesse Bare property
62 J. A. Smith deposit
63 J. A. Smith deposit
64 Piedmont tin mine
65 Ervin prospect
66 Ellers & Jones deposit
67 Cashion & Furchess deposit
68 Eames deposit
69 Unnamed prospect
70 Overton deposit
71 Steele exploration
72 Bennett prospect
VIRGINIA
TENNESSEE
GEORGIA
SOUTH CAROLINA
LITHO. A. HOEN & CO. BALTO. MD.

crystals and larger groups of crystals of the same mineral. The yellow stains are most common in the neighborhood of the mica plates and especially around the larger crystals and groups of crystals and in the cleavage cracks between their plates, where infiltration has carried iron compounds and deposited them. The mica itself within the kaolin appears to be almost wholly unchanged except comparatively near the surface, where it has become red and opaque and has lost its elasticity. Even when bleached by treatment with strong hydrochloric acid it remains opaque, except on thin edges, where it seems to be only slightly double refracting if not entirely isotropic. It has lost completely its homogeneity and has been changed to an aggregate of tiny transparent or translucent particles, which in the mass appear white and opaque, as if they were kaolinite. They are, however, so lacking in definite characteristics that their nature has not been determined. The microscope reveals the presence also of numerous particles of partly kaolinized feldspar, small plates of reddish-yellow decomposed muscovite, flakes of a brown pleochroic mica that may be biotite, little aggregates of brown-stained kaolinite, and a few highly refracting grains that may be zircon. Some of the biotite flakes contain slender black needles, like the needles of rutile commonly seen in the biotite of igneous rocks.

The washed clay as put upon the market consists mainly of kaolinite material in flakes and granules, considerable quartz in irregular grains, a small quantity of kaolinized feldspar, and a few frayed flakes and many fibers of muscovite together with here and there a little plate of slightly pleochroic brown mica. Most of the kaolinite particles measure about 0.01 to 0.03 millimeter in diameter, but they are commonly grouped together into clumps whose diameters are six or eight times as great as the diameters of the individual grains. However, these grains are interspersed among others of smaller size, whose diameter averages about 0.004 millimeter. The quartz, mica, and feldspar are usually in much larger grains, often measuring 0.06 to 0.08 millimeter. A few of the clumps of kaolin and also some of the particles of feldspar are stained yellowish brown.

An analysis of the washed clay is given on page 25. It is impossible to compute the composition of the kaolin with any close degree of accuracy, because some one of the constituents must have been determined by difference, and therefore if there is an error in the analysis it is not discoverable, and furthermore the proportion of muscovite and feldspar in the sample is not known. On the assumption that all the alkalies are in the muscovite and that the determination of combined water is correct the composition of the sample was about 90.50 per cent of kaolinite, 7.50 per cent of quartz, 1.33 per cent of alumina, 0.64 per cent of muscovite, and 0.08 per cent of miscellaneous minerals.

The plant, which is near the mine, is well equipped with washing and filter pressing apparatus. Its production during the past few years has been at the rate of 2,400 tons of refined kaolin annually, but if labor was abundant the output might perhaps be doubled. Changes made in the plant during the winter of 1918–19 may reduce its capacity to a slight extent, but the quality of the output will be improved. These changes consist in lengthening the mica troughs and in replacing the 100-mesh sieves by others of 130 mesh. It is hoped by these changes to reduce the quantity of quartz in the refined product.

The clay from this mine has been used in making china, porcelain, and other kinds of white ware. It is introduced into mixtures of imported and other domestic clays to the extent of 2½ to 15 per cent. Letters from the Bureau of Standards to the company under dates of December 5, 1917, and March 6, 1918, declared it to be of good grade for pottery. When burned to cone 8 (1,290° C.) the material was still a very excellent white. The sample submitted was fine grained, as much as 94.61 per cent passing the 300-mesh sieve. When introduced in the proportion of 28 per cent into a porcelain mixture and fired in the biscuit to cone 8 and in the glost to cone 4 (1,210° C.) a vitrified body of "a very satisfactory white resulted."

The following tests of the washed clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of washed kaolin from Woodrow, N. C.

Workability	Not very plastic; makes good bars.	
Color of unfired clay		White.
Water of plasticity, in terms of dry clay	per cent	47.5
Air shrinkage by volume, in terms of dry clay	do	28.91
Air shrinkage, linear, calculated	do	10.8
Moisture factor on dry basis	do	1.56
Fineness test:		
Residue, 20-mesh sieve	do	.00
Residue, 65-mesh sieve	do	.07
Residue, 100-mesh sieve	do	.04
Residue, 200-mesh sieve	do	.60
Amount passing 200-mesh sieve	do	99.34

Fire tests of washed kaolin from Woodrow, N. C.

Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).	Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).
1,190	39.4	17.1	1,370	31.4	27.3
1,250	39.4	19.3	1,410	27.2	31.0
1,310	37.7	19.7			

MICAVILLE, YANCEY COUNTY.

Wilson mine.—The Wilson mine of the Harris Kaolin Co. is 1 mile southeast of Micaville (fig. 10), and the washing plant is 1 mile to the northeast. There are two cuts on the same deposit, with one shaft in each cut.

Nothing of special geologic interest can be seen in the pits. The overburden is the common red clay, and its thickness ranges from 3 to 8 feet. Except for the thin veneer of overburden around its top, the walls of the pit are almost entirely formed of kaolin. At one place rock shows for a few feet, but otherwise only white clay is visible. From the present development it appears probable that the deposit ranges in width between 18 and 75 feet and that the merchantable kaolin is 30 to 50 feet deep. Its strike is N. 60° E., and its dip is about 85° SE.

The kaolin is very light cream-colored. It contains fine flakes of white mica, sand, fragments of quartz, and a little biotite that prevents the separation of the fine white mica as a commercial product. On the other hand, many streaks and isolated clumps of coarse white mica are scattered through the mass, and from this material about one hundred dollars' worth of sheet and punch mica is saved monthly. An analysis of the washed kaolin, made in 1914, is given on page 25.

The crude clay is sent to the washing plant, whose capacity is about 350 tons monthly, provided sufficient labor is available. From the washer it is sluiced 1¼ miles to the settling plant at Lamonti, on the Black Mountain Railroad.

The Wilson clay has been used with success in the manufacture of china and semivitreous porcelain of all types. About 15 per cent goes into the mix, together with six or seven other clays, for making semivitreous ware and a little less in that used for making table china. The major portion of the mix, besides flint and spar, is made up of English china and English ball clays.

Wyatt mine.—The Wyatt mine is a new opening about 1 mile northeast of Micaville. It is across the stream from the Lamonti plant, where the output of the mine will be prepared for shipment.

In September, 1918, the mine consisted of several openings on the side of a hill about 600 feet south of the Lamonti plant and about 100 feet above it. Toward the east end of the property two veins separated by 50 feet of rock are visible. About 600 feet southwest of the eastern opening, which is a shallow pit, the two veins unite and form a single vein 70 feet wide. In a tunnel a short distance south of the pit a mass of kaolin 35 feet in width is exposed. It contains streaks of mica and of red-stained material and is intersected by a nearly horizontal horse of red clay. At the end of the tunnel the kaolin fingers out in thin stringers, but 34 feet beyond more kaolin occurs in a deposit which is said to be 22 feet wide. According to Mr. Hise, the superintendent of the property, these two veins unite 300 feet southwest of the tunnel into a single wider vein. He says that the system of veins can be followed for 1,100 feet. The kaolin is covered by 4 feet of overburden, and the average depth of the workable clay, as revealed by borings, is 42 feet. In some places the depth to hard rock is 60 feet.

Only about 10 carloads of clay had been washed by September, 1918, but preparations were being made for systematic operation. The washer is on the hill near the mine. The slip is sluiced down to the plant at Lamonti, where it is mixed with that from the Wilson mine. The mixed kaolin is to be the standard commercial product in the future.

TOECANE, YANCEY COUNTY.

Job Thomas mine.—The Job Thomas mine (fig. 10, p. 62) has been worked since 1914 by the Intermont China Clay Co., of Erwin, Tenn., and Bandana, N. C. The mine is 3½ miles southwest of Toecane, on the north side of Chestnut Mountain. The deposits are pockety and therefore difficult to work, so that it is proposed to abandon the mine as soon as a new source of clay is developed.

The crude clay is like that of the Wilson mine. It is light cream-colored and contains sand, fine mica, and red streaks like the other crude kaolins of this district. The overburden consists of 3 to 8 feet of red clay.

The washer is near the mine. After passing through the usual troughs and screens the slip flows by gravity in a flume 2½ miles to the filter plant at Intermont, on the Carolina, Clinchfield & Ohio Railway, 2 miles south of Toecane. The capacity of the plant is 400 tons of refined kaolin monthly.

The kaolin from the Job Thomas mine has been used in the manufacture of china. Occasionally it is mixed with other domestic kaolins, but generally with Florida and English china clay and English and domestic ball clays, especially in the mix used for making porcelain.

Pit of the Clay Products Co.—At one time the Clay Products Co. (fig. 10, p. 62) operated a pit about 100 yards from the Job Thomas mine. It was probably on a parallel dike. The deposit was small and pockety. A tunnel that traversed it exposed good kaolin, which was intersected, however, by many streaks of schist. The place was never sufficiently developed to prove its value. It was worked a year, and after producing about 40 tons of refined kaolin that had been washed by hand it was abandoned.

SPRUCEPINE, MITCHELL COUNTY.

Sprucepine mine.—The present openings of the Sprucepine mine of the Harris Kaolin Co. (fig. 10) are on the slope of a hill about three-fourths of a mile southeast of Sprucepine station on the Carolina, Clinchfield & Ohio Railway, near the mouth of Beaver Creek. The settling tanks and pressing plant are on the railroad near the station.

The deposits now being operated were first opened in 1916. Before that time the product was obtained from a deposit 2¾ miles north of Sprucepine near the head of Beaver Creek and then was sluiced to the plant on the railroad.

The present mine consists of two openings about 500 feet apart. The western opening has been worked for two years and the eastern one since March, 1918. The western opening has been worked by open cut to a depth of 30 feet and by shafts to a further depth of 55 feet. At this depth dynamite is used to loosen the material and beyond this depth mining is unprofitable. The kaolin from this opening is light cream-colored. The overburden, composed of red clay and broken rock, is from 6 feet to 10 feet thick. The crude kaolin contains the usual impurities—quartz, mica, black lumps of manganese oxides, and here and there small masses of stained clay. The dike in which it occurs probably strikes about north, but its walls are not clearly enough revealed to warrant a definite opinion.

In the eastern pit two shafts were down 30 feet in August, 1918. Both contained so much water that pumping was necessary to keep them in condition to be worked. The kaolin obtained from this pit is white, not cream-colored, like that from the western pit, but it contains the same impurities, though in somewhat different forms. The quartz occurs in grains and also in little round pebble-like fragments. The appearance of their surfaces suggests that they have been corroded. The mica occurs in very fine flakes. In washing the kaolin the mica is separated from the slip by 100-mesh sieves. This mica after separation consists of plates of fresh muscovite between 0.2 and 0.5 millimeter in diameter, many smaller plates and shreds of the same mineral, a few flakes of a reddish-yellow mica that is probably an altered muscovite, and here and there a plate of a slightly pleochroic dark-yellowish red mica that may be a partly decomposed biotite. In addition, there is much kaolinite in very small flakes and shreds and a few clumps of dark material that may be stained kaolinite. About 90 per cent of the mass is fresh muscovite. About a thousand pounds is saved daily and sold as ground mica to rubber and roofing manufacturers. The other impurities are nodules of soft black material, probably manganese oxides, and streaks of yellow clay.

The deposit at this place is probably large. It has not yet been sufficiently developed to uncover distinct walls nor is the depth of kaolinization known. The kaolin, however, is cut by horses of red clay, some of which are 15 feet wide. These probably represent decomposed country rock, which may pass into well-defined rock.

at greater depths than have thus far been reached. Borings around the open pit in which the shafts are sunk show nothing but kaolin and streaks of yellow or red clay.

The crude clay is cleaned in washers near the pits and the resulting slips are sluiced in a common trough to the settling, drying, and filtering plant on the railroad. They are thoroughly intermingled before they reach the settling tanks, and in this way a uniform product is assured.

The present capacity of the mine and plant is about 5,500 tons annually, if labor is abundant, but this output is not always attained. With the completion of a hydroelectric plant on Toe River it may be possible to install labor-saving appliances, and the output may be increased.

The users of the Sprucepine kaolin include most of the potters who use also the kaolin from the Hog Rock and Roda mines near Webster. In the manufacture of china and white ware a mixture is made with imported clays and clays from Florida or Tennessee or with clays from both these States. The Sprucepine kaolin is a favorite among most of the potters who use it. Some of them employ it to the extent of 15 per cent of the total mix and contemplate increasing the quantity used in order to decrease the amount of imported clay now employed, whereas others report that they are gradually substituting for it some of the domestic clays from other sources. One potter declares that he uses no imported clay but makes his mix entirely of domestic materials. The Sprucepine kaolin is also used in the mixture of domestic clays employed in making spark plugs and other types of porcelain. Some of the largest manufacturers prefer it to foreign clay for these purposes, whereas others declare that they could not use it alone for semivitreous porcelain, as it would shrink badly. However, practically the whole output of the mine goes to china, porcelain, and other white-ware factories.

The following tests of the crude kaolin from the Sprucepine mine were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of crude kaolin from Sprucepine mine No. 1, Mitchell County, N. C.

Workability		Very gritty; short; molds with difficulty; dries well; no cracks.
Color of unfired clay		Cream.
Water of plasticity, in terms of dry clay	per cent	43.18
Air shrinkage by volume, in terms of dry clay	do	14.11
Air shrinkage, linear, calculated	do	5.00
Fineness test:		
Residue, 20-mesh sieve	do	21.18
Residue, 65-mesh sieve	do	29.87
Residue, 100-mesh sieve	do	2.28
Amount passing 200-mesh sieve	do	46.67

Fire tests of crude kaolin from Sprucepine mine No. 1, Mitchell County, N. C.

Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).	Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).
1,190	45.90	10.7	1,370	40.80	22.3
1,250	47.20	8.1	1,410	29.10	24.5
1,310	44.87	14.0			

General physical tests of crude kaolin from opening of Sprucepine mine, half a mile east-southeast of Sprucepine, Mitchell County, N. C.

Workability — Very sandy; no strength; corners tear.
Color of unfired clay — White.
Water of plasticity, in terms of dry clay — per cent — 36.69
Air shrinkage by volume, in terms of dry clay — do — 16.01
Air shrinkage, linear, calculated — do — 5.7
Moisture factor on dry basis — do — 1.317
Fineness test:
- Residue, 20-mesh sieve — do — 21.58
- Residue, 65-mesh sieve — do — 17.39
- Residue, 100-mesh sieve — do — 1.16
- Residue, 200-mesh sieve — do — 1.95

Amount passing 200-mesh sieve — do — 57.95

Fire tests of kaolin from opening of Sprucepine mine, half a mile east-southeast of Sprucepine, Mitchell County, N. C.

Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).	Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).
1,190	35.7	14.7	1,370	30.0	23.25
1,250	37.2	15.8	1,410	18.7	27.6
1,310	36.0	16.8			

Sparks mine.—The Sparks mine of the Harris Kaolin Co. is on the Carolina, Clinchfield & Ohio Railway about 2 miles northwest of Sprucepine and about midway between this village and Penland (fig. 10).

The deposit is on the slope of a hill several hundred feet above the washing plant, which is at the foot of the hill on the railroad. The mine was opened in the early part of 1914 and has been operating ever since. The main vein strikes about north. It is about 100 feet wide and is known to extend 1,000 feet north and south. A spur branches from the main vein to the northeast. This spur ranges in width between 65 feet and 75 feet and is several hundred feet long. Another vein 47 feet west of the main vein and parallel to it is 30 feet wide. The reserve, calculated on the assumption that kaolinization has proceeded to the depth of 60 feet and that 20 per cent of refined product can be recovered, is at least 60,000 tons.

The mine is worked in the usual way by open cut and shafts. In August, 1918, two shafts about 20 feet deep were being operated. Other shafts from 45 feet to 50 feet deep had been abandoned because of water and the hardness of the rock at their bottoms. The overburden of red clay and rock fragments is from 6 feet to 10 feet thick.

The crude kaolin is white and coarse. It contains abundant rounded quartz fragments, bunches of white and dark mica, quartz stringers, and much sand. On the walls of the shafts can be seen coarse quartz, quartz stringers, and dark and light mica flakes in bunches, forming streaks through the clay and abundant smaller plates of white mica scattered indiscriminately through the purer kaolin. Much of the darker mica is evidently badly decomposed, and some may itself be partly decomposed muscovite. A great deal of the white mica is fresh and in plates large enough to be of commercial value. This material is separated from the kaolin by hand and sold as punch and sheet stock.

The users of the Sparks kaolin are the same as those of the Sprucepine product, and the kaolin from both mines is practically the same in character. (See p. 38.) The potters that manufacture white ware and semiporcelain, who employ it in mixtures, report that as furnished to them in carload lots it burns to a very white body. It is used in the proportion of 10 to 16 per cent in the dry mix. It is also said to stand a very high fire and to be entirely satisfactory for the purpose to which it is put. The tile manufacturers employ it with New Jersey ball clay, flint, and feldspar, and as a uniform quality has been furnished, through the method of mixing the products from different pockets, it has given such good results that it has replaced completely the imported kaolin. The capacity of the plant is about the same as that of the Sprucepine mine.

The following tests of the washed kaolin were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of washed kaolin, from Sparks plant, Sprucepine, Mitchell County, N. C.

Workability	Short, sandy; corners tear; dries well (no cracks).	
Color of unfired clay		White.
Water of plasticity, in terms of dry clay	per cent	44.48
Air shrinkage by volume, in terms of dry clay	do	20.20
Air shrinkage, linear, calculated	do	7.3
Moisture factor on dry basis	do	.352
Fineness test:		
Residue, 20-mesh sieve	do	.00
Residue, 65-mesh sieve	do	.00
Residue, 100-mesh sieve	do	.00
Residue, 200-mesh sieve	do	2.92
Amount passing 200-mesh sieve	do	97.08

Fire tests of kaolin from Sparks plant, Sprucepine, Mitchell County, N. C.

Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).	Temperature (° C.).	Porosity (per cent in terms of burned volume).	Volume shrinkage (per cent in terms of volume of dry clay).
1,190	39.6	18.1	1,370	35.5	24.98
1,250	39.7	18.4	1,410	28.5	28.0
1,310	37.97	20.3			

FRANKLIN, MACON COUNTY.

Porter property.—The Porter property was formerly worked by the Gurney Clay Co. as the Gurney mine. It is 4 miles northwest of Franklin and 3 miles east of Burningtown on Iotla Creek. The shape of the pit, which has an average width of about 35 feet and is 400 feet long, indicates that the deposit is a narrow lens, but as the width differs widely in different places the kaolin was evidently pockety. Watts,[17] in describing the mine when in operation, says that "the kaolinized dike forms an expanded lens, averaging about 200 feet in width and 300 feet in length already proved. * * * The lens consists of bands varying in kaolin content," but by mining the entire width of the dike a uniform product was obtained. At first the mine was worked by shafts, some of which were 100 feet deep, but this method proved so expensive that the open-cut method was adopted. The mine was worked about 4 years and produced about 250 tons of merchantable kaolin monthly.

It was abandoned in 1914 not, Mr. Gurney says, because of lack of material, but because of the lack of demand for kaolin in that year and because of a red stain in the output, which was caused by decomposed biotite. This stained material could not be separated from the clay in mining and therefore it had to be removed by hand. The cost of this cleaning was as great as the cost of mining. The time required for sorting limited the output of the plant to 250 tons monthly, though its capacity was 500 tons.[18] Mr. Gurney believes he now has a method for eliminating the stained clay, which should enable the deposit to be operated successfully.

The relations of the clay to the rock in the pit are now concealed by wash, but several branching dikes can be seen in the pit. There are also indications that the kaolin is crossed by horses of partly decomposed feldspar and coarse quartz, and where the walls are exposed there are small veins of kaolin in the country rock and seemingly fragments of rock in the clay. (See Pl. III, *A*.) The fragments are probably parts of the country rock that have been surrounded by pegmatitic material. Bunches of muscovite are common

[17] Watts, A. S., op. cit., p. 133.
[18] Letter of Mr. J. W. Gurney of Aug. 14, 1918.

in the kaolin in many parts of the mine. In some parts the muscovite was so abundant that it was saved as a by-product. Biotite is also present but in smaller quantity, and it is generally associated with quartz. The waste heaps, which consist mainly of large fragments of quartz, indicate that much quartz was mined with the clay. The overburden was not more than 10 feet in thickness anywhere, and its average thickness was about 6 feet.

The crude clay was washed and pressed in a plant a few hundred yards from the pit and when dried was hauled by teams to Franklin. It was sold under the name "Iotla brand" and was used by many of the potters in the Ohio Valley.

The buildings of the washing plant are still in good repair, but some of the machinery has been removed.

Johnston property.—The Johnston property, about 1 mile northwest of Franklin, which is owned by W. R. Johnston, of Sylvester, Ga., was formerly worked by the Southern Clay Co. It was operated only two years, and then the lease was surrendered, the plant was dismantled, and the company was dissolved. One of the causes of the abandonment of the mine was the difficulty of handling the water. There were a number of openings on the northeast flank of Tremont Mountain, the largest of which was about 1 mile northwest of Franklin post office.

Little of interest can now be seen on the surface. Most of the workings have fallen in and their walls are concealed. About half a mile back of the main workings mica is now being taken from some of the old shafts and tunnels, and they have been cleaned out. Three of the openings expose kaolin about 10 feet in breadth, but much of it is badly stained near the surface. At increased depth, however, the staining diminishes, and at 25 feet underground the clay is uniformly white. It contains many bunches of large mica plates, which are now being removed for sale.

The main workings consist of an open pit 400 feet long and 50 feet wide and a shaft 125 feet deep to water. The walls of the pit are nearly vertical, and its trend is a little north of east. The crude clay contained some coarse quartz and a great deal of fine mica, beside clumps of large plates, like those that are being mined farther northeast. This mica was saved and sold. The fine mica was separated during the process of washing the clay and was thrown aside. Large dump heaps on the site of the old plant are composed almost exclusively of fine white mica scales, which might possibly have been saved and sold as ground mica.

Mr. Johnston reports that about 4,000 tons of refined clay were sold and that it was used in making white ware and tile.

Cunningham property.—Across a valley from the east end of the Johnston property, where the main dike of kaolin is reported to have disappeared, the dike reappears in the property of Mr. C. C. Cunningham, where it was worked through a number of shafts and pits as a source of mica. One shaft 25 feet deep is said to have penetrated 10 feet of overburden and 15 feet of clay. A boring in its bottom went through 35 feet more of similar clay. Two other shafts 25 feet deep and a third shaft 60 feet deep also exposed clay for their entire depth under the overburden. The depth of the kaolinization increases toward the east. Mr. Cunningham reports that borings and test pits outline a dike 22 feet wide and at least 1,500 feet long. It strikes a little north of east and dips about vertical. There is a great deal of mica in the clay and considerable quartz. It is possible that the kaolin and mica might be mined together.

Iotla mine.—The Iotla mine of the Franklin Kaolin & Mica Co. is 4¼ miles north of Franklin, on the west side of Little Tennessee River, at Iotla Bridge. The place is now abandoned. It was originally worked for mica and later for kaolin. Watts,[19] in his description of the mine shortly after it was abandoned, says that the development consisted of 10 tunnels and 12 shafts and that some of the shafts were 120 feet deep. The dike had been mined for a length of 550 feet and for a width that ranged from 10 to 100 feet. Although layers of sugar quartz bordered the kaolin and a streak ran through the center of the dike, the crude clay contained very little quartz. A sample taken by Watts [19] from one of the shafts yielded 42 per cent of white kaolin of excellent quality.

If the property was ever worked for kaolin it was probably worked on only a very small scale, as there is no indication that any large quantity of material was ever removed from the ground. Moreover, all the dumps consist almost exclusively of mica. The most accessible part of the mine at present is a tunnel 150 feet long at the base of the hill, near the river. This tunnel for nearly all of its length is in a white clay, cut here and there by horses of rock and crossed by numerous streaks of muscovite in crystals and groups of crystals. The clay surrounding the crystals of mica contains a comparatively small amount of quartz sand and abundant tiny flakes of white mica. Farther up on the hill slope six or seven other tunnels and a shaft penetrate clay, and near the top of the hill is a large tunnel through clay, mica, and quartz. Men who have worked on the property say that mica was much more plentiful near the top of the hill than lower down and that the quality of the kaolin was better at lower levels.

The large number of pits and shafts scattered over the property indicate that there are many small dikes of pegmatite and many

[19] Watts, A. S., op. cit., p. 133.

small pockets of kaolin. Some of the largest dikes appear to be promising.

ALMOND, SWAIN COUNTY.

Hewitt mine.—The Hewitt mine, which is no longer in operation, was worked by a number of openings in a belt that extends north and south at a distance of about 2 miles east of Almond (fig. 3) on the Murphy branch of the Southern Railway. The geologic associations here are unusual, for the wall rock is composed of graywacke and schists of the Great Smoky conglomerate, which is Lower Cambrian in age.[20] The wall rocks of all other kaolinized pegmatites are formed of gneisses and schists of pre-Cambrian age. Six deposits are mapped. In 1905 the company was working the deposits 2½ miles southeast of Almond on the east side of the road between this village and Needmore. The clay was being taken from the top and the southern slope of a small ridge. Test pits and a short tunnel proved its extent for about 450 feet in a northerly direction. About a mile farther north is another deposit of kaolin and one-fourth mile west still a third one. Other deposits have been opened up by tests pits 2 miles southwest and 1¾ miles northwest of the Hewitt mine. At the locality last indicated there are two separate veins, and the kaolin in them is at least 50 feet deep. Later the deposit on the west side of the road was opened. This deposit was abandoned a few years ago, and the entire plant has been closed. At this place [21] a dike 20 to 30 feet wide, which trended northward and dipped 75° E., had been removed for a distance of 275 feet and to a depth of 40 to 60 feet. The pegmatitic material was incompletely kaolinized. The crude material yielded 20 per cent of a pale cream-colored refined kaolin.

BRYSON, SWAIN COUNTY.

Payne & Sullivan mine.—The Payne & Sullivan mine, which is now abandoned, is 4 miles southwest of Bryson, near Yalaka Creek. The openings are a short distance from those formerly worked by the Carolina Clay Co. at the head of Buckner Branch. The Carolina Clay Co.'s deposits were abandoned some years ago, but there are other dikes of kaolinized pegmatite in the neighborhood, and on one of these dikes the Payne & Sullivan mine was opened. At the old Carolina mine the dike is reported to have been 16 feet wide.[22] It strikes N. 15° E. and dips 75° SE. It was rich in kaolin near the footwall but became progressively poorer toward the hanging wall, near which the dike material was nearly all sand. There were pockets of garnet-colored sand in the kaolin and streaks

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[20] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Nantahala folio (No. 143), p. 8, 1907.
[21] Watts, A. S., op. cit., p. 119.
[22] Watts, A. S., op. cit., p. 124.

of wall rock. A sample taken from across the entire width of the dike yielded 22 per cent of a yellowish kaolin. The Payne & Sullivan mine, which has also been closed down for several years, is farther south, on the top of a steep slope. The buildings of the washing plant are still in fairly good repair, but all the machinery has been removed. One of the present owners says that the former lessees, who built the plant, operated the mine but a short time. They took out material that yielded about 250 tons of washed kaolin, of which they shipped 100 tons. The remaining 150 tons is still in the storage sheds. When the mine was worked water was pumped 320 feet. The crude clay was trammed 300 feet from the mouth of the pit and sent down a chute to the refining plant at the bottom of the slope. The refined kaolin was hauled in wagons 1 mile to a private railroad known as the Yalaka Railroad and there loaded on standard cars. When the mine is reopened the crude material will be sent from the old pit to the plant by a flume, the new openings will be joined by a tramway already partly constructed, and the product will be sluiced, together with that of the old opening.

There are now two main openings on the property and a number of shafts, tunnels, and test pits, nearly all of which expose excellent clay. The old pit is known as No. 1. A newer pit about half a mile farther northeast is known as No. 2. Wherever the clay is exposed it appears to be in a dike that strikes about N. 20° E., or rather a series of ramifying dikes that have a general northeasterly trend. In pit No. 1 the width of the deposit is 40 or 45 feet, in pit No. 2 about 20 feet, and in a shaft and tunnel 375 feet south of pit No. 2 the maximum width of clear kaolin is 6 feet.

Pit No. 1 (Pl. III, *B*), which is 190 feet long and 40 feet wide, is an open cut along the strike of the dike. Its southeast wall is granite. Its contact with the kaolin is vertical, so far as it has been uncovered. The northwest wall is composed of kaolin that is crossed by narrow horses of quartz and feldspar, but for 50 feet from the north end this wall shows an intermixture of small streaks of clay in an undecomposed mass of quartz and feldspar. The kaolin has been worked out to the bottom of the pit by open-cut methods to a depth of about 65 feet from the original surface, except at the southwest end of the excavation, in the northwest corner, where terrace-like benches have been left. These benches are about 40 feet above the bottom of pit, and at the time the mine was abandoned material was being removed from the terrace with the aid of two shafts. At the west end of the terrace is a cliff 40 feet high that is pierced by a tunnel. Both cliff and tunnel expose kaolin that is traversed by many vertical streaks of quartz an inch wide.

The clay in this pit is dense and white. It is contaminated by little masses of partly decomposed feldspar, grains of quartz, soft crystals of partly decomposed muscovite, and hard black streaks of what is believed to be psilomelane or some other hard manganese oxide or hydroxide.

Pit No. 2 is a small open cut across a thoroughly kaolinized dike, about 26 feet wide, which exposes pure white clay. A tunnel, which has been drived into the face of the dike, extends back about 30 feet along its strike. Just beyond the end of the tunnel the dike ends in the face of a steep slope, which cuts it off. In the tunnel the relations of the dike to the country rock are well shown. On its north wall the pegmatite sends irregular tongues into the granite and gneiss, as illustrated in figure 1, and on the south wall the same relations are shown in a less marked degree.

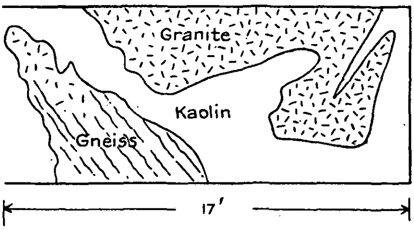

FIGURE 1.—Relations of kaolin and country rock in north wall of tunnel in pit No. 2 of the Payne & Sullivan mine, near Bryson, N. C.

Figure 2 shows the end and portion of the side of a crosscut, which reaches the side of a 6-foot dike of kaolin exposed in a shaft 375 feet south of pit No. 2. Here again the main dike fingers out into small veins that cut the country rock. Indeed, everywhere on the property the streaks of rock in the kaolin appear to be masses between tongues of kaolinized pegmatite.

The crude clay of pit No. 2 is like that of pit No. 1, but it contains more coarse quartz in sharp fragments and very little sand and mica. In some places in the tunnel it possesses a distinct graphic structure. The quantity of clay in sight in this pit is estimated to be sufficient to yield 1,000 tons of washed kaolin. In this estimate no account has been taken of the amount of crude clay in the extension of the dike southwest of the pit, since its length in this direction has not been explored.

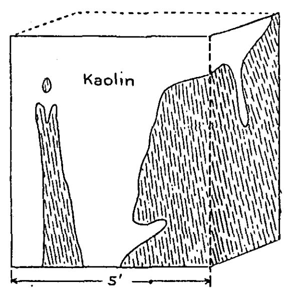

FIGURE 2.—Relations of kaolin to mica schist at end of crosscut in a pit in the Payne & Sullivan mine, Bryson, N. C.

Nearly all the openings between pits Nos. 1 and 2 have exposed excellent white, almost porcelain-like clay, containing as visible impurities only here and there coarse flakes of mica and a few particles of sand. A boring in the bottom of the most promising shaft penetrated 39 feet of this kind of clay.

Harris mine.—The Harris mine, now abandoned but formerly worked by the Harris Kaolin Co., of Dillsboro, N. C., was 2½ miles north of Bryson, on the east flank of Sharptop Mountain. It was in a dike 40 to 60 feet wide, in which there were many bands of wall rock. The dike trends N. 20° E., and it is crossed by faults at intervals of about 150 feet. The dike is irregularly kaolinized and in some places is stained yellow. In 1913 the deposit had been about worked out.

A similar deposit was opened about 1 mile southwest but was abandoned after a few months' work and a new opening was made 3 miles farther northwest, near Deep Creek. This place was later also abandoned. (See fig. 3.)

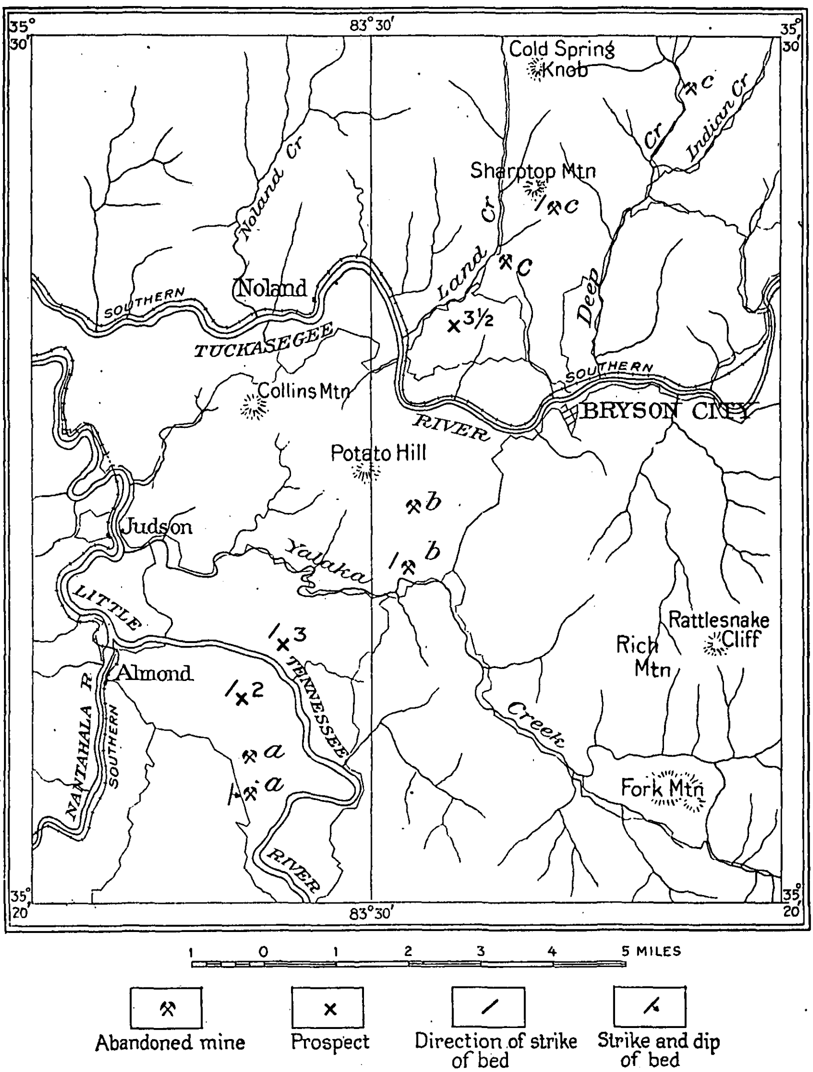

FIGURE 3.—Map of kaolin deposits near Bryson, N. C. Abandoned mines: *a*, Hewitt; *b*, Payne & Sullivan; *c*, Harris. Prospects: 2, Messer; 3, Hyde; 3½ Everett.

PENLAND, MITCHELL COUNTY.

Property of the Bailey Lumber Co.—The Bailey property, between Bear Creek and Toe River, contains two distinct deposits of kaolin in the neighborhood of Penland on the Carolina, Clinchfield & Ohio Railway. The western deposit was formerly worked as the

Penland mine of the Harris Clay Co., of Dillsboro. This deposit is on the railroad about half a mile east of Penland station. It was abandoned a few years ago. The other deposit, which is known as the Firescald property or the "New deposit," is three-fourths of a mile northeast of Penland and about three-fourths of a mile from the old Penland mine.

The old Penland mine (fig. 10, p. 62) was worked by the Harris Clay Co. for 11 years and previously by the C. J. Edgar Co. The area covers 21 acres. The openings from which the clay was taken are on a hill slope about 70 feet above the railroad. The washers were near the pits and the filter pressing plant was at the railroad. The deposit was worked by an open cut to a depth of 30 feet and by shafts to a further depth of 60 feet. The maximum length of the cut was 400 feet. At the depth of about 60 feet the rock became so hard that it had to be dynamited. The overburden was of the usual character and about 6 to 8 feet thick.

Although no definite wall can be seen, Watts says that at the time of his visit the southeast wall was well defined, but on the northwest side of the deposit "the dike material grades gradually into a hard, granitelike rock producing little or no kaolin." [23]

On the map furnished by Mr. B. B. Westphalen, engineer of the Bailey Lumber Co., which owns the mineral rights, the strike of the eastern wall of the worked deposit ranges from northwest to north and the general trend of its greater length is north, though it turns to the east at its northern end. (See fig. 4.) The maximum width of the opening from which kaolin was taken is about 200 feet, but this space was not all occupied by clay, for the clay is traversed by several small horses of micaceous schist, and toward the north the dike is separated into two parts by a central horse of the same schist which has a width of about 80 feet. Moreover, the east wall of the pit is formed by the west side of another horse, or at any rate by a strip of schist which separates the worked deposit from another one that has not been opened but which has been tested sufficiently thoroughly to show that it occupies a large area. Whether the different deposits are united and represent parts of a single great branching pegmatite dike, divided by inclusions of rock, or whether they are on independent dikes has not yet been disclosed by the mining operations.

On the side of one of the shafts still open small dikes of pegmatite cut through the clay. They not only retain their structure but apparently have escaped kaolinization to such an extent that their feldspathic components are still recognizable. One of these dikes consists of quartz, perfectly fresh orthoclase and microcline, and here and there a flake of muscovite. It is 3 feet wide and dips 45° SE.

[23] Watts, A. S., North Carolina Geol. Survey Bull. 53, p. 148, 1913.

Samples of the crude kaolin taken by Watts from the workings yielded 22 per cent of cream-colored refined kaolin. When burned the product was a cream-colored porcelain which had a translucency

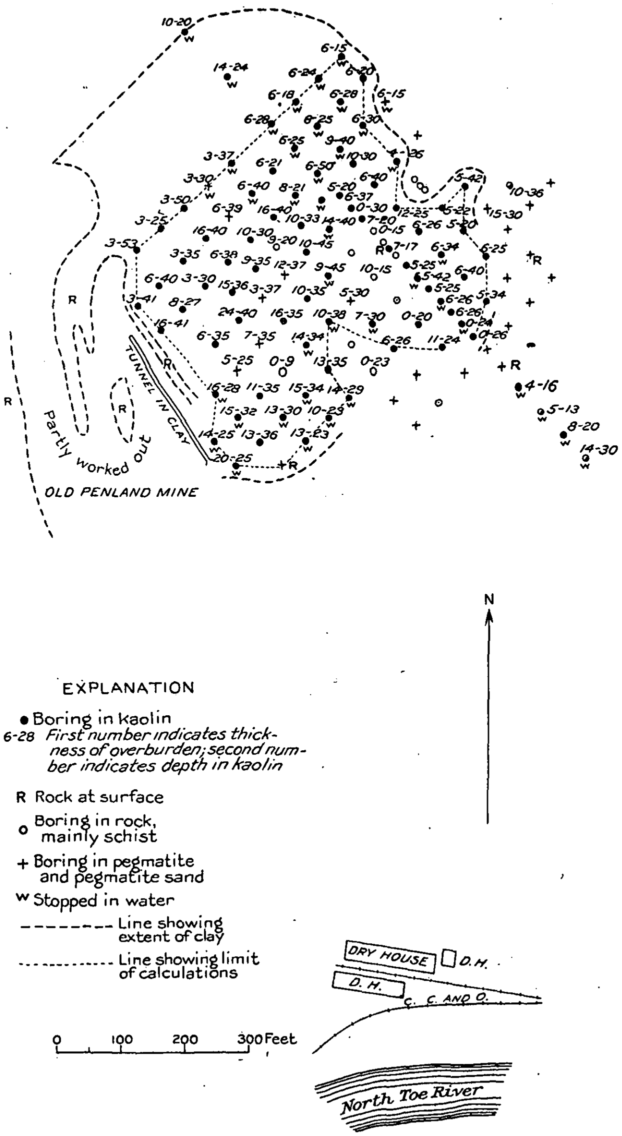

FIGURE 4.—Map of borings at Penland mine, Penland, N. C.

of 0.62 and showed a pale-green color under raw-lead and fritted glazes. The analysis of the commercial clay, as furnished by the Harris Kaolin Co., shows the following composition:

Analysis of washed clay from Penland mine, Mitchell County, N. C.

Silica (SiO_2)	45.61
Alumina (Al_2O_3)	38.63
Ferric oxide (Fe_2O_3) Ferrous oxide (FeO)	.46
Lime (CaO)	.08
Magnesia (MgO)	.08
Potash (K_2O)	.90
Soda (Na_2O)	.66
Titanic oxide (TiO_2)	Trace.
Water (H_2O)	13.57
	99.99

The clay from the Penland mine was used in the manufacture of white earthenware, semiporcelain, china, and tile. It was often substituted for the clay of the Sprucepine and Sparks mines. Like the kaolin of these mines, it was not used alone but in mixture with clays from Florida and Tennessee and English china clays.

Northeast of the old Penland openings and separated from them by a thin wall of rock lies an area of about 4⅔ acres which has been explored by borings. The borings were made along lines that trend northeasterly and northwesterly and at intervals of about 50 feet. The overburden averages not more than 7 or 8 feet in thickness, and the depth of the clay penetrated ranges from 20 to 45 feet. On the assumption that the average thickness of the clay is 30 feet and that the average yield of commercial kaolin is about 20 per cent of the crude tonnage, the tested area would yield about 70,000 tons of refined clay. However, the thickness of the kaolinized material is probably greater than 30 feet, and the yield of merchantable kaolin from the crude clay might run higher than 20 per cent.

The "New deposit," on the Firescald property, is three-fourths of a mile northeast of the old Penland mine. It has been tested by boring over about 15 acres by 200 holes at irregular intervals. The reserve on this area is estimated to be about 250,000 tons of commercial clay on the assumption that the whole area is occupied by kaolin, that the thickness of the deposit is 30 feet, and that the crude kaolin will yield 20 per cent of the refined product. The accompanying sketch map (fig. 5), furnished by the owners of the property, shows the distribution of the borings and the thickness of overburden and clay disclosed by them.

The character of the kaolin from the old Penland mine was very much like that from the Sparks mine. The crude clay, however, contained a larger proportion of coarse rounded fragments of quartz and pieces of partly kaolinized feldspar and a similar proportion of mica. The refined kaolin was used, apparently with satisfaction, by a number of white-ware and china potteries and by makers of vitrified tile in the Ohio Valley.

The material from the borings on the Firescald area is said to have been tested by several potters and other manufacturers and

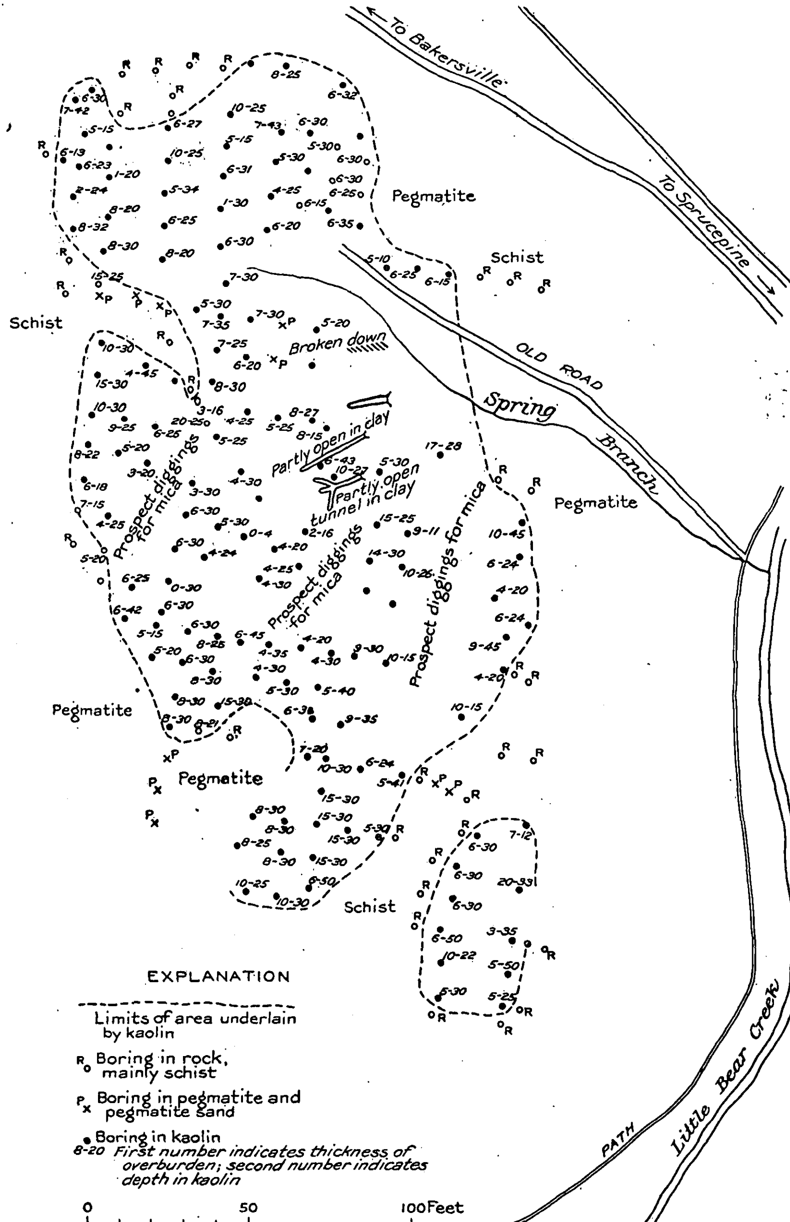

FIGURE 5.—Map of borings on the "Firescald" property, owned by I. C. Bailey, near Penland, N. C.

to be similar to the Hog Rock kaolin, but of course it has not been tried on a commercial scale.

UNDEVELOPED DEPOSITS.

FRANKLIN, MACON COUNTY.

Of the many other deposits in Macon County in addition to those now worked or which have been worked in the past, only a few have been prospected in a way to furnish any idea of their value. Most of them were originally opened as mica mines, and generally the value of the kaolin was completely disregarded. Moreover, most of them are so far from the railroad that the expense of marketing their product would be prohibitive, unless several of them in the

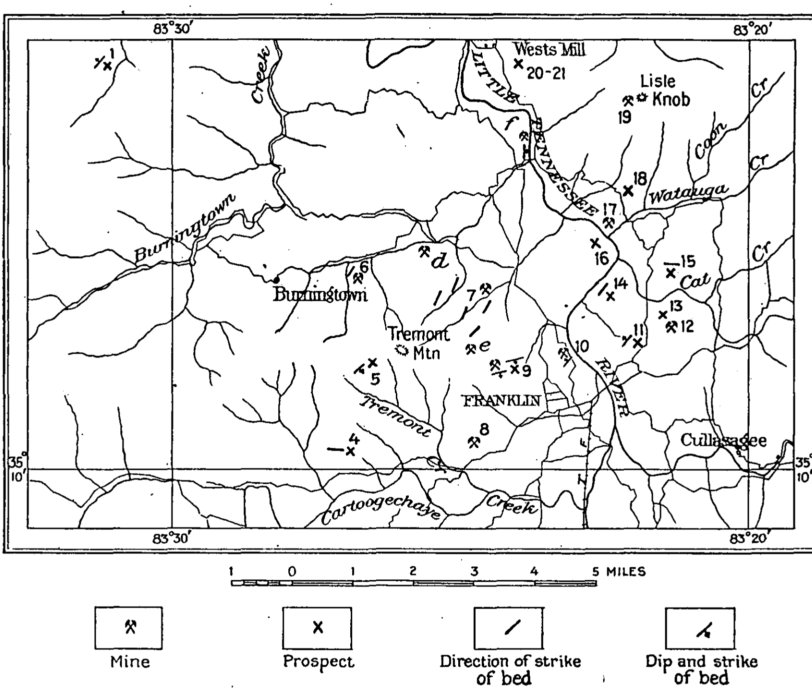

FIGURE 6.—Map of kaolin deposits near Franklin, N. C.

Abandoned mines:
- *d*, Gurney.
- *e*, Southern Clay Co.
- *f*, Iotla.

Prospects:
- 1, Smith.
- 4, Lenoir.
- 5, McGuire.
- 6, Chalk mica mine.
- 7, Raby mica mine.
- 8, Porter mica mine.
- 9, Cunningham.
- 10, Moore.
- 11, Lyle.
- 12, Kasson mica mine.
- 13, Billings.
- 14, Ferguson.
- 15, Frank.
- 16, Myers.
- 17, Sloan.
- 18, Sanders.
- 19, Rochester mica mine.
- 20, West.
- 21, Bryson.

same neighborhood should develop into much larger deposits than now seems probable. The positions of all the known deposits are indicated on the accompanying sketch map (fig. 6).

The two most favorable prospects are on the McGuire and the Ferguson properties.

McGuire property.—The McGuire property is about 3½ miles west of Franklin on the southwest slope of Tremont Mountain. The deposit is on a dike 18 feet wide that strikes northwest and dips 80° SW. Mr. J. H. Pratt made an examination of the property in 1915 and reported that at places over an area of about 2 square miles a number of openings have exposed kaolin, but only a few of them in commercial quantities. The largest of these openings are two tunnels. One of the tunnels is 72 feet long and runs N. 40° E. It penetrates kaolin for 22 feet and then enters country rock. At the contact of the kaolin and country rock a drift extends N. 100° E. for a distance of 15 feet. The original pegmatite has been almost completely kaolinized; the only unaltered rock observed in the dike is a little feldspar that is associated with a band of quartz. In the kaolin there is a little scattered mica and a few nests of "decomposed garnet." A second tunnel 200 yards S. 50° E. from the first one starts at the contact of the dike and the country rock and follows the hanging wall for 108 feet. At a point 56 feet from the mouth of the tunnel a crosscut that runs N. 30° E. crosses the dike, which is 18 feet wide. By assuming that the deposit is continuous between the two dikes and that kaolinization has extended to a depth of 100 feet, Pratt estimates that 18,000 tons of washed kaolin is present, provided the yield is 30 per cent of the crude clay.

About 900 feet S. 60° E. from the tunnel there is a shaft 20 feet deep that cuts 12 feet of kaolin like that in the tunnels. Kaolinized material is exposed east and west of the shaft for a distance of 1¼ miles, but at only one place, a tunnel in the woods west of the shaft, does the quantity seem to be large. The tunnel is cut into a hill for 120 feet, and at this point it encountered the footwall of a dike, which was again exposed in a shaft of 30 feet or more above the tunnel. At the extreme western end of the property a shaft on the top of a little hill that rises 60 feet above a creek struck clay at a depth of 30 feet. Another shaft 86 feet from this one reached clay at the same elevation, and several small pits exposed it in other places. These openings indicate the presence of a mass of kaolin about 100 feet broad, but its other dimensions were not disclosed. Some of the kaolin is stained by iron oxide, but otherwise it is good.

Mr. McGuire reports considerable boring on the property since Mr. Pratt's visit, but he can not give details as to the results.

A washing test of the material in the dikes yielded 42 per cent of a cream-colored kaolin, which was analyzed as follows:[24]

[24] Watts, A. S., op. cit., p. 137

Analysis of washed kaolin from McGuire property, near Franklin, N. C.

Silica (SiO_2)	46.35
Alumina (Al_2O_3)	39.00
Ferric oxide (Fe_2O_3)	.30
Lime (CaO)	Trace.
Magnesia (MgO)	Trace.
Soda (Na_2O)	.00
Potash (K_2O)	.50
Titanic oxide (TiO_2)	Trace.
Water (H_2O)	14.00
	100.15

Mr. Lillibridge, of the American Encaustic Tiling Co., for whom some of the boring was done, says in a letter to the writer that the kaolin is of a sufficiently high standard to meet the requirements of wall-tile manufacturers.

The kaolin can be economically mined, as there is a good supply of water for all purposes and a down grade to a good road.

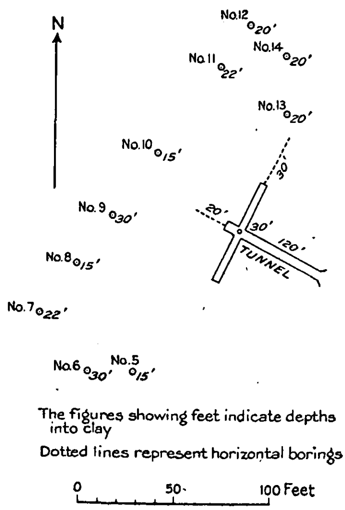

FIGURE 7.—Map of borings on Ferguson property, near Franklin, N. C.

Ferguson property.—The Ferguson property is 2½ miles northeast of Franklin and 1 mile southwest of Dean. The property has been explored by a tunnel that runs northeastward into the side of a ridge. The tunnel cuts 95 feet of kaolin in which there is a 20-foot horse of partly altered feldspar and streaks of quartz. Near the end of the tunnel there is a cross-cut about 50 feet long which is all in excellent clay. That on the northwest side of the tunnel contains considerable coarse mica that is probably merchantable. There is also a little feldspar that might prove of value. Near the end of the tunnel there is a shaft 14 feet deep, and in the bottom of this shaft a boring 20 feet deep reaches hard rock. As the mouth of the tunnel is 45 feet below the top of the ridge, it is safe to assume that the depth of the kaolinization is 70 feet.

A sketch showing the distribution of the borings with reference to the tunnel is given in figure 7. It is evident that these borings do not outline the deposit. On the assumption that the deposit has been proved for a length of 200 feet, a width of 48 feet, and a depth of 60 feet, and that 25 per cent of the kaolin in the crude material is recoverable, the quantity of refined kaolin is about 6,500 tons.

The kaolin in the tunnel is snow-white and free from grit and visible impurities of all kinds, except the large flakes of mica already referred to. That on the old dump at the mouth of the tunnel is slightly stained.

The deposit, where it is exposed, is near the top of a slope that rises 70 feet above its base, so that mining would be comparatively easy. Abundant water is available near by. It could be pumped to the top of the ridge and used for sluicing the crude clay to a washer situated in the valley 70 feet below.

DILLSBORO, JACKSON COUNTY.

Property of the Harris Kaolin Co.—Two other deposits near Dillsboro (fig. 8) have been tested by boring, but have not otherwise been explored. One of these deposits, known as the Ashe property, is about 5 miles southeast of Dillsboro, in the gap in the mountain about a mile west of Painter. Nothing definite is known about the deposit except that it was once opened by a pit on a vein reported to be about 15 feet wide. Borings indicate that the area underlain by kaolin is 200 feet long by 21 feet wide and that it may produce about 10,000 tons of refined kaolin.

The other explored deposit is about half a mile south of the plant of the Roda mine, on the south side of a hill. The area underlain by kaolin is 400 feet long by 50 feet wide. It contains about 15,000 tons of kaolin, which resembles that from the Hog Rock mine.

The kaolin from both these deposits can easily be prepared for market at the plant of the Harris Kaolin Co. near Webster.

The total reserve of the four properties of the Harris Kaolin Co. in Jackson County is estimated by the company to be between 40,000 and 50,000 tons of refined material.

BETA, JACKSON COUNTY.

Ross property.—The only promising prospect in Jackson County, besides those already mentioned, is near Beta, about half a mile southwest of the railroad station, on the west slope of the hill south of the railroad. It is now known as the Ross prospect, but it is probably the same as the Buchanan prospect described by Watts.[25] The principal openings are about 400 feet above Scott Creek. They comprise a number of test pits near the top of a ridge that trends northeasterly and several tunnels and shafts below these on its western slope. The only one of the tunnels that is now open to inspection is more than 200 feet long and has a right-angled turn about 125 feet from its mouth. Watts reports several dikes at this place which range in width from 10 to 18 feet, strike N. 40° E., and dip

[25] Watts, A. S., op. cit., p. 154.

80° NW. The upper of the two principal dikes has been opened by a few test pits and the lower, one-eighth of a mile farther west, by shafts 25 feet deep and by two tunnels. Both dikes contain lenses of garnet-colored sand mixed with altered biotite. Samples taken from the lower dike yielded 40 per cent of kaolin that had a refractory value above 1,730° C. Its analysis is given on page 25.

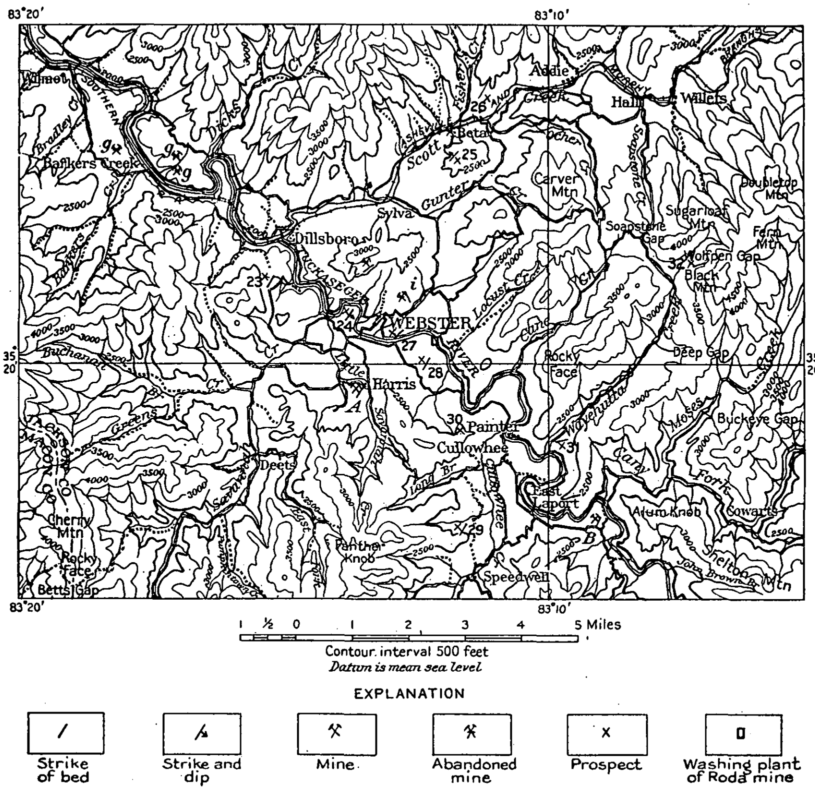

FIGURE 8.—Map of kaolin deposits near Dillsboro, N. C.

Active mines:
- *A*, Hog Rock.
- *B*, Roda.

Abandoned mines:
- *g*, American Land & Development Co.
- *h*, North Carolina Mining & Manufacturing Co.

Abandoned mines—Contd.
- *i*, Springer.
- *j*, Harris.

Prospects:
- 23, Cagle Gap mica mine.
- 24, Hall.
- 25, Ross.
- 26, Love.

Prospects—Continued.
- 27, Cowan.
- 28, Ashe.
- 29, Forest Hill mica mine.
- 30, Harris.
- 31, Long mica mine.
- 32, Wayehutta mica mine.

The walls of the main tunnel are composed of white clay and are crossed by many bands of quartzose pegmatite, 3 feet to 4 feet wide, running in all directions. The pegmatite is thoroughly decomposed, but its content of quartz is so high that much barren rock would have to be removed in mining. In most places the kaolin contains considerable quartz and mica, but some of the masses between the bands of pegmatite consist of nearly solid, dense kaolin. At 200 feet from the mouth of the tunnel is a pit that was not crossed, but in the walls beyond there appeared to be wide, clean exposures of clay.

The best samples taken from the best pockets differ from samples of the average material of the walls, exclusive of the pegmatite veins, only in being almost free from mica and coarse grains of quartz. The average sample is lumpy, but the selected samples are nearly uniform in structure. Both are gritty, but the grit in the better sample is so fine as to be scarcely visible, whereas that in the average sample consists of quartz grains one-eighth to one-quarter inch in diameter. Moreover, little groups of these grains together with mica flakes are aggregated into lumps. The cracks between the grains are badly stained by iron compounds that have infiltrated and oxidized, and therefore the crushing of the lumps seriously discolors the clay. The better samples are pure white when first taken, but upon standing in a dry atmosphere they turn pinkish or pinkish yellow, possibly through the oxidation of iron salts. These samples contain no visible impurities except tiny grains of sand.

Unquestionably deposits exposed by the pits and tunnels on this hill contain a great deal of kaolin, but it is very doubtful if any of the deposits are large enough to be worked economically. Besides the deposits described above a dozen others in the vicinity of Dillsboro and Webster have been mentioned in the different reports on the clays of the State but none of them are valuable at the present time. A few have been worked and abandoned after a year or two. Others have been prospected but not worked, and still others have merely been sampled. The locations of all those in which kaolin is known to occur are shown on the sketch map (fig. 8).

ETOWAH, HENDERSON COUNTY.

Valentine property.—Mr. G. H. Valentine, of Hendersonville, reports a deposit of kaolin in Henderson County close to the west bank of French Broad River, 1¼ miles north of Etowah. The deposit is known to be from 50 to 75 feet wide and more than 10 feet deep, but its length has not been determined. Several small excavations have been made in it, and the grade for the public highway cuts it. Most of the clay is white, but in some places it is pink or salmon colored. The deposit is a few hundred yards from the river and about 50 feet above it, and a mountain brook near by might furnish all the water needed in mining. A road 2 miles long, which is used for heavy hauling by trucks to a point less than one-fourth of a mile from the deposit, leads to Etowah, on the Toxaway branch of the Southern Railway.

The sample furnished by Mr. Valentine is a white gritty powder that becomes only slightly sticky when moistened with a little water. When shaken with water the mass rapidly separates into a sediment and a thin fluid of a very pale gray, almost white color. The sediment consists of small sharp-edged transparent quartz grains and larger masses of grains that are cemented by kaolinite, particles of material stained by limonite, and a few fragments of other substances, some of which are organic. The unwashed powder is composed of comparatively few small flakes of kaolinite, fragments of rosettes and wormlike aggregates of the same mineral, many fragments of clear, colorless quartz, and flakes and groups of grains and a few other particles that may be partly kaolinized feldspar. A few of the quartz grains are large, measuring about 0.3 millimeter in their longest dimensions, but most of them are between 0.05 and 0.07 millimeter.

The sample is composed mainly of a fine quartz sand together with a comparatively small proportion of kaolinite. Whether the material is residual or sedimentary in origin can not be determined from its appearance. If it is sedimentary, its components have not been carried far, for the quartz grains show little or no evidence of rounding. The area that contains the deposit is underlain by Henderson granite, which, according to Keith,[26] "upon complete decay * * * produces a yellowish or reddish clay, which is frequently leached out nearly white. This is mixed with sand and fragments of rock on the mountain sides and is of no great depth."

Material of this kind partly assorted by water might yield a product resembling the sample, which is very much like the samples from Richmond and Montgomery counties in North Carolina and from the vicinity of Abbeville in South Carolina.

HAZELWOOD, HAYWOOD COUNTY.

Herren property.—A deposit in Haywood County that has not hitherto been described is well up toward the top of a spur at the southwest end of Lickstone Mountain, on the property of J. P. Herren, of Waynesville, about 4½ miles south of Waynesville and 3½ miles southeast of Hazelwood. There are several openings on the property, but they are now filled with débris and difficult to study. The largest opening furnishes a vertical section 12 feet long and originally exposed a surface 12 feet high, including 7 feet of kaolin. The lower portion of the section is now covered by fallen material. The part now visible shows an almost horizontal contact between mica schist and a very quartzose stained kaolin that exhibits the structure of a pegmatite. It is cut by little quartz stringers and contains masses of decomposed black mica, flakes of decomposed white mica, and sharp-edged fragments of quartz. (See fig. 9.) Other

[26] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Pisgah folio (No. 147), p. 4, 1907.

openings a few hundred yards south of this pit show the same cap rock and the same kind of kaolin. At a distance of about 12 feet from the foot of the cliff in the larger pit is an exposure of mica schist, which is apparently the footwall of the dike. Accordingly, both footwall and hanging wall must be nearly flat, and their contacts with the dike are very irregular. When the pit was opened a little mica was taken from the neighborhood of the footwall. No kaolin was mined nor were any tests made of its quality. Samples obtained

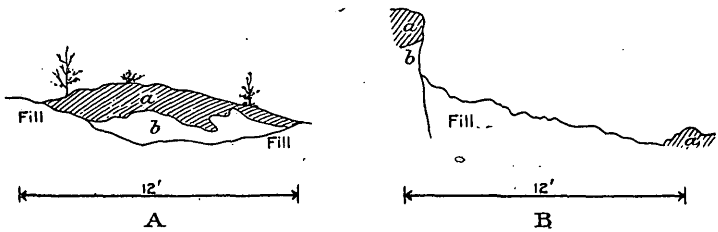

FIGURE 9.—Herren pit, Hazelwood, N. C. A, Vertical wall of pit; B Cross section of pit. *a*, Muscovite-biotite schist; *b*, Kaolin.

from that portion of the vein now exposed would give no fair idea of its value.

The deposit is not near the railroad, but there is abundant water in the vicinity for washing.

BIRDTOWN, SWAIN COUNTY.

Cole & Black property.—The Cole & Black prospect is about 7 miles northeast of Bryson and three-fourths of a mile southeast of Birdtown, about half a mile east of Oconalufty River and the Appalachian Railway along its side. A. B. Cole, of Bryson, N. C., is the representative of the owners. The location has been prospected by a series of test pits and several shafts.

The largest opening is a shaft 12 feet in diameter and 27 feet deep, at the bottom of which is a boring of equal depth. The upper 12 feet of the shaft passes through a clay overburden and a mass of dark schist (probably a micaceous hornblende gneiss), which is folded into a syncline that can be traced eastward for some distance. The schist forms a capping above the kaolin and separates it from the clay overburden on the surface. Below the capping the kaolin is continuous to the depth reached by the auger. In general the kaolin is very white, but it is streaked with yellow and red stains near the top. Farther down it is said to be free from stains, but only its upper part can now be seen. It contains also coarse fragments of quartz and is crossed by comparatively large horses of that mineral. Sand and black mica are also present in it, but not in large quantities. The strike of the bottom of the syncline is N.

20° E., which is also the strike of the kaolin deposit indicated by the lines of pits. Where wall rock can be seen it dips southeastward at a high angle. Three other shafts and a tunnel mark the extension of the dike for at least 300 feet along its strike.

A little farther to the west is another series of openings, consisting of several test pits and two shafts, one 20 feet deep and the other 57 feet deep. The walls of these shafts are not visible, but their dumps show considerable sandy kaolin mixed with quartz and black mica. The deposit marked by this series of openings is parallel to the more easterly one and is evidently on an independent dike.

Although very little definite information can be gathered from the prospecting, it has shown the presence of a great quantity of kaolin. However, it has not shown that the kaolin is in deposits large enough to be of commercial value. If systematic borings around the first shaft described above should outline a reasonably large deposit it might be worked economically by tramming 500 yards, sluicing to a washer placed a little below the mine, and sluicing by gravity to a settling plant on the river 400 yards distant. It would be necessary to pump water about 200 feet to the mine and to flush the sluice leading to the washer.

MICAVILLE, YANCEY COUNTY.

Thomas prospect.—The Thomas prospect is a deposit that is being held in reserve by the Harris Kaolin Co. It has been tested by tunnels and shafts, but has not yet been exploited. It is expected that the clay will be refined at the Lamonti plant. The deposit is about 1½ miles north of Micaville and 1 mile northwest of Lamonti. (See fig. 10.) The dike that contains the deposit strikes N. 45° E. According to Mr. Hise, the place has been thoroughly explored, revealing two dikes 60 and 175 feet wide and at least 1,000 feet long. Shafts and tunnels on the property have uncovered good kaolin, which contains a little sand and white and black mica and which is crossed by streaks of red mica that is apparently of the proper size and in sufficient quantity at greater depths to be commercially valuable. The deposits are also penetrated by horses of rock. The overburden ranges in thickness from 4 to 12 feet. If half of the clay can be removed, the yield of the deposit in refined kaolin may be 50,000 tons.

The kaolin is thought to be of the same quality as that at the Wilson mine. A flume line from the property to Lamonti has already been surveyed, and electric line poles have been set up, but the wires are not strung. Water will be pumped from a creek to the mine, 150 feet higher, and the slip will flow all the way to the plant by gravity.

Smith prospect.—Several other prospects in the vicinity of Micaville, besides those mentioned, are promising sources of kaolin, and a few others are known but have not been thoroughly tested, so that it is not possible to give any safe estimate of their value.

Perhaps the most promising prospect is that on the property of Misses E. E. and M. P. Smith, of Asheville, N. C., and Mrs. George R. Calvert, of New York. The deposit is 1½ miles east of Burnsville, alongside the Black Mountain Railroad. It was formerly worked for mica, and during the search for that mineral numerous holes were dug and a shaft 40 feet deep was sunk. The shaft cut 3 or 4 feet of overburden and about 35 feet of kaolin. It was abandoned because of caving. A tunnel 100 feet long also exposed kaolin. Abundant water is available for the use of a mine and washing plant. The place has not been visited. The description given here is based on the statements of Miss M. P. Smith.

Watts [27] states in his description of the deposit that it is on a dike, 25 to 35 feet in width, which strikes N. 20° E. and dips irregularly. The kaolin incloses lenses of semikaolinized material, but on the whole the dike is well kaolinized. Tunnels connected by a crosscut expose nearly the entire width of the dike and show 6 feet of well-kaolinized pegmatite along its west wall and 9 feet of semikaolinized material and 20 feet of kaolin adjoining its east wall. Test pits indicate that the dike may extend about half a mile.

The samples seen by the writer are pure white and contain very little grit. Large lumps break with a distinct cleavage and thus indicate that the part of the dike from which they came was an almost pure aggregate of coarse-grained feldspar. Close inspection reveals a few grains of quartz sand, a few flakes of fine mica, and a few minute spots of some yellow earthy material. Under the microscope the largest quartz grains seen had diameters of 0.1 to 0.15 millimeter. The mica is in very tiny flakes and shreds whose diameters are not more than 0.025 millimeter. A few stained clumps of kaolinite were the only other constituents noted. The sample is an especially pure kaolin. Offers are said to have been made to mine the kaolin on a royalty basis, but the amount of royalty tendered was not attractive enough to the owners to induce them to sign a contract. If the property is worked it may produce mica as a by-product.

MITCHELL COUNTY.

No properties in Mitchell County, besides those described on pages 36–41 and 47–51, have ever been worked for kaolin on a commercial basis. There have, however, been many workings for mica, and in some of these considerable kaolin of good quality has been encountered. In addition a few deposits have been explored for kaolin

[27] Watts, A. S., op. cit., p. 127.

alone. These deposits are indicated on the accompanying sketch map (fig. 10).

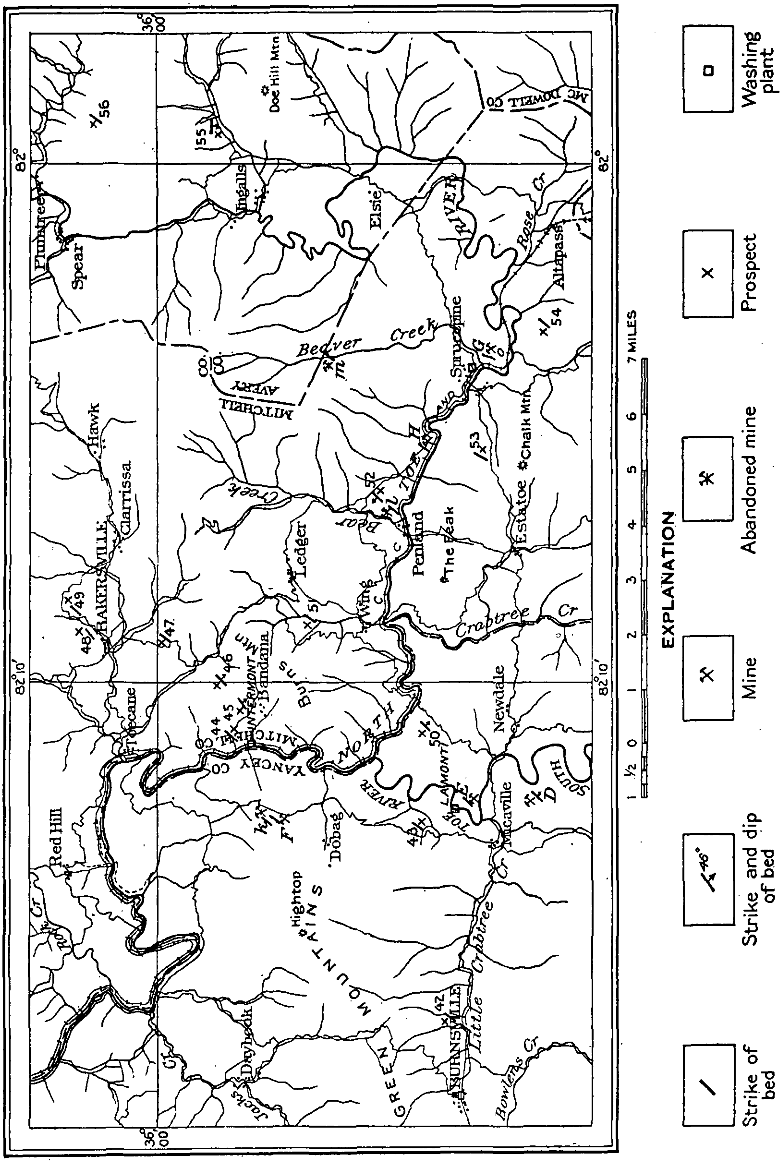

FIGURE 10.—Map of kaolin deposits in Mitchell, Yancey, and Avery counties, N. C.

Active mines:
- *G*, Sprucepine.
- *H*, Sparks.
- *D*, Wilson.
- *E*, Wyatt.
- *F*, Job Thomas.

Abandoned mines:
- *k*, Clay Products Co.
- *l*, Penland mine.
- *m*, Old Sprucepine mine.

Prospects:
- 42, Smith.
- 43, Thomas.
- 44, Howell.
- 45, Benner mica mine.
- 46, Flukin Ridge.
- 47, American Mica & Mining Co.
- 48, 49, McKinney.
- 50, Young.
- 51, Snow Creek.
- 52, Firescald.
- 53, Tolley mica mine.
- 54, Wiseman.
- 65, Ollis.
- 56, Wiseman.

On Snow Creek, about 1½ miles north of Wing post office, and about 2 miles north of Phillips station on the Carolina, Clinchfield &

Ohio Railway a deposit of kaolin is said to occur in a dike that strikes a little east of north and dips about 75° NW. It has been tested by a shaft, which penetrates excellent kaolin to a depth of 35 feet, and by borings at intervals of 20 feet. Most of the borings go to a depth of 40 feet in clay. The Harris Kaolin Co., owners of the mineral rights, declare that the deposit is at least 300 feet long by 150 feet wide, and that the clay is much like that at Sprucepine. The estimated reserve, calculated on the basis of a 20 per cent yield, is about 20,000 tons of refined kaolin. The slip could easily be delivered at the railroad by a flume.

The Flukin Ridge deposit consists of a series of openings that were originally made in the search for mica. They are on the top of Flukin Ridge, a northwest spur from Burns Mountain, 2¼ miles southwest of Bakersville and about 1½ miles east of the plant of the Intermont China Clay Co., on the Carolina, Clinchfield & Ohio Railway, at Intermont, about 2 miles south of Toecane, with which it may readily be connected by a flume. Watts [28] states that the area contains a large number of dikes of partly decomposed pegmatite, which strike N. 50° E. and dip 65° SE. He also states that tunnels and shafts had been dug over an area a half mile long and one-eighth of a mile wide, and that—

at one point a considerable quantity of fine white kaolin is encountered. There are, however, occasional streaks of fresh feldspar and on all sides of the lens there is semikaolinized material; these facts justify the assumption that the kaolin is merely an isolated lens and would not justify the equipment of an extensive outfit for handling it, although the presence in the neighborhood of other isolated kaolin deposits would justify the sinking of shafts and the removal of this kaolin to a central washing plant.

In 1915 the place was explored for kaolin by extending old tunnels and by boring. At present the shafts are inaccessible and the tunnels are accessible for only short distances from their openings. The borings are not mapped. However, representatives of the Intermont China Clay Co., which contemplates working the place, report that the borings indicate a vein 200 feet wide, including a few horses of rock, and 900 feet long. Near its southwest end a rock wedge penetrates it and splits it into two parts, the dimensions of which are not known. The best clay is said to lie near the footwall, where it is white, dense, and free from streaks of mica. Elsewhere there are streaks of mica and quartz, which increase toward the footwall. In one of the shafts put down near the center of the deposit fairly good kaolin shows in the walls to a depth of 72 feet, and a boring made in its bottom penetrates 11 feet more of good clay. A crosscut 46 feet from the bottom of the shaft toward the footwall is also all in kaolin. The quantity of refined clay that the deposit will

[28] Watts, A. S., op. cit., pp. 108, 121.

yield is estimated at about 75,000 tons. It is proposed to sluice the slip to the settling plant at Intermont, on the railroad. The length of the flume required would be about 3½ miles.

A sample was taken from the walls of a tunnel, near the footwall of the dike, where the clay is much interrupted by streaks of mica. If the deposit is worked mica may be obtained as a by-product.

The other properties in this vicinity that might contribute to a washer on a flume line between Flukin Ridge and Intermont are the old Benner mica mine, the Sinkhole Ridge prospect, and the P. H. Howell prospect. The first two mentioned are on Sinkhole Ridge, 3 miles southwest of Bakersville and about three-fourths mile southwest of Flukin Ridge. Neither of these places was seen.

JEFFERSON, ASHE COUNTY.

Bare property.—The Bare deposit is known only by its samples. It is on the property of Jesse Bare, sr., near the mouth of Dog Creek, 4½ miles east of Jefferson, in Ashe County. It has been opened by two trenches, 2 feet deep, in solid clay. One trench is 10 feet long and 2½ feet wide and the other 6 feet long and 4 feet wide. The overburden is 3 feet thick. Mr. Bare writes that the deposit is on top of a flat smooth ridge, and that it occupies about an acre, as is indicated by the distribution of the lumps turned up in plowing.

The sample sent is in very hard white granular porous masses that absorb a great quantity of water without disintegrating. Careful examination with a hand lens reveals many transparent colorless quartz grains in a white structureless cement. Here and there a larger quartz grain is embedded in the mass, and there are a few little groups of stained grains. When shaken with water and allowed to stand for a few minutes a sediment settles that consists almost exclusively of grains of quartz and a white opaque material that is probably kaolinized feldspar, as the particles are bounded by planes which appear to be the result of cleavage. No other constituents are observable when the crushed kaolin is viewed under the microscope. The quartz grains, which are jagged in outline, range from 0.3 to 0.15 millimeter in diameter. They are comparatively few as compared with the grains of kaolinized feldspar. These grains of feldspar are almost nonpolarizing. They are commonly straight edged, but a few of them are subangular. The smallest particles are plates of kaolin. They are not very abundant. A few wisps of muscovite are noted in places, but they are very rare.

The appearance of the material in the hand specimen and under the microscope indicates that it comes from an incompletely kaolinized, very feldspathic pegmatite.

KAOLINS IN THE PIEDMONT PLATEAU REGION.

Although all the kaolin deposits of North Carolina that are now being exploited are in the mountain district, nevertheless the deposits that have been found in the Piedmont Plateau (Pl. I) may be of commercial value when they have been thoroughly explored. A few of these deposits have resulted from the alteration of pegmatites and are similar to the deposits in the mountain district. Others have apparently resulted from the alteration of granites, of schistose feldspathic rocks, or even of slates. The deposits that have been derived from slates are of no great commercial value. Some of these deposits may produce material that can be utilized for some of the purposes to which kaolins are adapted, but most of their material is so impure that it will not burn white. They are mentioned in the following pages only where their description is necessary to complete the discussion of certain properties on which white-burning kaolins occur.

The kaolins that are derived from granites and schistose feldspathic rocks are as a rule less compact than those that are derived from pegmatites. They are generally fine grained, powdery, and very quartzose. They rarely contain large fragments of quartz or large pieces of partly kaolinized feldspar. They cover comparatively broad areas, and if derived from schists they commonly occur as layers between layers of very impure clay or of only slightly decomposed rocks. The dips of the layers may be high or low, depending upon the attitude of the beds of which they are a part. If the original layer of rock was thick the thickness of the kaolin will depend upon the depth to which kaolinization has proceeded. If the original layer was thin the resulting layer of kaolin must also be thin. In prospecting it is important to determine the thickness of deposits of this kind by actual test or by calculations based upon observations of dip.

The processes by which the granites and feldspathic schists were changed to kaolin were the same as those that changed the pegmatites, and therefore they need no special discussion. (See p. 20.)

KAOLINS FROM PEGMATITE AND GRANITE.

BESSEMER CITY, GASTON COUNTY.

Property of J. A. Smith.—The only kaolin deposits on the Piedmont Plateau that have been visited and that are believed to be derived from pegmatite or from granite are on the property of Mr. J. A. Smith, of Bessemer City.

Two openings are inside the city limits. One of these openings is a shaft 30 feet deep near the railroad station. It is now boarded up, but the walls can be seen to be composed of white clay that unuerlies an overburden of about 7 feet of red clay. The sample, which Mr. Smith says was taken from the side of this shaft 18 feet from the surface, is a white kaolin that dries into a powdery mass. It contains some sand, a little mica, and the usual black streaks. A boring in the bottom of the shaft went down 12 feet farther, all in clay. Wells in the vicinity of the shaft all passed through similar clay. Several carloads of material were shipped from these openings, two of which went to a tile manufacturer, who made from the kaolin a cream-colored translucent product.

About 1,800 feet northeast of the shaft is another opening, which is now partly filled. It is a pit that shows on its wall a 16-foot band of kaolin, which is said to be separated from another band 10 feet wide by a horse of red clay. Mr. Smith declares that borings indicate the existence of a belt of high-grade clay 300 feet wide, interrupted by horses of impure clay. The west wall of the deposit is as far as can be seen decomposed gneiss, as are also the horses of

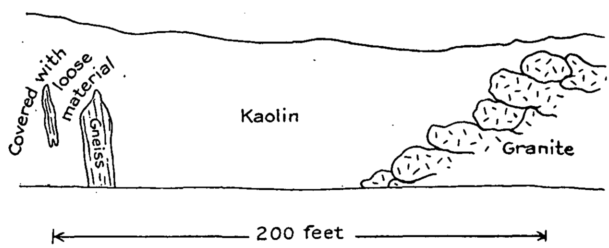

FIGURE 11.—Longitudinal section of kaolin deposit near Bessemer City, N. C.

clay. The other walls are not visible. Borings a short distance from this pit are reported to have outlined a dike 160 feet wide. Nearly all the holes that penetrated kaolin showed it to extend to a depth of at least 35 feet. The structure of the clay in the pit suggests a residual deposit. It is crossed by little veins of quartz and by streaks of yellow stain. Mr. Smith believes he has discovered a series of dikes from 10 to 200 feet wide which strike N. 22° E. and dip vertically. There is no reason to doubt this conclusion, though no evidence was at hand to confirm it.

Another deposit, 1½ miles northeast of the city, near Long Creek, is of an entirely different character. It is exposed in a long gully from 10 to 30 feet deep. At the upper end the floor of the gully contains numerous large granite boulders. Farther south these boulders become friable, and beyond, where the gully becomes deeper, they are partly disintegrated and covered with a layer of clay. Still farther south the gully is deep and clay extends to its bottom. The granite ends in a steep slope over which a little wet-weather stream cascades (fig. 11). About 100 feet downstream from the last boulder is an exposure of schist, which is separated from the granite by a deep deposit of white clay. At the bottom of the gully and in its walls at this place some of the kaolin seems to be a sedimentary clay, but on the whole it presents the texture of the granite—that is, it contains quartz grains of the same sizes and shapes as those in the granite, and a few streaks of black earthy substance that may be some decomposed ferruginous mineral, such as biotite, augite, or hornblende. The components are arranged like those of the granite, the feldspar in the rock being replaced by kaolinite in the clay. The conditions suggest a concentration of kaolin at the base of a granite slope by the washing of the decomposition products of the granite into a depression between granite and schist. The deeper kaolinization of the granite at this point and the consequent development of the steep slope are probably due to the presence here of the contact surface between granite and schist. Plainly the greater part of the kaolin is a residual deposit that is the result of the decomposition of granite. Where the overburden of red clay is visible it is 6 to 7 feet thick.

A sample of the clay was taken from a hole on the east side of the bottom of the gully and from a strip of its west wall 25 feet long. It is a plastic white kaolin containing grains of quartz, feldspar, white mica, a few specks of black earth, and a few yellow streaks.

There is unquestionably a large quantity of kaolin at this locality, but it is probably irregularly distributed. Whether it is capable of being worked economically can not be determined without a thorough exploration. Water is abundant for washing, and the locality is only 1½ miles from the Atlanta branch of the Southern Railway on a road that could easily be put in excellent condition for trucking.

LINCOLNTON, LINCOLN COUNTY.

Mine of the United States Tin Co.—At the old Piedmont tin mine, 2½ miles southeast of Lincolnton, the dikes in which the cassiterite occurs are fairly well kaolinized. The dikes occur [29] in a belt that strikes N. 20° E. and dips 80° NW.

The dike rock is a coarse-grained pegmatite that is composed mainly of quartz, several feldspars, muscovite, a colorless, somewhat brittle mica that may be margarite, and grains of cassiterite. Between the components are films of iron hydroxides that produce an orange-red stain. All the dike material is more or less kaolinized, and together with the kaolin there has been formed a reddish-yellow sandy product in which there are numerous plates of colorless mica, grains of quartz, and crystals of cassiterite. Where the original ma-

[29] Graton, L. C., Reconnaissance of some gold and tin deposits of the southern Appalachians: U. S. Geol. Survey Bull. 293, pp. 42, 51, 1906.

terial was nearly pure feldspar the kaolin consists of kaolinite, small scales of mica, a very little quartz sand, and a few crystals of cassiterite.

The decomposed pegmatite is washed to obtain the tin ore. It is possible that it might prove profitable to save the washings and separate the kaolin.

KAOLINS FROM SCHISTOSE ROCKS (PARTLY PEGMATITES).

As these schists may be sheared igneous rocks of feldspathic character and in places are cut by pegmatite dikes of variable size, the kaolins derived from them are placed in a separate group. Moreover, they are placed closer to other kaolins which are wholly derived from pegmatite.

Only a few deposits of the white powdery kaolin believed to be derived from schistose rocks have been examined by the writer. Samples of others which were not visited were furnished by the owners of the property on which the deposits occur. The deposit near Troy was not visited, nor were any samples from it seen, but from the descriptions of it given by Ries there is no doubt that it is like some of the deposits that are mentioned below. Consequently Ries's description is abstracted, in the belief that it furnishes an idea of the character of the material in these other deposits.

TROY, MONTGOMERY COUNTY.

A deposit 4 miles west of Troy is mentioned by Ries.[30] No account of the occurrence of the material is given, but from the description of its character it seems to be similar to that of the Candor and Eames deposits. Ries obtained two samples, one of them gray and the other white. The darker sample yielded 40 per cent of kaolin on washing. Both white and dark samples, when washed, burned to a buff color, and neither was suitable for the manufacture of white ware. As the characters of the Eames and Overton deposits are probably the same as those of the Troy deposits, a rather full abstract of Ries's account is given below.

The dark kaolin that was made into a workable paste with water shrank 3 per cent in drying and an additional 10 per cent in burning. The average tensile strength of the air-dried briquets was 9 pounds to the square inch. Incipient fusion took place at 2,100° F., vitrification at 2,300°, and viscosity at 2,500°.

The white kaolin shrank 3 per cent in drying and 9 per cent in burning. Air-dried briquets showed an average tensile strength of 10 pounds to the square inch. The behavior in the fire was the same as for the dark variety.

Analyses of the kaolins yielded the following results:

[30] Ries, H., Clay deposits and clay industry in North Carolina: North Carolina Geol. Survey Bull. 13, p. 64, 1897.

Analyses of crude kaolins from Troy, N. C.

	1	2
Silica (SiO_2)	63.10	86.03
Alumina (Al_2O_3)	23.33	6.46
Ferric oxide (Fe_2O_3)	2.97	2.14
Lime (CaO)	.15	.17
Magnesia (MgO)	.09	.04
Alkalies (Na_2O+K_2O)	1.90	1.00
Water (H_2O above 100° C.)	7.65	2.90
Moisture (H_2O below 100° C.)	.75	.53
	99.94	99.27

1. White kaolin.
2. Dark kaolin.

MOUNT GILEAD, MONTGOMERY COUNTY.

Property of P. M. Eames.—An exploration on the property of P. M. Eames is 5 miles northwest of Mount Gilead, to the left of Lowders Ferry road. Very little is known about the deposit. Mr. Eames judges by the distribution of the outcrops that the clay covers about 700 acres. Only a shallow opening 2 feet deep has been made in it, and from this opening a sample was taken.

The sample looks very much like that from the Iotla mine at Candor. It is a very fine gritty flourlike material of a very pale grayish-white color. When mixed with water it becomes buff-gray and exhibits almost no tendency to cohere. After washing carefully in a test tube a fine-grained pale-buff residue is left, which apparently consists entirely of quartz grains.

The crude material is made up mainly of small quartz grains that have diameters between 0.02 and 0.04 millimeter. In addition, there are a few particles of rutile, hydromica, and stained feldspar and a very few tiny plates of kaolinite. The quartz is in little sharp-edged splinters, in subangular grains, in very irregular-shaped particles, and in a very few rounded grains. Evidently the material has not been carried far from its source. It may be a residual mass, like that at the Iola mine, from which the kaolinite has been removed, perhaps by running water.

In its present condition the material represented by the sample is not a commercial source of kaolin.

OVERTON, MONTGOMERY COUNTY.

Property of A. J. Overton.—The Overton deposit is at the old Iola gold mine, which is 2½ miles west of Candor and 8 miles east of Troy in Montgomery County. At this mine mineralized quartz veins are associated with a slaty rock which Hafer[31] believes may be a sheared andesite. The kaolin is reported by Mr. A. J. Overton, the owner of the land, to occur over 10 acres under an overburden

[31] Min. World, vol. 28, p. 332, 1908.

of about 8 feet of sand and gravel. The mine shaft that has penetrated it is 60 feet deep, and there are drifts 100 feet long at its bottom.

The sample sent is a loose, very light pinkish gray gritty flour-like mixture of very fine quartz and kaolin. The few lumps in it are distinctly schistose, as though the original material from which the clay was derived was a fine-grained schistose or slaty rock, as for instance a sheared felsite. When mixed with water it forms a distinctly cream-colored paste, and the coarse gritty residue left after washing the crude material is flesh-colored, and it contains comparatively large iron-stained grains.

Under the microscope the principal constituents visible are rough quartz grains of all sizes from the most minute to those 0.2 millimeter in length, though perhaps the greatest number have diameters between 0.03 and 0.05 millimeters. Besides these there are a few white opaque grains with straight edges that may be altered grains of feldspar and a fair quantity of small particles of kaolinite of about the size of the smallest particles of quartz. There are a few shreds of kaolinite 0.06 millimeter long, but most particles are less than 0.004 millimeter across.

The washed samples of the three kaolins from Montgomery County contain a great deal of fine quartz, in which respect they differ markedly from the kaolins that are known to have originated by the decomposition of pegmatites. All of them were probably derived from fine-grained rocks like the rock associated with the kaolin at the Hill property at Abbeville, S. C., in the shaft west of the road. (See p. 80.)

CATAWBA, CATAWBA COUNTY.

Property of E. A. Ervin.—In Catawba County, on the State Central Highway, 3 miles east of Catawba village, on the property of E. A. Ervin, is a deposit of white powdery clay that has been used locally for whitewash. The clay appears for about 200 yards down the bottom of a stream. Upstream it is reported to be about 30 feet wide. At the lower end the color gradually changes to blue and dark gray.

The sample taken from the upstream end of the deposit is very much like the material from Mr. Valentine's deposit in Henderson County. It is a very fine grained gritty powder composed of spicules and irregular sharp-edged particles of quartz, few of them over 0.02 millimeter in their largest diameter, and numerous small flakes and fragments of aggregates of flakes of kaolinite. There are a few grains of quartz that measure 0.1 millimeter, but they are extremely rare. If the kaolin is sedimentary its components have traveled a very short distance, as many of the quartz spicules are extremely slender.

STATESVILLE, IREDELL COUNTY.

Property of Cashion & Furchess.—An apparently large deposit of kaolin occurs along the Charlotte branch of the Southern Railway 1 mile south of Statesville, on land belonging to Messrs. J. T. Cashion and H. V. Furchess. The property is undeveloped, but cuts on the railway and on the highway one-fourth of a mile west of the railroad expose kaolin.

On the east side of the right of way of the railroad a section of about 160 feet is exposed and between this section and the track are a couple of shallow pits. The section shows alternating schists and kaolin. At its north end a width of 20 feet of kaolin is shown, followed to the south by 20 feet of quartz, 110 feet of kaolin, and finally schists. (See fig. 12.) The schists consist of alternating mica schists and quartz-feldspar schists full of garnets. These schists are interlayered with rocks that appear to be sheared pegmatites. The feldspar in all the schists is kaolinized and one layer between slightly

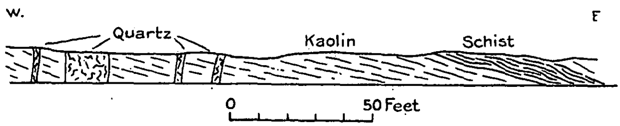

FIGURE 12.—Relations of kaolin in deposit owned by Cashion & Furchess, Statesville, N. C.

decomposed mica schists consists of a well-defined kaolin. The strike of the series of schists is N. 10° W. and its dip is 75° E. East of the railroad schists outcrop here and there, but in a well dug 500 yards east of the rails clay was struck at about 12 feet.

The clay exposed in the cut north of the schists is very sandy. It contains in addition to the sand tiny flakes of dark and light mica, little masses of soft black material that may be a manganese oxide, and little yellow spots that may represent decomposed garnets. The kaolin has an ill-defined structure that is parallel to the structure of the schists to the south and is crossed by vertical, or nearly vertical, veins of quartz. Most of these veins are narrow, but at the north end of the cut one of them is 20 feet wide. Northward in the cut the whole rock mass appears to disintegrate gradually, changing to layers of red-brown clay and white clay. The white clay becomes more abundant toward the north as though the clay-producing layer became thicker. Pits near the track show a cleaner and whiter clay than that in the cut, and from one of these pits the sample was taken. The clay probably represents a thick layer in the schist series, but whether this layer was composed of a feldspathic schist or of a sheared pegmatite running parallel to the foliation of the schists was not determined. The thickness of the kaolin is also unknown. As already stated, kaolin exists in a road cut about one-fourth of a mile west of the railroad. Near this place a well was dug that passed into white clay at a depth of 6 feet and continued in it for 55 feet. Between the well and the railroad there are no exposures and no explorations, so that it is impossible to determine whether a single layer is continuous through this distance or whether there are several layers separated by schists that are not kaolinized. The distribution of the kaolin is rather widespread. If its origin is as suggested it must occur on the surface in belts that strike nearly north.

The kaolin from the pit at the railroad is white and pulverulent. It contains comparatively few fragments of quartz, a good deal of sand, very small masses of soft brown clay, a few flakes of mica, and a few specks of a soft black substance. Under the microscope most of the quartz is seen to be in sharp-edged flakes and splinters. Some grains are rounded. Plates of hydromica and sharp-edged grains of partly kaolinized feldspar are common, as are also small plates and flakes of kaolinite. There are also a few black specks of opaque mineral and tiny reddish-brown plates that may be limonite. The material, as a whole, resembles closely the Overton kaolin.

BOSTICKS MILLS, RICHMOND COUNTY.

Property of R. L. Steele.—The Steele explorations cover an area the center of which is 2½ miles northwest of Ellerbe on the Norfolk Southern Railway near Bosticks Mills. The property on which the clay occurs consists of 38½ acres owned in fee by Robert L. Steele, sr., who owns also the mineral rights in 230 additional acres. When worked a few years ago it was operated under the name of the Steele Kaolin Works, with headquarters at Rockingham. In 1897 Ries[32] referred to openings in kaolin on the property of Mr. Steele, but none of these openings can be identified with those seen by the writer in 1918. However, as the clay evidently occurs over a fairly wide area, the conclusions of Ries as to the quality of the kaolins seen by him would probably apply nearly as well to those taken from the openings examined in 1918.

Ries states that the clay appears for a distance of 50 feet in a roadside ditch a mile south of Bostick post office and again on the opposite side of the road at the base of a hill. Between the two localities there is a red clay which is the product of the decomposition of a schist. Test pits sunk east of the road disclose a fine-grained clay, which contains comparatively few angular fragments and scattered stains of iron. Another series of pits a mile farther west, across a shallow valley, uncovers another deposit of whiter material. In no

[32] Ries, H., op. cit., p. 65, 1897.

pit was the overburden more than 1½ feet thick or the kaolin less than 9 feet thick.

The clay from the eastern pits (analysis 1) was a fine-grained kaolin with a little coarse grit. It slakes slowly but completely to a fine-grained mass. A workable paste shrank 4 per cent on drying and 9 per cent in burning. Air-dried briquets showed an average tensile strength of 10 pounds to the square inch. Incipient fusion began at 2,250° F., vitrification at 2,500°, and viscosity at 2,700°. The clay burned to a dense body that had a pale-yellow tint. A sample from another pit (analysis 2) underwent slightly less shrinkage. The average tensile strength of its briquets was 13 pounds, and incipient fusion began at 2,300° F. In other respects it was like the first sample. The kaolin from the western pits (analysis 3) was a somewhat porous, fine-grained white clay with comparatively little grit. In most respects it was nearly like the material from the eastern pits.

Analyses of this material gave the following results:

Analyses of samples of crude kaolin from Bosticks Mills, Richmond County, N. C.

	1	2	3	4
Silica (SiO_2)	70.63	68.15	73.70	71.12
Alumina (Al_2O_3)	21.81	19.99	16.03	19.61
Ferric oxide (Fe_2O_3)	1.49	1.86	1.57	2.18
Lime (CaO)	.20	.13	.38	.17
Magnesia (MgO)	.29	.16	.47	.08
Alkalies (K_2O+Na_2O)	1.45	2.85	1.90	2.48
Water (H_2O above 100°C.)	4.04	4.70	4.33	4.33
Moisture (H_2O below 100°C.)	.08	.17	....	....
	99.99	98.01	98.38	99.97

1, 2. Clay from the eastern pits.
2, 4. Clay from the western pits.

Samples Nos. 1 and 3 were washed. The first sample gave 40 per cent of settlings and the second 35 per cent. The washed sample No. 1 had the same properties as the crude sample No. 4. Washed sample No. 3 was pure white, but it burned to a body that had a faint yellowish tint. In all respects the washed material acted like the crude sample, except that its briquets had an average tensile strength of only 8 pounds to the square inch. The following table shows the calculated mineral composition of each of the four samples analyzed:

Mineral composition of samples of kaolin from Bosticks Mills, Richmond County, N. C.

	1	2	3	4
Clay substance	47.14	49.30	36.05	54.30
Feldspar	16.13	9.20	62.33	1.82
Quartz	36.73	41.50		43.85
Specific gravity	2.41	2.52	2.43	....

The openings that may be seen now are widely separated. One on a crossroad running east from the main road north from Ellerbe is on a dense, gray, massive, sticky clay that contains lines of limonite nodules, most of which are hollow or partly filled with red clay. Other nodules in the clay are concretions of quartz fragments, sand grains, and flakes of mica cemented into elongate bodies about 1½ inches long and half as thick. As the clay where exposed has a horizontal upper surface it resembles very closely a sedimentary deposit. Close examination of the walls of the pit, however, reveals the presence of a system of cross joints, such as appear in a sheared rock, and a number of tiny quartz veins that intersect the clay in nearly vertical planes. The exposure is too small to furnish much evidence of the origin of the clay, but the vertical quartz veins and the presence on the main road of rocks that might well be the source of such a clay indicate that the gray clay is a residual deposit, resulting from an alteration of a sheared clay shale or slate or perhaps a sheared volcanic rock. The hollow nodules of limonite may have been formed during the alteration of the slate to clay and the sandy concretions may originally have been little lenses of sand in the otherwise argillaceous rock. Only about 20 tons of the clay have been sold. The crude material was washed in a homemade washer and sold as a filler for cheap cotton goods. The unwashed clay burns gray.

On the main road, near Ellerbe, chocolate and ocher colored clays are exposed in the ditches. They are extremely fine grained and very slightly gritty and massive, but when broken apart many of the lumps show distinct schistosity. Mr. Steele says that a little of the yellower variety has been burned and sold as ocher. The clays of both colors are associated with jointed rocks that may be shales or slates, as they readily fall apart into lozenge-shaped fragments, some of which consist partly of yellow clay. The freshest rock that was seen in place is presumably a pale-gray clay slate, almost the same color as the gray clay at the pit. Although distinctly slaty, the clay is nevertheless very soft as if very compact.

The country about Ellerbe is underlain by slates or sheared volcanic rocks which differ in composition, and the different colored clays on the road are the result of their decomposition. The gray clay is possibly of a similar origin. It may have been derived from a less ferruginous rock than those that gave rise to the colored clays, or during its formation the iron compounds may have been leached out, in part forming the concretions found scattered through it. These concretions, when treated with hydrochloric acid, leave residues of white kaolin of the same shapes as the original nodules, indicating that the nodules were not present in the original rock but were secreted after or during the production of the kaolin.

West of the main road, about 1½ miles west of the pit in the gray clay, there is another opening on a hill covered with quartz boulders. No rock was seen in place. The pit has partly caved, but in some places around its sides a very white compact clay occurs, which, when it dries, breaks down into a very fine white powder that is quite gritty. When mixed with water it becomes very pale grayish white. The material, when examined microscopically, is seen to consist mainly of small splinters and tiny dustlike particles of quartz of 0.003 to 0.02 millimeter in diameter and small flakes of kaolin about 0.004 millimeter in diameter. No other constituents were noted, except here and there a shred of decomposed mica.

From the nature of the kaolin, its similarity in physical characters (except color) to the yellow and chocolate-colored clays in its neighborhood, and its likeness to the Overton and Eames clays (pp. 69–70) it is inferred that it is residual and that it was formed from some rock that occupied a fairly broad area and not from a pegmatite dike. At Candor and Troy the original rock was probably a feldspathic volcanic rock. At Ellerbe there may have been a series of slightly different volcanic rocks or of alternating slates and volcanic rocks.

Mr. Steele declares that borings about 30 or 40 feet apart over 25 acres penetrated from a thin film to 35 feet of sand and clay overburden and found underlying white and colored clays. Some borings found only colored clay, others only white clay, and others mixtures of the two. The holes were not located in order to determine the areal distribution of either kind, and consequently no estimate can be made of the quantity of the white clay available.

Neither one of the pits is now being operated. The eastern pit was worked in 1904, the clay being used mainly for cotton and paper filling. Only a small quantity was marketed, perhaps 150 or 200 tons. It was hauled by team 14½ miles to Rockingham. It could now be hauled by truck 4 miles to Norman and shipped by the Norfolk Southern Railroad.

KAOLIN RESERVES OF NORTH CAROLINA.

An estimate of the quantity of available kaolin in the known deposits of Mitchell, Yancey, and neighboring counties is of little value. Undoubtedly there is a large quantity of kaolin in the ground. Its distribution, however, is unknown. The slight development of most of the deposits does not indicate how much of the material can be mined with profit, even under the most favorable conditions, for the dimensions of the individual deposits are not known. The deposits that are now being exploited and those that have been explored by boring are estimated to contain more than

450,000 tons of commercial kaolin. This is a much smaller amount than that stated by the owners of some of the kaolin properties in this area, but in their estimates they assume that all the kaolin in the ground can be removed, which is impossible.

The aggregate quantity of kaolin in all the deposits in North Carolina is very great. Unfortunately, however, the expense of preparing the material for market precludes the working of many of them because of their small size. So far as now known only a few of them contain sufficient crude material to warrant the construction of the washing plants necessary to fit this material for market. The data now at hand indicate that there is enough material to furnish about 625,000 tons of refined product. The annual output of the State is 16,000 tons; consequently the supply is probably sufficient to last 39 years at the present rate of production. But because of lack of labor the production is less than the capacity of the plants. With plenty of labor the output may be increased 50 per cent. Moreover, as the methods of preparing the kaolin for market are improved there will unquestionably be an increase in the demand for the refined product and an enlargement of the plants to take care of the increased demand, and the life of the reserve will be correspondingly shortened.

A glance at the map (Pl. I), however, will show that the deposits now known center around a few points, notably Dillsboro, Spruce-pine, and Micaville. The most attractive deposits may occur in these areas, but more probably, however, the discovery of a few good deposits near these centers has encouraged the search for others in the same neighborhoods, and this may be the explanation of their peculiar distribution. It is known that pegmatite dikes are scattered rather uniformly through the mountain district, and the distribution of the mica openings corroborates this view. There is no reason to believe that the kaolinized dikes are less widely distributed than those that are being worked for mica. But kaolin will not bear as high costs of transportation as mica, consequently the profitable deposits of kaolin must be close to the railroad, whereas deposits of mica may be more distant. Large areas in the mountain districts have not been explored for kaolin, because of the difficulty of getting the product to market. It is probable that these areas contain deposits, which, except for the cost of transportation to the railroad, would furnish as profitable sources of kaolin as some of those now being exploited. With the extension of the system of hard roads into remote mountain regions the use of trucks will be more feasible and the cost of transporting the refined kaolin will decrease. Exploration of the mountains will then become more attractive, and unquestionably, as a consequence, new sources of kaolin will be discovered. It is impossible to make any estimate of the probable amount of material these new sources will contribute to the State's output, but there will undoubtedly be enough kaolin in deposits now unknown to lengthen the life of the kaolin industry several times beyond that indicated by the size of the reserve now known.

PROSPECTING FOR KAOLIN.

All the deposits of kaolin now being operated in North Carolina are on the slopes of hills in the mountain district, but unquestionably good deposits exist also in less exposed situations, where they are not so easily detected because usually covered by débris from the slopes. On slopes the débris produced by weathering is removed almost as rapidly as it is formed, and the white kaolin is exposed. At the bases of slopes the narrow kaolin masses are covered by creep or wash from the overhanging hills and many of them are nearly completely obscured.

In some places on flats or low slopes where the kaolin can not be seen its presence beneath the soil may be inferred from the large fragments or boulders of quartz on the surface. The boulders result from the decomposition of coarse pegmatites, as there are no other rocks in this portion of the State that yield quartz boulders upon weathering. Consequently the presence of quartz boulders suggests decomposed pegmatites, and as the decomposition of pegmatites commonly produces kaolin, it follows that the presence of the boulders on the surface may indicate the presence of kaolin beneath the surface.

After the existence of kaolin has been determined it is desirable to ascertain its extent before undertaking any expensive development to prove its value. This is done with an auger welded to a section of steel pipe long enough to enable the operator to penetrate the deposit at least 30 feet, and the usual precautions should be taken to see that the sample does not become contaminated with material scraped from the side of the bore hole by the auger. Borings should be made at intervals of about 15 feet in a series of lines at right angles to one another until the area tested is large enough to establish definitely the width of the deposit and its general direction. Care should be taken to make sure that its actual limits have been reached before abandoning the cross boring. It must be remembered that quartz horses are common in many of the deposits and that they will stop the auger as effectually as wall rock. Before abandoning the cross boring a sufficient number of holes should be sunk to rock to establish the fact that the limit of the deposit has been reached in that direction. After proving the width of the dike holes should be bored along its length through a distance that will leave no doubt as to its magnitude. These holes should be closely spaced along the borders of the deposit but may be more widely spaced within its borders.

After having determined that the size of the deposit is sufficient to warrant working, provided the quality of the kaolin is satisfactory, it is necessary to obtain as nearly as possible an average sample for study. Such a sample is best obtained by driving a tunnel from the face of a slope into the deposit and crosscutting, care being taken to grade the tunnel so that it will readily drain. Samples should be taken from the entire length of the walls of both tunnel and crosscut, omitting only those portions occupied by horses so large that they would have to be left during mining. With this exception, all horses should be sampled as well as the pure kaolin, so that the sample may represent a fairly complete section of the walls throughout the extent of the mass that would be removed in mining. The sample thus obtained should be mixed with samples from horizontal borings at definite intervals into the walls on both sides of the tunnel and crosscut and from vertical borings into the roof and floor. The samples should be preserved in bags and with each bag there should go a record explaining exactly how the sample was obtained and from what part of the deposit it was taken. This is necessary, as different portions of a deposit may yield materials that have different properties, and the probable proportions in which these materials occur should be determined.

After the several samples have been collected one or more general samples should be made by mixing the individual samples in their proper proportions, and these general samples should be subjected to the tests that have been prescribed for determining the value of a kaolin for the purposes for which kaolins are used. A chemical analysis is not necessary, but a burning test is essential.

In estimating the volume or the thickness of the deposit, or the waste material in streaks of impurities such as quartz veins, allowance should be made for the slant or dip of the pegmatite dikes, which usually increases the apparent thickness of a quartz vein, for instance, to an amount greater than its real thickness.

USES OF KAOLINS OF NORTH CAROLINA.

The kaolins of North Carolina are used in making china, semiporcelain, and porcelain, mosaic and other tile, and in the manufacture of spark plugs.

Their principal use is in the bodies used for different grades of china and other white ware. They constitute from 2½ to 15 per cent of the mixture, the other ingredients usually being English or domestic ball clay, English china clay, Florida clay, and often clays from other domestic sources. Some potters describe the kaolins of

North Carolina as very satisfactory when not introduced into the body in large quantity. Others declare that their use is objectionable in the manufacture of fine ware, but that if better cleaned they would be the equal of any English clay. Some of the product contains too much grit and some of it is contaminated with particles of yellow material, which appear as tiny black specks in the finished ware. In a few potteries it is apparently slowly replacing imported clay; in others its use is gradually being abandoned. One of the largest users reports that in his practice he has found it to burn to a greenish body marred by black dots, and that as the demand for more perfect ware is pressing he is compelled to diminish the quantity he has been using and is substituting for it English china clay. At one pottery, however, satisfactory ware is being produced from a mixture containing only American clays. In this mixture North Carolina kaolin constitutes about 20 per cent of the mass.

It is evident that although in the practice of some potters the kaolin from this State gives satisfactory results, it is generally not entirely satisfactory and consequently is used sparingly. As the troubles have been chiefly with plasticity and shrinkage it may be that with a change in the formulas at some of the potteries the quantity of the kaolin from North Carolina that could be introduced ino the mixture might be considerably increased. Nevertheless, a more certain means of extending its use would be to change the method of washing the crude clay sufficiently to assure the removal of all of the grit and other ingredients that are so objectionable to the potters.

An important recent use of the kaolin from North Carolina, though one that does not yet require large quantities, is in the manufacture of glass-melting pots. So far as known, commercial tests of the suitability of North Carolina kaolins to this purpose have not proceeded far enough to yield definite results. However, the Bureau of Standards has shown that a mixture containing 24 per cent of kaolin from North Carolina, together with white clays from Georgia and Florida and ball clays from Tennessee and Kentucky, worked up with an equal quantity of grog will produce a glass pot of satisfactory quality for ordinary purposes.[33]

SOUTH CAROLINA.

By W. S. Bayley.

ABBEVILLE COUNTY.

The only high-grade residual clays that occur in the area west of the fall line in South Carolina are near Abbeville, Abbeville County, and belong to the Abbeville-York series of Sloan.

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[33] Bleininger, A. V., Special pots for the melting of optical glass: Am. Ceramic Soc. Jour., vol. 1, No. 1, p. 15, 1918. See also Wright, J. W., and Fuller, D. H., Note on the casting of porcelain glass pots: Am. Ceramic Soc. Jour., vol. 2, p. 659, 1919.

Kaolin occurs on the property of Messrs. J. A. and W. E. Hill, 2½ miles south of Abbeville, at the Vienna Crossroads, but is poorly exposed by very little development. Mr. J. A. Hill reports that borings over 75 acres at 60-foot intervals have outlined a mass of clay 50 feet wide and 1 mile long. The kaolin is best seen on the west side of a cut in the road where it crosses over the top of a grade. Its relation to the neighboring rocks is shown in the accompanying sketch (fig. 13). The kaolin is in a dike 50 feet wide that strikes nearly northwest and dips 75° SW. Both above and below it is a coarse dark granite that has been almost completely decomposed so that it is now a mass of quartz particles in mottled clay with the appearance and structure of an aggregate of feldspar and some ferromagnesian mineral. The footwall granite near its contact with the kaolin is cut by tiny veinlets of kaolin that run nearly parallel to the contact with the dike. South of the upper granite and apparently overlying it is a breccia-like mass of clay, rock, and rounded quartz fragments that may represent a very coarse granite. The

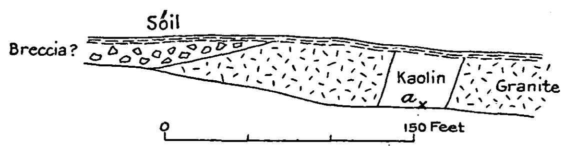

FIGURE 13.—Section in west side of cut in road 2½ miles south of Abbeville, S. C. *a*, Kaolin deposit.

whole is capped by an overburden of 4 to 10 feet of red clay. A shaft was sunk in the kaolin (*a*, fig. 13) to a depth of 36 feet without reaching rock. Here the kaolin is in all probability a decomposed pegmatite like the kaolins that are so common in the mountain regions of western North Carolina. It consists mainly of kaolinite, quartz, and partly kaolinized feldspar, with a very little decomposed muscovite and a few small flakes of brown mica. Scattered through it are little clumps of reddish gritty clay that are apparently completely decomposed garnet. When mixed with water the mass turns to a very dark cream-color or a distinct reddish yellow.

The quartz is in very irregular sharp-edged grains of all sizes from 0.2 millimeter in diameter down to dust. Many of the grains are cloudy and some are stained brown. The feldspar, which is white and opaque, is in more or less rounded grains, many of them colored reddish brown. Other brown masses may be iron-stained kaolin. The mica as a rule is also stained, and most of it is altered. The kaolinite is in comparatively large plates, measuring from 0.012 to 0.02 millimeter in diameter, and these are commonly grouped into rosettes and wormlike aggregates. Besides the plates there are very numerous small, dustlike grains like those that occur in all kaolins.

An analysis made by Dr. R. N. Brackett, of Clemson College, yielded the following results:

Analysis of kaolin from Abbeville, S. C.

Silica (SiO_2)	56.00
Alumina (Al_2O_3)	28.63
Ferric oxide (Fe_2O_3)	3.97
Lime (CaO)	1.20
Magnesia (MgO)	.21
Soda (Na_2O)	1.34
Potash (K_2O)	1.02
Manganous oxide (MnO)	Trace.
Titanic oxide (TiO_2)	Trace.
Water (H_2O)	8.00
	100.37

This composition corresponds to 10.14 per cent quartz, 29.46 per cent feldspar, and 60.77 per cent clay substance.

This clay burns to a dense cream-colored biscuit.

About 500 feet west of the road is another shaft where the conditions are somewhat different from those noted on the road. The shaft itself has collapsed and can not be entered, but on the dump lies a considerable quantity of coarse kaolin that looks very much like the crude material from North Carolina. It contains coarse quartz and a little white mica. Large boulders of a thoroughly kaolinized felsitic rock, probably a rhyolite, are scattered in the vicinity, and some of these are said to have been taken from the shaft. More common than these boulders, however, are great boulders of a coarse dark granite, which, of course, is much decomposed, but which has not yielded any great quantity of kaolin. The shaft is possibly in a decomposed pegmatite that was intruded in the felsite and granite, but more probably it was sunk in a portion of the felsite that was thoroughly altered. Whatever the original source of the kaolin at this place, unquestionably, both here and on the road, it is residual. Dr. Brackett also analyzed a sample of this clay and obtained the following results:

Analysis of residual clay from the vicinity of Abbeville, S. C.

Silica (SiO_2)	73.55
Alumina (Al_2O_3)	13.82
Ferric oxide (Fe_2O_3)	2.98
Lime (CaO)	1.80
Magnesia (MgO)	.28
Soda (Na_2O)	3.28
Potash (K_2O)	2.51
Manganous oxide (MnO)	Trace.
Titanic oxide (TiO_2)	Trace.
Water (H_2O)	1.85
	100.07

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This composition corresponds to 25.18 per cent quartz, 63.02 per cent feldspar, and 11.87 per cent clay substance.

GEORGIA.

Pegmatite dikes are known within the Piedmont region of Georgia, but no records of any valuable deposits of kaolin there have been found.

Veatch[34] in his report on the clays of Georgia has noted one deposit 4 miles northeast of Union Point, Greene County, from which a small quantity of kaolin was mined. It was rather siliceous, burned white at cone 5, faint cream at cone 13, and fused at cone 30.

ALABAMA.

Kaolins derived from pegmatites are reported from Milner, Pinetucky, and Micaville, Randolph County, and Stone Hill, Cleburne County, as well as from a few other localities, but they are undeveloped.

KAOLIN FROM CAMBRIAN SCHISTS IN PENNSYLVANIA.

Kaolins derived from siliceous schists are associated with the Cambrian formations of southeastern Pennsylvania. Although they occur at several localities, they have not been traced continuously from point to point, and as their mineral character differs appreciably, it is not certain that they are all formed from the same division of the Cambrian system of rocks.

The three localities from which these kaolins are known are Glen Loch, Delaware County; Mount Holly Springs, Cumberland County; and Narvon, Lancaster County.

The first two localities yield a residual clay that is practically white, but the clay from the last locality is not white, except in one opening.

GLEN LOCH, DELAWARE COUNTY.

Hopkins[35] in his report refers to a kaolin mine and washer $1\frac{1}{2}$ miles north of Glen Loch station on the north side of Little Chester Valley. The mine is near the contact of Ordovician limestone and Cambrian sandstone. The sandstone outcrops a short distance north of the mine and the limestone a short distance south, but neither

[34] Veatch, Otto, Clay deposits of Georgia: Georgia Geol. Survey Bull. 18, p. 256, 1909.

[35] Hopkins, T. C., Clays of southeastern Pennsylvania (in part): Pennsylvania State Coll. Ann. Rept. for 1898–99, Appendix, p. 30, 1900.

rock is in contact with the clay. Large masses of coarsely granular white quartz occur in and near the kaolin, and some of these contain wavellite. The kaolin deposit dips into the hill and thence runs under the iron ore which is north of it. Hopkins comments on the remarkable similarity of this clay to the South Mountain kaolins.

The writer has not seen this locality but has received a sample from it, which is a grayish-white sandy clay that appears to be free from mica. This sample indicates that the deposit bears a closer physical resemblance to the South Mountain deposits, which also carry wavellite and iron ore in places, than to the deposits derived from pegmatite which lie to the south.

The crude clay, when examined under the microscope, shows abundant grains of quartz, some grains of hydromica, and abundant grains of kaolinite, as well as a little rutile.

The clay has moderate plasticity. One sample, which was fired at cone 10, burned grayish white; its absorption was 18.7 per cent and its porosity 36 per cent. It is therefore not a very dense-burning clay. At cone 10 it was nearly steel hard. It would be necessary to wash the clay for market, and the percentage of washed product would not be very high.

SOUTH MOUNTAIN REGION, CUMBERLAND COUNTY.

General features of the deposits.—The deposits in this region have been described in some detail by Hopkins [36] and Stose.[37] Since their reports were issued some deposits formerly operated have closed down, and others have been developed.

South Mountain, on whose flanks the white clays occur, extends from Potomac River, at Weverton, north and east to Susquehanna River south of Harrisburg. It is composed of several parallel ridges with steep-sided longitudinal valleys in between them. These ridges are composed chiefly of hard Cambrian sandstone, whereas the valleys, according to Stose, are underlain by shale. The sandstones form part of a great anticlinorium or arch, which has vertical or overturned dips on the northwest side. To the southeast of the sandstone ridges lie volcanic rocks, which form the core of the fold, whereas to the northwest the Cumberland Valley is underlain by Cambrian and Ordovician limestones. The area in which clay may occur is therefore rather well defined.

[36] Hopkins, T. C., Pennsylvania State Coll. Ann. Rept. for 1899–1900, Appendix, 1901.
[37] Stose, G. W., White clays of South Mountain, Pa.: U. S. Geol. Survey Bull. 315, p. 322, 1907.

The deposits of clay occur chiefly southeast and southwest of Mount Holly Springs (see fig. 14), but most of the pits have been opened in the valley of Mountain Creek.

All the clays are residual and have been derived from a siliceous schist; indeed specimens showing all stages in the transition from schist to clay can be found.

Hopkins states that the white clay has been derived from hydromica slates, " which occur intercalated in the Cambro-Ordovician limestones and in the Cambrian slates, sandstones, and quartzite."

No limestone was seen by the writer in association with the clay, but Stose states that some is found in one of the Philadelphia Clay Co.'s tunnels.

Two structural features seem to be constant in the Holly Springs region. First, that the clay bed is usually under a distinct topographic bench on the mountain slope. Second, that in driving a tunnel into the mountain at different localities there is encountered first a colored plastic clay, which usually contains iron ore, then a white clay that differs in thickness in different localities, and lastly sandstone, which underlies the other beds stratigraphically.

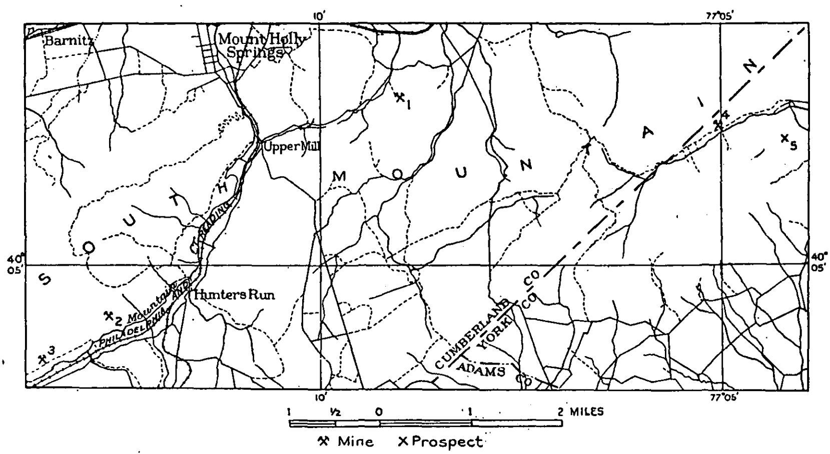


FIGURE 14.—Map showing clay mines in South Mountain district, Pa. 1, Holly Clay Corporation; 2, Philadelphia Clay Co.; 3, Sandusky Portland Cement Co.; 4, Russell's tunnel; 5, Fishel's prospect pits.

The clay ground is commonly soft, wet, and treacherous, so that underground mining seems to have been the method preferred in several places, presumably because the operators though that an open cut would tend to slide so as to interfere with the work of excavation.

The clays are all fine grained and contain a high percentage of very fine silt, which is difficult to eliminate in washing. They burn to a very light cream color and have a somewhat high fire shrinkage.

They have not thus far been used much for pottery manufacture, but their chief application has been as a filler for paper and in paints. All of them have to be washed to eliminate as much of the fine sand as possible.

Property of the Cumberland Clay Co.—The property of the Cumberland Clay Co. was in the eastern end of Mountain Creek Valley, east of Upper Mill. The deposit, which was quite extensive, had a steep dip. The property is no longer in operation.

Property of the Philadelphia Clay Co.—The Philadelphia Clay Co. continues to be the largest producer in this region. The mine is on the northwest side of Mountain Creek Valley about 2½ miles southwest of Upper Mill. Its plant was described somewhat fully by Stose, but permission to publish any recent data regarding it is withheld at present. It may be said, however, that the deposit is mined by tunnels that penetrate the colored clay to the white material, which is then worked out as far as practicable from the one tunnel, after which a new one is driven.

The crude clay and the washed product, on examination under the microscope, gave the following results:

Crude clay: Sample, as a whole, medium-grained with dustlike specks. Quartz, abundant; hydromica, fairly common; kaolinite, abundant; rutile, numerous in very minute needles; tourmaline, a few grains.

Washed clay: Texture as a whole, fine. Quartz, fairly common; hydromica, common and much of it in flocculated grains; kaolinite, abundant; tourmaline and rutile, present in a few small grains.

The chief difference between the crude and washed clay appears to be in the finer size of the quartz grains, although the quantity of this material is somewhat less.

Property of the Sandusky Portland Cement Co.—The Sandusky Portland Cement Co. has a mine about three-quarters of a mile southwest of the mine of the Philadelphia Clay Co. The clay does not outcrop. The company has driven two tunnels, the upper one of which is closed. The lower tunnel is somewhat winding and about 800 feet long. It branches into several headings near the end. The first part of the tunnel is in the usual colored clay. The product from this mine is used in the manufacture of Portland cement.

A sample of creamy-white, hard sandy, clay showing laminated structure, which was taken from the tunnel heading, was examined under the microscope. It was medium to fine grained. Quartz was very common, as was also the hydromica; kaolinite was abundant. Rutile also appeared to be common but was in very minute prisms.

A sample of the softer clay, like that being shipped from this locality, was also examined microscopically. This sample was medium to coarse grained and the quartz was fairly abundant. Hydromica, partly flocculated and partly in the form of tiny needles, was abundant, and kaolinite was more so. There were numerous tiny grains of rutile and a few grains of both tourmaline and chlorite.

The clay is fairly plastic, though it contains much fine quartz.

A sample of it fired at 1,150° C. had 6.4 per cent absorption and 15.9 per cent porosity, while another fired at 1,300° C. had 0.1 per cent absorption and 1.2 per cent porosity. The clay burned buff at the lower temperature as well as steel hard, but at the higher temperature it was gray.

Henry Clay mine.—The Henry Clay mine is near Henry Clay, on the southeast side of the valley. It was formerly worked by tunnel and shafts to supply the Mount Holly Brick & Clay Co., but is no longer in operation.

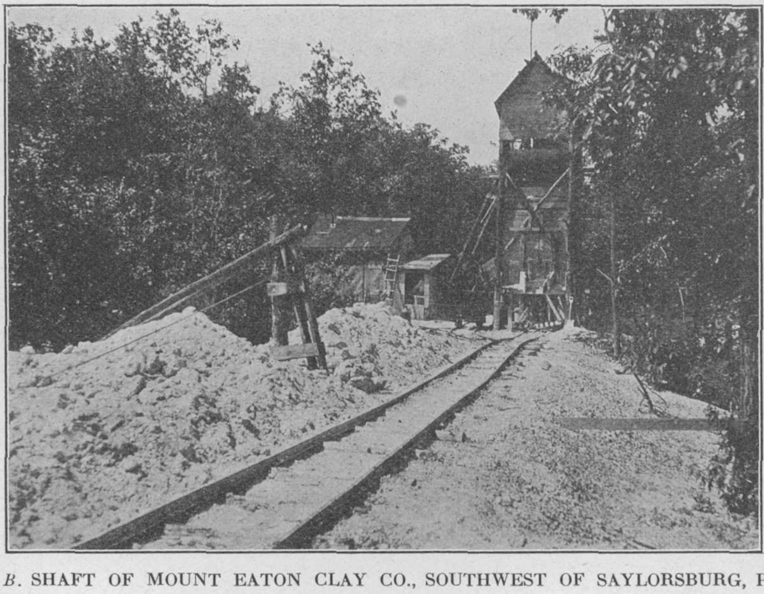
Property of the Holly Clay Corporation.—The Holly Clay Corporation has recently begun operations on the northwest side of South Mountain and about 2 miles east of Mount Holly Springs. Some years ago clay was dug here for brick manufacture. The deposit underlies the bench on the north slope of the mountain, and the pit is about 2,000 feet south of the Philadelphia & Reading Railway tracks. Unlike the other companies, this one is working the deposit as an open pit (Pl. IV, *A*), digging the clay with a steam shovel. At the time of our visit the pit showed 15 feet of overburden and 12 to 15 feet of clay.

Test holes bored up the sloping surface of the bench for a distance of about 600 feet show white clay covered by 10 to 26 feet of overburden, and white sand usually immediately over the clay.

The clay in the pit is light-grayish white, though in places it is mottled with limonite. Here and there occur streaks of clean sand and also sandy clay. Angular lumps of quartzite are scattered through the clay, and these are in some places in bands, as though they represented thin beds of quartzite in the schist from which the clay is derived.

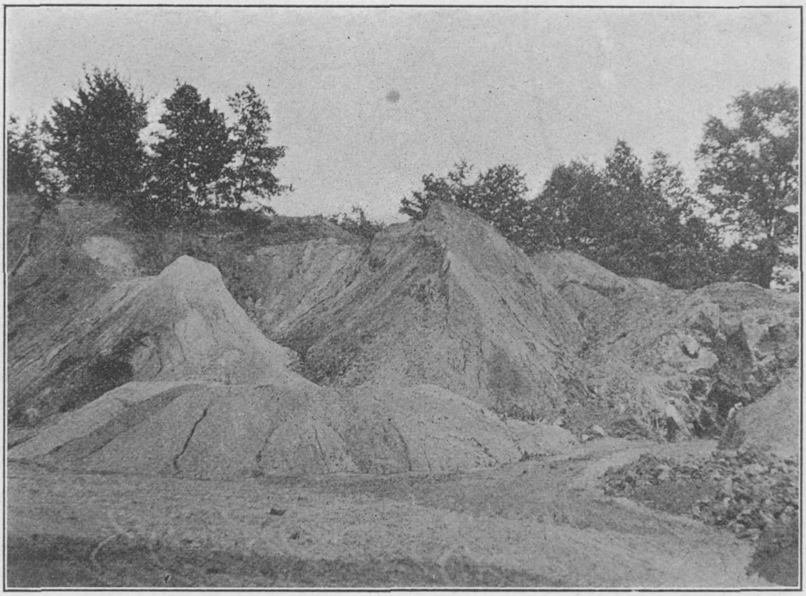
The method of treatment here is unique in the clay industry, because of the types of purifying apparatus used. At the pit the clay is dumped into a log washer, from which it passes to a short trough, where the stones are separated. It then goes to a Dorr classifier, whose action is similar to a blunger. The clay and water are then taken up a pipe line to the washing plant, where it passes successively through a Dorr hydroseparator, 50-foot sections of trough, Dorr thickener, filter press, and dryer.

A. PIT OF HOLLY CLAY CORPORATION, MOUNT HOLLY SPRINGS, PA.



B. SHAFT OF MOUNT EATON CLAY CO., SOUTHWEST OF SAYLORSBURG, PA.

A. WHITTAKER RESIDUAL CLAY PIT, NARVON, PA.



B. RESIDUAL CLAY FROM CAMBRIAN CLAYEY SANDSTONE, DUNGARVIN, PA.

Sodium carbonate is added in the log washer, in order to deflocculate the clay, and sulphuric acid to neutralize the alkali as the clay leaves the trough.

It is claimed that the plant will deliver 60 tons of washed product each 24 hours.

The crude clay is gritty but fairly plastic. Washing, however, removes most of the coarse grit and some of the fine, without increasing the plasticity much, and the washed clay does not appear to burn as dense as the crude.

The following tests give some idea of the porosity and color of the kaolin after burning:

Physical tests of kaolin from Mount Holly Springs, Pa.

	Crude.		Washed.	
Temperature (°C.)	1,150	1,300	1,150	1,300
Absorption (per cent)	3	0.5	8.4	1.5
Porosity (per cent)	10	2	19.5	3.4
Color	Buff.	Gray.	Cream-white.	Gray-buff.
Hardness	Steel hard.	Steel hard.	Steel hard.	Steel hard.

Tests of a washed sample supplied by the Pennsylvania Geological Survey gave the following results:

Linear air shrinkage, 2.26 per cent. At cone 8 (1,290° C.), linear fire shrinkage, 14.12 per cent; color, grayish white. At cone 15 (1,430° C.), linear fire shrinkage, 10.15 per cent; absorption, 0.6 per cent; color, grayish white. The expansion at the higher cone due to the high content of silica is noticeable.

Under the microscope the clays showed the following mineral composition:

Crude kaolin: Quartz grains of all sizes, common; hydromica scales, common: kaolinite, abundant: tourmaline, rutile, and zircon, a few grains.

Washed kaolin: Quartz grains, less abundant and all fine; hydromica, fairly common; kaolinite, very abundant; rutile, many tiny grains: epidote, rare.

Thin sections of clay that had been fired to 1,150° C. (Pl. XXIX, *B*, p. 300) contained abundant grains of quartz in a groundmass which was mostly isotropic, though a few grains had the interference colors of kaolinite. The hydromica had all disappeared. Some of the quartz showed signs of resorption (Pl. XXIX, *B*). The grains of rutile were not noticed. A thin section of the clay fired to 1,300° C. was similar to that burned at the lower temperature, but there appeared to be more isotropic material in the groundmass.

The washed clay fired at 1,150° C. appeared similar to the crude, except that there was much less quartz, and in this specimen very small grains of rutile were noticed. A specimen fired to 1,300° C. showed the same increase in isotropic material in the groundmass as the crude clay.

Several samples of sands from the washing troughs were also examined under the microscope and gave the following results:

Head of first length of trough: Sand grains from 0.004 to 0.240 millimeter, average about 0.12 millimeter. Grains mostly quartz, but some rutile, titanite, zircon, epidote, and tourmaline was present.

Bottom of first length of trough: Grains from 0.004 to 2 millimeters, average 0.1 millimeter. Same minerals, although there were fewer of those of high refractive index. In addition a little kaolinite was present.

Bottom of sixth length of trough: Grains from 0.001 to 0.16 millimeter, average 0.08 millimeter. Same minerals, except that there was no kaolinite.

Head of eleventh length of trough: Grains from 0.002 to 0.16 millimeter, average 0.06 millimeter. Same minerals, including a little kaolinite.

Beavertown.—White residual clays derived from Cambrian schists have also been prospected in the valley of Dogwood Creek about 2 miles west of Beavertown.

On the north side of the creek a tunnel has been run into the mountain in a northerly direction for over 500 feet. It first traverses the colored clay, which contains streaks of white and some pockets and bands of limonite, but near the end white clay is encountered. The dip of the beds is 30° N. at the tunnel entrance, but it steepens to 70° farther in.

The weathered, streaked schist at the entrance to the tunnel shows petrographic characters not unlike that of the white clay. Although very gritty it was medium to fine grained, and quartz was fairly common. Hydromica was scarce, but kaolinite was abundant. Rutile was scarce, and a few grains of zircon were present. The grains were abundantly stained with colloidal hematite.

A second but short tunnel has been started about 75 feet higher than the first and about 200 feet to the south, and the clay exposed in this tunnel between the timbers is mostly white. It is also claimed that borings made on the bench of the slope show much white clay. This deposit has not yet been opened.

On the south side of Dogwood Creek, about 1¼ miles S. 80° W. from Beavertown, several test pits have been put down by Mr.

Fishel. The holes were all covered, but the dumps around them showed whitish siliceous clay.

Uses of the kaolins from the South Mountain region.—The crude clay from one mine has been used in the manufacture of white Portland cement.

The washed clays of this type can be used by some paper manufacturers; they are also available for making paint and can be employed in plaster-board manufacture. Up to the present time they have not been much used in the manufacture of white pottery, floor, or wall tile.

Future of the region.—This region probably contains a considerable amount of clay, but the difficulties of mining it may prevent the complete extraction of the supply.

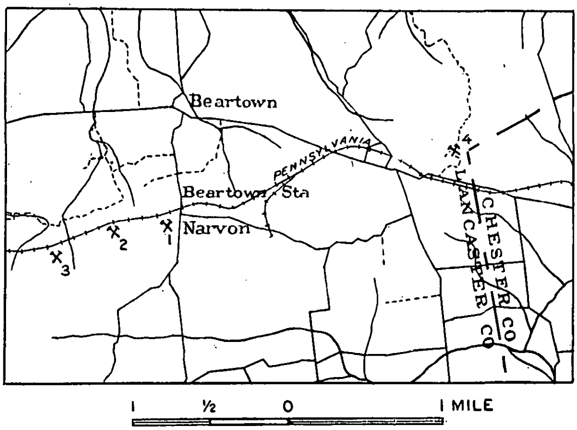


FIGURE 15.—Map showing clay pits in Narvon district, Pa. 1, Whittaker pit; 2, Diller pit; 3, Walters pit; 4, sandstone quarry with deposit of kaolinized feldspathic quartzite.

NARVON, LANCASTER COUNTY.

Residual clay derived from Cambrian schist and also from feldspathic quartzite is found at several localities in a belt extending from Honeybrook to Narvon (fig. 15). The schist is a member of the Chickies quartzite and is probably coextensive with the Cambrian of Welsh Mountain, which forms the northwest limb of a great arch.[38] The belt of schist along the ridge is underlain by Chickies quartzite. This quartzite ranges from a pure quartz rock to an arkose and shows practically no evidence of weathering except where it is feldspathic, but the schists have been deeply weathered. A description of the clays

[38] Personal communication from F. Bascom.

derived from the schists has no legitimate place in this report, for they are not high grade and are mentioned here simply to indicate how the clays derived from the Cambrian in Pennsylvania may change from place to place.

Three openings have been made in the north slope of the ridge west of Narvon, and two of them are described below. The third one (said to belong to Dr. Walters, of Lancaster, Pa.) had not reached the shipping stage at the time of our visit (July, 1918).

Pit of the Whittaker Clay Co.—The Whittaker Clay Co.'s pit is located about 500 feet southwest of Narvon station. The pit (Pl. V, *A*) is a long, narrow excavation about 275 feet from end to end, made in the northern slope of the ridge and lying above the track level. At the south end of the pit the working face is probably 70 feet high.

The entrance cut shows feldspathic quartzite that strikes S. 70° W. and dips 35° SE. This rock changes within a short distance to schist, having the same strike and slightly lower dip.

This schist by decay has yielded a sandy residual clay, in which the decomposition has gone so far that few fresh grains of mica are visible, but there are numerous tiny black specks. Most of the clay is gray, but that at the head of the pit is decidedly ferruginous. About 5 acres of the clay have been tested out, and the owners claim that it extends 140 feet below the level of the track, but this estimate is based on the dip of the quartzite and not on actual borings.

The clay does not burn white and is of interest here for comparison with some of the other deposits in this region, which are yielded by the same formation.

Tests supplied by the Pennsylvania Geological Survey showed that the clay has 2.26 per cent linear drying shrinkage. At cone 8 (1,290° C.) the linear fire shrinkage is 10.79 per cent, absorption 1.3 per cent, and color buff. At cone 15 (1,430° C.) it is overfired.

The best clay is gray when dry, hard, and very gritty to the taste. It is quite sticky when wet. When air-dried it slakes very slowly in water. It probably has good bonding power.

Under the microscope it shows quartz in abundance and some hydromica and kaolinite, of which the kaolinite is the more abundant. Tourmaline grains were common (Pl. XXVII, *B*, p. 296), and rutile and zircon were present but rather scarce.

Pit of the Diller Clay Co.—This pit is about half a mile a little south of west from Narvon and also close to the railroad track. The excavation is smaller than that of the Whittaker Clay Co. and shows no quartzite. The clay is also derived from schist and is gray and iron stained and sandy, but the beds, instead of having a uniform dip, are folded into a syncline.

Under the microscope the clay is seen to be medium to coarse grained. Quartz grains are abundant. Both hydromica and kaolinite are abundant. Rutile is present in the form of numerous tiny grains. Epidote, titanite, zircon, and tourmaline are present but scarce, the tourmaline being the commonest of the four minerals.

Test shafts dug on the slope to the north show that the clay extends up the hill, but its depth is not known.

Both this clay and the clay from the Whittaker Clay Co.'s mine are of a type used by steel works. Where the clay has been formed from the schist there seems little chance of getting a white product, but where it has been formed from the feldspathic quartzite there is a much better chance of getting white material. The quartzite rock does not decompose as readily, however, as the schist.

Uses of the clays from Narvon.—The residual clays dug near Narvon are not white enough to be used in paper, paints, or pottery. Their chief use is at steel works.

HONEYBROOK, CHESTER COUNTY.

J. C. Budding & Co. have a large quarry in the Chickies quartzite 2 miles northwest of Honeybrook.

The beds dip northwest, are massive, and in places feldspathic or arkosic. This material, however, does not seem to have decomposed to clay save at one point in the quarry, where a bed of arkose about 30 feet thick has weathered to a white clay, which was worked some years ago. The deposit strikes northeastward. It is undoubtedly derived from the feldspathic sandstone, for specimens showing every stage in the transition from sandstone to clay can be seen. At the base or footwall of the deposit lies a quartz vein which contains a black mineral that appears to be tourmaline. The clay is very white but is no longer worked, as the deposit is not very extensive. This deposit of white residual clay is the only one that the writer knows of in this district. If others are present they lie in the quartzite belt and not in the schist.

A sample of this kaolin, when examined under the microscope, was found to be medium to coarse grained. Quartz was very abundant. Hydromica was common, some of the grains being large and showing optical characters close to sericite; kaolinite was doubtfully present in very fine grains; rutile was common in both small and medium sized grains. A little tourmaline was noticed.

KAOLIN FROM CAMBRIAN QUARTZITE IN CENTRAL PENNSYLVANIA.

By E. S. Moore.

GEOLOGIC OCCURRENCE.

There are a number of deposits of residual clay in central Pennsylvania (fig. 16) all of which occur under similar conditions, and

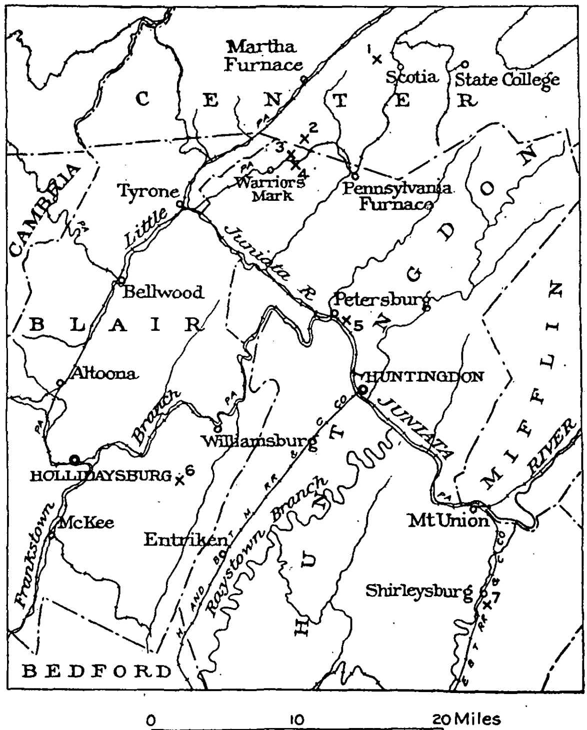


Figure 16.—Map showing residual clay deposits in Huntingdon, Blair, and Center counties, Pa. 1, Blair property; 2, Colonial Clay Co.; 3, Patton property; 4, Throop property; 5, Petersburg; 6, Woodbury Clay Co.; 7, Rock Mill Clay Co. In 1, 2, 3, 4, and 6 the clay is residual from sandstones of Gatesburg formation; in 5 it is residual under Oriskany, and in 7 over Oriskany.

most of them consist of white material. They are found chiefly in the Nittany Valley, and they invariably occur in Upper Cambrian sandstones forming a part of the Gatesburg formation.[39] As they are distributed in a linear arrangement parallel to the strike of the strata of the Gatesburg they have evidently been derived from the weathering of argillaceous strata in that formation, which in many places contains beds of impure dolomite and beds of sandstone mixed with clay. On account of this relation between the clay and the

[39] Butts, Charles, Geologic section of Blair and Huntingdon counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, p. 527, 1918.

sandstone there is evidently no sharp line of demarkation between the clay and the sandstone along the strike of the strata, but the two rocks grade imperceptibly into each other. In some pits a body of clay may be dug a few feet from a deposit of very fine, almost pure, white sand, but this sudden change is more likely to occur transverse to the strike of the beds than parallel to them.

The bulk of the clay comes from the borders of abandoned iron mines, and a great deal of clay of this type has been taken out in the past while the iron was being worked. The clay occurs in lenses, seams, and irregular masses associated with the limonite ore but as a rule outside the ore body, as the clay within the area worked for ore is usually stained with iron. There are all gradations of material from clay that carries considerable iron and is of no use in the ceramic industry through red and pink to pure-white clay, just as there are all gradations between the pure clay and clay high in sand. The association of the clay and iron is probably due to the fact that the iron has been carried in solution by underground water and concentrated in areas where beds of argillaceous dolomite are associated with the sandstones. As these beds are easily weathered out, the sandstones break down and thus an area is formed through which water very readily circulates. The circulating waters readily remove the soluble constituents, depositing the iron oxide through replacement of the dolomite and leaving the insoluble argillaceous materials as clay. The tendency is to carry all soluble materials toward the center of this area, where the downward circulation of the water is good and to leave the insoluble materials around the borders of a sort of basin. In this basin there will be more resistant masses, which will not crumble down, and these may be comparatively free from iron and contain some white clay. The waters that enter the basin are of course carried away by good circulation underground, in some places directed and aided by fractures in the strata. Faults have probably in many places directed the course of the circulating waters, producing these deposits of iron and clay.

Observations show that the clay occurs as a rule along the flank of a ridge or knoll of sandstone, and the presence of a deposit is commonly indicated by a small depression in the surface. In prospecting for clay this fact should be kept in mind, but the depressions caused by underground circulation should not be confused with stream channels, which may bear no relation to the strata from which the clay is derived, for streams flowing over the surface generally mix the clay with the other materials and spoil it for use as a white clay. There is no doubt that some of the clay is transported, and there is a concentrating process going on in these depressions by the underground water, but the extent of the movement of the clay particles is very slight.

DISTRIBUTION OF THE CLAYS.

The white clays in the Gatesburg formation are being or have been worked at a number of localities in Center, Huntingdon, and Blair counties. During the summer of 1918 clay was being shipped from the Colonial Clay Co.'s pit near Furnace Road, just east of the Huntingdon-Center county line; the Dungarvin pit, at Dungarvin station in Huntingdon County; and the Woodbury Clay Co.'s pit, near Mines post office, in Blair County.

In addition to these properties, which have been shipping, there is a deposit about 2 miles west of Scotia, or Benore, in Center County, on which considerable work has been done. Drilling was carried on all summer on another property generally known as the Patton property, about 2 miles east of Warriorsmark and not far from Dungarvin station. A considerable amount of clay has also been taken from the Pennington ore pits in the past.

MINES AND PROSPECTS.

Blair property.—The property controlled by Mr. Frank Blair, of Bellefonte, Pa., is in Center County, between Benore, or Scotia, and Stormstown. It covers a low ridge of Gatesburg sandstone. Many years ago a great deal of limonite was mined in this vicinity, and it is said that several thousand tons of clay were removed from this area while the iron mines were in operation. About four years ago a further attempt was made to work the clay, and a derrick was erected for hoisting. A hole was dug about 30 feet deep, and three years later, in the spring of 1918, a shaft was sunk to a depth of 28 feet, in which, it is claimed, 21 feet of nearly white clay was exposed beneath reddish clay.

About 300 feet eastward from this shaft a pit 10 to 12 feet deep shows cream-colored clay, and 50 feet northeast of this pit there is another, said to be 30 feet deep, that has about 14 feet of clay. Still another pit, about 50 feet northeast of the one last mentioned, shows reddish clay. Near this pit is an old drift from which clay was mined a good many years ago. These deposits are arranged roughly in a line which is approximately parallel to the strike of the inclosing beds.

All these workings were full of water at the time of the writer's visit, so that it was impossible to examine the clay deposits in detail. Their situation along a depression has made drainage difficult, and future operations must provide some means of carrying the water which collects there, either into the sandstone, where it is free from clay and porous, or by a ditch down the valley.

The clay is gritty and grades into sand, but it can be washed so that it is almost entirely free from grit. The color is a cream-white, and it grades into a brick-red where the clay is high in iron. The clay has good plasticity, even though it is coarse grained and gritty. Under the microscope quartz and kaolinite are seen to be abundant. No hydromica was noticed, but rutile is fairly common.

Physical tests on this clay gave the following result. At 1,150° C.: Absorption, 16.2 per cent; hardness, not steel hard; color, faint cream-white. At 1,350° C.: Absorption, 15.7 per cent; hardness, steel hard; color, faint cream-white. Another sample from the same deposit showed 29 per cent absorption at 1,150° C., and 19.1 per cent at 1,300° C.

The clay would probably be suitable after washing for white ware and paper making and also for pottery.

Colonial Clay Co.—The property of the Colonial Clay Co. is often spoken of as the Gates property because it is being operated by Mr. T. J. Gates, of Tyrone. It is in Center County just northeast of the boundary between Huntingdon and Center counties and about 1 mile north-northeast from Furnace Road, a station on the Tyrone-Scotia branch of the Pennsylvania Railroad. The clay pits are associated with the abandoned iron-ore workings, and some of them are in these workings.

The clay on this property, like that in other parts of the Nittany Valley, occurs as very irregular deposits in Gatesburg sandstone, which forms a broad, low ridge in this locality. These deposits are in a depression along the flank of a minor ridge on the main mass of sandstone, and small subsidiary depressions in the main one commonly indicate the presence of clay beneath the surface. Their linear arrangement suggests that they were derived as a residual deposit from the weathering of certain strata in the sandstone.

At the time the writer visited the property the operations were being carried on in a large pit and a face of nearly white clay 20 feet high was exposed, the clay extending from the soil at the top to the bottom of the pit. The white clay grades either into red clay high in iron or into white sand, and all degrees of variations may be seen. Care has not always been exercised to prevent the caving of the overburden, and much soil and sand have therefore become mixed with the white clay in some parts of the pit.

The clay is hauled in wagons to a railroad siding about three-quarters of a mile distant, and the quantity shipped is stated as four to seven cars a week, depending upon the labor supply.

The clay has good plasticity but contains some coarse grit. Under the microscope it shows an abundance of quartz and kaolinite, the kaolinite being as a rule in bunches. Rutile in the form of tiny grains is common. Hydromica is scarce, and there are a few medium-sized grains of zircon.

Physical tests made on a sample of the nearly white to cream clay showed that it possesses the following properties: At 1,150° C., absorption, 28.90 per cent; hardness, not steel hard; color, white. At 1,300° C., absorption, 24.80 per cent; hardness, steel hard; color, very faint cream-white. The plasticity is good, but the clay is gritty and would be improved by washing.

The crude clay is used by manufacturers of white ware in sagger mixtures and at steel plants, where it is employed as a binder in mixtures for lining Bessemer converters, hot-metal ladles, and cupolas.

Patton property.—The Patton property lies about 2 miles east of Warriorsmark, in Huntingdon County. Formerly some iron was mined and considerable sand has been shipped from this property by a tramway connecting with the Scotia branch of the Pennsylvania Railroad. There is an old pit from which several tons of good paper clay is said to have been dug some years ago.

The West Virginia Pulp & Paper Co. has recently investigated the property with a view to obtain white paper clays for their mills at Tyrone and elsewhere. The writer is indebted to Mr. S. A. Okell, chemist of this company, for information regarding the work. A good many holes have been sunk by driving pipes with the aid of a gasoline engine.

The clay occurs in the weathered portion of the Gatesburg formation along the northeast side of a ridge of the Warrior limestone,[40] which underlies the Gatesburg, and is probably in the vicinity of a fault. As in other areas, it is found in the lower places, and there is little use in drilling on the higher land. The depth of the holes drilled ranged from 50 to 75 feet, and the materials commonly encountered were sand and white or yellow clay. The depth of the surface material above the clay or sand ranges from 5 to 17 feet, and the depth of the white clay below the surface ranges from 15 to 40 feet. The thickest body of white clay penetrated was about 33 feet thick and was struck at a depth of over 20 feet. The drilling indicated that the deposits are very irregular in form and of little horizontal extent. The clay forms pockets, and though a drill hole may pass through a large body of clay at one point another hole only a few feet away may miss it altogether, as the material grades into impure clay or sand.

There is a great deal of sand with most of the clay. It may carry from 30 to 40 per cent of free silica, but it can be readily washed, and a good separation obtained. Physical tests of a good sample gave the following results: At 1,150° C.: Porosity, 37.1 per cent; hardness, steel hard; color, white. At 1,300° C.: Porosity, 26.9

[40] Butts, Charles, op. cit.

per cent; hardness, steel hard; color, faint cream-white. It is fairly plastic.

A sample of the good clay was examined microscopically. As was inferred from its gritty nature, quartz was very common. Kaolinite was very abundant, but hydromica was scarce. Rutile was present in the form of numerous tiny grains. There were some grains of titanite and a few of tourmaline.

Not far from this locality and along the railroad is a deposit of residual clay and sand derived from the sandstone. The material is very sandy, and the pit when visited was being worked for sand, as the clay is insufficient in quantity to be of any commercial value. Its mineral composition is somewhat similar to the preceding clay, for it shows abundant quartz and kaolinite; fairly abundant hydromica; and a few grains of rutile, titanite, zircon, and epidote.

Dungarvin station.—On the border of a large pit known as the Dungarvin iron mine, near the station of Dungarvin, on the Scotia branch of the Pennsylvania Railroad and just over a ridge of Gatesburg sandstone to the south from the Patton property, clay is being mined in considerable quantities. This property is controlled by Joseph D. Thropp, who has leased portions of it to two parties who are carrying on the work. Messrs. P. D. Deeters and H. F. Harpster, of Warriorsmark, are mining an extremely tough, plastic, pinkish clay, which would appear to be suitable for saggers and similar ware. (See Pl. V, *B*.)

Very close to the spot where Deeters and Harpster are working and on the edge of the same pit, Mr. William L. Likens, also of Warriorsmark, is mining a cream-colored to white clay. Some of this clay is very gritty, and it grades into a pure fine sand. It is said to be used by steel works.

These deposits are both very irregular in outline and the appearance of a working face may change rapidly from day to day. They lie close to the surface and right on the edge of the old ore pit. The white clay seems to be very similar in physical properties to the clays described above. The following tests were supplied by the Pennsylvania Geological Survey:

Sample 1. Air shrinkage, 6.47. At cone 8 (1,290° C.), linear fire shrinkage, 11.76 per cent; color, cream; absorption, 3.8 per cent. At cone 15 (1,430° C.), linear shrinkage, 11.76 per cent; color, blue-gray; absorption, 1.9 per cent.

Sample 2. Air shrinkage, 6.47 per cent. At cone 8, linear shrinkage, 1.47 per cent; color, cream; absorption, 16.3 per cent. At cone 15, linear shrinkage, 0.67 per cent; color, light tan; absorption, 15.4 per cent.

There are traces of clay in the Gatesburg formation in several places near Dungarvin and a thin seam similar to the clay on the

Patton property may be seen in a sand bank which is being operated at a point close to the railroad about two-thirds of a mile northwest from Dungarvin.

Woodbury Clay Co.—The Woodbury Clay Co. is digging clay with steam shovels in an old iron-ore pit about 1 mile from Mines and about 6 miles from Williamsburg, Blair County. The pit is about 900 feet long, and in places it reaches a depth of about 40 feet. It lies in Gatesburg sandstone, and the clay deposits are similar to those already described. The clay is irregular in color and distribution, being in some places nearly pure white or cream-colored and in others a dirty gray, though it weathers white. It grades into sand, and it fills cracks and pores in the weathered sandstone, indicating that it has been derived from the weathering of a clayey sandstone.

From this deposit about four carloads a day were being shipped in the summer of 1918.

POSSIBILITIES OF FUTURE DEVELOPMENT.

The typical association of white clays with the sandstones of the Gatesburg formation in central Pennsylvania suggests that this formation may contain deposits in the wooded areas underlain by it. Although these deposits are generally associated with the limonite ore, which has been so extensively worked in this section in previous years, and most of them have doubtless been discovered in working the iron, the writer believes that other clay-bearing areas may be found. The sandstones of the Gatesburg formation should not be confused with the Ridgely sandstone of the Oriskany group, which is much later geologically than the Gatesburg, but which also contains iron ore and clay in some localities. Near Shirleysburg the Oriskany group carries a good deposit of clay in its upper strata (Ridgely sandstone), and in some other places clay occurs lower down in the group and at its base. This younger sandstone is the deposit so widely used in Pennsylvania for the manufacture of glass sand, but the sandstones of the Gatesburg are not suitable for this purpose.

USES OF THE KAOLINS FROM CENTRAL PENNSYLVANIA.

The kaolins from the Gatesburg formation appear to be shipped chiefly to steel works. Some of them are white enough in their unburned condition to be used in paper manufacture, but for this purpose they have to be washed in order to free them from the grit that they contain, and this is done. Of course, this work involves the construction of a washing plant, which would not be warranted unless there was a sufficiency of material in sight. As they do not turn white it is questionable whether they could be used in the manufacture of white ware. The white clay, if sufficiently free from grit when washed, might also be used by the paint and rubber trade. Not a little of the crude clay is used in sagger manufacture by different firms in the United States and Canada.

KAOLIN FROM FELDSPATHIC QUARTZITE IN CONNECTICUT.

A unique deposit of kaolin west of West Cornwall, Conn., is derived from a somewhat steeply dipping feldspathic quartzite. Here and there in the deposit beds of unweathered sandrock occur. The material has been extracted chiefly by underground mining, and because of the mode of occurrence some difficulties have been encountered in the operations.

The crude clay is very silty and has to be washed before being marketed. It is obtained by forcing water down a pipe into the deposit, loosening the material, and then pumping the water and suspended clay up another pipe to the surface. It is then carried through a 6-inch pipe line to the washing plant down in the valley along the New York, New Haven & Hartford Railroad track. The mine has been an intermittent producer for the last 20 years, and the product is said to be marketed as a paper clay. It was not operated in 1918. The following notes on this clay are given by Loughlin:[41]

Analysis of kaolin from West Cornwall, Conn.

Silica (SiO_2)	47.50
Alumina (Al_2O_3)	37.40
Ferric oxide (Fe_2O_3)	.80
Lime (CaO)	Trace.
Magnesia (MgO)	------
Alkalies (Na_2O+K_2O)	1.10
Water (H_2O)	12.48
	99.28

The washed clay is very white, is rather granular to the feel, and apparently lacks plasticity, but several experiments and practical tests have shown that when mixed in a body the mixture is equal in plasticity to that of bodies made from other kaolins. The burned clay is very white and begins to show a mere tinge of yellow, due to the small amount of iron present, when heated to a high temperature such as would be required in the manufacture of china.

KAOLIN FROM CAMBRIAN SHALE IN VIRGINIA.

Investigations made in recent years by the Virginia Geological Survey have revealed a number of deposits of white to light-gray residual clay along the western side of the Blue Ridge, or on the eastern side of the Great Valley, in Virginia.

All these deposits appear to have been derived by the weathering of the steeply dipping Cambrian shales which rest on the quartzite

[41] Loughlin, G. F., The clays and clay industries of Connecticut: Connecticut Geol. and Nat. Hist. Survey Bull. 4, p. 57, 1905.

that forms the west slope of the Blue Ridge. The development of the deposits of iron and manganese ores in this same belt has probably led to the discovery of several of the kaolin deposits. Most of the deposits that have been discovered or tested lie between Basic City, Augusta County, and Balcony Falls, Rockbridge County. Some have been reported farther north and even on the west side of the valley, near Buffalo Gap, Augusta County.

The area within which prospecting should be carried on is that underlain by the formation with which these kaolins are associated. However, as the deposits lie on the slopes of the mountain, the clay is commonly covered by a deposit of soil and stones of varying thickness.

The following information regarding these deposits is abstracted from a report of the Virginia Geological Survey.[41a]

LIPSCOMB, AUGUSTA COUNTY.

Several discoveries of whitish residual clay have been made in the area south of Lipscomb and east of Stuarts Draft, most of which were found in digging wells. The clay, which in places lies within 8 feet of the surface, shows a variable amount of iron mottling and streaks of sand. It apparently is also cherty in some places, suggesting that some of it at least may be derived from limestone.

The only locality in this area where a systematic attempt has been made to extract any of this white clay is about one-half mile southwest of Lipscomb, on the property of J. W. Goode. The clay from this locality was used after the Civil War for Rockingham ware and at a later date for fire bricks. Some of it was also washed and shipped to potteries. At present the clay can only be examined in an abandoned shaft.

The following tests of clay from this shaft have been furnished by the Virginia Geological Survey:

Tests of clay from shaft on Goode property, near Lipscomb, Va.

	1	2	3
Water of plasticity ... per cent	50	45	45
Plasticity	Good.	Good.	Good.
Air shrinkage	8.6	9.3	8.8
Cone 010 (950° C.):			
Fire shrinkage	....	....	3.4
Absorption	....	....	31.4
Cone 05 (1,050° C.):			
Fire shrinkage	....	....	3.7
Absorption	....	....	31.6
Cone 1 (1,150° C.):			
Fire shrinkage	9.7	7.3	....
Absorption	28.1	28.9	....
Cone 9 (1,310° C.):			
Fire shrinkage	16.4	11.3	....
Absorption	7.76	11.5	....

1. White clay with yellow streaks, representing the best material.
2. Washed sample of No. 1.
3. Second-grade clay.

[41a] Ries, H., and Somers, R. E., The clays and shales of Virginia west of the Blue Ridge: Virginia Geol. Survey Bull. 20, 1920.

All three samples burn cream white and become steel hard at cone 05 (1,050° C.). There is not much difference between the washed and unwashed clay, except in the shrinkage and absorption at cone 9 (1,310° C.), which is probably due to the fact that the sample obtainable contained but little sand.

The material does not burn white enough for white earthenware. It might be used in the commoner grades of paper stock or even in other industries where a whitish clay comparatively free from grit is demanded, but it would have to be washed before shipment to market.

COLD SPRING, AUGUSTA COUNTY.

A deposit of limonite was formerly worked on the mountain slope about 2 miles southeast of Cold Spring station on the Norfolk & Western Railway. In running a tunnel from the mountain slope into the pit a body of white clay about 100 feet thick was encountered. Other test pits showed that the clay continued southward along the strike for fully 600 feet, but nothing further in the way of development was done for some years. Recently the clay has been opened to a depth of about 60 feet without reaching bottom. (See Pl. VI, *A*.)

Of course it is impossible to tell how deep the clay extends, but its depth may be considerable, as the rocks on the mountain slopes have been deeply weathered.

The overburden, which consists of dirt and waterworn quartzite cobbles, differs in thickness from place to place and will probably average not less than 15 or 20 feet, but in view of the probable size of the deposit it will not prove to be a great obstacle to development.

The clay is dense, massive, and free from bedding planes, as the stratification of the shale rock has been but little preserved. It is white to light gray and contains little grit, but the cracks in the upper part of the deposit show light stains of iron oxide. An analysis of the material gave the following results:

Analysis of kaolin from Cold Spring, Va.

Silica (SiO_2)	43.31
Alumina (Al_2O_3)	39.42
Ferric oxide (Fe_2O_3)	2.86
Lime (CaO)	0.00
Magnesia (MgO)	.04
Potash (K_2O)	.25
Soda (Na_2O)	.30
Loss on ignition	13.58
	99.76

This clay has an unusual composition in that the proportion of silica to alumina is much lower than that required for kaolinite.

Under the microscope the material was seen to be medium to fine grained. There was practically no quartz, and only a few grains of hydromica. Kaolinite was abundant, and there were also a number of very fine grains of indeterminable character. Rutile was abundant, both in grains and tiny needles. A few grains of tourmaline and zircon were present.

The following tests of this clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of white residual clay from Cold Spring, Va.

Workability		Plastic, smooth, fair drying.
Water of plasticity	per cent	41.32
Air shrinkage, by volume	do	16.48
Air shrinkage, linear, calculated	do	5.5
Modulus of rupture:		
Raw clay	pounds per square inch	47.1
Mixture of clay and sand in proportion of 1:1	do	21.36
Screen test: Residue on 330-mesh sieve	per cent	24.66

Fire tests of white residual clay from Cold Spring, Va.

Temperature (°C.).	Porosity (per cent).	Color.	Volumetric shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	39.30	Light cream-white	22.40	8.0
1,250	36.67	do	28.05	10.4
1,310	33.24	do	31.26	11.8
1,370	30.70	do	34.30	13.1
1,410	18.90	Cream-white	42.30	16.8

Fusion point, cone 31. Nearly steel hard at 1,310° C.; steel hard at 1,370° C. Develops small surface cracks in burning.

The clay has very low bonding strength and is not to be classed as a bond clay nor does it fire to a very dense body. Its color after firing is not sufficiently white for white ware. Its refractoriness is fair.

The deposit is operated by the Product Sales Co., of Baltimore, Md.

The chief use for this clay seems to be in paper, paint, and rubber manufacture. A small quantity of it might be used in some ceramic wares, but the chief objection to it is that it does not burn white. Experiments have shown that it can be used in electrical porcelain.

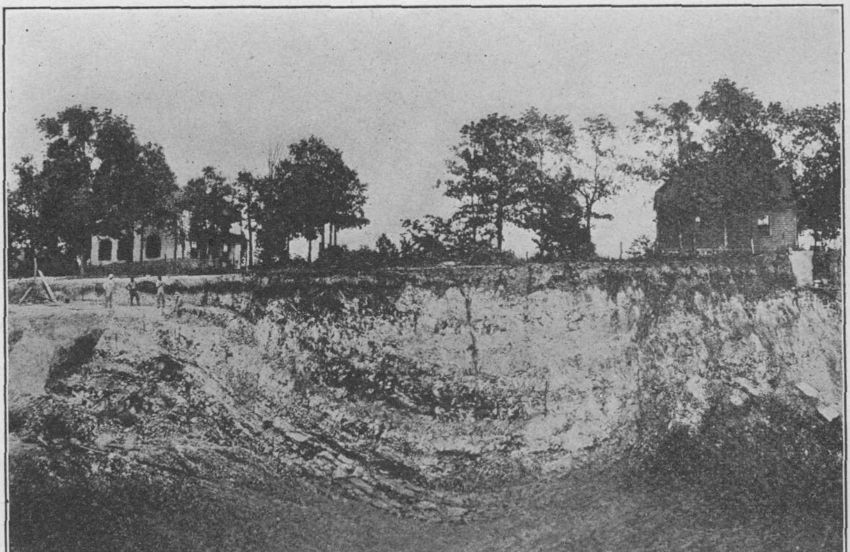
LOFTON, AUGUSTA COUNTY.

Another deposit of Cambrian residual clay occurs on the property of A. R. Shulz, on the east side of the Norfolk & Western Railway, about one-half mile northeast of Lofton station.

A. PIT OF PRODUCT SALES CO., COLD SPRING, AUGUSTA COUNTY, VA.

B. SHALLOW SHAFT AND HOISTING DRUM AT KAOLIN MINE NEAR LUTESVILLE MO.

A. COX FLINT-CLAY PIT, NORTH OF HOFFLIN, MO.



B. SASSMAN FLINT-CLAY PIT, OWENSVILLE, MO.

One of the few pits in which a distinctly bedded structure was observed.

The deposit underlies a swamp of about 15 acres extent and is not less than 40 feet deep. The material is grayish white in its upper part but at depth shows light-yellowish mottlings.

The clay is fine grained and very plastic. Though it was derived by the weathering of Cambrian shale it has a somewhat different composition from the material southeast of Cold Spring, as shown by the following analysis:

Analysis of clay from Lofton, Va.

Silica (SiO_2)	52.10
Alumina (Al_2O_3)	31.54
Ferric oxide (Fe_2O_3)	2.38
Lime (CaO)	.10
Magnesia (MgO)	.58
Potash (K_2O)	1.89
Soda (Na_2O)	.27
Loss on ignition	10.89
	99.75

The physical tests gave the following results: Water of plasticity, 47.7 per cent; plasticity, good; air shrinkage, 8.1 per cent.

Fire tests of clay from Lofton, Va.

Temperature (°C.).	Fire shrinkage.	Absorption.	Porosity.
1,000	3.37	21.70	42.49
1,150	12.50	6.49	15.56
1,250	15.00	.18	....
1,410	15.00	.16	....

The clay burns steel hard at cone 08 (990° C.) and develops a creamy-white color. This clay, in strong contrast to the clay from Cold Spring, shows very high fire shrinkage and burns very dense. This high shrinkage would interfere with the use of the clay alone in burned wares, although it might be used in small quantity.

It could be used unburned for purposes in which a light-gray clay of good plasticity is desired, possibly rubber or paints.

VESUVIUS, AUGUSTA COUNTY.

A deposit of white residual clay occurs on the property of T. L. Shelton about 2½ miles northeast of Vesuvius. Borings are said to have shown a length of 240 feet and a depth of about 30 feet. The width of the deposit is not known.

The clay has fair plasticity. One sample burned at cone 9 (1,310° C.) had a total shrinkage of 10 per cent and absorption of 18.9 per cent. Its color was cream-white and it was steel hard.

BUENA VISTA, ROCKBRIDGE COUNTY.

Excavations for limonite along the foot of the Blue Ridge, northeast of Buena Vista, have revealed pockets of yellowish and white residual clay, mostly of small size.

One large mass 1¼ miles northeast of the town has been worked for some years to make fire brick.

This clay, which is somewhat gritty, had 28 per cent water of plasticity, was quite plastic, and had 4 per cent air shrinkage. The fire tests are given below:

Fire tests of clay from Buena Vista, Va.

Cone.	Fire shrinkage.	Absorption.
010 (950° C.)	3	27.7
03 (1,090° C.)	1	23.0
1 (1,150° C.)	4	16.55
9 (1,310° C.)	6.6	12.00

The clay burns to a cream color and is nearly steel hard at cone 03. It would not be suitable for making white ware.

KAOLINS FROM CAMBRIAN LIMESTONE IN MISSOURI.

General features of the deposits.—Wheeler, in his report on the Missouri clays,[a] says:

All the kaolin thus far found in Missouri occurs south of the Missouri River on limestones of Paleozoic age. The belt containing it is extensively worked in Cape Girardeau and Bollinger counties, in the southeast, from whence it extends to Howell County, forming the southeastern kaolin district. It is also worked, but much less extensively, in Morgan and Cooper counties, in the central part of the State, which is called the central district.

It is found, though thus far not worked, near Aurora, in Lawrence County, which is known as the southwestern district.

In the first district the kaolin, according to Wheeler, is associated with Ordovician and Cambrian limestones, in the second with upper members of the Ordovician limestones, and in the third with early Carboniferous or Mississippian limestones.

Since Wheeler's report was published kaolin mining has decreased, and the only mines now in operation are in the southeastern district. The counties of Cape Girardeau and Bollinger, in this district, ranked highest, Bollinger being the more promising of the two. In Bollinger County the present-day mining is being carried on.

In former years some of these clays were utilized by local potteries and others were shipped as far even as East Liverpool, Ohio.

[a] Wheeler, H. A., Clay deposits: Missouri Geol. Survey, vol. 11, p. 161, 1896.

Lack of transportation facilities has probably prevented the use of these clays if they occur in sufficient quantity. There is only one railroad line across Bollinger County, and the roads for hauling the clay from the mine to the railroad are poor. Careless mining may also have hindered development, for, according to Wheeler, and the writer's work corroborates his statement, care must be taken in selecting the material for shipment. Washing might improve the clay, but a washer should not be erected unless an adequate supply of clay is assured.

These kaolins were the subject of a somewhat exhaustive study some years ago by Orton,[43] who states their properties as follows:

> The proportions of kaolin [44] and silica vary from 30 per cent kaolin and 70 per cent sand in sample 16 to 60 per cent kaolin and 40 per cent sand in sample 7. The average is represented by sample 10 containing 45 per cent kaolin and 50 per cent sand. * * *
>
> They are immensely fine grained. The coarsest contained 60 per cent of material which would pass a 200-mesh screen. The finest passed 200 mesh completely. Sample after sample lost less than 10 per cent in passing 200 mesh.
>
> They are very weak, on account of the large quantity of fine silica. They crumble like chalk when dry and show almost no tensile strength. They are plastic as any fine-grained mass is plastic, but they have almost no fatness or cohesion or bonding power. They would not do to add to other clays as a bond. * * * They shrink little in drying. * * *
>
> They shrink but little at a high temperature, remaining soft and porous. * * * They remain or become most unusually white on firing to a high temperature.

Orton called attention to the fact that even the stained clays may burn white. He expresses the belief that the silica in them is so fine-grained that it will be difficult to eliminate by washing.

There is no doubt that the deposits of Bollinger County represent a rather uncommon type of kaolin.

The country rock is chiefly dolomitic limestone, which is generally cherty and in places contains cavities lined with crystals of calcite. It is evident that the clay in this region is all residual and has been derived from the weathering of dolomite.

As Orton pointed out, it is somewhat irregular in its occurrence, as the white clay and the stained clay are more or less mixed. Consequently, in order to select the whitest and leave the poorest material in the ground, the stopes in the mines are somewhat irregular. The writer can not estimate how much white clay there is in the district, but from what he saw he is inclined to believe that its occurrence is probably pockety.

A brief examination was made of several samples collected from this district, which showed some variation in their characters.

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[43] Orton, Edward, jr., The kaolin deposits of Bollinger County, Mo.: Am. Ceramic Soc. Trans., vol. 9, p. 62, 1907.

[44] By kaolin Orton evidently means the clay particles.

Sample graded as No. 1, from an operating mine, had very fair plasticity. It was medium grained, and under the microscope the small quartz grains were seen to be fairly common; hydromica was fairly abundant and commonly coagulated; kaolinite was abundant; rutile was scarce; and only a grain or two of epidote and chlorite could be seen.

The clay behaved as follows in burning:

Fire test of kaolin No. 1, from Bollinger County, Mo.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150 [a]	6.2	14.4	Faint cream-white.
1,300	0	.8	Buff.

[a] Steel hard.

This sample evidently burned denser than the samples tested by Orton.

Thin sections of the burned clay, when examined under the microscope, showed grains of quartz embedded in a fine-grained mass, which was partly isotropic and partly composed of crystalline grains showing the interference colors of kaolinite.

As all the hydromica had disappeared at 1,150° C., there was little difference in the appearance of the clay burned at the two temperatures.

Grade No. 2 from the same mine was distinctly more gritty and mottled with stains of limonite. When wet it was plastic.

Under the microscope this material was seen to be medium to fine grained. Quartz was very common; hydromica, common; kaolinite, abundant; rutile, in very numerous tiny grains; epidote and tourmaline, a few grains.

Two fire tests yielded the figures given below:

Fire tests of kaolin No. 2, from Bollinger County, Mo.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150 [a]	8.7	22.9	Buff.
1,300 [a]	7.6	18.4	Do.

[a] Steel hard.

A third sample, which had moderate plasticity when wet but was almost chalklike when dry, behaved quite differently from the above in the fire tests.

Fire tests of kaolin of sample No. 3, from Bollinger County, Mo.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	29.7	44.4	White.
1,300	26.9	42.8	Do.

This clay, it will be seen, is a much more open burning clay than the others.

Several companies have clay holdings in this region, but only two have been doing any mining recently.

Property of American China Clay Co.—The American China Clay Co., of Lutesville, Mo., is mining clay 4½ miles southwest of Lutesville. It owns 120 acres and has 800 acres more under lease.

In June, 1918, it was operating a new shaft 50 feet deep. (See Pl. VI, *B*.) This shaft showed an overburden of cherty iron-stained clay but stopped in grayish-white clay. Three drifts had been run from the bottom of the shaft at right angles to each other. The longest drift runs S. 50° E. for 50 feet and then runs S. 20° E. for 25 feet.

The clay, which is dense and plastic, shows traces of bedding planes, and contains scattered nodules of chert, which is called spar by the miners, but in places these chert lumps are arranged in lines, just as they occur in the fresh rock, and may follow directions of bedding. The chert is gray, white, or in places iron stained, and some of it shows a fine zonal structure. These chert bands, which average 6 to 8 inches in thickness, are commonly wavy and show a distinct dip, whereas the dolomite beds on the surface (but not near the shaft) are practically flat. If the inclined layers of chert represent the position of the bedding planes, it is possible that these have been disturbed by faulting, as a steep fault plane that strikes S. 32° E. was observed in the mine. The striations on it were vertical. The face of the fault is iron-stained and so is the clay bordering the fault.

Two grades of clay are sorted out, known as No. 1 and No. 2, but they are separated by hand picking, for there is no regularity of their occurrence in the deposit. Indeed, the presumption based on underground observations is that the occurrence of the whitish clay may be more or less irregular. That the white clay occurs at other points in the deposit is shown by the fact that an earlier shaft, 80 feet distant from the present one, in a direction N. 60° W., penetrated the whitish clay. Again, a test pit sunk about 400 feet, S. 50° W., from the present shaft showed white clay close to the surface.

The clay is all hauled to Lutesville, where it is delivered to the mill of the Sampson Plaster Board Co. This company does not wish to publish any details regarding the method of treatment at their mill. The writer was told that some of the clay was also used in china and paint manufacture.

Bausch mine.—Another operator in this district is F. E. Bausch, of St. Louis, who has sunk two shafts. One of these shafts, not open to inspection, is 2 miles due west of Glen Allen and 2½ miles northwest of Lutesville. It is said that the clay in one shaft is less than 7 feet below the surface and 30 feet below in the other, but in both deposits the good clay is more or less pockety. The shaft that was visited passes through a 3-foot bed of quartzite about 30 feet below the surface.

The clay has to be sorted by hand. The No. 1 grade, known as chalk clay, is quite white when dry, whereas the No. 2 grade is light gray and shows some iron stains. The material on the dump contains the same kind of chert nodules that were found in the other deposit.

KAOLINS FROM SHALES AND LIMESTONES OF THE ORISKANY GROUP IN THE APPALACHIAN STATES.

OCCURRENCE AND DISTRIBUTION.

The Oriskany deposits of the Devonian are widely distributed in the Appalachian States from New York southward. The sandstone of the Oriskany does not weather down to clay except where it is feldspathic, but in some localities beds of shale and impure limestone, the latter somewhat cherty, are associated with it, and in these localities the beds may yield clays when broken by weathering. Although these clays have been known, locally at least, for many years, no one seems to have considered the isolated occurrences as a special group whose representatives are so widely distributed as to make the search for additional deposits worth while.

Natural conditions in places render prospecting troublesome, for the Oriskany of the Eastern States usually occurs in regions of highly folded rocks. Therefore, because of its resistant character it commonly forms prominent ridges, and as the clay-yielding rocks seem as a rule to underlie it, the clay deposits occur mostly on the ridge slopes, where they may be covered by wash, and this perhaps in turn by a forest growth. To find the clay, therefore, means much trenching, digging many test pits, and much boring.

The areas in which the deposits may occur are indicated on the geologic maps of Pennsylvania, Maryland, Virginia, and West Virginia, by the distribution of the Oriskany formation.

Two other facts should be emphasized—first, that the shales and limestones of the Oriskany have not been weathered to residual clays throughout their extent, and second, that the residual clays formed as above described may range from ferruginous to white materials.

The white clays of course are the only ones of interest in the present discussion.

The localities thus far known at which these Oriskany clays may occur are: Saylorsburg, Monroe County, Pa.; Petersburg and Shirleysburg, Huntingdon County, Pa.; Hampshire County, W. Va.; Frederick County, Va.; and Lignite, Botetourt County, Va. Of these localities, Saylorsburg is the most notable, but clay is being worked at Petersburg and Shirleysburg also. The other localities are undeveloped.

PENNSYLVANIA.

SAYLORSBURG DISTRICT.

GEOLOGY.

By F. B. PECK.

The clays at Saylorsburg have been formed by the weathering of calcareous sandy shales and cherty limestones that underlie the sandstone of the Oriskany. This sandstone forms a prominent ridge, which extends from the Delaware Water Gap southwestward through Saylorsburg and beyond. Its thickness increases from about 50 feet on Delaware River to nearly 200 feet on the Lehigh. Underlying this sandstone there is a series of gray calcareous shales, which is best developed in the region around Stormville and called the "Stormville series" by the Second Geological Survey of Pennsylvania.[45] These strata are approximately 100 feet thick in the Saylorsburg district and in their lower portion include some beds of cherty limestone. They thin out in a short distance southwestward toward the Lehigh and are replaced by coarse gritty Oriskany sandstone.

Under the "Stormville series" (of Helderberg age, except its uppermost beds, which are of Oriskany age)[46] is the Bossardville limestone,[47] which is about 90 feet thick; the upper two-thirds is very slaty, and the lower third is a banded limestone.

The clay mines all lie on the northern slope of Chestnut and Cherry ridges (fig. 17), which structurally are formed by a series of parallel folds in the Bossardville, "Stormville," and Oriskany formations. The clay is found near the summit of an anticline that parallels the crest of the ridges but lies on their northwestern slope, so that the clay beds dip southeastward at steep angles (60° to 90°) into and under the ridges. The same beds outcrop in places on the south-

[45] White, I. C., The geology of Pike and Monroe counties: Pennsylvania Second Geol. Survey Rept. G6, pp. 128, 131, 1882.
[46] Reeside, J. B., U. S. Geol. Survey Prof. Paper 108, p. 186, 1917.
[47] White, I. C., op. cit., p. 141, 1882.

eastern slopes of the ridges, but there they do not seem to have altered to clay.

The formation of the clay, therefore, is due to a local weathering of the "Stormville" and Bossardville beds along a stretch of about 3 miles, Saylorsburg being about midway in this distance.

In the eastern part of the Saylorsburg region the white clay seems to have been derived from the "Stormville shale series," and it immediately underlies Oriskany sandstone. The clay, which contains much fine sand, is about 23 feet thick.

In the Mount Eaton district, 1½ miles southwest of Saylorsburg, the clay appears to have been formed from the upper slaty member

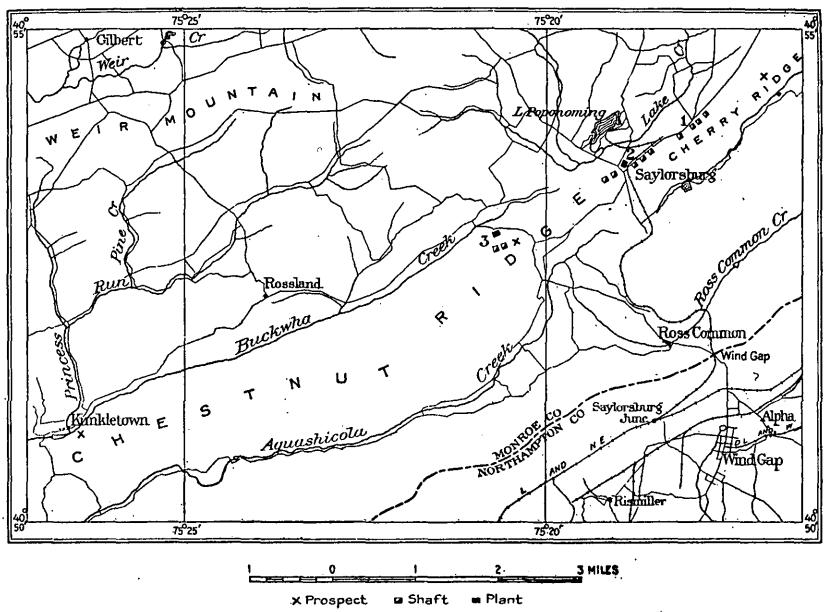


FIGURE 17.—Map showing location of shafts in white residual clay in Saylorsburg district, Pa. 1, Atlas Portland Cement Co.; 2, Keystone Clay & Reduction Co.; 3, Mount Eaton Clay Co.

of the Bossardville limestone, and the "Stormville series" has diminished materially in thickness. The No. 1 white clay beds are 6 to 20 feet thick, but lie 50 feet stratigraphically below the hard Oriskany sandstone, instead of immediately below it, as at the eastern end of the clay belt in the Atlas Portland Cement Co.'s mine, 1½ miles northeast of Saylorsburg.

The distribution of the clay seems to coincide with a former drainage system, the remnants of which are seen in the Wind Gap of Blue Mountain and the two gaps in Chestnut and Cherry ridges, the one at Saylorsburg and the other 1¼ miles southwest of Saylorsburg, where the highway crosses Chestnut Ridge, north of Mount Eaton.

Immediately under this drainage system the lime has been leached from these rocks and they have been altered to clay.

CHARACTER AND USES OF THE CLAYS.

The residual clays of this region are in part white and in part colored, but only the white clays are utilized. They are very gritty, and the sandy impurities are mostly very fine grained.

In their crude form the clays are used in the manufacture of white Portland cement. For all other purposes they have to be washed. After treatment clays of this type can be utilized as a filler for certain grades of paper, in paint manufacture, and as a filler for rubber. Preliminary tests of some of them indicate the possibility of their use in pottery, but most of the clays from this region do not burn sufficiently white.

MINES.

Three companies are operating in the Saylorsburg region at present. A fourth one formerly operated at Kunkletown, to the southwest. (See fig. 17.)

Mine of the Keystone Clay & Reduction Co.—The mine of the Keystone Clay & Reduction Co. is at Saylorsburg. (See fig. 17.) The deposit is worked by means of a shaft. As much clay as possible is worked through one shaft, and then another is sunk. Altogether eight shafts have been sunk, which range from 45 to 116 feet in depth and average 90 feet.

At the bottom of the present shaft, which is 45 feet deep, a drift has been run 100 feet to the southeast. The bottom of the shaft is in black clay, and the drift cuts it for 20 feet; then comes 50 feet of gray No. 2 clay, and finally 30 to 36 feet of white No. 1 clay. The last two clays are mined. The beds in this locality form an arch. The shaft is nearly on the crest, and the level has been driven on the south limb. The hanging wall overlying the No. 1 clay is Oriskany sandstone.

A sample of the crude clay from this mine that was examined under the microscope showed a medium to fine grain. Quartz was very common, slivers of hydromica were rather abundant, kaolinite was very abundant, and minute needles of rutile were also abundant. Several small rounded grains of a titanium mineral and also a little tourmaline were present.

A sample of the washed clay was medium to fine grained, and the grains were of quite uniform size. Quartz was in much smaller quantity than in the crude clay, needles of hydromica were rather abundant, kaolinite was abundant, and needles of rutile were very numerous and small.

The clay shows fair plasticity and burns steel hard at 1,150° C. Some additional properties after firing are stated below:

Fire tests of washed clay from Saylorsburg, Pa.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	1	5.9	Buff.
1,300	0	.4	Gray-buff.

Thin sections of the clay fired at the temperatures stated in the table showed a finely granular aggregate of quartz grains in a fine-grained groundmass, which is more or less isotropic. At 1,150° C. the hydromicas had nearly disappeared, and at 1,300° C. none remained. The grains of rutile existed at the higher temperature, and some grains that showed the interference colors of kaolinite were still present.

Another sample, representing the second-grade crude clay, differed from the first grade in being more gritty and also in being stained somewhat with limonite.

This sample under the microscope showed quartz, abundant kaolinite and hydromica, and a few grains of rutile. The material is quite plastic, but at the lower temperature it burns more open than the washed clay, as shown by the tests below:

Fire tests of No. 2 crude clay from Saylorsburg, Pa.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	8.6	21.9	Buff.
1,300	0	.5	Gray-buff.

The clay was steel hard at the lower cone.

The burned clay under the microscope showed a granular aggregate of quartz in a fine-grained groundmass, which was mostly isotropic. Rutile was still in evidence at 1,300° C.

Tests made for the Pennsylvania Geological Survey of a sample from Saylorsville gave the following results: Air shrinkage, 3.42 per cent. At cone 8 (1,290° C.), linear shrinkage, 11.97 per cent; absorption, 0; color, grayish white. At cone 15 (1,430° C.), overfired.

Property of the Mount Eaton Clay Co.—The plant of this company is on the northwest side of Chestnut Ridge, about 1½ miles southwest of Saylorsburg. (See fig. 17.) The deposit was opened by sinking a shaft 90 feet deep, from which a drift that ended in hard shaly sandstone was run S. 25° E. for 250 feet. (See Pl. IV, *B*.)

At a distance of 200 feet from the base of the shaft there are two crosscuts that run at right angles to the drift. One of these crosscuts runs 200 feet southwest and the other 100 feet northeast. Both of them are in clay. The shaft penetrated first 25 feet of wash, then 15 feet of discolored clay, and 50 feet of white clay that contained fragments of chert.

The clay body appears to dip 55° SE. It seems to have been derived, in part at least, from a cherty limestone at the base of the Oriskany, and the fragments of chert may occur as isolated lumps or in lines parallel with the original bedding planes.

The best clay is white and finely gritty and may be sandy along certain layers. After mining, the clay is sent down the gravity incline 1,200 feet long to the washing plant, and the washed product is hauled 2 miles to the railroad at Saylorsburg.

Property of the Atlas Portland Cement Co.—This company has put down a line of shafts northeast of Saylorsburg on the southeast side of the highway. (See fig. 17.) These shafts are irregularly spaced, and as soon as the clay within workable distance of one is exhausted another is sunk.

Shaft No. 7, which was being worked during the summer of 1918, had been sunk to a depth of 90 feet. The clay averaged 30 feet in thickness and was penetrated less than 22 feet below the surface. The shaft had two levels, one at 60 feet and the other at 90 feet. The drift from the foot of the shaft passed first through discolored cherty clay before the white clay was reached. The white clay is fairly plastic and gritty and contains scattered lumps of chert from the original limestone. All the product is used in the manufacture of white Portland cement.

Under the microscope the clays show a medium to fine grain with scattered fine dustlike grains. Quartz is common, as is also hydromica, and kaolinite is abundant. Tiny grains of rutile are very numerous. Grains of tourmaline and zircon are also present.

The crude clay does not fire as dense as that mined at Saylorsburg, as the following partial tests show:

Fire tests of crude clay from mines northeast of Saylorsburg, Pa.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150 [a]	12.8	1.5	Buff.
1,300	31.2	2.9	Light gray.

[a] Steel hard.

The appearance of thin sections of the burned clay was much like that described from the preceding mine.

KUNKLETOWN, MONROE COUNTY.

Some years ago a brick plant was erected at Kunkletown, and obtained its clay from the ridge about three-fourths of a mile northeast of the works. The material was brought down by a wire-rope tramway. The brick works is no longer in operation, but the excavation made on the ridge was a large one, and a considerable quantity of clay was, no doubt, taken out, for the pit is about 50 feet deep and 400 feet long. Unfortunately, the walls have slid considerably, so that it is difficult to get much information regarding the relationships of the clay deposit. On the east side of the excavation Oriskany sandstone forms a steep hanging wall, and the foot wall on the west is black shale, also of Oriskany age. The black shale is not well shown in the pit, but outcrops in a fresh condition near the works. The only clay visible is a mass of mottled, iron-stained, sandy material at the entrance to the cut.

A boring in the southeast corner of the pit showed a grayish-white gritty clay that contained mottlings of limonite, which may be of superficial character. It is claimed that borings have been made in this clay to a depth of over 20 feet. Much more boring would have to be done to demonstrate the extent of the clay deposit.

Though the clay looks similar to that mined near Saylorsburg, Mr. Peck considers that it lies at a higher horizon, and is in Oriskany sandstone. The brick formerly made here were buff.

The petrographic character of the clay is little different from that of the clay mined at Saylorsburg. For comparison there is also given a description of disintegrated Oriskany quartzite, which forms the immediate hanging wall.

Disintegrated Oriskany quartzite: Coarse grains of quartz very common; grains of kaolinite scarce; rutile present as inclusions in the quartz. There seems to be little material in this rock to yield clay.

Crude clay from bottom of pit: Texture medium. Quartz very common, hydromica common, kaolinite very abundant, numerous tiny needles of rutile, and a few grains of epidote and tourmaline.

This clay had 16.6 per cent absorption at 1,150° C. and 2.6 per cent absorption at 1,300° C.

Washed sample of preceding clay: Texture medium to fine. Quartz common, hydromica common, kaolinite abundant, many minute needles of rutile, and a little epidote.

Fire tests of crude clay, Kunkletown, Pa.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150 [a]	12.0	27.5	Buff.
1,300	0	0	Gray.

[a] Steel hard.

No thin section was made of the burned clay.

The following tests of the clay from Kunkletown were supplied by the Pennsylvania Geological Survey:

Fire tests of clay from Kunkletown, Pa.

Sample No.	Air shrinkage (per cent).	Cone 8 (1,290° C.).			Cone 15 (1,430° C.).		
		Linear fire shrinkage (per cent).	Absorption (per cent).	Color.	Linear fire shrinkage (per cent).	Absorption (per cent).	Color.
1	2.84	3.41	9.7	Cream	6.57	9.2	Buff.
2	2.26	12.42	0	Gray-white	Overfired	.8	
3	3.42	11.97	0	do	do		

PETERSBURG, HUNTINGDON COUNTY.

About 300 feet north of Petersburg station (see fig. 16, p. 92) is a steep gravity plane that leads up to a clay pit about 500 feet above the track. The deposit, which is worked by the Alexandrian Fire Clay Co., of Alexandria, Pa., does not contain high-grade material, but it is interesting because it occurs at about the same horizon as those at Saylorsburg.

The beds strike N. 60° E. and dip 25° SE., and the main face of the quarry shows a thick deposit of residual clay overlain by sandstone. The clay is probably derived from the shaly limestone of the Shriver formation, the basal formation of the Oriskany group in this area, and the sandstone over it is Ridgely sandstone,[48] the upper formation of the Oriskany group. A sandy shale, which also belongs to the Shriver formation, lies between the limestone and the sandstone. There is no white clay here, as at Saylorsburg, and the material is all red or black. It is ground before shipment, but the uses are not known.

SHIRLEYSBURG, HUNTINGDON COUNTY.

The Rock Hill Clay Co. of Orbisonia, is operating a residual clay on the Walker farm 1½ miles southeast of Shirleysburg. (See fig. 16, p. 92.) There is no doubt regarding the residual character of the clay and its close association with the Ridgely sandstone, but some doubt has been expressed as to whether the clay underlies or overlies the Ridgely.

According to the geologic map of Huntingdon County, published by the Pennsylvania Geological Survey, the Oriskany deposits at the locality where the mine is operated form a syncline, bordered on

[48] Butts, Charles, Geologic section of Blair and Huntingdon counties, central Pennsylvania: Am. Jour. Sci., 4th ser., vol. 46, p. 532, 1918.

either side by Helderberg limestone, and thus the clay would lie on top of the Ridgely, but the west flank of this syncline is also the east flank of an anticline, whose crest has been eroded, and the west flank of this anticline lies to the west, along the base of the hill.

This theory of the structure seems to be borne out by the dip of the rocks. Thus, in leaving the main road south of Shirleysburg and ascending the hill toward the mine, there is encountered, first the westwardly dipping Oriskany beds, followed by the underlying Helderberg limestones, which dip in the same direction. Farther up the hill the dips are reversed, and the Ridgely sandstone or upper Oriskany is again encountered. This upper outcrop of sandstone is then the eastern limb of the anticline and also the western limit of the syncline in which the clay appears to lie. The sandstone occurs in a tunnel just west of the clay pit but is so fractured that it is difficult to determine the dip. Beyond the clay pit to the east the Ridgely again outcrops and dips to the east. If the clay, then, lies on top of the Oriskany it probably occupies a shallow basin and will thin out both to the northeast and to the southwest, as the underlying Oriskany disappears.

The clay itself is derived from a shale, which, if it overlies the Oriskany, may be of Marcellus age. In pit No. 2 of the Pennsylvania Glass Sand Co. east of Mapleton, the shale overlies and is in contact with the Ridgely sandstone of the Oriskany group, but there it shows no alteration to residual clay.

The pit has a maximum depth of 15 feet, of which the lower 6 feet includes the clay that is being shipped, and the upper 9 feet has been stripped off by steam shovel for some distance in advance of the working face. Boring has shown that the clay, in places at least, extends 17 feet below the present bottom of the pit.

The clay is dense, tough, and dark gray when wet but dries out almost white. It is very plastic. Some of the clay in the upper parts of the bank shows a mottled iron stain due to weathering, and parts of the fresh material are rather dark.

Microscopic examination of the gray clay showed the following minerals: Quartz not very abundant, hydromica common, kaolinite abundant, numerous tiny grains of rutile, and a few grains of zircon. In texture the clay is fine and even grained. At 1,150° C. it had 8.35 per cent absorption and was light buff and steel hard. At 1,300° C. it had 0.3 per cent absorption and was brown.

The clay is loaded on motor trucks and hauled to the railroad.

HOLLIDAYSBURG, BLAIR COUNTY.

Residual clay, not a kaolin, is said to be obtained from the Oriskany formation, near Hollidaysburg, Pa. It is a plastic, siliceous, open-burning clay, used to some extent in glass refractories.

WEST VIRGINIA AND VIRGINIA.

HAMPSHIRE COUNTY, W. VA., AND FREDERICK COUNTY, VA.

White residual clay has been found at several localities in the region around Bloomery, Hampshire County, W. Va., and along the southeastern slopes of Great North Mountain, in Frederick County, Va.

The best clay so far discovered in Hampshire County, W. Va., lies at the head of Bloomfield Hollow, on the Eaton farm, about 4 miles southwest of Cacapon Forks. The clay is probably residual from the Romney shale, which here occupies a synclinal trough in the Oriskany sandstone. The evidence obtained from borings indicates a considerable body of clay. The clay, which is white or white with mottlings of yellow, ranges from fine-textured dense material to more sandy grades. It would probably have to be washed before shipment to market.

On the southeastern slope of Great North Mountain, Frederick County, Va., about a mile northwest of Mountain Falls post office, there is a whitish residual clay, also probably derived from Devonian shale. It burns buff and hence is not suited for white-ware bodies. Its characters are more like those of a stoneware clay.

LIGNITE, BOTETOURT COUNTY, VA.

At Lignite, Va., there are extensive mines of Oriskany brown ore that have been in operation for some years. They belong to the Alleghany Ore & Iron Co., and the deposits were opened up first by a long cut that followed the outcrop of the ore body. The footwall is of limestone and the hanging wall is of Oriskany sandstone. Above the sandstone is Devonian shale.

The shale in the cut is no longer fresh but has weathered to a whitish clay, whose thickness ranges from 5 to 10 feet and which extends quite persistently along the face of the excavation above the ore. This whitish clay grades upward into a reddish clay. The white clay can be traced for a distance of about 300 feet along the face of the cut and has been followed for a distance of fully 2,000 feet beyond it.

A churn-drill boring farther down the dip is said to have penetrated the black shale and then the white clay, but the black shale does not appear in the face of the cut unless it is represented by the red clay.

The white clay is dense and massive and in structure somewhat resembles the fire clay at Buena Vista, although, of course, it is of later age. Mr. Stull, the manager, states that in places it shows a nodular structure, but its composition does not resemble that of bauxite. A chemical analysis of the clay gave the following results:

Analysis of residual clay, Lignite, Va.

Silica (SiO_2)	59.17
Alumina (Al_2O_3)	24.26
Ferric oxide (Fe_2O_3)	4.62
Lime (CaO)	------
Magnesia (MgO)	1.06
Potash (K_2O)	4.94
Soda (Na_2O)	.27
Water (H_2O)	5.72
	100.04

This clay shows a curious composition because of its high content of potash, but this is explained by the microscopic examination of the material, which shows abundant hydromica.

The clay worked up with 35 per cent of water to a mass of good plasticity which gave 6.1 per cent air shrinkage.

The firing tests resulted as follows:

Fire tests of clay from Lignite, Va.

Cone.	Fire shrinkage.	Absorption.
05 (1,000° C.)	5.2	11.00
03 (1,090° C.)	10.6	.30
1 (1,150° C.)	10.5	.00
3 (1,190° C.)	10.8	.20
5 (1,230° C.)	11.3	.00
9 (1,310° C.)	8.3	.50

The clay burned buff, but became gray at cone 9. It was steel hard at cone 03. It became practically nonporous at cone 03 and remained so to cone 5, but was overfired at cone 9.

The following tests of this clay were made at the laboratory of the Bureau of Mines, Columbus, Ohio.

General physical tests of clay from Lignite, Botetourt County, Va.

Workability	Very plastic, sticky.
Water of plasticity .... per cent..	34.46
Air shrinkage, by volume .... do....	21.28
Air shrinkage, linear, calculated .... do....	7.00
Modulus of rupture:	
Raw clay .... pounds per square inch..	122.1
Mixture of clay and sand in proportion of 1:1 ... do....	68.05

Fire tests of clay from Lignite, Botetourt County, Va.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Calculated linear shrinkage (per cent).
1,130	0.40	Gray-brown	34.60	13.5
1,190	1.70	do	14.1	5.0
1,250	.00	do	34.98	13.3
1,310	.00	do	32.61	12.5
1,370	.90	Gray	24.30	8.6

Fusion point, cone 28+. Steel hard at 1,190° C.

This clay hardly deserves to be classed as a high-grade clay, for in spite of its white color when unburned it fires to a gray-brown body. The bonding strength is low. The clay is overfired at 1,370° C., and is of low refractoriness. It can be used in stoneware, but would work better if mixed with a stronger clay.

The following tests of a mixture containing 50 per cent of the clay from Lignite and 50 per cent of the white clay from Cold Spring (see p. 101) were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of mixture of clays from Lignite and Cold Spring, Va.

Workability		Plastic; works well.
Water of plasticity	per cent	40.43
Air shrinkage, by volume	do	24.41
Air shrinkage, linear, calculated	do	9.00
Modulus of rupture:		
Raw clay	pounds per square inch	134.41
Mixture of clay and sand in proportion of 1:1	do	60.31

Fire tests of mixture of clays from Lignite and Cold Spring, Va.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	0.60	Brown, white spots	37.70	15.0
1,250	1.04	Gray-brown, white spots	39.54	15.5
1,310	1.09	do	39.77	15.5
1,370	.80	Light brown, white spots	39.90	15.5
1,410	.70	do	32.10	12.0

Fusion point, cone 28. Steel hard at 1,190° C.

The mixture has a somewhat high air shrinkage, and also fire shrinkage, but it burns to a very dense body, which has begun to overfire at 1,410° C. The modulus of rupture is not high. The clay could be used in stoneware if mixed with a plastic clay of greater strength. The addition of 50 per cent of the white clay to the clay from Lignite has not affected its porosity and shrinkage in firing very much.

NOTES ON OCCURRENCES OF KAOLIN WEST OF THE MISSISSIPPI.

ARKANSAS.

Bauxite.—Mead,[49] in his paper on the bauxite deposits of Arkansas, refers to the kaolinization of syenite and the occurrence of clay both under the bauxite and as horses and stringers within it. Indeed, he says that the presence of clay in some mines causes 40 per cent of the waste. Some of the analyses of kaolinized syenite which he gives show a very low content of ferric oxide, which would indicate that there might be valuable refractory clays associated with the ore.

Examination of several of the pits near Bauxite, Ark., in 1918, however, showed that there was no doubt much clay associated with the ore, but that most of it is too heavily stained with iron to be classed with the grades considered especially in this bulletin. It is true that some whitish clays underlie the bauxite in at least some of the pits, but the material is in small pockets. Although the clay is of no economic value, its microscopic characters are of interest. Practically no quartz was present, and hydromica was rather scarce, but kaolinite appeared in great abundance, many of the grains showing the characteristic "fans" (Pl. XXVII, *A*). There were a few large flakes of some pale mica, and a few grains of zircon and rutile were noticed.

Little Rock.—At the Radcliffe mine of the Republic Mining & Manufacturing Co., 5 miles southeast of Little Rock, the following section was obtained:

Section at Radcliffe mine, southeast of Little Rock, Ark.

	Feet.
Overburden	3
Bauxite, maximum	12
Gray clay	Variable.

The clay under the ore is said to be 2 feet thick, but in the woods east of the pit the under clay was struck in a number of bore holes, and Mr. Watters, the manager, claims that it ranges from 10 to 15 feet in thickness. It is possibly of refractory character, but its physical properties and the exact extent of the deposit are not known. No tests have been made of it. The material could be easily obtained if it is of commercial value.

Gray clay is reported in greater quantity around Mabelvale, between Benton and Little Rock.

[49] Mead, W. J., Bauxite deposits of Arkansas: Econ. Geology, vol. 10, p. 28, 1915.

Branner[50] has referred to the occurrence of residual clays in the Fourche Mountain district, near Little Rock. He notes the occurrence of surface exposures in secs. 5 and 9, T. 1 S., R. 12 W., and secs. 2, 10, 11, and 12, T. 1 S., R. 13 W., and discoveries in wells in secs. 25, 26, 35, and 36, T. 1 N., R. 12 W.

Nothing definite appears to be known regarding the extent of the individual deposits, although some of the samples gave promising results on firing.

NEVADA.

By J. P. Buwalda.

The discovery of an abundant supply of white-burning plastic clays in the far West would be highly desirable, as some of the factories along the Pacific coast now have to obtain these materials from the East. Any occurrences that give any promise of being valuable should therefore be recorded.

The United States Geological Survey has received reports regarding several occurrences in Nevada.

OREANA.

Pitt-Rowland mine.—The Pitt-Rowland mine is on the east slope of the Humboldt Range, about 12 miles east of Oreana, Nev., and about 24 miles south of Mill City. The road to Oreana is bad and has steep grades, but that to Mill City is good and nearly level. R. H. Rowland, of Oreana, and W. C. Pitt, of Lovelocks, are the owners.

The clay is a white fault gouge, in which perhaps 10 per cent of the mass consists of uncrushed fragments of the wall rock, which appears to be a bluish-white quartz porphyry or rhyolite. The deposit is sheared by slickensided surfaces, which dip 20° E. and strike N. 20° W., and this appears from the underground development work also to be the attitude of the clay body. The clay is pure white underground, except that it contains bluish-white fragments of solid rock and here and there reddish or pinkish streaks caused by cinnabar and by traces of iron. The deposit also includes some large slabs of solid uncrushed rock, which measure several feet in diameter. The property was originally unsuccessfully worked for cinnabar by means of several hundred feet of tunnels and drifts which have three openings to the surface. The wall rock was not seen, but country rock and uncrushed fragments in the clay appear to be rhyolite.

About 300 tons of the clay was shipped in 1917 to California, and is said to have been used for blending with other clays, largely im-

[50] Branner, J. C., Clays of Arkansas: U. S. Geol. Survey Bull. 351, p. 162, 1908.

ported. No clay was shipped in 1918. It is said to have been necessary to treat the clay in a tube mill before it could be used; also that when the solid fragments were ground up they were as satisfactory for use as the clay itself.

The dimensions of the deposit can not be determined on the surface, but the underground workings have exposed a body at least 200 by 200 by 12 feet, and the actual dimensions are believed to be many times these figures. Rough computation indicates tens of thousands of tons of clay in sight underground, and there are several thousand tons now on the dumps. The clay would probably have to be mined; not much of it could be dug out of quarry pits. Timbering in the tunnels is not required, but where large volumes are removed in drifts, the roof needs timbering, as the clay body dips eastward into the hill. The openings are 50 to 75 feet above the floor of an open canyon. Water is available on the ground.

The samples sent by Mr. Buwalda represent an exceedingly gritty coarse-grained clay of low plasticity. Under the microscope it shows abundant quartz, sericite, and kaolinite, and a few large grains of epidote and some rutile.

The grittiness of the material is well illustrated by its porosity after firing, as shown by the tests given below:

Fire tests of kaolin from the vicinity of Oreana, Nev.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	30	51.1	Light cream white.
1,300	15.9	30.8	Do.

If this material is to be used in pottery manufacture, it will have to be ground, washed, or sifted.

Thin sections of the burned clay were very interesting, for they showed a coarse-grained mixture, chiefly of quartz and mica (sericite), the structure of the sericite being well preserved at both the temperatures stated.

At 1,150° C. very little of the normal interference color of the sericite remains, except in the centers of the grains, where it is somewhat dimmed, and the outer part of each grain shows interference colors of kaolinite. At the higher temperature this condition is emphasized, and some of the groundmass has become isotropic. In Plate XXIX, *A* (p. 300), there is shown a thin section of this clay fired at 1,150° C. as seen with crossed nicols.

LOVELOCKS.

Adamson-Dickson property.—The property of Messrs. A. H. Dickson and D. C. Adamson, of Unionville, Nev., is at the mouth of New York Canyon, formerly known as Sinclair Canyon, on the west flank of the East Range. It is 75 miles southwest of Winnemucca, Nev., 34 miles south of Unionville, and 25 miles east by southeast of Lovelocks.

The clay seems to be a sedimentary deposit on a series of Paleozoic sandstones and shales, of which series it presumably is a member, and the bed is between 75 and 100 feet thick. The clay is white and fairly hard in the deposit. It breaks out in rough, angular pieces. At one locality in the bed of the creek in New York Canyon the clay much resembles putty in its fineness, extreme stickiness, and other physical characters, but is pure white.

It is reported that no clay has been shipped. The clay forms a stratum 75 to 100 feet thick at or near the surface in a strip at the base of the foothills of the range, extending for about 4 miles. Though the material is a sedimentary deposit, its clayey nature may be due to weathering, and it may therefore be classed as a kaolin. It is covered to a shallow depth in some areas by coarse desert waste materials, but outcrops abundantly elsewhere, so that it could be taken out in vast quantities by surface digging. A tunnel about 50 feet long has been driven into the clay half a mile northeast of New York Canyon.

The thickness of the layer of very sticky, putty-like clay exposed in the bed of New York Canyon was not ascertained, as it is exposed over an area of only a few square feet. It forms part of the thickness of the clay deposit.

The road to Lovelocks is good and is nearly level the entire distance of 25 miles. Water is present at the clay deposit.

The clay stratum slopes gently westward and northwestward toward the valley and away from the East Range, on the edge of the foothills of which it lies.

The clay is lean and exceedingly gritty; indeed, under the microscope it looks more like sand than clay. Quartz is very abundant in small grains, but kaolinite is also rather abundant and may help to give it what little plasticity it possesses. Grains of rutile occur sparingly, but stains of limonite are fairly common.

With so much quartz present, the material is naturally very open burning, as the following figures indicate:

Fire tests of white clay from area southeast of Lovelocks, Nev.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	32.4	48.9	White.
1,300	28.9	45.2	Light cream-white.

The clay is not steel hard, even at the higher temperature.

A thin section of the burned clay shows little change in appearance from the crude clay, even at the higher temperature, and this is probably due to the high percentage of sand and to the absence of hydromica.

TELLURIDE.

Shepard property.—The property of H. S. Shepard is about 9 miles by road east of Beatty, Nye County, which is the railroad point. The deposit lies perhaps 3 miles north of the abandoned camp of Telluride in the midst of a relatively flat or gently rolling area on the summit of the range next east of Beatty at an elevation of about 2,000 feet above Beatty.

The property was visited November 26, 1918. The clay outcrops over an area about 700 feet long that trends northwestward and is about 125 feet wide. Three pits have been sunk in the middle portion of the prospect, each to a depth of about 10 feet, without cutting through the clay. There are certainly several thousand tons of the material available. The clay is jointed so that it can be quarried out in angular masses after blasting. There is practically no overburden of waste to be removed.

The clay is very white. It breaks into angular blocks with rough surfaces. A few included particles 0.5 to 1 millimeter in diameter prove to be euhedral bipyramids of quartz such as are commonly found as phenocrysts in quartz porphyries. The clay is of uniform character throughout the deposit so far as opened up.

The deposit lies in an area of volcanic rocks, mainly rhyolitic lavas and tuffs, and though the relatively flat topography in the immediate vicinity does not afford means of determining the relations of the deposit, the clay is probably an alteration product of quartz porphyry or of tuff.

Mr. Shepard reports that he shipped one carload of the clay to a pottery in California in April, 1918, and that though he was urged to ship several additional carloads the price offered was not satisfactory to him, and therefore no further shipments were made.

The deposit was first opened as a cinnabar prospect, but this mineral is not present in paying quantities, although traces of it occur.

No slickensides were seen in the openings in the deposit.

The clay can easily be mined in open pits. A fairly good road extends to Beatty; on leaving the property the road climbs a very gentle grade for about 3 miles to a low summit, beyond which it continues with an even downward grade into Beatty.

A physical examination of a sample from this pit showed it to be white and somewhat claylike in appearance. It feels very gritty and slakes little or not at all in water. Moreover, when ground sufficiently fine to pass through a 20-mesh sieve it yielded a sandy mass that was entirely lacking in plasticity when mixed with water. If all the material is like this it could not be used as the clayey ingredient of a pottery mixture.

Kiernan property.—The property of J. B. Kiernan is on the flanks of Bare Mountain, near Telluride, Nev., and 8 miles from Beatty, the nearest railroad point. It is near the Bond & Marks clay property. The writer could not visit the deposit when at Beatty, late in November, 1918. Mr. Shepard, who aided in the operation of the deposit stated that one car of clay was shipped to a California pottery in February, 1917, but the presence of hematite in too large quantity resulted in failure to secure further orders. An aerial tram 400 feet long was built to convey the material down the steep mountain face to the truck road below.

The deposit occurs in an area of limestone and quartzite, but its relations are not known to the writer, nor are there dependable data at hand regarding its size.

BEATTY.

Bond & Marks deposit.—Beatty was visited late in November, 1918, but the Bond & Marks deposit could not be examined, according to Mr. H. S. Shepard, who had aided in the operation of the Bond & Marks property.

Bond & Marks have shipped four cars to a California pottery—the last car about June, 1918. No further shipments were made, it is said, because of too much hematite in the clay.

The deposit lies near the summit of the mountain, 8 miles southeast of Beatty, Nev. The mountain consists of limestones and quartzites. The location of the deposit is high above the valley, on a bold mountain face, which renders difficult the task of transporting the clay from the deposit to the road below, where it can be loaded on trucks or wagons for transport to Beatty.

A specimen of this clay, sent to the United States Geological Survey, was remarkably white and free from grit. It may have been an exceptionally fine piece rather than representative of the average clay.

Its mineral composition is curious, for under the microscope (Pl. XXX, *A*, p. 301) it is seen to consist almost entirely of plates of what is probably halloysite and a small amount of kaolinite. There also appear to be some very small grains of rutile.

The clay is fairly plastic and very sticky. It burned snow-white and to a very porous body, as shown by the following tests:

Fire tests of clay from Beatty, Nev.

Cone.	Absorption (per cent).	Porosity (per cent).	Color.
1 (1,150° C.)	47.9	59.2	White.
10 (1,333° C.)[a]	19.7	36.9	Do.

[a] Steel hard.

Thin sections of the clay after firing showed the following characters:

Clay burned to cone 1 (1,150° C.) : Shows a rather fine fibrous aggregate, with a higher index than balsam and a very low interference color.

Clay burned to cone 10 (1,330° C.) : Same as cone 1, but interference colors increased.

Clay burned to cone 14 (1,410° C.) : Same as cone 10, but interference colors increased still more, and the lighter portions of the section are full of small dendritic stains.

If the clay were all as fine and white as the sample sent to the Survey, it might be used in paint or paper manufacture.

IDAHO.

Some interesting deposits of white residual clay derived from granites and pegmatites occur in Latah County, Idaho, and in neighboring regions. They are said by Soper [51] to have been used in the manufacture of fire brick, but possibly if washed they might be useful for much higher grade ware.

CALIFORNIA.

Antioch.—The Survey has received samples of a white clay mined near Antioch, Calif., but no information is available regarding the field relationships of the deposit.

The clay, which is washed before shipment to market, is white and suitable for the manufacture of white pottery and tile.

Under the microscope it shows medium to fine texture and a very little quartz and hydromica. Kaolinite is very abundant, and some of it is exceedingly fine grained. Tourmaline and rutile are only sparingly present. The petrographic examination suggests that the material may be of an open-burning character, and that it might not vitrify at a temperature as low as 1,150° C. Two samples that were fired showed an absorption of 33.3 per cent at 1,150° C. and 22.5 per cent at 1,300° C. The clay was a faint grayish white at the higher temperature, and nearly steel hard.

SUMMARY.

The deposits of white residual clay are somewhat widely distributed in the United States, and they occur in probably a greater number of formations than most persons have hitherto imagined.

Only a few of these clays burn white—those derived from the pegmatites, the best grade of those from Bollinger County, Mo., and some of those from Nevada. The kaolins from Missouri, however,

[51] Soper, E. K., Fire clays in northern Idaho: Am. Ceramic Soc. Jour., vol. 1, p. 94, 1918.

contain very finely divided silica, which is difficult to remove in washing, and those from Nevada are so sandy at times that they may yield a very low return in washed product. The sample from California is faint cream white when fired.

For paper and paint the color after burning matters not, as the material is used in its crude condition.

Practically all the eastern deposits, with the few exceptions noted in the preceding pages, are comparatively near to transportation routes, and the deposits that are worked ship their product chiefly to markets east of the Mississippi Valley.

Bayley has pointed out that in North Carolina there are probably large reserves. It may be some time before all the known deposits become available, and in addition new deposits may be discovered.

The South Mountain district of Pennsylvania undoubtedly contains reserve supplies, but it is difficult to estimate them.

Little is known regarding the reserve tonnage in the Cambrian belt along the west side of the Blue Ridge in Virginia, but this belt offers a very promising field for prospecting, as does also the Oriskany area of northwestern Virginia and adjoining portions of West Virginia.

The reserve tonnage in southeastern Missouri is uncertain.

In the East, therefore, the most evident reserves are in North Carolina and Virginia.

Production has been stimulated by the war, but difficulties with labor and transportation interfered with efforts to meet the greater demand. However, the decrease in imports did not perhaps benefit the miners of residual clay as much as it did those working the sedimentary clays.

KAOLIN MINING AND REFINING.

Kaolin may be mined in three different ways, as follows:

1. By circular shafts. (See Pl. II, p. 32.) In this method a shaft about 25 feet in diameter is sunk to the bottom of the deposit and is lined with cribwork as the sinking proceeds. When all the clay is mined out the shaft is filled up and the cribbing removed. Another shaft is then sunk near by, and so on until all the clay in the deposit has been extracted.

2. By underground mining. A rectangular shaft is sunk, either in the clay or in the solid wall rock, and from this shaft levels are run off at convenient intervals. The clay is then stoped out between levels. Timbering is usually required to hold up the ground, and if the latter is very wet it is likely to cause trouble by squeezing or caving. A modification of this method, which is practiced in the

Mount Holly Springs district in Pennsylvania, consists in running a tunnel into the hillside until the good clay is encountered, and then stoping it out.

3. By open pits. This method is practiced at a few localities, the clay being dug by hand, or in one locality by steam shovel. It is very necessary to keep the overburden removed well ahead of the clay face to prevent it from washing down over the clay and staining it.

With few exceptions kaolins have to be washed before shipment to the market in order to eliminate the sand. The method still prevalent is to disintegrate the clay in water and then run this mixture of water and clay through a series of troughs in which the sand settles out, after which the water with the suspended clay passes to the settling tank.

An electrolyte like sodium carbonate is sometimes used to deflocculate the clay and to facilitate the settling of the fine sand. Some producers use a modification of the troughing system with apparently good results, but there is still room for improvement, and the development of a better controllable washing apparatus, which will insure more uniform and better results, is highly desired.

More careful oversight of mining and preparation is essential, and there should be closer cooperation between the producer and consumer.

The kaolins mined at Cold Spring, Va., and Lutesville, Mo., are shipped crude, but neither of these is used primarily for white ware.

RESIDUAL CLAYS OF UNDETERMINED DERIVATION.

ALABAMA.

The writer visited several deposits of residual clay in Alabama which should not really be classed as kaolins, for they are not white clays, although one deposit contains some white clay.

Most of these deposits, which are described below, were idle during the summer of 1918.

FORT PAYNE, DEKALB COUNTY.

A deposit that appears to be a residual clay derived from Cambrian rocks has been opened by F. E. Ladd about 4 miles north of Fort Payne, just north of the Gibson Gap road. The exact shape and extent of the deposit are not known, but a cut about 200 feet long, 20 feet in greatest depth, and about 50 feet in greatest width has been excavated. The overburden consists of 3 to 4 feet of ferruginous cherty clay. The land rises slightly to the west, and the overburden increases somewhat in this direction.

Mr. Ladd states that a shaft sunk 200 feet west of the pit struck the clay, and that a boring in the bottom of the large pit showed 28 feet more of clay. Similar clay occurs in a valley about three-fourths of a mile north of Mr. Ladd's pit, but no clay was found on the south side of the Gibson Gap road.

The clay is gray, though it contains a few yellowish mottlings, and very tough but gritty.

Under the microscope quartz is seen to be fairly common, and hydromica and kaolinite abundant. Rutile is present in numerous tiny grains, and there is a little tourmaline.

A chemical analysis of the clay was supplied by Mr. Ladd, as follows:

Analysis of fire clay from pit of F. E. Ladd, Fort Payne, Ala.

Silica (SiO_2)	60.26
Alumina (Al_2O_3)	28.56
Ferric oxide (Fe_2O_3)	.49
Lime (CaO)	.60
Magnesia (MgO)	.07
Soda (Na_2O)	.54
Loss on ignition	10.15
	100.67

The clay is very smooth and plastic and burns steel hard at 1,150° C. The porosity at this temperature is 25.6 per cent and the color cream white. At 1,300° C. the porosity is 15.5 per cent and the color light buff.

A thin section of the clay which was burned at 1,150° C. formed a compact body, with a groundmass that showed low interference colors and some isotropic material. The appearance of the clay burned at 1,300° C. was similar, except that the number of isotropic grains had somewhat increased.

The clay has been used for making fire bricks at Fort Payne, and some of it has been shipped to Pennsylvania for use in glass-pot mixtures.

There is a good road for hauling the clay to Fort Payne, but the line of the Southern Railway is not more than 1½ miles from the pit.

Another opening has been made in the hill slope about 8 miles north of Fort Payne and 3 miles west of Allen's switch. This pit, which is operated by the Consolidated Mining Co., is worked mainly for bauxite. Associated with the bauxite in irregular masses is a gray and grayish-brown clay. The visible quantity is not very large, and it could be worked only in connection with the bauxite. It has not been used up to the present time.

BYNUM, CALHOUN COUNTY.

A curious deposit of clay that is residual, derived apparently from schistose rocks, has been opened on the Pope farm, 3 miles west of Bynum, on the south side of the Alabama Great Southern Railroad. The material has been worked by means of an open pit and shaft, which were idle and partly filled with water at the time of the writer's visit.

The walls of the pit consist of gray and ferruginous sandy residual clay, but in this clay there occur lenslike masses of a whitish and a black clay, which are the materials sought.

The whitish clay is fairly dense, but the black clay ranges from dense material not unlike the Klingenberg clay in appearance to light porous, clay. The black color is evidently due to carbonaceous matter. These clays have been used in crucible mixtures.

Under the microscope the black clay appears to be very fine grained. It shows no quartz, but hydromica is fairly common, and grains of rutile are fairly numerous. There are a few small grains of zircon and a very few of chlorite. The rest of the material consists of exceedingly small, deeply stained particles of indeterminate character, which may be colloidal matter.

The white clay is fine to medium grained. It shows abundant hydromica, which is commonly coagulated, and abundant kaolinite, which exhibits a few fans and vermiculites. Grains of rutile are present and a very little tourmaline.

The following tests of the black clay were made at the laboratory of the Bureau of Mines in Columbus, Ohio:

Tests of black clay from Bynum, Ala.

Character of raw clay	Fluffy; low specific gravity.
Workability	Very plastic, sticky.
Drying quality	Good.
Water of plasticity ....per cent	48.60
Air shrinkage by volume ....do	18.24
Air shrinkage, linear, calculated ....do	6.6
Modulus of rupture ....pounds per square inch	136.5

Fire tests of black clay from Bynum, Ala.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Calculated linear shrinkage (per cent in terms of dry clay).
1,190	33.9	Nearly white	38.50	15.0
1,250	33.45	....do	41.38	16.4
1,310	16.70	....do	50.78	20.9
1,370	7.40	....do	54.50	23.1
1,410	2.40	Creamy white	56.70	24.3

Deformation temperature, cone 34 (1,810° C.). Steel hard at 1,250° C. Develops small cracks in firing.

This clay shows excellent refractoriness and burns sufficiently white for the manufacture of pottery. Its shrinkage is not excessive, but it shows low strength in the unfired condition. It could be used as an ingredient of mixture for making pottery and other products that require a refractory, white-burning, open-textured clay.

CLAYS OF CARBONIFEROUS AGE (CHIEFLY SEDIMENTARY).

The abundant supplies of refractory clay in the Carboniferous rocks have long been known, and this clay is utilized at many localities for the manufacture of refractory wares.

Few of these localities need be mentioned here, as most of them are not significant in the present discussion. The chief deposits described in this bulletin are those of value to manufacturers of glass refractories, especially the deposits of the St. Louis district and southern Ohio. In addition the high-alumina clays of central Missouri and the indianaite deposits of Huron County, Ind., are considered.

ST. LOUIS DISTRICT, MO.

The area around St. Louis has long been an important center of the refractories industry, which has been built up on the local clay deposits.[52]

All the fire clay in this district is obtained from a single bed, known as the Cheltenham fire clay, which stratigraphically lies near the base of the Pennsylvanian series of that region. It was deposited in upper Pottsville time.

The thickness of this bed ranges from 1 to 21 feet, but where worked it is commonly from 3 to 8 feet, and in some of the areas where the thickness exceeds 8 feet only the best portion of the bed is mined. The roof is a micaceous sandstone, and the floor is commonly pyritiferous sand. In some of the mines the floor shows rolls, which may rise to such an extent as completely to pinch out the clay.

The Cheltenham clay is hard or shaly, and usually gray. It may differ from point to point in the district, and there may also be a variation from the top to the bottom of the bed. It is therefore not uncommon to sort the material. Fenneman states that in the western part of the field the lowest clay in the bed is the best; in Cheltenham the middle clay is the best; and in the southern part of the field the

[52] Wheeler, H. A., Clay deposits: Missouri Geol. Survey, vol. 11, 1897.
Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Mo.-Ill.: U. S. Geol. Survey Bull. 438, 1911.

top clay is the best. Although most of the Cheltenham clay is used in the manufacture of fire brick, the better grades have a wide reputation because of their value in the manufacture of glass pots, zinc retorts, and graphite crucibles.

The pot clay, then, which is not found in all the mines, represents the best-grade material. After mining it is piled upon the surface and allowed to weather for at least a year, and some of it for two years. It is then put through a washing process, not so much to remove the fine sand as the coarser impurities, consisting of concretions and lumps of pyrite.

The growth of the city of St. Louis has interfered with the working out of all the clay reserves of the district. The bed has been mined, however, at several somewhat widely separated points, as south of Clayton, at Castello, 9 miles northwest of Cheltenham, and north of Baden. Therefore, further prospecting may reveal its presence in other localities.

The firms that reported production of glass-pot clays in 1917 were F. E. Bausch, G. J. Berresheim, Cheltenham Fire Clay Co., Grand View Fire Clay Works, Highland Fire Clay Co., Laclede-Christy Clay Products Co., and Walsh Fire Clay Co.

The variation in the character of the clay is shown by the following tests, given by Bleininger.[53]

Physical tests of Cheltenham fire clay, St. Louis, Mo.

No. of sample as given by Bleininger and Loomis.	Water in terms of dry weight.	Ratio of pore water to shrinkage water.	Shrinkage by volume in terms of dry volume.	Time of slaking.	Modulus of rupture of dried clay (pounds per square inch).	Modulus of rupture of dried mixture, clay 1: sand 1 (pounds per square inch).	Temperature of vitrification (° C.).	Temperature of overfiring (° C.).	Softening point (cone).	Remarks.
4	31.14	.57	38.42	52	838	399	1,290	1,320	27	No difficulty in drying. Not a high-grade bond clay.
6	43.63	.72	43.63	33	328	351	1,200	1,430	32	Very fat but dries well. Promising as a crucible material.
14	34.66	.54	42.63	117	990	554	1,200	1,320	27	Excellent plasticity; dries well; not suited for steel-melting crucibles or glass refractories. Should be useful for brass-melting work.
16	29.54	......	37.02	26	575	351	....	1,320	......	Good plasticity; dries well.
27	25.52	.74	28.52	46	489	263	1,400	1,425	31	Good plasticity; dries well. Vitrification proceeds steadily to 1,400° C. Burns satisfactorily. Somewhat deficient in bonding power.

[53] Bleininger, A. V., and Loomis, G. A., The properties of some American bond clays: Am. Ceramic Soc. Trans., vol. 19, p. 601, 1917.

A microscopic examination has not shown much, especially as we have no burned samples by which to check it. However, the data at hand are shown in the following table:

Minerals in Cheltenham fire clay.

	Quartz.	Hydromica.	Kaolinite.	Rutile.	Epidote.	Zircon.	Tourmaline.	Titanite.
Washed pot clay.	Common.	Abundant.	Abundant.	Few small grains.				
Weathered pot clay (another firm).	Common.	Abundant.	Common.	Common.		One or two grains.	Several grains.	
Fire-brick clay.	Common.	Abundant.	Scarce.	One grain.				Two or three grains.
Selected crude clay.	Common.	Abundant.	Scarce.	Scarce.				
Washed pot clay (another firm).	Some.	Abundant.	Common.	Common.	One or two grains.			

The main fact brought out in the table is that in the washed pot clay the hydromica and kaolinite are more abundant than in the other grades. The minor minerals are of no special significance.

GLASS-POT CLAYS IN OHIO.

By Wilbur Stout.

In the Portsmouth district, Ohio, clay for glass pots is regularly prepared by only one firm, the Harbison-Walker Refractories Co.

The clay used is the Lower Kittanning or No. 5, which underlies the Lower Kittanning coal.

The section at the mine, which is in Spencer Hollow, sec. 3, Washington Township, Lawrence County, is as follows:

Section at Spencer Hollow, Lawrence County, Ohio.

	Ft.	in.
Shale and sandstone	12	
Clay, in part flinty (Oak Hill)	4	6
Coal		10
Clay (Lower Kittanning)		2
Coal		4
Clay, dark, ferruginous, usually excluded (Lower Kittanning)		2
Clay, plastic, light (glass-pot clay)	5	
Clay, light, plastic, siliceous	2	6
Sandstone, clay bonded	2	

The clay is mined both by stripping and by drifting. The portion generally preferred is that near but not on the outcrop, under about 5 to 15 feet of covering, where the overlying coal is partly or even badly weathered.

The clay averages about 6 feet in thickness but may range from 4 to 12 feet.

The clay bed is generally divided into two parts, the lower siliceous, and the upper, which commonly ranges in thickness from 2 to 4 feet, quite free from siliceous matter and very plastic.

About 4 inches of the clay just beneath the coal is generally ferruginous, and this material must be thrown out in mining.

The quantity of clay available for glass refractories in eastern Scioto, southern Jackson, and western and northern Lawrence counties is very large, as the bed is persistent over several townships and maintains both its thickness and its quality.

The clay from the Spencer Hollow mine is shipped to the company's mill on Frederick Creek, near Scioto Furnace, Scioto County, where it is prepared for the market.

Clay in the crude form or ground only in the dry pan is also shipped by Morgan & Horton, of Eifert, Scioto County, but not much of this is used by the glass-pot trade.

The Federal Clay Products Co., at Mineral City, Tuscarawas County, has been furnishing calcined clay from the Lower Kittanning bed to the glass-pot trade. The company also manufactures blocks, floats, and other articles for the industry.

The section at the mine includes the following beds:

Section in mine of Federal Clay Products Co. at Mineral City, Ohio.

	Ft.	in.
Coal (Lower Kittanning)	3	6
Clay, plastic, impure, not used	5	
Clay, flint, used for glass-pot trade (Lower Kittanning)	3	6
Clay, plastic, used for bonding	5	
Sandstone.		

Bleininger and Loomis[54] give the following tests of some refractory bond clays from southern Ohio. No. 1 is not regarded as the highest type but is considered to be useful in a mixture with other clays; No. 2 is somewhat similar; and No. 3, a washed clay, is regarded as useful for bonding in a mixture for steel-melting crucibles and glass refractories.

[54] Bleininger, A. V., and Loomis, G. A., Properties of some American bond clays: Am. Ceramic Soc. Trans., vol. 19, p. 601, 1917.

Physical tests of refractory bond clays from Ohio.

	1	2	3
Water of plasticity....per cent..	22.08	25.30	26.84
Ratio of pore water to shrinkage water....	.80	.83	.72
Shrinkage by volume in terms of dry volume....per cent..	24.46	27.92	26.98
Time of slaking....minutes..	8	8½	10
Modulus of rupture of dried clay....pounds per square inch..	479	452	328
Modulus of rupture of 1 part of clay to 1 part of sand....do....	281	309	227
Fusion cone....	31	30½	31½

Temperature (° C.).	1		2		3	
	Porosity (per cent).	Volume shrinkage.	Porosity (per cent).	Volume shrinkage.	Porosity (per cent).	Volume shrinkage.
1,050....	22.83	7.34	23.55	6.66	25.42	7.08
1,075....	18.91	10.10	21.72	9.97	22.43	11.02
1,100....	15.82	12.85	17.61	11.95	19.15	14.50
1,125....	14.35	14.87	15.01	15.61	16.76	16.30
1,150....	12.95	16.06	12.05	17.95	16.38	17.12
1,175....	12.02	17.15	10.26	18.21	16.20	18.25
1,200....	11.56	17.10	9.71	19.78	14.50	20.20
1,230....	8.66	17.38	6.90	20.83	12.22	22.08
1,260....	8.71	17.80	3.14	21.69	7.25	25.12
1,290....	6.82	18.06	.49	21.80	.19	26.02
1,320....	2.50	18.18	.09	20.65	.71	21.60
1,350....	.52	13.78	2.83	16.20	1.46	26.32
1,400....	4.56	14.21	(a)	....	3.56	25.41
1,425....	6.01	9.08	....	....	....	....
1,450....	5.60	....	....	....	....	....

a Overfired.

PENNSYLVANIA.

Some of the semiplastic clays of Pennsylvania have been used from time to time in tank blocks. Flint clay from the lower Mercer bed is obtained at Dean, Cambria County, Pa. It is used for tank blocks and pots. Clay for pots and blocks is also obtained at Huefner and Lucinda, Clarion County.

FLINT CLAYS OF CENTRAL MISSOURI.

OCCURRENCE AND DISTRIBUTION.

Wheeler[55] in 1897 called attention to a remarkable series of deposits of flint clay in Missouri that are unlike any others found in the United States. These deposits occur in the central part of the State, more particularly in the east-central district, of which Gasconade County is the center.

Wheeler also notes that they are abundant in Warren and Montgomery counties, along the Wabash Railway, in Callaway County, and also in Osage, Franklin, Crawford, and Phelps counties.

Other known deposits extend the area as far north as Monroe County, as far west as Morgan and St. Clair counties, and as far south as Dent County.

[55] Wheeler, H. A., Clay deposits of Missouri: Missouri Geol. Survey, vol. 11, p. 201, 1897.

Wheeler states that the deposits are not confined to any particular geologic formation but occur in Cambrian, Ordovician, and Silurian rocks. He says that they are invariably basin-shaped and occupy sink holes in limestone. The basins are from 50 to 200 feet in diameter and 15 to 50 feet in depth. Generally a sheet of sandstone several feet in thickness lies between the limestone wall of the basin and the flint clay. He comments on their irregularly jointed structure and massive character, which, he says, in a few places suggest a water-laid deposit.

The following analyses, taken from Wheeler's report, give some idea of the composition of the flint clays:

Analyses of flint clays from Missouri.

	1	2	3
Silica (SiO_2)	45.12	44.70	40.50
Alumina (Al_2O_3)	40.46	35.90	43.22
Water (H_2O)	13.34	12.20	14.15
Ferric oxide (Fe_2O_3)	.47	3.35	.31
Lime (CaO)	.29	3.00	1.11
Magnesia (MgO)	Trace.	.21	Trace.
Alkalies (Na_2O, K_2O)	.30	.29	.51
	99.98	99.65	99.80

1. High Hill, Montgomery County.
2. Owensville, Gasconade County.
3. Drake, Gasconade County.

Some of these clays show an abnormally high percentage of alumina, exceeding even the flint clays of Kentucky,[56] which have been shown by Galpin[57] to contain gibbsite.

Wheeler comments on their high content of alumina, as much as 44 per cent, as well as on the contamination by red iron oxide in many places.

The writer had occasion to visit a number of these deposits in the summer of 1918 and found that several interesting developments had taken place since Wheeler had examined them.

The deposits visited are in Crawford and Gasconade counties (fig. 18), most of them along the line of the Chicago, Rock Island & Pacific Railway or near it.

All the deposits examined appeared to lie in the Pennsylvania sandstone, and none of the pits seen showed any limestone in their walls or in the vicinity. They show no uniformity in elevation, for some of them occur on high ground and some in depressions.

[56] Greaves-Walker, A. F., Note on a high-alumina flint clay: Am. Ceramic Soc. Trans., vol. 8, p. 297, 1906.

[57] Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, p. 301, 1912.

A good opportunity to determine the stratigraphic relationships of these clays in the area visited was found near Bland. Here the clay pit of Campbell & Lichte lies near the top of a broad ridge. Along this ridge a short distance northwest of the town the Pennsylvania sandstone shows in its lower portion a breccia that contains angular fragments of the "cotton rock" and chert of the underlying Jefferson City limestone, which crops out farther down the hill. Still farther down below this bed is the Roubideau formation.

All the deposits of flint clay that were visited occupied cavities in the sandstone which appear to be of irregular shape, and some

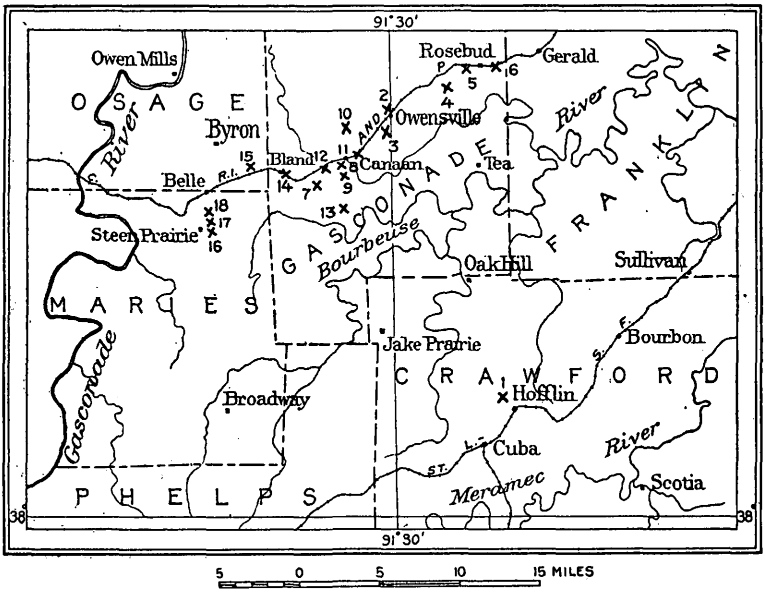


FIGURE 18.—Map showing flint-clay pits in central Missouri.

1. Cox's pit.
2. Sassman pit.
3. Connell pit.
4. Charles Brown pit.
5. Heidel & Toelke pit.
6. Bauer & Watkins pit.
7. Haynes pit.
8. Hensley pit.
9. Baxter pit.
10. Helm pit.
11. Lacey pit.
12. Dittman pit.
13. Myers pit.
14, 15. Campbell & Lichte pit.
16. Travis pit.
17. Pointer pit.
18. Jackson pit.

have a depth of not less than 50 feet. In only one, the Sassman pit, at Owensville, was the country rock found near the quarry, and there it was sandstone. The walls of the pits where they were exposed consist of sandstone, whose surface in some places dips under the flint clay but in other places overhangs it. In the pit at Hofflin the sandstone contains angular fragments of the flint clay.

Two samples of this sandstone were examined under the microscope. One of these samples, from Cox's pit near Hofflin, was made up entirely of grains of quartz embedded in a little clay cement.

The quartz contained little prisms of an indeterminable mineral and a few cavities that were partly filled with liquid. A second sample, from the south side of Connell's pit, at Owensville, showed abundant quartz in rounded grains embedded in a matrix that consisted chiefly of kaolinite. Grains of diaspore were very scarce. Rutile was present, both as inclusions in the quartz and in the matrix. A few grains of tourmaline and zircon were seen.

Mr. H. T. Darlington, of Natrona, Pa., says that in some places a granular rock that is associated with the flint clay and that is full of grains of diaspore is easily mistaken for the quartz rock.

CHARACTER OF THE CLAYS.

The flint clay is buff to gray, massive, and fine grained. It has conchoidal fracture and a hardness of about 2.

Under the microscope the clay is found to be exceedingly fine grained; indeed some of the smallest indeterminable particles may be colloidal, although others show interference colors.

Among the identifiable grains in the samples examined kaolinite was noted and in places was very abundant; hydromica was present in different amounts in different samples; diaspore was common in one sample, but scarce in another, in which it occurred in fine grains; rutile was invariably present, but not in the same amounts; zircon and tourmaline were rare.

Organic material appears to be rare. In one pit near Bland it occurred in a finely divided condition associated with small fragments of stems and leaves. In Heidel & Toelke's pit at Rosebud a thin bed of impure coal occurs in the clay.

Sassman's pit, at Owensville, and Heidel & Toelke's pit, at Rosebud, are the only pits where the flint clay shows any stratification, but it is fractured by numerous joint planes which show no regularity, and it exhibits stains along these joints.

In some pits the flint clay is slightly softer than usual, but still retains its other features. In others there is a soft plastic, in places whitish clay associated with the flint near the edge of the deposit, which probably represents a weathered form of the flinty material.

In several of the pits red or red and white mottled clay is associated with the flint. In Cox & Sassman's pit, near Owensville, the mottled clay forms a distinct bed overlying the flint clay, but in Heidel & Toelke's pit, near Rosebud, the relations are not as clear, although they may be similar. This variegated clay is exceedingly fine grained; indeed, under the microscope most of the grains appear to be isotropic, suggesting that they may be colloidal. Some hydromica and kaolinite are recognizable. Aside from the hematite coloring on the grains, the red and white bands or portions show no difference.

The most remarkable material in these flint clay deposits is a hard dolitic clay, which is called "rough clay" by the workmen. This material in places is harder than the flint clay and consists of small rounded bodies or oolites, the largest of which are one-sixteenth or three thirty-seconds inch in diameter, embedded in a fine-grained groundmass. This clay is gray, brown, or buff in color, and though generally compact it shows in places a slightly pitted structure. It is not present in every deposit, and, though it does not occupy any definite position, it occurs in most places in the middle or near the top. The masses of it are of irregular shape and differ in size, and there is usually a gradation from the oolitic clay into the normal flint clay. In at least one pit there are two distinct types of oolitic clay, which form more or less distinct beds.

This oolitic clay does not appear to have been known when Wheeler prepared his report, but it is a valuable product of the flint-clay district at the present time. Its value lies chiefly in its high percentage of alumina, which is due to the presence of the mineral diaspore ($Al_2O_3.H_2O$). Although diaspore may be present in the finer-grained normal flint clays it is probably confined chiefly to the oolitic clays.

Under the microscope the grains of diaspore are easily recognized. They are abundant, although they vary in texture; some are very fine, but others are much coarser.

Sections through the oolites examined under the microscope show that some of them consist of a mixture of grains of diaspore stained with iron oxide, through which extend streaks or circles of clear grains of diaspore. (See Pl. XXVIII, *A*.)

The grains of diaspore are commonly associated with abundant kaolinite, but hydromica, on the other hand, is generally rare.

The following partial analyses of diaspore clay have been supplied by M. H. Thornberry, of the experiment station of the University of Missouri.

Partial analyses of flint clay from Missouri.

	1	2	3	4	5	6	7
Silica (SiO_2)	11.50	18.84	10.15	6.24	3.60	1.68	13.54
Alumina (Al_2O_3)	74.03	62.69	72.87	68.02	81.68	68.96	71.83
Ferric oxide (Fe_2O_3)	.97	1.21	.84	12.48	1.32	9.28	1.21
Loss on ignition	13.20	13.77	14.95	13.10	13.72	13.77	12.71

Mr. Thornberry states that in several analyses which he has seen, in which titanium oxide was determined, this constituent amounted to about 3 per cent.

In the petrographic descriptions of these clays the presence of rutile is noted. Analysis No. 5, above, approaches somewhat closely to the theoretic composition of diaspore, which has 85 per cent alumina and 15 per cent water.

No definite name has been suggested for this high-alumina clay. It is not an ordinary flint clay, and hence that name does not apply. Mr. H. T. Darlington, of Natrona, Pa., has suggested the name of jehyte, formed by the initial letters of J. E. Hutchinson, who called it to his attention. It seems to the writer, however, that diaspore clay would be a better name to use.

GRADES OF CLAY SHIPPED.

The grades of clay shipped from the district visited consist of hard flint clay, diaspore clay, and plastic clay.

The first clay is used in part for refractory materials and in part as a filler in certain manufactured products not classed as ceramic wares, for which, so far as known, some of the semihard flint clay is also used.

The diaspore clay is of value in the manufacture of refractories; in fact, it might be used as a substitute for bauxite. It can not be used alone, or at least without previous calcination, as its fire shrinkage is too high.

The plastic clay, which appears to be weathered flint clay, is sold to manufacturers of fire brick and also to manufacturers of rubber goods for a filler.

FUTURE OF THE DISTRICT.

It is somewhat difficult to predict the future of the district, but it seems safe to say that there will be a demand for the materials obtained from the clay pits as long as the supply lasts. The deposits appear to differ in size and to be liberally but irregularly distributed over the country. They do not occur at any uniform elevation, for some of them are on ridges and others are in depressions. Individual mining operations are usually small, and many of the pits are worked on a royalty basis. The farmer on whose land they are opened commonly does the digging. The actual amount of diaspore clay in sight in the pits visited was not large, but new deposits are continually being opened.

DETAILS OF THE FLINT-CLAY PITS.

HOFFLIN, CRAWFORD COUNTY.

A pit on the land of Dr. Cox, three-fourths of a mile northwest of Hofflin station, is about 50 feet in diameter and about 20 feet deep in the center. (See Pl. VII, *A*.)

Sandstone forms the southerly dipping, hanging wall on the south side, but the other walls show flint clay at most points, and the boundary of the deposit does not appear to have been reached. Sandstone is said to underlie the flint clay but was not visible.

On the north side of the pit, but practically in the center of the deposit, there is a mass of oolitic diaspore clay which extends to the surface. As exposed, the mass was about 10 feet maximum depth, 30 feet long and 25 feet wide. It was surrounded on all sides by flint clay.

The flint clay is fine grained, buff, and fairly hard. It has two sets of steeply dipping joints, and the joint planes in places show iron stains.

Most of it is smooth but in places it shows an oolite. A microscopic examination of the clay reveals its very fine grain, some of the parti-

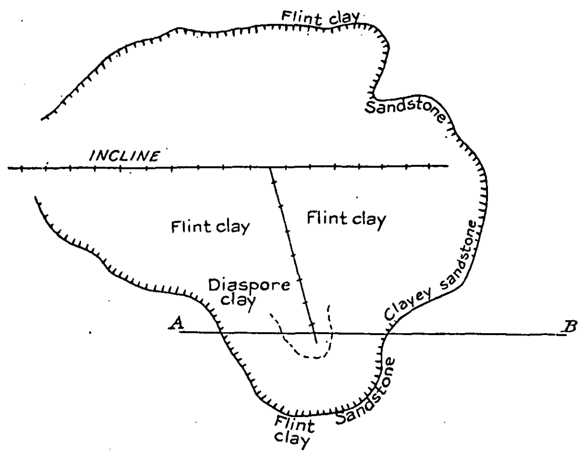


FIGURE 19.—Plan of Connell flint-clay pit, Owensville, Mo. For section along line *A–B* see figure 20.

cles being too small for identification and apparently of an isotropic nature. Kaolinite is in places rather abundant, but hydromica is scarce. A little fine-grained diaspore is present. Tourmaline and zircon are very scarce, but tiny needles of rutile are numerous.

The diaspore clay grades into the flint, and about 2½ carloads of it have been taken from this pit.

The country rock is sandstone.

OWENSVILLE, GASCONADE COUNTY.

Connell pit.—The largest pit near Owensville is operated by Mr. J. P. Connell and is about a quarter of a mile west of the town. The pit is an irregular opening (fig. 19) whose largest diameter is about 500 feet, and the product is mostly flint clay of the usual structure and texture. The best grade is gray and contains a few oolites.

Diaspore clay was seen only in small amounts and is of irregular occurrence. In places around the edge of the deposits there are masses of a softer semiplastic clay.

Sandstone occurs around the deposit and is exposed in some of the walls, but the boundary between it and the clay is irregular. Thus at one point in the west side of the pit the clay dips under it, but in the southwest side it projects outward into the deposit and is surrounded by clay on three sides. (See fig. 20.)

I am informed by Mr. H. T. Darlington, of Natrona, Pa., that above this sandrock lies one of similar texture and appearance, which contains grains of diaspore instead of quartz, and that on sight the one is likely to be mistaken for the other.

A thin section of the flint clay showed it to be very fine grained and to consist of a mixture of kaolinite, hydromica, and diaspore, together with a few tiny needles of rutile. Scattered through it were some small oolites made up of coarser grains of diaspore.

Another thin section of the flint clay, which contained more oolites than the one just mentioned, showed a fine-grained aggregate of abundant diaspore and kaolinite, together with a few grains of rutile and zircon. The oolites in the fine-grained groundmass are composed of diaspore that is more coarsely crystalline than the rest, but some of it is clear and some of it is stained with iron oxide.

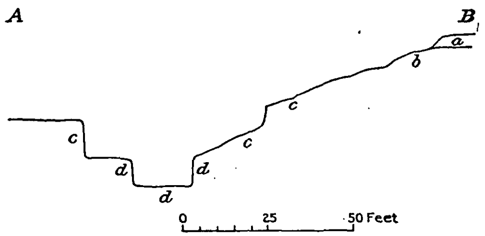


FIGURE 20.—Section along line *A–B* in plan of Connell flint-clay pit (fig. 19). *a*, Residual soil with chert; *b*, soft clay; *c*, clayey sandstone; *d*, flint clay.

Two samples of the clay that were examined contained abundant oolites in a fine-grained groundmass. Both samples showed considerable material that may be colloidal. Diaspore and kaolinite were common in one, but both together with hydromica were rather scarce in the other, except in the oolites, which showed much diaspore. Grains of rutile, titanite, and epidote were noticed.

About 70,000 tons have been shipped from this deposit.

Sassman pit.—Mr. C. C. Sassman has a small pit just northwest of Owensville. The excavation, which trends north and south, is about 130 feet long and 25 feet deep. The east face shows a pronounced synclinal structure, indicating that the clay was deposited in a basin. (See fig. 21 and Pl. VII, *B*.)

In the center of the section, below the overburden, which is 4 to 5 feet thick, there is a bed of red and white mottled clay, about 12 feet thick, and this is underlain by 8 feet of flint clay, which Mr. Sassman states has been proved to a depth of 20 feet below the bottom of the pit.

The mottled clay consists chiefly of red and white patches indiscriminately mixed, but some of it shows thin alternating red and white bands.

Under the microscope this material is found to be extremely fine grained and much of it isotropic, possibly colloidal. Kaolinite and hydromica are only sparingly recognizable. The only difference between the red and white material to be seen under the microscope is that the red grains are stained with hematite and the white are not.

The flint clay shows the usual texture and structure but not the usual hardness, and at the south end it grades upward into a whitish plastic clay. Diaspore clay occurs in the flint in a few small, irregular masses, but none was visible at the time of the writer's visit except a small patch on the west wall of the excavation, and this was not high grade. Whenever any good diaspore clay is found, it is put in a separate pile until enough has accumulated for shipment.

It is probable that the excavation marks almost the limit of the deposit from north to south, for sandstone occurs a little beyond

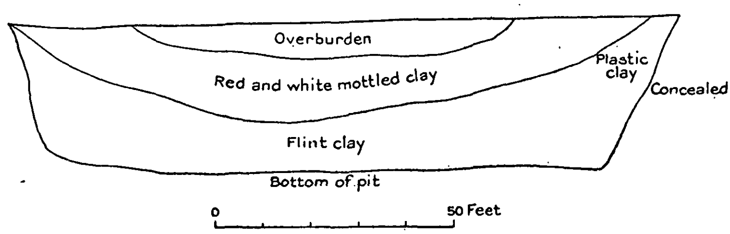


FIGURE 21.—Section in Sassman flint-clay pit, Owensville, Mo.

the south wall, and 50 feet northwest of the pit there is an outcrop of a massive fine-grained sandstone, which seems to dip gently toward the excavation.

The clay, however, extends probably 300 feet west of the excavation, and soft, oolitic clay lies close to the surface about 100 feet west of the opening.

Under the microscope the flint clay is found to be composed of exceedingly fine grains, mostly indeterminate, although a few grains of kaolinite are recognizable. There are numerous tiny grains of rutile.

The low-grade diaspore clay on the west side of the pit is harder than the flint clay. It shows abundant kaolinite, and diaspore is fairly common but very fine grained. There are some small oolites of coarser grains of diaspore. Rutile is very abundant but occurs mostly in tiny grains. There are also one or two grains of tourmaline and quartz.

The flint clay is the chief product of the pit, although the rough clay is marketed when enough has accumulated. Some white plastic clay has also been shipped. The mottled clay is thrown on the dump.

ROSEBUD, GASCONADE COUNTY.

Brown pit.—A small excavation on land belonging to Mr. Charles Brown, about 2½ miles southwest of Rosebud, was opened in the summer of 1918. The pit is leased by Dr. Cox, of Cuba. The product is hauled to Owensville.

The pit showed practically nothing but diaspore clay in the working face, the maximum length of which was 40 feet and the maximum height about 10 feet. A section of the pit is shown in figure 22. The diaspore clay was not of uniform quality from top to bottom; indeed it appeared to occur in beds. The upper bed was brownish, oolitic, and sandy, as well as more or less porous, and below this bed was a somewhat harder and denser diaspore clay in which the larger oolites were more scattered.

A sample of the lower bed was studied in this section. Under the microscope it shows a very fine-grained matrix that contains abundant kaolinite as well as diaspore. Coarser grains of diaspore make up the oolites. Rutile is very scarce.

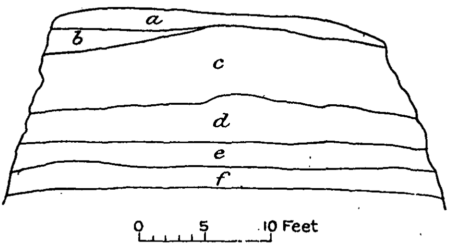


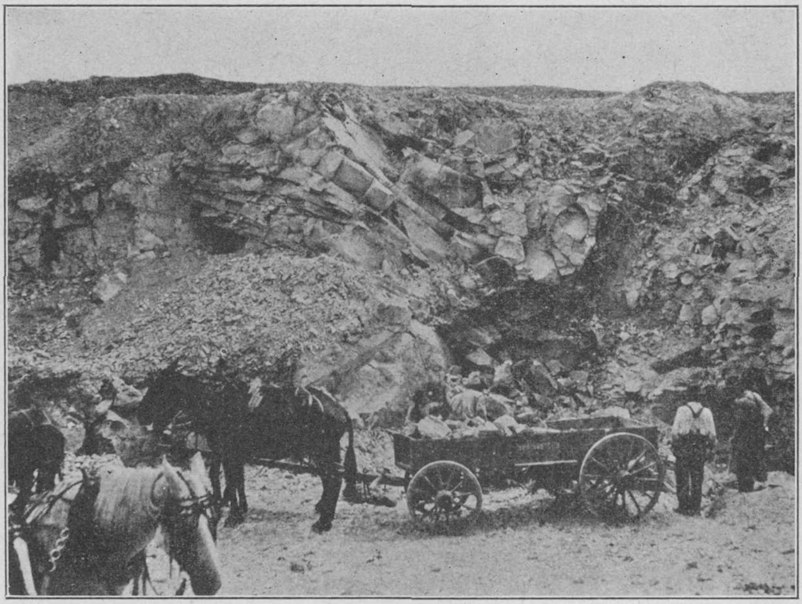
FIGURE 22.—Section in Charles Brown flint-clay pit, 2½ miles southwest of Rosebud, Mo. *a*, Overburden; *b*, flint clay; *c*, rough-textured porous diaspore clay; *d*, oolitic flint clay; *e*, hard diaspore clay; *f*, smooth flint clay, largely concealed.

There were no outcrops around the pit, and the size of the deposit is not known. It may or may not grade into the ordinary type of flint clay.

Bauers & Watkins pit.—The firm of Bauers & Watkins operates a pit 1 mile east of Rosebud which has been in operation for two years. The main opening is about 125 feet long and about 75 feet in maximum width, but only the south side showed a good working face, as no excavating was being done at the other sides. At the west end the pit has run into sandrock, but it is claimed that the deposit extends beyond the limits of the excavation on the north and south. The material is all flint clay, of fine-grained texture and massive structure. There is no evidence of bedding, but the entire mass exposed in the working face (Pl. VIII, *A*), which is about 20 feet high, shows irregular jointing.

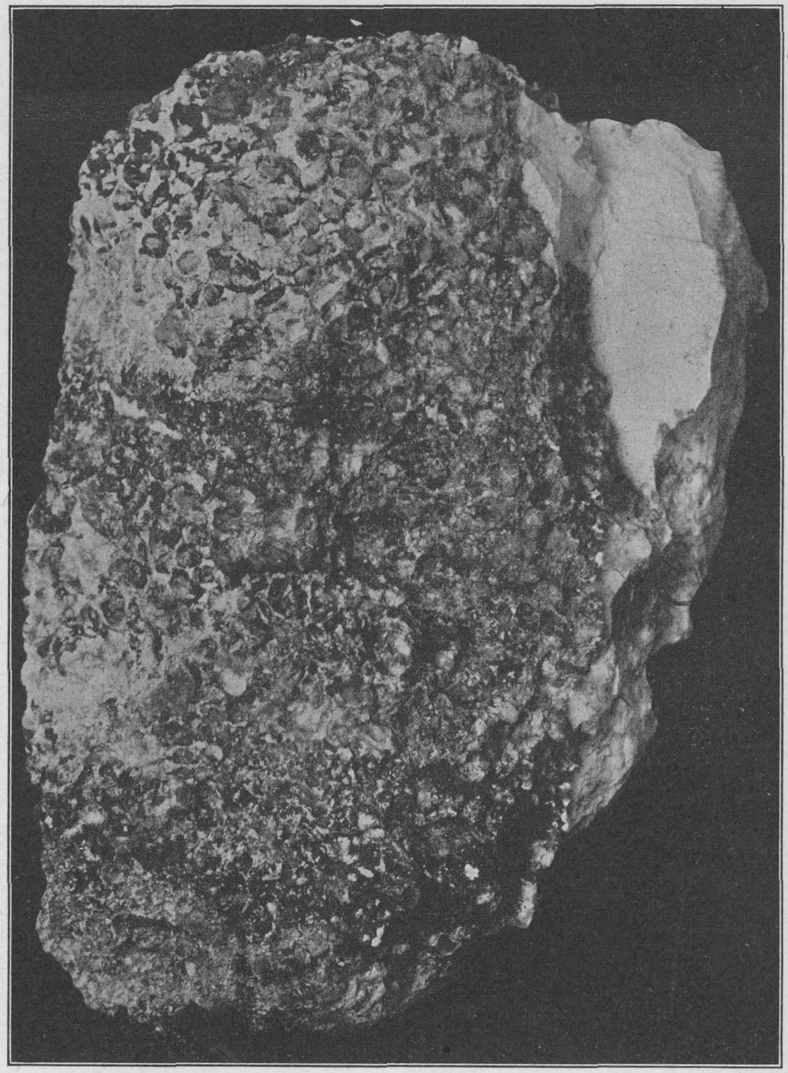
A small opening had been made in August, 1918, about 600 feet west of the first pit, but it was not over 8 feet deep. Only the normal flint clay had been uncovered.

Heidel & Toelke pit.—The firm of Heidel & Toelke has two pits near Rosebud. The pit that was being worked is 1 mile west of town. The opening is irregularly crescent-shaped (fig. 23) but has maximum diameters of about 250 and 200 feet.



A. BAUERS & WATKINS FLINT-CLAY PIT, ROSEBUD, MO.

B. FLINT CLAY IN TOELKE & HEIDEL PIT, ROSEBUD, MO.



INDIANAITE ATTACHED TO PEBBLY POTTSVILLE SANDSTONE.

The indianaite occurs also as cement between the pebbles.

Most of the material is the usual hard flint clay (see Pl. VIII, *B*), but much red mottled clay and also some coal is associated with it.

The coal, which is somewhat impure, occurs on the south side of the pit, where it forms a horizontal and in places a well-defined bed at least 1 foot in thickness. In some places it seems to be sharply separated from the flint clay, but at others it grades into the flint clay. Indeed, along the boundary the material is a mixture of gray-brown massive clay and a conglomerate-like mass composed of rounded pellets and grains of flint clay embedded in a blackish matrix. These pellets and grains are elongated parallel to the bedding of the clay. Lumps and grains of pyrite occur both in the coal and in the clay near the coal. A little gypsum was also noticed, in the form of small scales of selenite.

The conglomeratic material was fine grained throughout, but in general the same minerals were recognizable in the pellets as in the matrix. Among these minerals diaspore was abundant but very fine, kaolinite was fairly common, and there were the usual tiny grains of rutile.

The matrix surrounding the pellets had a chocolate-colored stain, but the pellets were practically free from it. No oolites were noticed.

In the west end of the pit the wall is sandrock, the northwest side of the pit is in reddish clay, and at the east end there is a flint clay that is streaked with red. The east face presents a most striking appearance, the thin red bands in general dip toward the north, but in places show curious contortions.

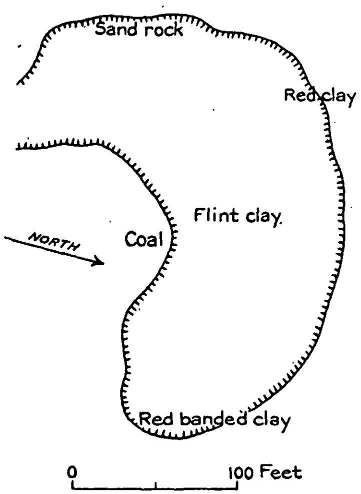


FIGURE 23.—Plan of Heidel & Toelke pit, Rosebud, Mo.

The flint clay is said to extend 20 feet below the present floor of the pit.

BLAND, GASCONADE COUNTY.

Shockley pit.—H. H. Shockley has a small pit about 1½ miles west of Bland, on the north side of the Chicago, Rock Island & Pacific Railway, but is mining only plastic clay at present.

Campbell & Lichte pit.—The firm of Campbell & Lichte has opened a pit one-eighth of a mile southeast of Bland on the property of D. Werfelman and has been operating for about a year. The total diameter of the deposit is said to be about 300 feet, and the pit, which has a much smaller diameter, is 40 to 50 feet deep. Clay outcrops on the north and west sides, but in the south and east walls sandrock is encountered.

Hard clay had been found only in the lower part of the pit on the east side. All the rest of the clay was plastic. Most of it had the structure and texture of the normal flint but was appreciably softer. In places the clay is distinctly carbonaceous and contains plant fragments, none of them large enough, however, to be identifiable.

This clay is very fine grained and contains abundant kaolinite and hydromica but no observable diaspore. A few grains of rutile were also identified.

This firm has two flint-clay pits 2½ miles west of Bland and three-fourths of a mile south of the railroad.

CANAAN, GASCONADE COUNTY.

A number of pits have been opened around Canaan, but only two were visited.

The pit of S. Haynes is 2 miles south of Ellis Spur. The diaspore clay forms a large lens, mostly on top of the flint clay, although some of the flint clay lies over it. There is no sharp line of separation between the diaspore clay and the flint clay, the two grading into each other in a distance of about a foot. Only the best diaspore clay is shipped.

The following tests of the diaspore clay were made at the Bureau or Mines laboratory, Columbus, Ohio:

General physical tests of diaspore clay from Haynes pit, Ellis Spur, near Canaan, Mo.

Workability	Short; lacks plasticity; molds with difficulty; cracks slightly in drying; grit visible.
Water of plasticity per cent	23.69
Air shrinkage, by volume do	12.90
Air shrinkage, linear, calculated do	4.5
Modulus of rupture of raw clay pounds per square inch	77.2

Fire tests of diaspore clay from Haynes pit, Ellis Spur, near Canaan, Mo.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage, (per cent in terms of volume of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	31.40	Buff	10.60	3.8
1,250	31.40	do	10.61	3.8
1,310	34.96	do	11.69	4.0
1,370	34.50	do	12.80	4.6
1,410	32.80	Gray	13.50	4.7

Fusion point, cone 35+. Steel hard at 1,190° C.

This is a very refractory clay of low bonding power. It can, however, be used for high-grade refractories if it is mixed with a more plastic clay.

The Hensley pit, just west of Canaan, which is operated by Cox & Sassman, is worked only for smooth flint clay.

The Baxter pit, 1 mile south of Canaan, produces smooth flint clay.

The Helm pit, 1¾ miles north of Canaan, which was opened in the summer of 1918, is said to contain some diaspore clay.

The Lacey pit, three-fourths of a mile northeast of Canaan, produces only smooth flint clay.

The Dittmar pit, three-fourths of a mile southeast of Ellis Spur, or 2½ miles southwest of Canaan, is worked by Cox & Sassman. It supplies both smooth flint clay and diaspore clay, but the diaspore clay is the one that is chiefly shipped.

The two Myers pits are 3 miles south of Canaan. They supply only smooth flint clay and contain no diaspore clay.

BELLE, MARIES COUNTY.

Three pits were being operated near Belle in 1918, as follows:

The Travis pit, 2½ miles south of Belle, supplies both flint clay and diaspore clay.

The Pointer pit, 2 miles south of Belle, ships only flint clay.

The Jackson pit, 1½ miles southeast of Belle, produces only flint clay.

These pits are being worked by Heck Bros., who sell, in part at least, to Cox & Sassman.

INDIANAITE OF INDIANA.

Geologists and others have for many years known of the occurrence of a white clay in south-central Indiana, to which the name of indianaite was given by Cox in 1874.[58] Dana[59] subsequently included this clay under halloysite, and Blatchley[60] still later refers to it as "kaolin or indianaite," but says that some of it consists of the mineral allophane.

Although this clay is widely distributed, its commercial use has never been long successful, and consequently it has never been extensively developed.

GENERAL FEATURES OF THE DEPOSITS.

By W. N. Logan.

GEOGRAPHIC DISTRIBUTION.

Indianaite occurs along the contact of the Mississippian and Pennsylvanian rocks in Indiana, which extends from Benton County north

[58] Cox, E. T., Porcelain, tile, and potter's clays: Indiana Geol. Survey Eighth, Ninth, and Tenth Ann. Repts., p. 154, 1879.

[59] System of Mineralogy, 6th ed., p. 688, 1892.

[60] Blatchley, W. S., The clays and clay industries of Indiana: Indiana Dept. Geology and Nat. Res., Twenty-ninth Ann. Rept., p. 54, 1905.

of Wabash River, on the northwest, to Perry County, on Ohio River at the south. The zone of this contact passes through the counties of Benton, Warren, Fountain, Montgomery, Parke, Putnam, Clay, Owen, Monroe, Greene, Lawrence, Martin, Orange, Dubois, Crawford, and Perry. (See fig. 24.) The contact is concealed by glacial

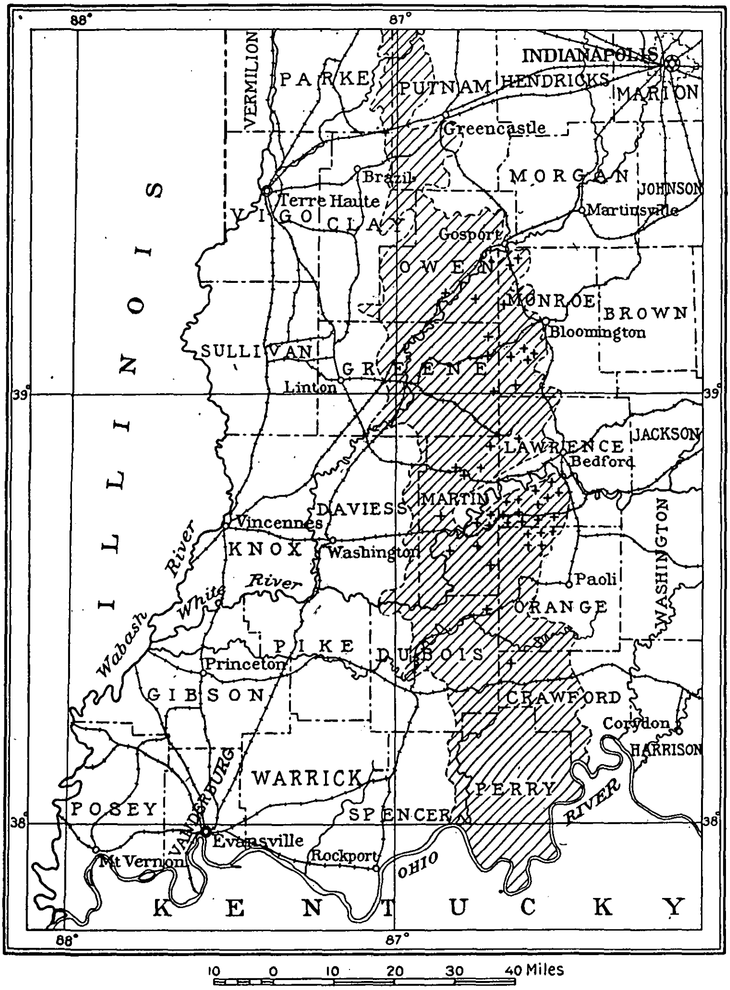


FIGURE 24.—Map of part of Indiana showing area (shaded) that may contain indianaite. +, Known outcrop.

overburden in the northern part of the area, but from Monroe County southward the contact lies in the nonglaciated portion of the State, and hence in this region outcrops are more abundant. The width of the area where the contact is accessible differs from place to place but is about 12 miles in the northern part and about 18 miles in the southern part. The attenuated margin of the Pennsylvanian rocks has been eroded in this region to such an extent that, as a rule, they remain only on the tops of the high ridges which form the divides between the present drainage lines. In places these ridges rise 300 feet or more above the adjacent valleys, and the line of contact between the Mississippian and Pennsylvanian rocks is in many places 200 feet or more above the valleys. The ridges are decidedly irregular, and their margins are serrated by the indentations of minor drainage lines and their intervening spurs. The ridges in most places are capped by a soft sandstone which crumbles easily and therefore works down over and conceals the outcrops of the indianaite along the contact zone. Indeed, the mantle of sand thus produced is so general along the contact that good outcrops are exceptional. In some places a stream may cut in against the line of contact and expose the indianaite. In other places a spring may discharge its waters from beneath the bed of indianaite, and the quantity of water may be sufficient to carry away the detritus and form a perpendicular face at the outcrop.

Indianaite has not been reported from all the counties along the contact zone. It occurs in Owen, Greene, Monroe, Lawrence, Martin, and Orange counties, and has been reported from Dubois and Crawford counties. Serious attempts at development have been made only in Lawrence County, but even there actual production has been confined almost entirely to a small part of a half section. Outcrops of white clay occur in many places and test drifts, pits, and drill holes have revealed its presence in many sections in the southwestern part of the county. Explorations have been more extensive in this county than elsewhere in the indianaite belt, and for this reason the prospects there appear to be the best. Martin County probably offers the next best field for exploration and development, and Orange, Greene, Monroe, and Owen counties would follow, perhaps, in the order named.

GEOLOGIC OCCURRENCE.

The indianaite occurs near the contact between the Mississippian and Pennsylvanian rocks in Indiana. It seems to rest upon the Mississippian beds at practically all horizons, at some places as low as the top of the Mitchell limestone, at others on the lower Chester, at still others on the middle Chester, or even near the top of the Chester. It underlies the Pottsville ("Mansfield sandstone" of early reports) and lies at different horizons of the Chester, so that it must belong to the Pennsylvanian series. Further proof of its age is found in the occurrence, at one point at least, of a small body of indianaite above the main bed and in Pottsville sandstone, which rests upon the main bed of indianaite at this point. Another proof is found in the presence at one point of a stratum of clay that contains small quartz pebbles, similar to those which occur at this point and elsewhere in the base of the Pottsville and which have not been found in the Chester. This stratum of clay rests immediately below the indianaite and in one place projects into the indianaite. (See fig. 25.)

CHARACTER OF THE OUTCROP.

The presence of pure white indianaite at the outcrop is rare, but not uncommonly small particles of white indianaite are distributed through the detritus that covers the outcrop. The weathered part of the bed at and near the outcrop consists of a mahogany-colored clay, which contains small fragments of the white indianaite, especially in its upper part, which lies under sandstone ledges that are fairly compact. The mahogany color of the clay has doubtless originated in part from the staining of white indianaite by oxide

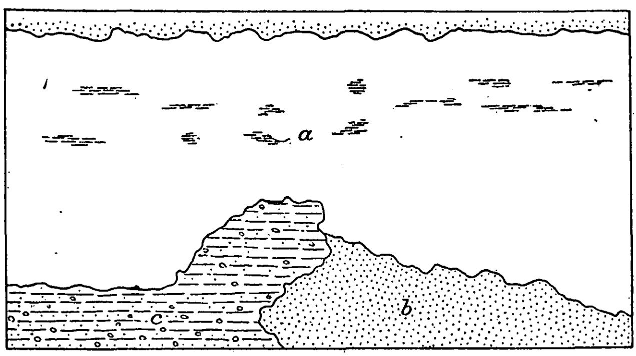


FIGURE 25.—Neck of clay projecting into indianaite in the Gardner mine, near Huron, Ind. *a*, White indianaite; *b*, sandstone; *c*, black laminated clay.

of iron. The following analysis shows the composition of a sample of this material:

Analysis of mahogany-colored clay from Indiana.

Silica (SiO_2)	33.04
Alumina (Al_2O_3)	17.33
Ferric oxide (Fe_2O_3)	27.96
Manganese oxide (MnO)	2.22
Lime (CaO)	1.52
Magnesia (MgO)	1.11
Titanium oxide (TiO_2)	.69
Alkalies (Na_2O,K_2O)	1.77
Volatile matter	13.87
	99.51

GENERAL CHARACTER OF THE CLAY.

In the mass the indianaite occurs either as coarsely granular material or as concretionary or other masses of porcelain-like appearance. These porcelain-like masses break into irregular fragments, which exhibit on some surfaces a conchoidal fracture. In some places the porcelain-like material has a wavy laminated structure and is marked by stained lines and surfaces that are covered with projecting botryoidal masses of the white material that separates the layers of porcelain-like indianaite. In other places it is pitted with these small white granules of clay, which produce an amygdaloidal structure. These small granules have about the same degree of hardness as the surrounding indianaite. Under the microscope the porcelain-like indianaite exhibits a granular appearance. The grains are apparently spherical in form and in some sections are arranged in a dendritic structure. The dendritic structure may be due to the loss of water and consequent shrinkage when the section is heated during its preparation. In some places the white indianaite presents an irregular laminated appearance. This lamination seems to be more clearly marked in the yellow clay than in the white. In some sections, however, the laminated appearance is due to the presence of thin layers of yellow clay within the white. Concretionary masses occur in places in the white indianaite. These masses range in size from a few inches to 9 or 10 inches in diameter. The concentric layers are separated by thin lines of black and yellow stain. The white indianaite as a rule is hard, but in some places it is soft and very plastic, resembling in appearance a white ball clay. In other places the plastic clay is yellow and is interstratified with yellow or brown sand.

Both the granular and the massive varieties of indianaite may be translucent and greenish or they may show an opaque white body which resembles the fracture surface of bisque. The translucent form is in places composed of a series of small geode-like masses, arranged in a generally horizontal position. The walls are about one-eighth of an inch in thickness and the diameter of the cavities is from one-tenth to one-eighth of an inch. The interiors of the cavities are lined with a layer of milk-colored indianaite, which has a mammillary surface, and some of the cavities are wholly or partly filled with rounded grains of the same material. In one hand specimen five of these cavities are arranged in a horizontal distance of 2 inches. Cavities of different sizes are common in the indianaite. The porcelain-like form fractures irregularly and also has a conchoidal fracture.

The composition of a sample of the mine-run white clay is as follows:

Analysis of mine-run sample of white indianaite from Gardner mine.

Silica (SiO_2)	40.48
Alumina (Al_2O_3)	39.60
Hygroscopic water (H_2O below 100° C.)	5.01
Combined water (H_2O above 100° C.)	15.03
Ferric oxide (Fe_2O_3)	.11
	100.23

Layers of coarse or disconnected masses of coarse sand or sandstone, stained with iron oxide and containing small particles of white indianaite, occur in many portions of the bed of indianaite. (See fig. 28.) Separate blocks of sandstone are in places almost, if not completely, surrounded with white indianaite (fig. 26), and locally masses of sandstone are penetrated by a veinlike body of indianaite. (See fig. 27.) In one place a dark laminated necklike body of clay extends from a floor of similar material up into the indianaite. This clay contains pellet-like bodies of white clay, which are soft and plastic in place but hard and granular when dry. It contains also white quartz pebbles, such as are found in the basal sandstone members of the Pottsville.

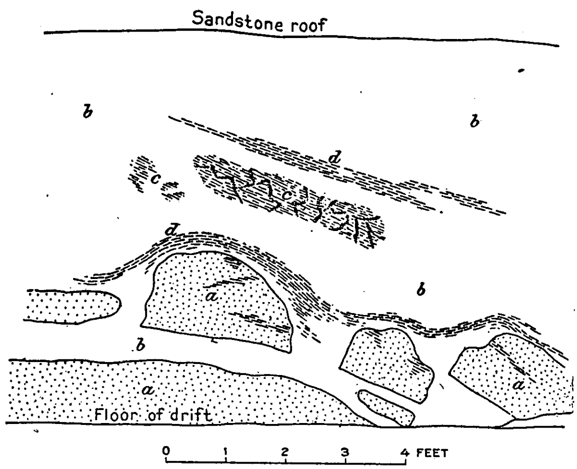


FIGURE 26.—Section along north side of second cross entry on east side of tunnel in the Gardner mine, near Huron, Ind. *a*, Sandstone; *b*, milk-white clay; *c*, waxy clay; *d*, clay that shows banded structure. (From a sketch made by H. Ries.)

The clay has a fetid odor similar to that of muck and contains concretionary masses of marcasite. At another point in the bed of indianaite next to the sandstone roof there were white and dark layers of indianaite above, then a layer of white, partly laminated indianaite below, and then a 4-foot layer of sandstone, which occupies the lower part of the deposit. The sandstone layer was divided near its central part by a vein of white indianaite which extends through the 4-foot layer of sandstone. The layer of sandstone has a thin fin that extended upward obliquely into the white indianaite. This fin was about 5 feet in length and 1 foot thick in its thickest part. Above the lens of sandstone there are several concretion-like masses of indianaite, the porcelain-like layers of which are separated by dark stains. (See fig. 27.)

ASSOCIATED ROCKS.

The rock which everywhere overlies the indianaite, so far as observations go, is sandstone of Pennsylvanian or Mississippian age. The character of the layer in immediate contact with the upper surface of the indianaite is variable. The roof in places is composed of soft pink sandstone, in others of conglomeratic sandstone, and in still others of a rock that is firmly cemented and almost an iron ore in composition. The underlying rock in most places is a shale or clay.

In one locality a small body of white indianaite is completely surrounded with sandstone, in another thin layers of sandstone underlie the indianaite, and in a few others lenslike masses of limonite occur at the base of the indianaite. These masses of limonite contain quartz pebbles characteristic of the Pottsville formation.

Within the mahogany clay irregular eroded masses of limestone are sometimes found, and microscopic sections of this limestone show it to be highly fossiliferous. Within the indianaite bed the chief associated materials are sandstone, sand, conglomerate, and concre-

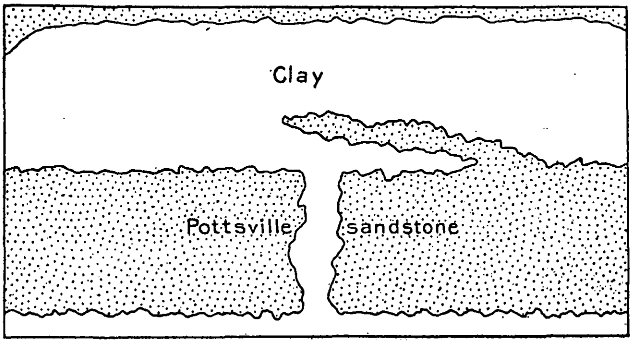


FIGURE 27.—White indianaite (clay) overlying sandstone, vein of indianaite crossing the sandstone, and fin of sandstone extending upward into the indianaite in the Gardner mine, near Huron, Ind.

tionary masses of limonite. A sample of the limonite from the base of the indianaite has the following composition:

Analysis of limonite at base of indianaite from Lawrence County, Ind.

Iron oxide	83.73
Insoluble matter	2.56
Loss on ignition	12.02
	100.31
Total iron	58.61

A geologic section that was measured near Huron shows the relation of the indianaite to the underlying and overlying rocks. The section is as follows:

Geologic section near Huron, Ind.

	Feet.
Red, brown, and pinkish sandstone, conglomeratic at the base	100
Indianaite, 6 to 11 feet, average about	6
Black laminated clay, some gravel	3
Unconformity.	
Shale, light green (Mississippian)	10
Limestone, bedding irregular	20
Shale, plastic	38
Limestone, reddish, thin-bedded	7
Shale, similar to above	21
Limestone, thick layers	15

These limestones and shales below the unconformity belong to the Chester group of the upper Mississippian.

RESOURCES OF INDIANAITE.

A question of absorbing interest is, What is the available quantity of the white clay? In the present state of development this question is difficult to answer. If the judgment is based upon the number of outcrops, the conclusion is inevitable that the quantity is large. If the judgment is based upon the results of the meager development or upon the visible quantity of mahogany clay, the conclusion is similar. After going over the greater part of the field the writer believes that there is a large quantity of clay of all grades. In fact, it underlies thousands of acres of land in the counties mentioned, although how much of it is pure white can not be estimated from the data which are at hand, but the total amount is probably large.[61]

THE DEPOSIT OF INDIANAITE NEAR HURON, LAWRENCE COUNTY, IND.

By H. Ries.

STRUCTURE OF THE BEDS.

The writer has not had the opportunity of making so extended a study of these deposits as Prof. Logan, with whom he spent two days in the field. During that time he visited several outcrops, as well as one accessible mine in Lawrence County, 4 miles northeast of Huron and 3 miles south of Williams. The opening is on the north side of the ridge on the Gardner property, where a tunnel has been driven southward into the hill for a distance of 300 feet. As the tunnel slopes gently downward from the entrance, it was not possible to examine it for a distance of more than 150 feet on account of accumulated water.

[61] Blatchley, W. S., Clays and clay industries of Indiana: Twenty-ninth Ann. Rept. Indiana Dept. Geology and Nat. Res., pp. 13–657, 1905.

The clay, as far as it was followed, occurs as a nearly horizontal deposit whose thickness ranges from 5 to 11 feet. The roof is formed by Pottsville ("Mansfield") sandstone of coarse pebbly character. The pebbles are of quartz, and the rock is open textured. In most places there seems to be a sharp line of demarcation between it and the clay, but in some places the contact is gradational. The con-

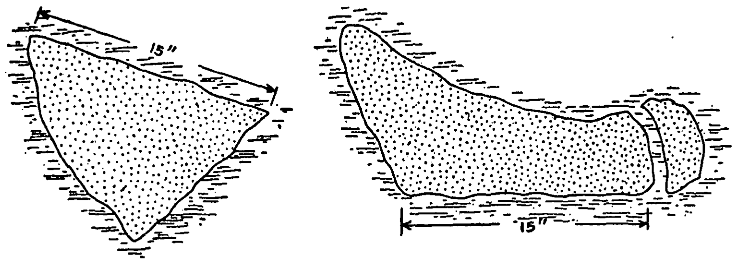


FIGURE 28.—Angular pieces of pebbly sandstone completely surrounded by white clay in wall of crosscut about 50 feet from entrance of tunnel in the Gardner mine, near Huron, Ind.

tact of the clay with the roof is usually nearly horizontal, but at one place the roof dips so steeply toward the floor that in this entry the tunnel has been stopped. At this point also sandstone underlies the clay, and at one place the section shows a depression in the underlying sandstone about 12 inches wide and 12 inches deep, in which the boundaries are not perfectly sharp.

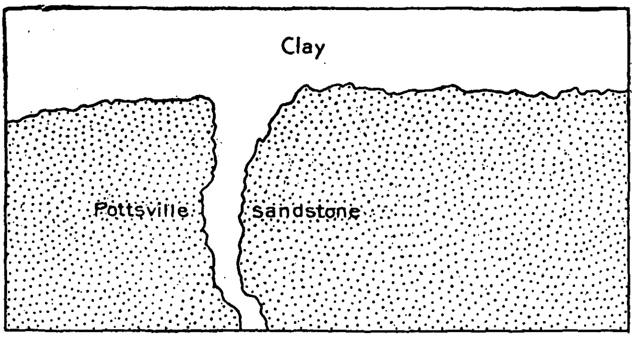


FIGURE 29.—Indianaite overlying sandstone and vein of indianaite extending into the sandstone in the Gardner mine, near Huron, Ind. The specimen shown in Pl. IX was taken from the right wall of the vein sketched in the figure.

The floor in most of the mine was not clearly visible but was said to be mainly of Chester shale, although in places sandstone extended to the floor level.

Three curious and perhaps significant structural features are the occurrence of loose blocks of the sandstone in the clay (fig. 28); the occurrence of veinlike masses of the clay which cut across the bedding planes of the sandstone (fig. 29), one of them fully 8 or 10 inches wide and 4 feet long; and the dissemination of clay in the loose blocks of sandstone which are embedded in the clay bed. The clay occurs in the blocks of sandstone either as stringers that enter the blocks from the outside, or else apparently it forms the matrix around the pebbles.

PHYSICAL CHARACTER OF THE CLAY.

The waxy or earthy character of the white clay, the presence of druses, and the banded structure have already been mentioned by Prof. Logan. In several places the writer observed that the banding seems to follow the boundaries of the inclosed blocks of sandstone.

The clay is very fine grained. The waxy variety is massive and lustrous, and some of it is translucent on the edges.

On exposure to the atmosphere it dries out, loses its luster, and assumes a milky appearance. This change is accompanied by the development of cracks, owing to the loss of moisture, and bleaching. Thus, a sample that when fresh had a blue color closely resembling turquoise lost it almost completely in less than a month indoors.

The earthy variety is fine grained, soft, and generally white, but some of it is stained by iron or manganese. As far as the writer was able to enter the workings the clay was mainly white, but in the inner half of the tunnel it is mostly colored.

PETROGRAPHIC CHARACTER.

Two samples of the clay were examined petrographically. The massive waxy material contained a number of large flakes which are nearly or quite isotropic, except for minute inclusions. In addition, there were numerous spherulite-like grains (Pl. XXVIII, *B*, p. 297) which showed the interference colors of kaolinite. Rutile was fairly abundant in exceedingly minute grains.

The earthy variety of the clay showed numerous radiating bunches and even spherulites of a hydromica, possibly sericite. Kaolinite was also abundant, but in addition there were a number of comparatively large, clear, transparent flakes that had a slight bluish tinge and a moderate refractive index. Rutile was scarce.

One rounded lump of Pottsville sandstone was surrounded by a white claylike material that had a hyaline appearance when examined with a hand lens. This material when crushed and examined under the microscope showed a mass of granular colorless isotropic fragments that had an index of refraction between 1.501 and 1.53. When tested with hot hydrochloric acid it gelatinized.

The hyaline character and the result of the gelatinization test agree with the properties of both allophane and schroetterite, although only allophane has been reported in the indianaite. There is a difference, however, in their chemical composition.

The waxlike material, which has a slight luster when fresh, contained a considerable quantity of an isotropic mineral, which might be either halloysite or allophane. This material did not gelatinize with hydrochloric acid so abundantly as did the hyaline material. This, however, was to be expected, for it did not contain so much of the isotropic mineral. The drusy material is made up entirely of isotropic colorless grains.

As the two types of material are made up largely or wholly of isotropic grains, it is evident that some mineral other than kaolinite is present, and, as already stated, the clay has been described by different writers as containing halloysite and allophane.

It seemed probable, therefore, that the deposit might contain more than one hydrous aluminum silicate, and so partial analyses were made of the two principal types—the waxy clay and the hyaline material which occurs close to the pebbly sandstone in places and also forms drusy masses. The composition of these two types of material, together with the theoretic composition of allophane, schroetterite, and halloysite, are given in the following table.

Analyses of clays from Gardner mine, near Huron, Lawrence County, Ind., and composition of allophane, schroetterite, and halloysite.

	1	2	3	4	5
Silica (SiO_2)	43.47	10.70	23.80	11.70	43.5
Alumina (Al_2O_3)	38.03	54.53	40.5	53.1	36.9
Water above 100° C. (H_2O+)	14.73	29.48	35.7	35.2	19.6
Ferric oxide (Fe_2O_3) } Ferrous oxide (FeO) }	.25	.37	....	....	....
Water below 100° C. (H_2O-)	3.82	5.26	....	....	....

1. Waxy clay, Gardner mine. George Steiger, analyst.
2. Hyaline material, same place. George Steiger, analyst.
3. Allophane. Dana, System of mineralogy, 6th ed., p. 693, 1912.
4. Schroetterite. Idem, p. 694.
5. Halloysite. Idem, p. 688.

A comparison of the analyses given in the table shows that the hyaline material resembles schroetterite, but the waxy clay agrees more closely with halloysite than allophane. It is not pure halloysite, however, for the microscopic examination shows that the material contains some kaolinite and hydrous mica.

Both samples from the Gardner mine probably contained more moisture when collected than they did when analyzed, for they lost some of it by air drying.

The local occurrence of schroetterite in the Gardner mine in botryoidal masses indicates that it was evidently deposited from solution, and several of the occurrences mentioned by Dana[62] appear to have a similar origin.

[62] System of mineralogy, 6th ed., p. 694, 1912.

RELATIONS OF THE CLAY TO THE ROCKS ASSOCIATED WITH IT.

Further interesting facts are observed on examining the relation of the clay to the pebbly sandstone.

A specimen of pebbly Pottsville sandstone with white clay attached is shown in Plate IX. The clay is the marginal portion of a well-defined vein that cuts directly across the bedding of the sandstone. (See fig. 29.) Although the contact between the clay and the wall rock appears to be sharp, nevertheless close examination shows that the clay penetrates the pores of the rock, and even cracks in the pebbles. One pebble 0.2 by 0.3 inch is cut across by a veinlet of white clay 0.01 inch wide. The sides of the clay-filled crack are irregular and the projections on one wall of the crack are not opposite any corresponding depression on the opposite side.

The pebbles of the sandstone commonly show decided evidence of corrosion, and in places there are clayey patches larger than the usual interstitial spaces between the pebbles. Both clay and limonite may be present in the pore spaces of the rock.

There is no doubt that this clay is markedly different in mode of occurrence from any other deposit yet described.

It is clearly rather closely associated with the unconformity between the Pottsville and the Chester, but apparently lies in places in the Pottsville or (according to Logan) in places even within the Mississippian. This contact, which is an erosive unconformity, is very irregular and does not lie at a uniform elevation, even though the beds locally may appear to be practically flat. The horizon of the white clay may change in altitude 100 feet in a comparatively short distance, and between Bloomington and Huron, according to Logan, the difference in the elevation of the clay is 250 feet.

Although the clay has been found at many points it is not definitely known to be a continuous deposit.

Whatever theory of origin is advanced, it seems to the writer that the following facts must be borne in mind:

1. The deposit is essentially bedlike in its character.
2. It may surround lenses of Pottsville sandstone.
3. It may contain angular or rounded blocks of Pottsville sandstone.
4. Bodies of the clay may occur in Pottsville sandstone.
5. The clay is in places sharply separated from the sandstone, but in other places it grades into the sandstone.
6. Stringers or veinlike masses of the clay penetrate the Pottsville in places directly across the bedding.
7. The clay locally shows a banded structure parallel with the horizontal surface either of the sandstone or of the inclosed blocks of the sandstone.

8. The waxy clay forms irregular patches in the earthy material.

9. Cavities lined with drusy masses of a whitish material occur in the clay.

10. At one point a pipelike mass of shale containing pellets of the white clay extends upward into the main clay deposit.

THEORIES OF ORIGIN.

COMBUSTION OF COAL BED.

In 1859 Leo Lesquereux,[63] in writing of the white clay, expressed the opinion that it represented the residue left by the burning of a bed of coal. This view can not be correct, for the reason that the heat of the burning coal would have dehydrated the clay and baked it, which has not occurred. Some interesting data on this point have recently been given by Rogers.[64]

ALTERATION OF LIMESTONE.

E. T. Cox[65] conceived the idea that the clay had been formed by the decomposition of a bed of limestone, which at other points lies at the same horizon instead of the clay. Logan[66] states that the limestone mentioned by Cox has been brought to the approximate elevation of the deposit of indianaite by a fault that trends about N. 60° E. in that region.

It is interesting to quote a portion of Cox's description, even though his theory was probably incorrect. He says:

> The clay (kaolin) lies immediately beneath the Millstone grit or pebbly conglomerate of the coal measures and here occupies the place of a bed of *Archimedes* limestone, which is seen in situ about 2 miles southeast of the mine. Though similar in its composition to kaolin, this clay differs physically and owes its origin to an entirely distinct set of causes and effects. While the former is derived from the decomposition of the feldspar of feldspathic rocks, such as granite, porphyry, etc., the porcelain clay of Lawrence County has resulted from the decomposition, by chemical waters, of a bed of limestone and the mutual interchange of molecules in the solution, brought about by chemical precipitation and affinity.

Although this explanation is a little vague, it seems to indicate the idea of replacement.

Maurice Thompson[67] thought Cox's theory was correct but added the explanation that rain water filtering through the overlying

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[63] Lesquereux, Leo, Report on the distribution of the geological strata in the coal measures of Indiana: Report of a geological reconnaissance of Indiana made in 1859–60 by R. Owen, p. 320, 1862.

[64] Rogers, G. S., Baked shale and slag formed by the burning of coal beds: U. S. Geol. Survey Prof. Paper 108, pp. 1–10, 1917.

[65] Cox, E. T., Indiana Geol. Survey Sixth Ann. Rept., p. 15, 1874.

[66] Private communication.

[67] Thompson, Maurice, The clays of Indiana: Indiana Dept. Geology and Nat. Hist. Fifteenth Ann. Rept., p. 37, 1886.

pebbly sandstone gathered and carried down with it sufficient silica and alumina to replace the carbonate of lime dissolved.

A modification of this theory was later suggested by W. H. Thompson,[68] who believed that the silica and alumina of the clay were a combination of the insoluble constituents of the limestone, together with additional quantities of the same substances leached out of the overlying sandstone by percolating meteoric waters. He also thought these waters brought down a trace of mica in a fine state of division.

DEPOSITS OF RESIDUAL CLAY.

According to another theory the clay was derived by the weathering of Chester shale or Pottsville sandstone. However, the sandstone in places lies between the clay and the shale, and even where the sandstone is not present, there seems to be no transition zone showing the passage of the clay into shale, so that it is not likely that the clay was derived from the shale. It could not have been derived from the sandstone where that rock overlies it, for the material of which the sandstone is composed is not likely to form residual clay.

IGNEOUS INTRUSION.

According to still another theory the clay represents a decomposed sheet of intrusive rock. There are serious objections to this theory, because the clay shows no evidence of remains of the original texture, and it seems unlikely that such a sheet should have followed the uneven contact so closely; nor would it account for the bodies of clay, some of them of indefinite boundary that occur in the sandstone above the main body of the clay. Moreover, such an intrusion would have affected the shale, and there is no evidence that this occurred. Furthermore, in such an apparently extensive deposit of clay some less altered igneous rock would probably remain, and besides the areal extent of the deposit seems too great for that of an igneous mass of such slight thickness.

VEIN DEPOSITS.

According to another theory the clay was deposited in veins, having been introduced in solution along the lines of contact between formations. The deposition of hydrous aluminum silicates by this method has not usually been recognized, and, moreover, it is difficult to conceive how a horizontal cavity from 5 to 11 feet high could have been formed and held open until it was filled.

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[68] Thompson, W. H., Outline sketch of the most valuable minerals of Indiana: Indiana Dept. Geology and Nat. Hist. Sixteenth Ann. Rept., p. 78, 1888.

Bastin and Laney,[69] however, have noted the occurrence of kaolinite in cavities, where they state it has been deposited either from suspension or solution. The curious banding observed in places and the geodal cavities tend to favor the theory of deposition in veins, but it is perfectly possible to find geodes in sedimentary clay deposits. Indeed, the writer has seen quartz-lined geodes 3 inches across in the clay of the Fort Payne chert in Alabama.

SEDIMENTARY DEPOSITS.

The theory that the clay is of sedimentary origin is likewise inapplicable. It may appeal to one on first thought, but if true how are the detached blocks of Pottsville sandstone found in the clay to be accounted for? They show no evidence of having been detached from the roof and sinking into the clay, nor does it seem possible that they are a type of intraformational conglomerate, because veinlets and impregnations of the clay extend from the exterior of the blocks toward their interior. Any correct theory must explain these details.

BIOCHEMICAL REACTIONS.

Logan [70] suggests that bacteria have played an important part in the production of aluminum sulphate, which has reacted with the quartz of the Pottsville sandstone and produced the white clay. The full details of the theory have been published elsewhere.[70a]

REPLACEMENT OF QUARTZ PEBBLES.

The theory favored by the writer is that the white clay was formed by the replacement of the quartz pebbles of Pottsville sandstone, at least where the clay occurs in that formation. So far as the end result is concerned this theory agrees in part with Logan's theory.

The details of the process are not perfectly clear and would require considerable field and laboratory study, but the conclusions are based mainly upon a somewhat careful study of the tunnel in the Gardner mine and of specimens collected there.

Certain facts, however, seem to warrant the conclusions drawn. The pyrite of the Chester shales would by contact with underground waters be decomposed and yield sulphuric acid, which would attack the alumina of the shales and form aluminum sulphate. As the unconformity between the Chester group and the Pottsville is a line of weakness, and the sandstone of the Pottsville is very porous, a good

[69] Bastin, E. S., and Laney, F. B., The genesis of the ores of Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, p. 38, 1918.

[70] Logan, W. N., A biochemical theory of the origin of indianaite: Science, new ser., vol. 49, p. 197, 1919.

[70a] Logan, W. N., Kaolin of Indiana: Indiana Dept. Conservation Pub. 6, pp. 35–76, 1919.

path is formed for the circulating waters to follow, and hence the sulphate solutions would be brought in contact with the quartz pebbles of the Pottsville. Aluminum sulphate will attack silica, although the exact reaction by which the hydrous aluminum silicate is formed can not be stated. The pebbles of the sandstone show distinct evidence of corrosion and replacement, as noted on page 158.

This theory would also account for the isolated blocks of sandstone in the clay, the irregular boundaries between clay and sandstone, the veins of clay in sandstone, the gradation of one into the other, and the isolated bodies of clay in the sandstone such as are seen above the main entrance to the Gardner tunnel.[70b]

If this theory is correct the clay must be of post-Pennsylvanian age.

The formation of white clay by replacement has not ordinarily been recognized, and yet it does not seem to be impossible. Certain hard kaolins of the Tintic mining district, Utah, are said to have been formed by the replacement of crystalline limestone by descending waters,[71] but there is no evidence that this process has operated to any appreciable extent in the igneous rocks of the district.

SEDIMENTARY CLAYS OF THE COASTAL PLAIN AND THE EMBAYMENT AREA.

GEOLOGIC RELATIONS.

Along the Atlantic border of the United States from Cape Cod to Florida there is a plain which slopes gently seaward and which at its southern end swings westward through Alabama, Mississippi, and Louisiana to Texas. Near the coast the plain is near sea level and the sections exposed in the stream valleys are not very deep, but toward its inner edge the surface is several hundred feet higher and the streams have cut deeper into the formations, so that thicker sections are exposed.

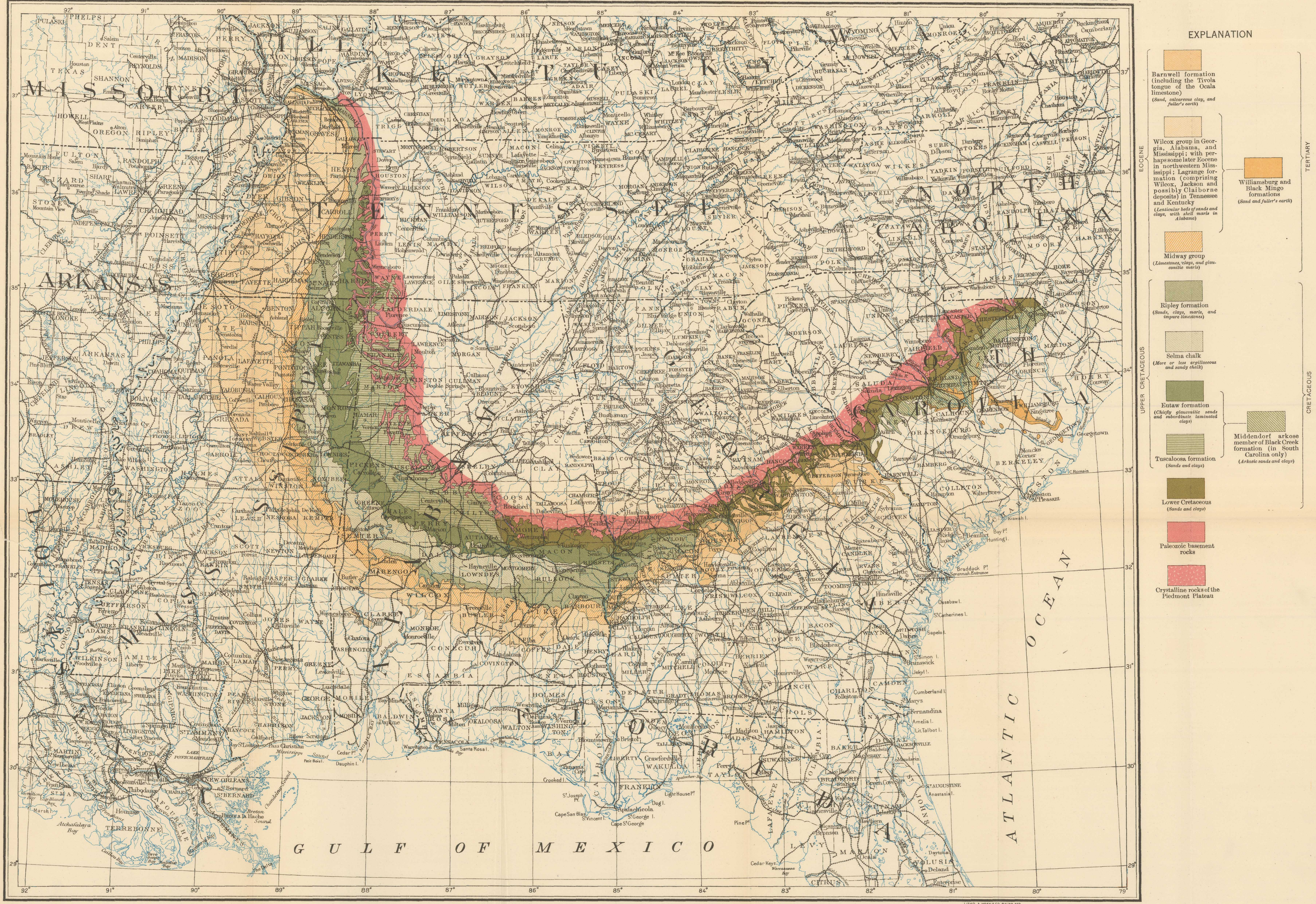
Underlying the surface of this Atlantic and Gulf Coastal Plain (Pl. X) occurs a series of Cretaceous and Tertiary deposits which dip gently seaward, and as the Cretaceous beds are the older geologically, where they are present they outcrop in general along the inner border of the plain.

Overlying these deposits unconformably still later formations in places conceal the older ones, except where cut through by stream erosion.

These uppermost formations might therefore, even though thin, effectively hide the underlying beds.

[70b] The writer has recently seen several small deposits of indianaite in Hardin County, Ky., where it occurs immediately below the Pottsville conglomerate and probably represents a replacement of it.

[71] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 258–261, 1919.



MAP OF SOUTHEASTERN STATES

Showing distribution of Tertiary and Cretaceous formations, which carry high-grade clays

Scale 1/2500000

25 0 25 50 75 100 Miles

1922

Geologic distribution of high-grade clays in the Coastal Plain and the Embayment Area.[a]

<table>
<tr><th></th><th>West Kentucky.</th><th>West Tennessee.</th><th>Northern Mississippi.</th><th>Western Alabama.</th><th>Central Alabama.</th><th>Eastern Alabama.</th><th>Western Georgia.</th><th>Central Georgia.</th><th>Eastern Georgia.</th><th>South Carolina.</th><th>North Carolina.</th><th>Virginia.</th><th>Maryland.</th><th>New Jersey.</th></tr>
<tr><td rowspan="2">Eocene.</td><td>Lagrange.[b] Ball clay, sagger clay, refractory bond clay.</td><td>Lagrange.[b] Ball clay, refractory bond clay, sagger clay.</td><td>Wilcox. Refractory bond clay, stoneware clay.</td><td>Wilcox. No high-grade clays.</td><td>Wilcox. No high-grade clays.</td><td>Wilcox. No high-grade clays.</td><td>Wilcox. No high-grade clays.</td><td>Absent.</td><td>Absent.</td><td>Williamsburg. No high-grade clays.</td><td>Absent.</td><td>Pamunkey. No high-grade clays.</td><td>Pamunkey. No high-grade clays.</td><td>Absent.</td></tr>
<tr><td>Porters Creek. Wad clay.</td><td>Porters Creek. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Midway. No high-grade clays.</td><td>Absent.</td><td>Black Mingo. No high-grade clays.</td><td>Absent.</td><td>Absent.</td><td>Absent.</td><td>Absent.</td></tr>
<tr><td rowspan="7">Upper Cretaceous.</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="7">Not exposed in Virginia. Known in well borings only.</td><td>Absent.</td><td>Manasquan. No high-grade clays.</td></tr>
<tr><td>Rancocas. No high-grade clays.</td><td>Rancocas. No high-grade clays.</td></tr>
<tr><td rowspan="2">Ripley. No high-grade clays known.</td><td>Ripley. Ball clay and sagger clay.</td><td>Ripley.</td><td rowspan="2">Selma chalk. No high-grade clays.</td><td>Ripley.</td><td rowspan="2">Ripley. No clays.</td><td rowspan="2">Ripley. Some white refractory clays.</td><td rowspan="2">Ripley. Some white refractory clays not white burning.</td><td rowspan="2">Absent.</td><td>Peedee. No clays.</td><td>Peedee. No clays.</td><td>Monmouth. No high-grade clays.</td><td>Monmouth. No high-grade clays.</td></tr>
<tr><td>Selma chalk.</td><td>Selma chalk. No high-grade clays.</td><td>Selma chalk. No high-grade clays.</td><td rowspan="3">Black Creek. White plastic clays in Middendorf arkose member. ....(?)........</td><td rowspan="3">Black Creek. No clays. ....(?)........</td><td>Matawan. No high-grade clays.</td><td>Matawan. No high-grade clays.</td></tr>
<tr><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Eutaw. No high-grade clays.</td><td>Absent.</td><td>Absent.</td><td>Magothy. No high-grade clays.</td><td>Magothy. No high-grade clays.</td></tr>
<tr><td rowspan="2">Tuscaloosa. Probably no clays.</td><td rowspan="2">Tuscaloosa. Probably no clays.</td><td rowspan="2">Tuscaloosa. White clays.</td><td rowspan="2">Tuscaloosa. Well-developed white clays.</td><td rowspan="2">Tuscaloosa. White clays.</td><td colspan="4" rowspan="2">Absent.</td><td>Break.</td><td>Break.</td></tr>
<tr><td colspan="2"></td><td>Raritan. Small lenses of white sandy clay.</td><td>Raritan. Valuable series of fire clays, sagger clays, some ball clays, etc.</td></tr>
<tr><td rowspan="3">Lower Cretaceous.</td><td colspan="5" rowspan="3">Not exposed and not known to be present.</td><td rowspan="3">Present.</td><td rowspan="3">Present. Plastic white clays.</td><td rowspan="3">Present. Plastic white clays.</td><td rowspan="3">Present. Plastic white clays.</td><td rowspan="3">Present. Plastic white clays.</td><td rowspan="3">Present. Correlated with Patuxent formation. No high-grade clays have yet been discovered.</td><td>Patapsco. No high-grade clays.</td><td>Patapsco. Possibly refractory bond clays.</td><td rowspan="3">Absent.</td></tr>
<tr><td>Arundel. No high-grade clays.</td><td>Arundel. Some crucible clays.</td></tr>
<tr><td>Patuxent. No high-grade clays.</td><td>Patuxent. No high-grade clays.</td></tr>
</table>

[a] The white clays of Florida lie geologically above formations shown in this table. In Arkansas and Illinois small deposits of clay are known in the Wilcox and Lagrange formations.
[b] The Lagrange formation includes beds of Wilcox, Jackson, and possibly of Claiborne age.

An extension of the Coastal Plain formations stretches northward in the Mississippi Valley from Mississippi and Texas, across eastern Arkansas, southeastern Missouri, and western Kentucky and Tennessee as far as southern Illinois. This extension is known as the Embayment Area, because the beds were deposited in a long, broad arm of the sea.

The Cretaceous and Tertiary deposits are of special interest to us in this discussion. They consist in general of a series of clays, sands, gravels, sandstones, limestones, and similar materials.

In the Atlantic Coastal Plain they dip gently toward the Atlantic Ocean, in the Gulf Coastal Plain toward the Gulf, and in the Embayment Area toward the Mississippi.

As a whole they show two marked features: 1. Any one formation is not continuous throughout the Coastal Plain and the Embayment Area, either because it was not deposited over the entire region or because it may have been worn away in places. 2. The individual formations in general show a marked lithologic change in tracing them from one State to another. Thus, a formation which contains valuable deposits of clay in one State may be made up almost exclusively of sands in another.

Some idea of this variation may be seen from the series of columnar sections given in the accompanying table, which includes the Upper and Lower Cretaceous and part of the Tertiary. This table also shows the States in which the different formations carry high-grade clays, and Plate X shows the areal distribution of these formations in most of the Coastal Plain and Embayment Area.

The table shows, for example, that the Lower Cretaceous deposits, so valuable as a source of the white clays of Georgia and South Carolina, do not outcrop west of eastern Alabama, nor are they definitely identified north of South Carolina, although the Lower Cretaceous Patuxent formation of North Carolina and Maryland may possibly be the northward continuation of them. Even so, it is of quite different lithologic character. On the other hand, the Ripley formation has been identified as a broken belt from Kentucky all the way to central Georgia, but it carries few clays of value.

The clays of the several formations are described separately, and their distribution, characters, and uses are indicated.

METHODS OF MINING.

With very few exceptions the clays of the Coastal Plain and the embayment area are worked as open pits. In southern Illinois, however, shaft mining is common.

The overburden, if thin, is removed with picks and shovels or scrapers, but where it is thick steam shovels are not infrequently employed, and in the larger pits the stripping so removed is loaded into cars, which are hauled to the dump by steam power.

The white clays of Georgia and South Carolina are in places excavated with a steam shovel, but this method is inapplicable at most pits in western Tennessee and Kentucky for the reason that the same pit may contain several grades of clay of different thicknesses, so that the only way to excavate the material is by hand.

In Florida a unique method of dredging the clay is employed, and the conditions there favor it.

Throughout this region washing the clay for market is practiced only in certain States. Some of the New Jersey ball clay has been washed; most of the Georgia white clay, some of the South Carolina clay, and all of the Florida white clays are washed for market. At all other localities the clay is shipped as mined, except that in some places it is crushed.

Shippers of white clays from Georgia and South Carolina especially should see that the product is properly dried before sending it to the market, and all the clay that is shipped crude should be carefully sorted to avoid the inclusion of discolored or sandy streaks, which may injure the quality of the shipment.

LOWER CRETACEOUS CLAYS.

The Lower Cretaceous deposits are not extensive in the Coastal Plain region, though they occur from western South Carolina to central Alabama (Pl. X). It is unfortunate that they are not more extensive, because they contain some of the purest clays found in the Coastal Plain area, which have been used in part to replace some of the white clays hitherto imported from England.

The materials that make up the Lower Cretaceous deposits in this area consist of irregularly bedded, coarse feldspathic and micaceous sands, together with lenses and beds of clay, some of them of high purity. They rest unconformably on the older crystalline rocks and are in turn overlain unconformably by the Upper Cretaceous and Tertiary formations.

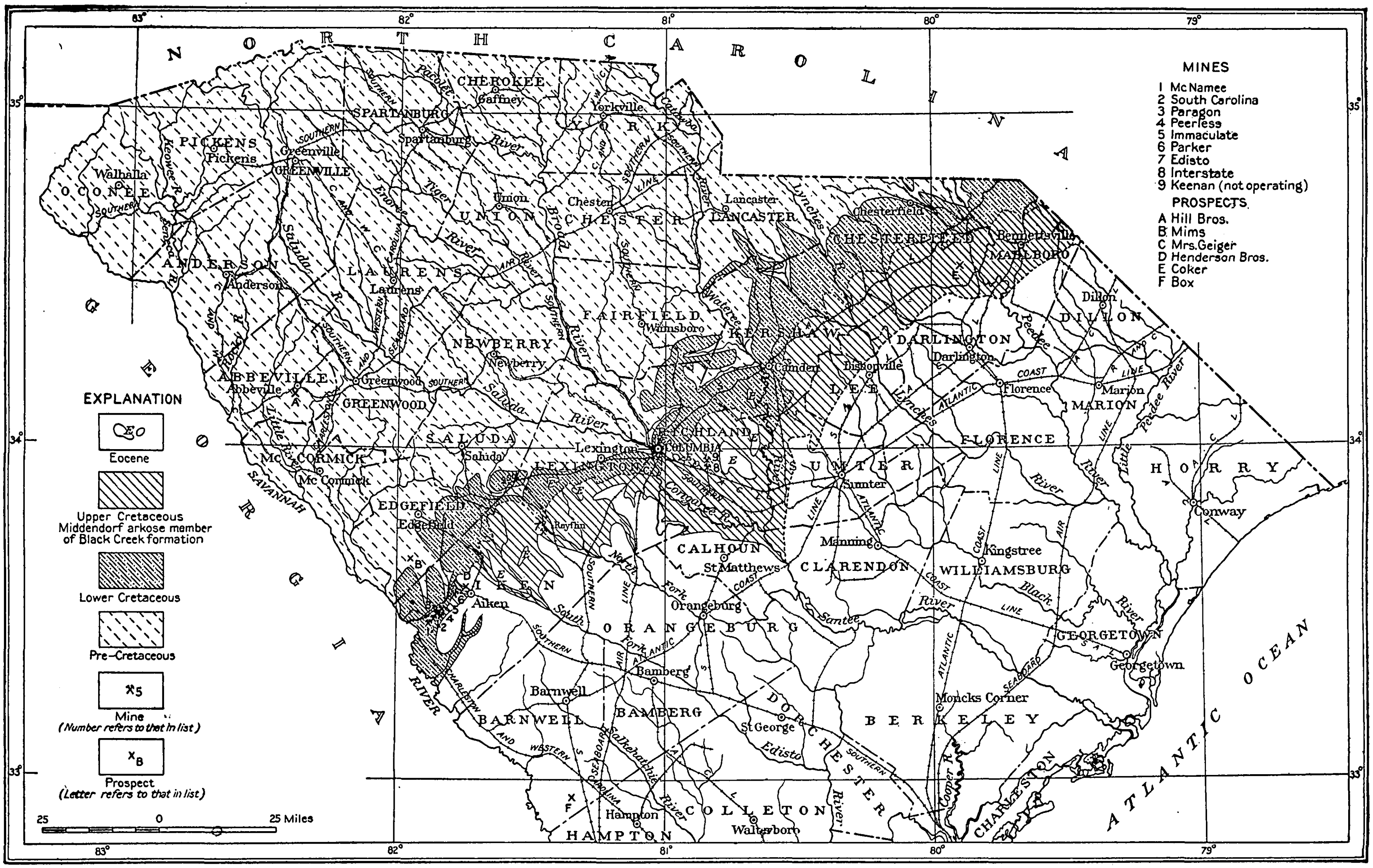
A short distance west of Alabama River the Lower Cretaceous passes under and is completely buried by the overlapping beds of the Tuscaloosa formation.

SOUTH CAROLINA.

By W. S. Bayley.

THE CLAY-BEARING FORMATIONS.

The white sedimentary clays of South Carolina occur in the Lower Cretaceous and also in the Middendorf arkose member of the Black Creek formation of the Upper Cretaceous, but most of the production comes from the Lower Cretaceous.



MAP OF SOUTH CAROLINA SHOWING DISTRIBUTION OF CRETACEOUS CLAY-BEARING FORMATIONS AND CLAY MINES.

77412—22. (Face p. 164.)

The accompanying map (Pl. XI) shows the extent of the white clay-bearing formations in South Carolina, as well as the operating pits and some other properties that are still undeveloped. The undeveloped properties that are represented include only those that were visited, and there are no doubt a number of others.

The Cretaceous area that contains the white clays forms a belt between the "fall line" and the Tertiary area to the east. This belt is narrow at Aiken, but it increases in width to the northeast and is 45 miles wide between the Congaree and Wateree rivers, though it is not continuous throughout this distance. Beyond this point it is about 30 miles wide. All the productive clay deposits are within this belt, though a few promising deposits that may be productive in the future lie in the crystalline area to the west.

The Lower Cretaceous beds in South Carolina are divided by Sloan into the "Lower Hamburg beds" and "Upper Hamburg beds." They are overlain unconformably in some places by the younger Cretaceous beds and in others by the Eocene formations, and these in turn are overlain by still later deposits. In some places the Tertiary beds are absent, and the post-Tertiary beds rest directly on the younger or Upper Cretaceous beds.

Near the fall line, as has been stated, the Cretaceous deposits lie at the surface, but toward the southeast they disappear under younger beds, and these in turn occupy the surface in succession.

The Cretaceous beds, where they are well exposed, as in the Aiken district, are about 275 feet thick, the various members being distributed as follows:

Geologic section in Aiken district, S. C.

	Feet.
Pliocene:	
Unconformity.	
Eocene:	
Unconformity.	
Upper Cretaceous:	
Peedee formation—	
Marls.	
Black Creek formation—	
Black shales and clays.	
Middendorf arkose member—	
Greenish-yellow and white hard clay	18
Micaceous sands	12
Greenish-yellow and white hard clay	15
Mixed sands	9
White-clay nodules.	
Erosional unconformity.	
Cross-bedded white and colored sands	30
Erosional unconformity.	
Thin layers of clay and sand	7
Round quartz pebbles and sand	2
Unconformity.	

	Feet.
Lower Cretaceous:	
"Upper Hamburg beds"—	
Fine white plastic clay	14
White sands and white clay	9
White and yellow sands with white-clay lenses	28
Nodules of white clay.	
Erosional unconformity.	
"Lower Hamburg beds"—	
Mealy, micaceous sands; White and colored sands and white clay; Harsh sands	51
Harsh white arkose	19
Purple clay	11
Coarse white and yellow sands	25
Fragments of quartz and gneiss in clay	4
Unconformity.	
Pre-Cretaceous shales, gneiss, granite, and other rocks.	

The position of the "Hamburg beds" in the geologic column has not been definitely established. They are unquestionably near the base of the Cretaceous, and probably, according to Stephenson,[72] correspond to the Patuxent ("Cape Fear") formation of North Carolina.

In this paper both the "Lower Hamburg beds" and "Upper Hamburg beds" of Sloan[73] are classed together as Lower Cretaceous without any more specific designation.

The Middendorf beds are placed by Stephenson[74] in the Upper Cretaceous and are regarded by him as a shallow-water phase of the lower part of the Black Creek formation. The typical beds of the Black Creek formation occur in the valley of Peedee River and its tributaries, and the Middendorf arkose member is seen in a comparatively narrow belt from Chesterfield southwest to Aiken County. The narrowing down of the surface exposures of the Middendorf to the south is due to an overlap of Eocene beds from the southeast.

THE CLAY BEDS.

Clay occurs in distinct beds over a large part of the area that is mapped as underlain by Cretaceous rocks (Pl. X). It outcrops in numerous places, and there is no reason to believe that it is not continuous between outcrops under the sands that form the uplands between the stream valleys.

Though the clays seem to form somewhat continuous deposits, they occur at different horizons in the Lower Cretaceous deposits and in the Middendorf member. The lowermost horizon is in the Lower

[72] Stephenson, L. W., Index to the stratigraphy of North America: U. S. Geol. Survey Prof. Paper 71, p. 605, 1912.

[73] Sloan, Earle, A preliminary report on the clays of South Carolina: South Carolina Geol. Survey, ser 4, Bull. 1 (Reports on Resolutions, vol. 2), pp. 816, 823, 1904.

[74] Stephenson, L. W., op. cit., p. 659.

Cretaceous about 30 feet above its base. In some places the clay reaches 11 feet in thickness, but in other places it is entirely absent. It is generally fine grained and smooth, but in some places it is gritty and indurated. In the main it is stained purple with organic matter,[75] but locally it is white.

Streaks and lenses of white clay are also interbedded with sands in the lower portions of the Lower Cretaceous, but the principal bed and the one which is by far the most productive in the State is that at the top of this series. It is exploited at Bath and Langley, where it is exposed on the sides of gullies at an average elevation of 307 feet. It dips steeply eastward and southward and passes under the overlying Middendorf beds. To the north and west it rises to the surface and disappears as the result of erosion. Its maximum thickness is about 18 feet, and its average thickness where worked is about 12 feet. In some of the valleys it has been cut through by streams and removed from the bottoms. In other places it was removed by erosion before the overlying beds were laid down, and in still other places perhaps it was never deposited. As a rule, the clay in this bed is white, fine grained, smooth, and very plastic. It is put on the market without other preparation than drying, except that some of it is crushed. In some places it is stained purple like the bed in the lower part of the Lower Cretaceous and in other places it is stained yellowish or brownish by iron hydroxides.

Unconformably above the Lower Cretaceous beds lie the Middendorf beds, in the lower portion of which other streaks of white clay are interbedded with sands. At its top, however, occur two beds, 15 feet and 18 feet thick, which in some places are separated by 12 feet of sand but in other places coalesce and form a single bed 24 feet thick. In the vicinity of Langley the upper surface of the clay is about 95 feet above that of the Lower Cretaceous white clay. This clay differs from the lower clay in some respects. It is dense, has a somewhat waxy luster, and most of it is pale drab, though locally it is white or very pale green. This bed is noted by Sloan[76] as "the most extensively distributed, approximately homogeneous member of the Cretaceous formations exposed in South Carolina. It is the only one of the Cretaceous white clay beds that even roughly approximates regional continuity." Its character changes abruptly from place to place. It is gritty at some places, fine grained at others, and dense and waxy at still others.

Analyses of characteristic samples of both the Lower Cretaceous and the Middendorf clays are given below. They are all quoted from Sloan's report.

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[75] Sloan, Earle, op. cit., p. 817.
[76] Idem, p. 821.

Analyses of Cretaceous clays from South Carolina.

	1	2	3	4	5	6	7
Silica (SiO_2)	45.02	44.66	44.23	45.07	45.69	47.49	46.99
Alumina (Al_2O_3)	38.98	37.90	38.92	35.61	37.47	35.56	36.08
Ferric oxide (Fe_2O_3)	.77	2.53	2.31	2.21	1.01	2.47	1.02
Lime (CaO)	.03	.08	.12	.16	Trace.	Trace.	Trace.
Magnesia (MgO)	.07	Trace.	Trace.	.25	....	Trace.	Trace.
Soda (Na_2O)	.55	.41	.26	1.37	.69	.74	1.09
Potash (K_2O)	.26	.36	.30	1.10	.08	.13	.20
Titanium oxide (TiO_2)	.85	1.29	1.21	1.56	1.44	.94	.86
Loss on ignition	13.58	13.17	12.90	12.39	13.98	12.86	13.82
	100.11	100.40	100.25	99.72	100.36	100.19	100.06
Clay substance	96.95	99.60	99.29	90.62	94.68	96.43	88.99
Quartz	2.00	.16	.49	3.52	3.76	2.27	4.53
Feldspar	1.16	.64	.47	5.58	1.92	1.49	6.54

1. Lower Cretaceous clay, McNamee pit, near Bath.
2. Lower Cretaceous clay, Peerless Clay Co., near Langley.
3. Lower Cretaceous clay, Immaculate Kaolin Co., near Langley.
4. Lower Cretaceous clay, Langley Manufacturing Co., near Langley.
5. Middendorf clay, Imperial Kaolin Co., near Seivern.
6. Middendorf clay, Richard place, Wise Creek area.
7. Middendorf clay, Edisto Kaolin Co., Rayflin.

PITS IN LOWER CRETACEOUS CLAYS.

BATH, AIKEN COUNTY.

Property of the McNamee Kaolin Co.—The property of the McNamee Kaolin Co. comprises about 2,000 acres about 1½ miles northeast of Bath. The main office is at Broadway and Fifty-fourth Street, New York. As the company has been operating for forty years, all the clay has been removed from an area of several acres, and a number of large pits have been left.

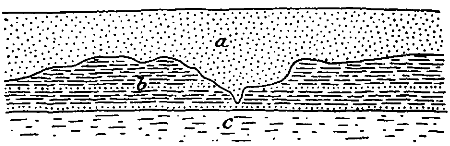


FIGURE 30.—Section showing unconformity in pit of McNamee Kaolin Co., near Bath, S. C. *a*, Red sand; *b*, white sand and layers of clay; *c*, clay.

In the pit now being worked red and white sand constitute the main portion of the overburden, which ranges in thickness from 3 to 33 feet, depending upon the topography. Evenly bedded interlayered white sand and thin streaks of clay with a coarse pebble layer at the bottom, occur in apparent unconformity (fig. 30) beneath the overburden, and beneath this material is the main clay bed, which has a maximum thickness of 18 feet. On the lower slopes of the valleys the thickness is less, and from many of the valley bottoms all the clay has been eroded. If only one-third the acreage is underlain by clay, the reserve is over 3,000,000 tons. Below the clay there is coarse gritty sand of unknown thickness.

Two grades of crushed clay are marketed. A pulverizer run by electric power has been installed in one end of the dry shed, so that in the future pulverized clay will also be furnished. The No. 1 clay is a white, very finely granular, brittle material made up mainly of tiny flecks of kaolinite not over 0.004 millimeter in diameter. In addition there is very little decomposed mica in grains of the same dimensions, and a few grains of zircon and possibly tourmaline, as well as numerous tiny grains of rutile. Besides the fine grains of kaolinite there are many larger flakes about 0.02 millimeter in diameter, a few that measure 0.15 millimeter, and some wormlike aggregates of the same minerals. There is no grit.

No. 2 clay is cream colored. It differs from No. 1 mineralogically in containing a greater abundance of mica and a few diatoms that may have been accidentally introduced.

The McNamee clay slakes rapidly, forms a slightly creamy, viscous mass with water, and settles very slowly, forming a smooth, almost structureless precipitate. An analysis is given on page 168. Commercial analyses show very little difference between grade No. 1 and grade No. 2.

In mining the overburden is removed by steam shovel and hauled to the dump in the valley below the pit. The clay after removal from the pit is dried and then sent by a narrow-gage road to Bath, where it is transferred to the Southern Railway. It is expected soon to change the spur to a standard-gage road and to haul to the main line by electricity.

The present capacity of the plant is about 15,000 tons annually. With abundant labor the output could be increased to 30,000 tons, and by working a night shift it could be increased still further. The mine is not able to supply the demand for its product, and consequently steps are being taken to enlarge its working capital, so that its output can be raised to 100,000 tons a year.

The following tests of a sample of white clay from the pit of the McNamee Clay Co. have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio. The sample (Bureau of Mines No. 1.65) represents a mixture of several clays.

General physical tests of sample of clay from pit of McNamee Clay Co., Bath, S. C. (Bureau of Mines No. 1.65).

Workability	Very plastic; makes good bars; cracks some.
Water of plasticity, in terms of dry clay ... per cent	43.4
Air shrinkage by volume ... do	22.54
Air shrinkage, linear, calculated ... do	8.20

Fire tests of sample of clay from pit of McNamee Clay Co., Bath, S. C. (Bureau of Mines No. 1.65).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	40.97	White	22.65	8.2
1,250	38.70	do	25.30	9.3
1,310	31.20	do	32.40	12.2
1,370	22.20	do	41.70	16.5
1,410	9.81	do	45.37	18.3

Cone of fusion, 33.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.65.

Workability	Plastic; made good bars and bats.	
Water of plasticity, in terms of dry clay	per cent	34.31
Volume shrinkage	do	18.18
Air shrinkage, linear, calculated	do	6.5
Modulus of rupture	pounds per square inch	137.9

Fire tests of porcelain body containing clay of sample No. 1.65.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	25.3	White	20.20	7.3	2,833
1,250	28.87	do	21.12	7.6	4,775
1,310	23.12	do	21.89	7.9	4,044
1,370	4.69	do	35.42	12.6	5,243
1,410	.40	Light pale smoke-gray	36.50	14.1	8,640

The following tests of a second sample of white clay (Bureau of Mines No. 1.66) from the same pit gave the results noted below:

General physical tests of sample of clay from pit of McNamee Clay Co., Bath, S. C. (Bureau of Mines No. 1.66).

Workability	Good; fat; makes good bars; cracks slightly.	
Water of plasticity, in terms of dry clay	per cent	34.41
Air shrinkage by volume	do	12.86
Air shrinkage, linear, calculated	do	4.5

Fire tests of sample of clay from pit of McNamee Clay Co., Bath, S. C. (Bureau of Mines No. 1.66).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	36.70	White	21.60	7.8
1,250	34.50	do	24.40	8.9
1,310	27.32	do	29.29	10.9
1,370	34.20	do	35.10	13.4
1,410	13.10	do	41.30	16.3

Cone of fusion, 32½.

A sample of this clay was used in a porcelain body and gave the following results:

General physical tests of porcelain body containing clay of sample No. 1.66.

Workability	Plastic, molded well; good in jiggering.	
Water of plasticity, in terms of dry clay	per cent	27.52
Volume shrinkage	do	14.66
Air shrinkage, linear, calculated	do	5.2
Modulus of rupture	pounds per square inch	187.9

Fire tests of porcelain body containing clay of sample No. 1.66.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	24.2	White	18.7	6.7	1,552
1,250	23.62	do	20.06	7.2	4,774
1,310	20.39	do	22.89	8.3	3,639
1,370	5.11	do	30.30	11.3	5,415
1,410	.20	Pale gull-gray	33.50	12.7	8,823

The McNamee product has a very wide use as a paper clay, not only for wall paper, in the manufacture of which it enters as filler, for coating, and for top printing, but also for high-grade print papers and cardboard. It is somewhat more transparent and a little darker than English clay, and therefore is usually mixed with the imported material when intended to be used for coating. However, some manufacturers employ it alone for coating cheaper stock, and many employ it alone or mixed with other domestic clays or with talc as a filler for manila and newsprint paper and to some extent for high-grade book and magazine papers. In this field it has replaced imported china clays to a large extent. Some lithographic paper coated with a mixture of talc and McNamee clay is satisfactory for many purposes, though not of as high grade as paper coated with a mixture in which some English clay has been added.

In making pottery the record of the McNamee clay is almost equally good. It is used by some potters in the manufacture of electrical and chemical porcelain, hotel china, and china door knobs in a mixture in which there is no imported clay. To this extent it replaces the imported article and has been substituted for English china clay with success in the manufacture of floor tile. Another important use of the clay is in the manufacture of the medicinal preparation known as antiphlogistine.

LANGLEY, AIKEN COUNTY.

Property of the South Carolina Clay Co.—The South Carolina Clay Co. is another long-established corporation in this part of the State. Its main office is in West Chester, Pa. The property consists of about 400 acres about 2 miles south of Langley, all of which is believed to be underlain by clay. About 15 or 20 acres have been bored. The thickness of the clay bed ranges from 4 to 22 feet, depending upon the topography, and that of the overburden from 30 to 55 feet. The total quantity of clay in the 20 acres is about 700,000 tons, of which 20,000 tons are uncovered in the pit. The total reserve in the 400 acres is estimated to be over 10,000,000 tons, but how much of it is available under present conditions of working is not known.

In places the walls of the pit expose excellent sections, of which a typical one is shown in figure 31. In some places the cross-bedded coarse white sand with clay lenses becomes a distinct clay conglomerate from 3 to 18 feet thick, in which the "pebbles" are little round nodules of clay.

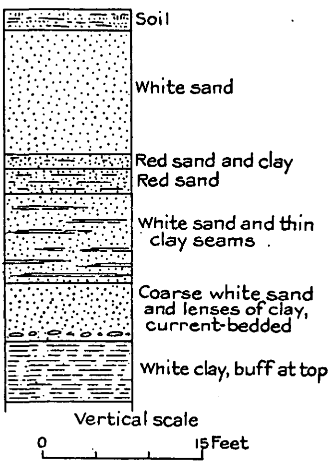


FIGURE 31.—Section in pit of South Carolina Clay Co., south of Langley, S. C.

The upper part of the clay bed is commonly a buff or badly stained reddish clay that ranges in thickness from 5 to 20 feet. Under this clay is in most places a little sand and beneath this sand the commercial white clay. Where the colored clay is thickest the white clay is thinnest and vice versa.

Only one grade of clay is shipped, but this is in two sizes—crushed and pulverized. The clay is dense or extremely fine grained and brittle, and it contains almost no grit. The kaolinite is in flakes and shreds, most of them very small, though some are fairly large. The small flakes measure about 0.004 millimeter in diameter, and some of the large flakes as much as 0.05 millimeter. Perhaps the average size of the large grains is 0.035 millimeter. Besides kaolinite there are a few flakes of muscovite, 0.05 millimeter in diameter, and many small shreds 0.01 millimeter in length. Grains of titanite and rutile are comparatively numerous, and here and there are scattered grains of zircon. When mixed with an excess of water the clay slakes rapidly, forming a mixture which is very pale cream-colored. From this solution the clay settles rapidly as a slightly flocculent sediment.

The overburden is removed by a drag scraper. The clay is dried and sacked and is hauled over a narrow-gage road to the shipping point at Langley, on the Southern Railway.

The present capacity of the plant is 600 tons monthly, but this can be increased to 700 tons with sufficient labor and to 3,000 tons by working a night shift with the new pulverizer just installed. The plant can supply clay pulverized either to 200 or 300 mesh.

The following tests of a sample of white clay (Bureau of Mines, No. 1.18) from the pit of the South Carolina Clay Co. have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of sample of clay from pit of South Carolina Clay Co. at Langley, S. C.

Workability	Fairly fat; makes good bars; dries fairly well.	
Water of plasticity, in terms of dry clay	per cent	39.61
Air shrinkage, by volume	do	15.83
Air shrinkage, linear, calculated	do	5.60

Fire tests of sample of clay from pit of South Carolina Clay Co., Langley, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	38.17	White	22.21	8.1
1,250	34.20	do	27.00	10.0
1,310	32.67	do	32.20	12.2
1,370	24.25	do	36.87	14.2
1,410	12.50	do	44.20	17.7

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of South Carolina Clay Co., Langley, S. C.

Workability	Plastic; molded well; fair jiggering body; good drying qualities.	
Water of plasticity, in terms of dry clay	per cent	33.95
Volume shrinkage	do	22.60
Air shrinkage, linear, calculated	do	8.20
Modulus of rupture	pounds per square inch	167.30

Fire tests of porcelain body containing clay from pit of South Carolina Clay Co., Langley, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	25.60	White	20.10	7.2	3,323
1,250	24.03	do	21.43	7.7	3,709
1,310	18.68	do	22.88	8.3	3,881
1,370	1.01	do	33.90	12.9	7,788
1,410	.10	Light pale olive-gray	35.30	13.6	7,383

This clay is used for a great variety of purposes. It is employed for coating and top-printing wall paper and as a filler in cheap print paper, and for both purposes it has entirely supplanted the English china clay that was formerly used to some extent. It is also used for coating book papers, but as a rule only in mixtures with English clays. It forms part of the mixture from which crayons and pencil leads are manufactured, and for this use it appears to be better than the English clay. It is also used alone or in mixtures employed as filling materials in paint compositions and in the manufacture of lakes for aniline dyes, though it is not white enough for white pigments. Some potters state that it has entirely replaced the foreign clay that was once used in making glazed wall tile and vitreous floor tile, and it is being used by some potters as a substitute for other more expensive china clays in the manufacture of semiporcelain ware. In the porcelain mixture, however, it is employed in small quantities only; but experiments are now being made in the expectation that it may be so used in larger quantities.

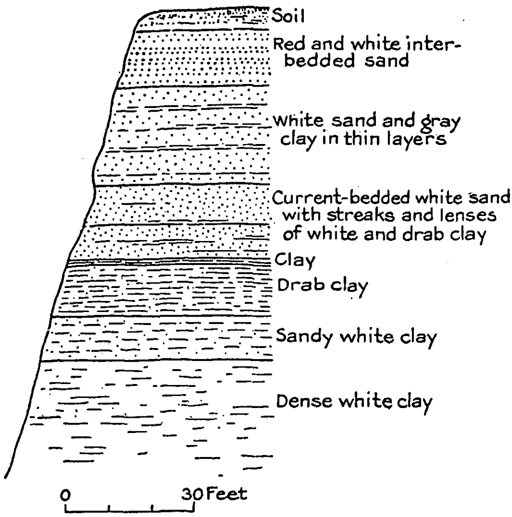


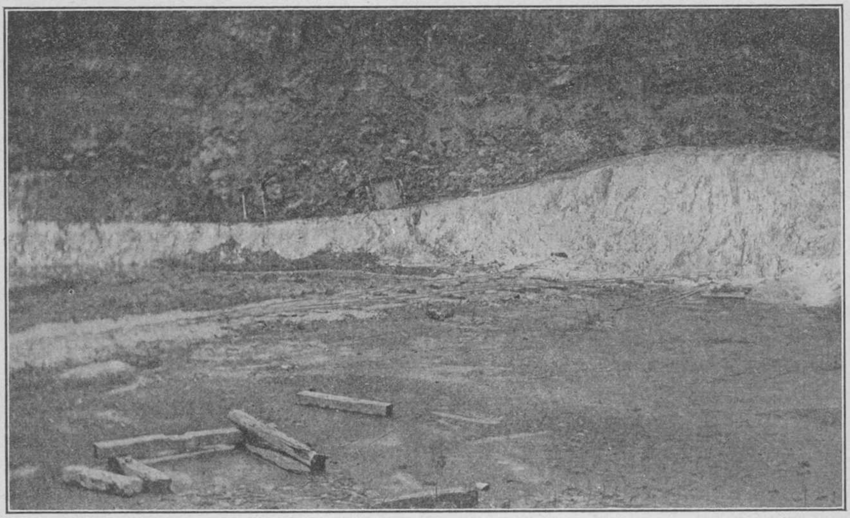
FIGURE 32.—Section in pit of Paragon Kaolin Co., south of Langley, S. C.

Property of the Paragon Kaolin Co.—The Paragon Kaolin Co., whose office is at Langley, S. C., has been operating the same pit for about 35 years. It is about 2 miles south of Langley and about three-fourths of a mile west of the Peerless mine. The property consists of 234 acres held in fee and the mineral rights on 50 acres more. Borings indicate the presence of clay 12 feet in average thickness under the entire acreage. Based on these data the tonnage in reserve is about 6,500,000.

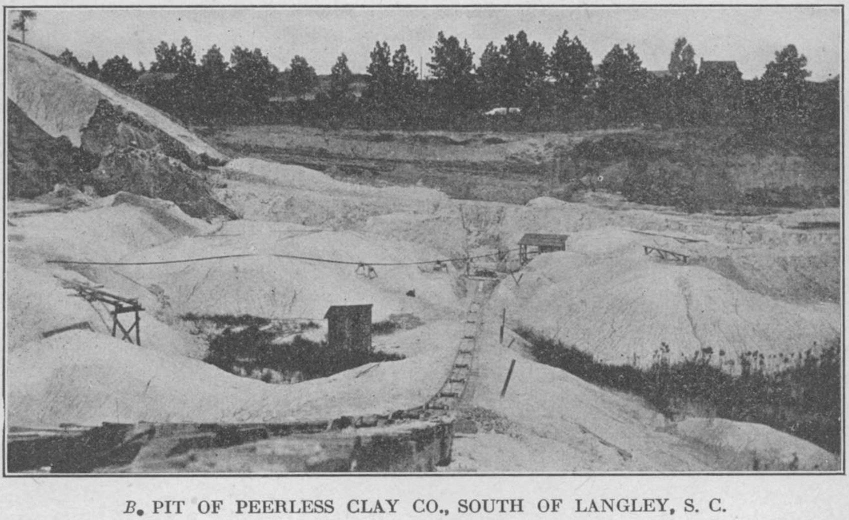
The general section in the pit is shown in figure 32.

An unconformity between the drab clay and the white sand is shown in an old pit near by. (See Pl. XII, *A*.)

Only crude clay is now being shipped, and this is mainly of one grade, which is nearly white and very finely granular. When mixed with water it forms a viscous mass, from which the clay settles slowly as a structureless precipitate. Under the microscope the kaolin is seen to differ very little from that of the McNamee and Peerless pits. The greater portion of the kaolinite is in little flakes



A. UNCONFORMITY BETWEEN DRAB CLAY AND WHITE SAND IN PIT OF PARAGON CLAY CO., LANGLEY, S. C.



B. PIT OF PEERLESS CLAY CO., SOUTH OF LANGLEY, S. C.

about 0.004 millimeter in diameter, but there are present also a great many flakes from 0.03 to 0.05 millimeter in diameter and a comparatively large number of the wormlike aggregates. Mica is scarce. Grade No. 2 is furnished only on special orders.

The active pits are kept dry by pumping. The overburden, which ranges in thickness from a few feet to 50 feet, is removed by shovels and carts. The dried clay is sacked and hauled by a narrow-gage road to the Southern Railway at Langley for shipment.

In the near future it is expected that the overburden will be stripped by steam shovel and hauled away in dump cars by a dummy engine.

The production is about 600 tons monthly. When improved machinery is installed the output should be increased materially.

The following tests of a sample of white clay (Bureau of Mines No. 1.2) from the pit of the Paragon Kaolin Co. have been supplied by the laboratory of the Bureau of Mines, at Columbus, Ohio:

General physical tests of sample of clay from pit of Paragon Kaolin Co., Langley, S. C. (Bureau of Mines No. 1.2).

Workability	Fairly plastic,; makes good bars.
Water of plasticity, in terms of dry clay...per cent..	35.20
Air shrinkage by volume...do....	18.67
Air shrinkage, linear, calculated...do....	6.70

Fire tests of sample of clay from pit of Paragon Kaolin Co., Langley, S. C. (Bureau of Mines No. 1.2).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent)
1,190	34.76	White	21.47	7.8
1,250	31.00	....do	22.44	8.1
1,310	29.63	....do	28.49	10.6
1,370	26.21	....do	32.12	12.2
1,410	14.30	....do	37.80	14.7

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.2.

Workability	Good drying properties.
Water of plasticity, in terms of dry clay...per cent..	27.92
Volume shrinkage...do....	16.63
Air shrinkage, linear, calculated...do....	5.9
Modulus of rupture...pounds per square inch..	155.4

Fire tests of porcelain body containing clay of sample No. 1.2.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	26.3	White	16.10	5.7	2,646
1,250	24.53	do	17.59	6.3	2,690
1,310	21.37	do	19.54	7.0	4,199
1,370	8.87	do	27.51	10.2	4,523
1,410	.20	Pale olive-buff	32.50	12.3	5,812

A second sample of white clay (Bureau of Mines No. 1.21) from the same pit showed the following properties:

General physical tests of sample of clay from pit of Paragon Kaolin Co., Langley, S. C. (Bureau of Mines No. 1.21).

Workability	Fairly plastic; makes fine bars.	
Water of plasticity, in terms of dry clay	per cent	36.10
Air shrinkage, by volume	do	16.64
Air shrinkage, linear, calculated	do	5.90

Fire tests of sample of clay from pit of Paragon Kaolin Co., Langley, S. C. (Bureau of Mines No. 1.21).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	34.45	White	23.13	8.4
1,250	31.60	do	25.80	4.5
1,310	29.62	do	30.07	11.3
1,370	20.20	do	35.3	13.6
1,410	7.90	do	43.6	17.4

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.21.

Workability	Plastic and smooth; makes excellent bars; jiggers well; dries well.	
Water of plasticity, in terms of dry clay	per cent	28.51
Volume shrinkage	do	15.61
Air shrinkage, linear, calculated	do	5.50
Modulus of rupture	pounds per square inch	193.8

Fire tests of sample of clay from pit of Paragon Kaolin Co., Langley, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	24.50	White	18.60	6.7	3,044
1,250	23.29	do	20.79	7.5	3,850
1,310	20.20	do	20.81	7.5	4,689
1,370	4.87	do	30.11	11.3	5,780
1,410	.35	Pale olive-buff	32.18	12.2	6,546

The clay from the Paragon mine is used with success as a filler for manila paper, for this purpose replacing foreign clay, and wall paper. It is also used in coating and top printing wall paper. An extensive use is as a filler for high-grade calendered paper, such as is employed in the best magazines and in illustrated catalogues.

Property of the Peerless Clay Co.—The Peerless Clay Co. is another comparatively old organization. Its plant is 2 miles south of Langley and about one-quarter of a mile north of that of the Immaculate Kaolin Co. Its pit is extensive and covers several acres. (See Pl. XII, *B*.) The company states that borings over 200 acres have shown good clay underlying the entire area with a thickness ranging from 8 to 15 feet. On the assumption that the average thickness is 12 feet and that 80 per cent of the clay is merchantable, the reserve is estimated to be over 4,000,000 tons. The overburden, 7 to 20 feet thick, consists of sand and of sand and clay interlayered. The clay bed has very much the same characteristics as that at the Immaculate pit (p. 182), except that here and there through it are scattered lenses of pink clay, sand pockets, and spots of ocher which must be removed in mining. In places near the bottom of the bed are masses of black, probably carbonaceous clay that also must be discarded. The quantity of these objectionable materials present is not known.

The product is supplied in two grades and in two conditions—crushed and pulverized. No. 1 clay is a white, smooth, slightly granular clay, composed almost exclusively of tiny grains of kaolinite, few of which are more than 0.004 millimeter in diameter. There are a few highly refracting wisps of a colorless mineral that is probably muscovite and a very few brown grains that are believed to be rutile. The clay slakes easily and forms a very pale cream-colored viscous mass, from which the clay settles very slowly as an almost structureless sediment. No. 2 clay is light cream-colored and slightly gritty, through the presence of a few quartz grains. It contains a little more mica than No. 1, but otherwise the two grades are similar.

An analysis of a sample of No. 1 clay, made by H. H. Craver, of the Pittsburgh Testing Laboratory, gave the results shown in the first column of the table below. In the second column is given the analysis published by Sloan.

Analyses of clay from pit of Peerless Clay Co. near Langley, S. C.

	1[a]	2
Silica (SiO_2)	44.00	44.66
Alumina (Al_2O_3)	40.25	37.90
Ferric oxide (Fe_2O_3)	1.43	2.53
Lime (CaO)	.28	.08
Magnesia (MgO)	Trace.	Trace.
Soda (Na_2O)	} .40	.41
Potash (K_2O)		.36
Titanium oxide	1.50	1.29
Water (H_2O)	12.14	13.17
	100.00	100.40

[a] In this analysis the iron is given as iron oxide, and the water, which was determined by difference, is reported as combined water.

1. Pittsburgh Testing Laboratory. H. H. Craver, analyst.
2. Sloan, Earle, South Carolina Geol. Survey, ser. 4, Bull. 1 (Reports and Resolutions, vol. 2), p. 863, 1904.

The overburden is removed by a drag excavator. The clay after drying is crushed and pulverized. Shipment is made in standard cars on a spur of the Southern Railway that joins the main line at Langley.

The present output of the plant is about 1,200 tons monthly, but with abundant labor this could be increased to 3,000 tons, without working a night shift.

Four samples of clay from this company's pit were tested at the laboratory of the Bureau of Mines at Columbus, Ohio, and the results are given below:

General physical tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.15).

Workability		Very plastic; makes good bars.
Air shrinkage by volume	per cent	31.61
Air shrinkage, linear, calculated	do	11.90

Fire tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.15).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	39.23	White; very faint tinge of light buff.	30.01	11.3
1,250	30.40	(same)	39.10	15.2
1,310	.80	Light drab	55.90	23.9
1,370	2.10	Brown	55.54	23.7
1,410	1.20	Drab-gray, buff lines	53.50	22 5

Cone of fusion, 34½.

A sample of this clay was used in a porcelain body and gave the following results:

General physical tests of porcelain body containing clay of sample No. 1.15.

Workability____ Very plastic and smooth; makes excellent bars; jiggers well; smooth and hard when it dries well.
Water of plasticity, in terms of dry clay______per cent__ 35.37
Volume shrinkage________________________________do____ 22.43
Air shrinkage, linear, calculated__________________do____ 8.20
Modulus of rupture______________pounds per square inch__ 259.20

Fire tests of porcelain body containing clay of sample No. 1.15.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	19.00	Very pale buff	29.00	10.40	1,493
1,250	17.40	.....do	29.98	11.20	935
1,310	8.49	.....do	28.06	10.40	2,317
1,370	.51	Pale olive-gray	40.40	15.80	4,258
1,410	.30	Light drab-gray	35.60	13.60	4,282

General physical tests of sample of clay from pit of Peerless Clay Co., Langley S. C. (Bureau of Mines No. 1.16).

Workability__________Fairly plastic; makes fair bars; dries well.
Water of plasticity, in terms of dry clay______per cent____ 42.20
Air shrinkage by volume______________________do________ 17.65
Air shrinkage, linear, calculated________________do________ 6.30

Fire tests of sample of clay from pit of Peerless Clay Co., Langley, S. C., (Bureau of Mines No. 1.16).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	37.60	Very light cartridge-buff	22.65	8.2
1,250	32.90	Very light cartridge-buff	28.50	18.6
1,310	23.18	Light cartridge-buff	37.60	14.5
1,370	14.20	Light cartridge-buff	42.90	17.0
1,410	6.10	Cartridge-buff	46.00	18.6

Cone of fusion, 33.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.16.

Workability____Works well; very good jiggered body; dries well.
Water of plasticity, in terms of dry clay_____per cent____ 28.31
Volume shrinkage____________________________do________ 15.52
Air shrinkage, linear, calculated________________do________ 5.50
Modulus of rupture__________pounds per square inch____ 145.20

Fire tests of porcelain body containing clay of sample No. 1.16.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	22.70	Light cartridge-buff	20.30	7.3	3,921
1,250	20.51	Light cartridge-buff	23.05	8.4	3,259
1,310	15.18	Light cartridge-buff	27.64	10.2	3,820
1,370	.40	Pale olive-gray	34.36	13.1	8,030
1,410	.20	Light drab-gray	33.00	12.5	6,844

General physical tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.17).

Workability — Very plastic; makes good bars; cracks badly.
Water of plasticity, in terms of dry clay — per cent — 56.25
Air shrinkage by volume — do — 25.80
Air shrinkage, linear, calculated — do — 9.50

Fire tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.17).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	28.80	Light ivory-yellow	39.10	15.3
1,250	22.80	Very light cartridge-buff	46.70	18.9
1,310	2.03	Walnut-brown	55.50	23.6
1,370	3.22	do	54.37	22.0
1,410	2.50	do	56.00	23.9

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.17.

Workability — Very plastic; makes good bars; jiggers well; dries nicely.
Water of plasticity, in terms of dry clay — per cent — 36.20
Volume shrinkage — do — 22.88
Air shrinkage, linear, calculated — do — 8.30
Modulus of rupture — pounds per square inch — 161.50

Fire tests of porcelain body containing clay of sample No. 1.17.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	19.30	Very light ivory-yellow	28.00	10.4	807
1,250	17.90	Very light ivory-yellow	28.70	10.7	4,069
1,310	12.22	Light cartridge-buff	32.26	12.2	2,821
1,370	.37	Pearl-gray	39.89	15.6	4,229
1,410	.30	Olive-buff	38.70	15.0	3,683

General physical tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.19).

Workability__________Fairly fat; makes good bars; cracks badly.
Water of plasticity, in terms of dry clay________per cent__ 52.27
Air shrinkage by volume__________________________do____ 23.78
Air shrinkage, linear, calculated_________________do____ 8.70

Fire tests of sample of clay from pit of Peerless Clay Co., Langley, S. C. (Bureau of Mines No. 1.19).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	38.10	Light buff	27.00	10.0
1,250	32.50	....do	37.20	14.4
1,310	13.10	....do	48.50	17.3
1,370	3.77	Brown	52.66	22.1
1,410	2.20	....do	54.50	23.1

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.19.

Workability_Fairly plastic; makes good bars; fair jiggering quality.
Water of plasticity, in terms of dry clay_______per cent__ 37.04
Volume of shrinkage____________________________do____ 22.24
Air shrinkage, linear, calculated________________do____ 8.1
Modulus of rupture____________pounds per square inch__ 160.0

Fire tests of porcelain body containing clay of sample No. 1.19.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	22.60	Very light buff	25.70	9.4	3,912
1,250	21.17	....do	27.19	10.1	4,022
1,310	14.08	....do	31.69	11.9	6,277
1,370	.51	Pale smoke-gray	38.75	15.1	9,711
1,410	.20	....do	38.20	14.9	5,853

The clay from this pit has been used as a filler in high-grade print paper and in cardboard and for coating high-grade book paper. Some manufacturers declare that it is replacing English clay in their works, but others express regret that they are unable to use it except in small quantity. It is employed in cold-water paints, and to some extent as an inert pigment in oil paints and in some brands of cement mixtures. It is also used as filler and in coating and top-printing wall papers and for producing a hard, smooth finish on certain brands of roofing material.

Property of the Immaculate Kaolin Co.—The pit of the Immaculate Kaolin Co. is about 2¼ miles southeast of Langley. The main office is in Easton, Pa.

Shipments have been made from the property during the past 24 years without materially diminishing the supply available. Borings have blocked out a five-years' supply ahead, and about 300 acres have not been explored. As the clay bed is horizontal and as it outcrops in all the stream valleys and gullies crossing the property, there is no reason to doubt that clay of the same general character as that now being mined underlies the entire acreage, except in the bottoms of the valleys. If this inference is correct, the total reserve must be over 6,000,000 tons.

The overburden in the area explored is from 30 to 35 feet thick, and the clay bed ranges from 10 to 20 feet in thickness, though the general average is 15 feet. The variation in the thickness of the clay bed is due partly to variation in the position of the surface, but more commonly to undulations in the top of the bed itself.

In the walls of the pit in September, 1918, the beds were exposed as follows, beginning at the top:

Section in pit of Immaculate Kaolin Co.

	Feet.
Soil	2
Red sand, with layers of limonite in somewhat wavy beds	7
Yellow sand with sparse pebbles and layers of pebbly sand in lower part	20
White clay with few feet of drab clay on top and scattered purple-stained masses	12

The layers of limonite are much more nearly horizontal than the top of the clay, which may indicate that the undulations of the upper surface of the clay are due to erosion and that an unconformity exists between the clay and the pebbly sand above it. This relation is suggested also by the relations of the clay to the overlying sands in the neighboring Paragon pit (fig. 32, p. 174).

The clay bed is by no means uniformly pure. Iron rust, pink stains, pockets of gravel, and local layers of dark clay necessitate careful sorting in the pit. This sorting, however, is readily accomplished, so that the material sent to the driers is uniform in character.

Two distinct grades of clay are produced. No. 1 clay is a smooth, pale cream-colored, dense, brittle variety. When mixed with water most of it slakes rapidly, breaking down to form a cream-colored, thin liquid from which the clay settles rapidly in a loose, flocculent mass, but even after several days there remain many soft, flaky granules that have not broken down. When finally powdered the whole mass slakes without leaving a granular residue. The clay consists almost exclusively of tiny granules of kaolinite, whose average diameter is 0.004 millimeter, but many of these by clustering together give rise to little round clumps which have five or six times the diameter of the individual grains. A few larger flakes of kaolinite, a few large wisps and a few minute scales of mica, and scattered grains of a mineral that is probably rutile are the only other constituents noted. Many of the clumps of kaolinite are brownish, suggesting that the tiny flakes of which they are composed are slightly surface stained.

No. 2 clay differs from No. 1 only in its color, which is distinctly creamy. It acts like No. 1 with water, but the thin slip produced is yellowish. The precipitate that settles upon allowing the liquid to stand is more flocculent than the precipitate of No. 1 clay, and the little granules are more sticky. Under the microscope the principal difference noted between the two grades is that the clumps of kaolinite in No. 2 are reddish brown, indicating that the granules of kaolinite are more deeply stained than those in No. 1. The stain is due to iron hydroxide.

Both grades are furnished in lump and pulverized. In addition, on special orders, drab clay and a mixture of inferior No. 2 and drab are sold to plaster-board and beaver-board manufacturers.

The following tests of a sample of white clay (Bureau of Mines No. 1.14) from the pit of the Immaculate Kaolin Co. have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of sample of clay from pit of Immaculate Kaolin Co., Langley, S. C.

Workability	Fat; makes good bars; cracks slightly in drying.	
Water of plasticity, in terms of dry clay	per cent	49.09
Air shrinkage by volume	do	18.94
Air shrinkage, linear, calculated	do	6.8

Fire tests of sample of clay from pit of Immaculate Kaolin Co., Langley, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent)
1,190	39.15	Very light buff	27.10	10.00
1,250	28.70	do	38.20	14.80
1,310	13.10	Light buff	48.50	19.80
1,370	7.93	Buff to brown	48.95	20.10
1,410	2.60	Cinnamon, buff lines	52.80	22.10

Cone of fusion, 34½.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of Immaculate Kaolin Co., Langley, S. C.

Workability	Slightly short; worked fairly well; jiggers well; dries well; does not crack.	
Water of plasticity, in terms of dry clay	per cent	35.43
Volume shrinkage	do	19.31
Air shrinkage, linear, calculated	do	6.90
Modulus of rupture	pounds per square inch	119.20

Fire tests of porcelain body containing clay from pit of Immaculate Kaolin Co., Langley, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	22.50	Very light buff	24.40	8.9	1,698
1,250	21.10	do	26.50	9.8	2,435
1,310	16.37	do	28.97	10.8	2,403
1,370	.30	Pale olive-gray	38.29	14.9	2,894
1,410	.02	Olive-buff	36.50	14.1	3,589

An analysis of the clay is given on page 168.

In mining the overburden is removed by a cable excavator and the clay is mined by hand. After drying the clay is pulverized so that 92 per cent is guaranteed to pass a 200-mesh screen.

The clay is shipped over a spur of the Southern Railway to Langley.

The capacity of the plant is about 600 tons monthly. This quantity could easily be raised to 850 tons with abundant labor, and this quantity in turn could be nearly doubled by working at night.

The Immaculate clay is used mainly by paper makers, though it is used also to a small extent for giving plasticity to gypsum plasters and as a coating finish to flour sacks and other food containers, for which purpose it has replaced almost entirely English china clay. In the paper trade it is used for nearly all purposes for which clay can be used. It is employed as a filler and for coating wall paper, as a filler for high-grade printing paper and cardboard, where it has supplanted English clay, for coating printing paper either alone or mixed with foreign clay, and for coating glazed paper. For coating expensive glazed papers it is usually mixed with English china clay, but for the cheaper grades it is used alone, and by some manufacturers is preferred to the imported clay.

DIXIANA, LEXINGTON COUNTY.

Geiger property.—Mrs. Lizzie B. Geiger, of New Brookland, owns 79 acres of unexplored land on the Seaboard Air Line Railway, 4 miles from Dixiana in Lexington County. Several small pits have uncovered a deposit of smooth white clay, the extent of which is unknown.

The property is in the area underlain by the Lower Cretaceous beds, and the clay has the properties of the clay belonging to those beds. It is white, very fine grained, almost structureless, and fairly brittle. It slacks rapidly to a thin suspension, from which the clay separates rapidly as a very fine, almost structureless precipitate. The clay consists almost exclusively of flakes and grains of kaolinite, most of which measure approximately 0.003 to 0.004 millimeter in diameter. Other pieces are about ten times as great in their dimension, and there are all graduations in size between these extremes. A very few tiny grains of quartz and wisps of mica are also present and the usual grains of rutile.

TRENTON, EDGEFIELD COUNTY.

Mims property.—The Mims property is on the Dixie Highway, about 8 miles southwest of Trenton, S. C., and 12 miles northeast of Augusta, Ga. The property consists of about 200 acres, and at least 40 acres is underlain by clay. Where the clay comes to the surface it has been cut out by depressions.

There are two wells and a shaft about 150 yards apart in a line, a boring 50 feet deep about 50 feet south of the shaft, which is west of the wells, and an exposure 100 yards south of the boring. The well to the east shows 40 feet of overburden and 3 feet of clay. A boring in its bottom passes through 30 feet of clay. The next opening to the west passes through 27 feet of overburden and 2 feet of clay, and a boring penetrates the clay for a further distance of 18 feet. The shaft, which is on lower ground, exposes 6 feet of overburden and 6 feet of clay, and has been stopped in clay. The boring shows 10 feet of overburden and more than 6 feet of clay. The overburden is sand or sand and clay interlayered. The clay bed ranges in thickness from 6 to 30 feet, and under it is quicksand.

The clay is uniformly finely granular, slightly grayish white, and a little gritty. It is chalky in character. It lacks coherence and breaks up between the fingers under very slight pressure, acting very much like a washed clay. It consists of small flakes of kaolinite, 0.004 millimeter in diameter, and tiny grains of the same mineral, abundant quartz grains of all sizes, the largest 0.1 millimeter in diameter, a very little altered mica, a few splinters of a mineral that appears to be epidote, and numerous tiny grains of rutile. The clay slakes very rapidly and forms with water a very smooth mixture which has a slight grayish tinge.

In a report made by A. S. Watts in 1917 this clay is said to be of a very pale cream color. A 1-inch cube slakes in water in about 5 minutes. When washed through a 200-mesh sieve a residue of quartz and mica amounting to 2.6 per cent of the total is obtained. When passed through a 300-mesh sieve the residue amounts to 5.3 per cent. The product resulting from washing the crude clay is 93 per cent of the refined clay that will pass 300 mesh. The color of the washed product is a little better than that of the crude material, but is not pure white. It is not improved by chemical treatment. When burned at cone 10 (1,330° C.) the product is light buff.

Watts concludes that though the clay would not be acceptable for porcelain manufacture it should nevertheless be acceptable to paper makers, for its working behavior is excellent. He quotes an analysis of the crude clay, as follows:

Analysis of clay from pit on Mims property, 8 miles southwest of Trenton, S. C.

Silica (SiO_2)	58.10
Alumina (Al_2O_3)	29.79
Ferric oxide (Fe_2O_3)	.11
Lime (CaO)	.40
Magnesia (MgO)	Trace.
Soda (Na_2O)	Trace.
Potash (K_2O)	.40
Titanium oxide (TiO_2)	1.50
Water (H_2O)	9.90
	100.20

In spite of the location of the deposit in an area indicated on the map (Pl. XI) as underlain by crystalline rocks, the character of the clay and its occurrence in a bed that seems to be horizontal lead to the view that it is a sedimentary deposit. It may be an outlier of the Cretaceous deposits or possibly a deposit of much later age. Opportunities were not afforded for determining the question of age.

Water is abundant on the property, and an electric-power line is only 4 miles away. If mining is undertaken the product could be carried in trucks 7 miles to Day's siding on the Southern Railway.

USES OF THE CRETACEOUS CLAYS OF SOUTH CAROLINA.

Varieties of clay.—The sedimentary white clays of the Cretaceous of South Carolina are nearly pure, closely resembling kaolinite in composition. They contain as a rule only about 5 per cent of impurities, the most common of which is quartz. Subordinate amounts of feldspar, mica, pyrite, and other minerals are present, but in the better grades they are rare. In the clay from some of the pits the total amount of components other than clay is less than 1 per cent.

In addition to the white clay some of the pits also yield a product that is slightly yellow or cream-colored or even bright-yellow and dark-purple varieties. The yellow and purple varieties are employed to a small extent in making cheap paints, but they are not in great demand. The cream-colored grade is used for fillers in certain kinds of cheap textiles, cardboard, and paper, in the manufacture of colored tile and colored hardware porcelain, in making certain grades of electrical porcelain, in top printing wall paper and in making cold-water paints. It is also employed as a filler in rubber goods, in oilcloth, and in the manufacture of certain kinds of patent roofing.

The white varieties are used for all the purposes enumerated above and also for filling print, book, and magazine paper and white cotton goods, for coating paper and cardboard, for coating and top printing wall paper in light shades, for making white and light colored kalsomine, and in the manufacture of white electrical and chemical porcelain, semiporcelain, china, white ware, and vitreous floor tiling. The percentage of the State's output that is used for pottery and tile, as compared with the other uses, is small, although it has increased since the war began.

Paper.—All varieties of the lighter-colored clays are used as fillers in wall paper, as the color of the stock, except in high-grade papers, is not of great importance. The paper is prepared by first coating its surface and is then decorated by printing on this prepared surface. When a very white ground surface is desired some makers prefer to use imported clay, but for most wall papers South Carolina clay, either alone or mixed with other domestic clays, appears to be satisfactory. The proportion of imported clay used for this purpose is gradually diminishing, and if the southern clay were more uniform in color—that is, if the shipping stock were more carefully selected—it might supplant English clay almost completely. There is some complaint that much of the clay contains yellow streaks or is gritty and therefore has to be rejected. Washing would probably remove at least the grittiness, if not also the other defects. After the paper is coated it is decorated by top printing with a mixture of clay and pigment. As a rule, aniline compounds which are transparent furnish the color, and the clay serves as the medium and produces opacity. The clays of South Carolina are used very widely for top printing and give nearly universal satisfaction. That they are not used more widely is due to the difficulty of obtaining them promptly.

As a filler for manila and newsprint paper all the clays from South Carolina seem to be equally satisfactory. In some factories they are being used in place of English clay that was formerly imported for this purpose, but in a few factories English clay has never been used.

With regard to their use as a filler for book and magazine paper the testimony is more conflicting. Some manufacturers use mixtures of different clays from South Carolina with some other domestic clays in making high-grade calendered book paper, but other manufacturers state that it is necessary to add a considerable quantity of English clay to the mixture in order to obtain a whiter stock, and still others declare that they can not use domestic clay for book papers because it contains too much grit or too large a proportion of components that will not float under a slight pressure. This last statement evidently applies to the unwashed clay from most of the South Carolina mines, for it is repeatedly stated by paper men that the pulverized clay would be more satisfactory if it were crushed as fine as the English clay or if it were washed so that it might disintegrate more readily. Much of the unwashed clay slakes poorly, leaving considerable material in soft lumps that clogs the screens in the paper mills. There is very little grit, but the clogging of the screens interferes with the continuous smooth operation of the machinery. The washed clay is broken into its component particles. In the filter press these particles are made to cohere, but the compression is not so severe that they cohere so strongly as before washing. When treated with water they readily fall apart, leaving no undivided lumps to choke the screens.

The English clay is regarded by most paper makers as superior to American clays because of its uniformly high plasticity, its good color, its freedom from grit, and the readiness with which it makes a paste with water. Some of the clays of South Carolina possess most of these properties, but their color is not pure white, and some of the most nearly white are hard to mix with water. These last-mentioned clays would be most benefited by washing.

For coating cheap paper and cardboard the white clays of South Carolina are widely employed, and many of the makers, particularly of cardboard, state that they have no intention of going back to the imported clay, although the domestic clay is a little more transparent than the foreign material. For coating paper of a better grade the clay from this State has replaced entirely the imported clay in some mills, but in most of them some English clay is still used in the coating mixtures, and for the best work the imported clay is used exclusively. The principal objection to using more of the domestic clay appears to be its color, which is said to be less uniform than that of the imported material. Where color is not important, as in very cheap glazed paper and in the coarse paper used in making flour bags and other food containers, the clay from South Carolina appears to be satisfactory.

Pigments.—For making paints the clay must be white, dry, plastic, and free from grit. There is some complaint that the clay furnished by the South Carolina mines contains too much moisture to be entirely satisfactory. Common requirements are that it shall contain not more than 1 per cent of water, and that it shall not leave more than 1 per cent of residue on a 350-mesh screen nor contain more than 3 per cent of still finer grit after passing it. Many of the shipments evidently meet these requirements, for a number of the paint makers rather widely distributed over the country use clay from South Carolina as an inert pigment to dilute strong colors, to give body to some white paints, and to help float heavy opaque pigments and prevent their settling in the manufactured paint.

Floor and wall tile.—In the manufacture of glazed wall tile and vitreous floor tile the clay from South Carolina seems to be widely used. Although some large makers of tile state that they can not employ it as a substitute for English clay, others who are still using English clay in part declare that they would replace it with domestic clay were it not for the uncertainty of shipments from the South. Several manufacturers state that clays from South Carolina and Florida make up the greater part of their mixture.

Pottery.—According to some manufacturers, the domestic clay is slowly replacing imported clay for pottery. The eastern potters are not so favorably disposed toward the southern clay as the western potters, but even in the East it is being used in an ever-increasing amount. One obstacle to its larger use appears to be difficulty in procuring prompt delivery. A few potters declare that they can not use the clay from South Carolina in their formulas, but acknowledge that in other formulas it might be satisfactory. However this may be, clay from all the South Carolina mines is being used with satisfactory results by many potters in the Ohio Valley and in the West and by a few in the East. It has been used with success in the mixtures employed in manufacturing vitreous china sanitary earthenware, semiporcelain cooking ware, semiporcelain toilet ware, dinner ware, and hotel ware. In some potteries it has replaced entirely the imported clay formerly used, but in others it is mixed with more or less English china clay. The experience with reference to porcelain has varied. The clay from South Carolina is used in making chemical porcelain and hard table porcelain, but there is complaint that if more than a small quantity is put into the mixture the product will not be white. To remedy this defect English clay is added. On the other hand, at least one firm uses only domestic clay in its mixture and produces an excellent chemical porcelain, the other ingredients being clays from other domestic sources in addition, of course, to the flint and feldspar that are invariably used. A mixture of domestic clays, of which a large proportion consists of clay from South Carolina, is also used in making electrical porcelain and hotel china.

Filler.—Considerable quantities of the white clay from this State are used in the process of starching and filling low-priced cotton ticking, and for this purpose it is equally as good as the imported china clay that it has replaced. It is also employed as a filler for linoleum, wall fabrics, and window-shade cloth. For these purposes the clay must be plastic, and this quality the clay from South Carolina possesses to a satisfactory degree. For filling window-shade cloth, however, it is not so good as the imported clay because of its greater translucency and yellowish tinge and because it contains as a rule too much grit when used without thorough washing. Consequently, when employed for this purpose, more or less English clay is always mixed with it.

Miscellaneous uses.—Besides the purposes already mentioned the clays of South Carolina are employed for a great many other purposes but not in as great quantities. They are mixed with washed clays from other sources and made into kalsomine or cold-water paint, replacing imported china clay. For this purpose the clay must meet the same specification in regard to grit as that which is employed in paint pigments and must have a slippery surface. In the latter respect the clay from South Carolina is peculiarly satisfactory, but unfortunately it is not as uniformly white as some other domestic clays. On the whole, it is regarded by some makers of cold-water paints as superior to the imported clay. It is also employed for filtering aniline dyes, in the manufacture of plasters, cements, fireproofing materials, and roofing, and is mixed with rubber for molding into shaped rubber goods, such as rubber heels.

Because of its binding qualities some of the clay from South Carolina is added to the mixtures from which lumber crayons, school crayons, and pencil leads are made. For this purpose it is regarded as superior to the foreign clay by some manufacturers.

Some of the clay is employed in making antiphlogistine.

Defects and their remedy.—The objections raised by some manufacturers to the broader use of the clays from South Carolina fall into five classes—(1) objections to color, (2) objections to the presence of yellow streaks, (3) objections to the presence of grit and lumps that will not disintegrate, (4) objections to lack of opacity, and (5) objections to sizing. The lack of opacity perhaps can not be remedied, although some manufacturers believe that it may be counteracted by the use of a small quantity of talc or other opaque substance in the mixture employed. Most of the other defects, however, might be reduced, if not removed entirely, by more careful preparation. Only one mine that was visited is provided with apparatus for washing the clay. The product of the other mines is said to need no washing, as the market will take all the output in its present condition. This is no doubt true at the present time, when, owing to the shortage of labor, no mine in the State is working at its full capacity. However, washed clay would bring a price enough higher than that of the crude clay to pay all the cost of washing and leave a good profit besides, so that the present practice of shipping crude clay must be regarded as uneconomical.

Careful washing would remove most of the yellow streaks, or so break them up that their color would be distributed through the mass without affecting it noticeably, and it would eliminate nearly all of the grit and cause the whole mass to disintegrate easily on being mixed with water. This treatment would improve the clay for filling and coating paper and for filling window-shade cloth and also for use in paints. It would benefit the clay to some extent for potters' use, but as the process would remove very little if any of the titanium that is found in all the clays from South Carolina they could not be used alone in the manufacture of white china, porcelain, or semiporcelain.

Most of the critics of the clays from this State insist that their grain is neither uniform nor fine enough. Washing would remedy both these defects to some extent. Pulverizing carefully would also remedy them. Some of the mines are equipped with pulverizers, but most of them pulverize to a 200 mesh only. The pulverization could be made to a finer mesh without much additional cost, and there would be a corresponding improvement in quality. Pulverizing, however, does not remove grit or other objectionable ingredients, but it may simply crush them finer. This, of course, improves the quality of the clay, but a greater improvement would result if the objectionable materials could be removed. This removal is accomplished at some of the mines by sizing with fans. The air currents generated by the fans carry the finely crushed clay into bags, whereas the harder, gritty material, which resists more effectually the crushing process, is left behind. Unfortunately, in some plants the rejected material is carried back into the pulverizer and again crushed until nearly all of it finally passes into the bags in which clay is shipped. With proper adjustment of the pulverizer and of the fans it should be possible to separate the clay from the grit so effectually that the undesirable material would be carried out by the air current, and then it could be removed from the bagger and thrown aside, instead of being sent back to the pulverizer, as is now done. Several mines not now using mechanical baggers contemplate adding them to their equipment, and one or two are considering the construction of washing plants.

CONDITIONS THAT AFFECT OPERATION.

Location.—As the clay beds are nearly horizontal and as their character changes very slightly from place to place within short distances from one another, their availability for operation depends principally upon their nearness to lines of transportation and upon their depth beneath the surface; that is, upon the amount of overburden that must be removed before the clay is uncovered.

Most of the operating mines are either on main lines of railroad or are connected with them by short spurs. Other mines are connected with the main lines by narrow-gage private roads operated by steam or gasoline locomotives and small cars. A few haul their output by teams over ordinary country roads. Naturally the producers who can ship directly from their plants have an advantage over those that must transfer their shipments from narrow-gage cars to those of standard gage at points of junction with the main lines of railroad, and these in turn are more advantageously situated than those who have to haul to the main lines and reload in cars on sidings. The companies not on the main lines of traffic must not only handle their shipments twice but they must also provide sacks or other receptacles in which to carry the material to the shipping points in order to reduce the cost of rehandling. Those who haul to the shipping points must, in addition, stand the cost of haulage, which, especially in busy times, is much greater than the cost of movement by cars. In dull seasons, when the movement of the clay is slow, the private lines are not much more economical than horses and carts, because of the necessity of having high-priced men for train service; but at these times the operators on standard-gage railroads, whether main line or spurs, are in a particularly favorable situation, for they suffer no loss through the idleness of the transportation plant. When the cost of loading at the point of shipment is 10 to 12 per cent of the price obtained for the product, as it is in some places, it is evident that the shipper is seriously handicapped in his attempt to compete with others who are not subject to such a charge. Fortunately, at the present time the demand for the clay of South Carolina is so heavy that competition between the clay miners is a negligible consideration. The great handicaps of the trade during the war were lack of labor and lack of cars. In the future, when competition is sharper, only those mines will be able to operate successfully that are on railroads or near them on good roads that will afford cheap haulage by carts or by trucks. A clay bank on a road that will stand trucking, however, may be operated at a much greater distance from a railroad than one on a road that will stand only teaming.

Overburden.—The overburden of the sedimentary clays is composed mainly of sand and gravel, together with a little valueless clay in some places. Its thickness above the commercial clay differs in different localities according to the topography. The area underlain by the clay beds is a sloping plain that is dissected by stream valleys.

Its upper surface is about 680 feet above sea level at the fall line, and it declines about 20 feet to the mile seaward. Near its western margin the clays may reach the surface on the uplands, and there the bottoms of the stream valleys are below the clay beds. Where the Middendorf clay bed forms the surface, the Lower Cretaceous clay may outcrop on the valley slopes or may cover its bottom, depending upon the depth to which the stream has cut. As the clays dip seaward more steeply than the surface of the plain they soon pass beneath this surface and are covered by younger sediments that form an overburden. Where the streams have cut down to the depth of the overburden the clay is exposed in their bottoms, and where the streams have cut beneath the bottom of the overburden the clay beds outcrop on the valley sides, at about the same elevation on opposite sides and throughout the lengths of short valleys, because their dips are so low that their departure from the horizontal is scarcely noticeable within a short distance. Naturally, most discoveries of the clay beds have been made in valleys and most of the clay pits are on or near the valley slopes, for in these localities there is little overburden to remove before reaching the clay, and the valley furnishes a convenient dumping ground for the material removed.

As the clay bed is followed into the side of the valley the overburden increases in thickness, for the surface of the plain gradually rises away from the streams until at the divide between neighboring streams its thickness reaches a maximum. In some localities, where the clay outcrops at a moderate distance below the surface of the plain, the entire area between neighboring streams may be profitably worked. In other places the clay bed is so deep beneath the surface that it can be worked only around the margins of the valleys. At the present time it is not considered profitable to work a bed if the thickness of the overburden is more than about 3½ times the thickness of the good clay beneath it.

ECONOMIC PROBLEMS.

The two great difficulties with which the South Carolina clay producers have to contend is lack of fuel during periods of freight congestion and lack of permanent labor at all times. As fuel is used mainly for power production and as the State is rapidly being crisscrossed by the transmission lines of hydroelectric companies, the problem of securing abundant power will soon be solved for most of the mines now being operated.

The labor problem is more difficult to solve. Most of the labor is drawn from the farms, so that it can not be depended upon for steady work. In dull seasons it is abundant, but in busy seasons, especially during the spring and late summer and autumn, it is unreliable. Wages in 1918 were $1.75 or $2 for a day of 8 hours, which was not high enough to attract the ambitious steady workman, and yet it was about as high as was practicable, when crushed No. 1 clay brought $6.50 or $7 a ton free on board cars. The only remedy for these conditions appears to be the installation of more machinery, both for saving labor and for the preparation of a higher-grade product that will commend a higher price.

Some of the operators are even now trying to solve the problem by installing pulverizers of large capacity to take the place of the smaller ones now in use, by the substitution of power machines for hand labor where it appears advisable, and in other ways they are attempting to reduce the man power required to handle their output.

FUTURE DEVELOPMENT OF THE WHITE CLAYS OF SOUTH CAROLINA.

The total amount of high-grade clay in South Carolina in deposits that are being developed is about 60,000,000 tons, and the output of the mining companies is about 75,000 tons annually. With plenty of labor and improved machinery the annual output could easily be increased to 125,000 tons. The reserve is therefore sufficient to last a long time, even if the rate of production of the mines should stand at the higher figure. But only a small portion of the acreage known to be underlain by good clay has been explored. If only a small part of the unexplored area contains proportionately as great an amount of clay as the explored area, the quantity of white clay still in the ground is many times greater than the estimated reserve of the few mines that are now operating.

The reported production for the last 10 years shows more or less fluctuation. The figures for 1915–1918 are as follows:

White clay from South Carolina marketed in 1915–1918.

Year.	Short tons.	Value.
1915	24,688	$118,388
1916	32,556	168,120
1917	40,173	171,506
1918	[a] 35,000	[a] 230,000

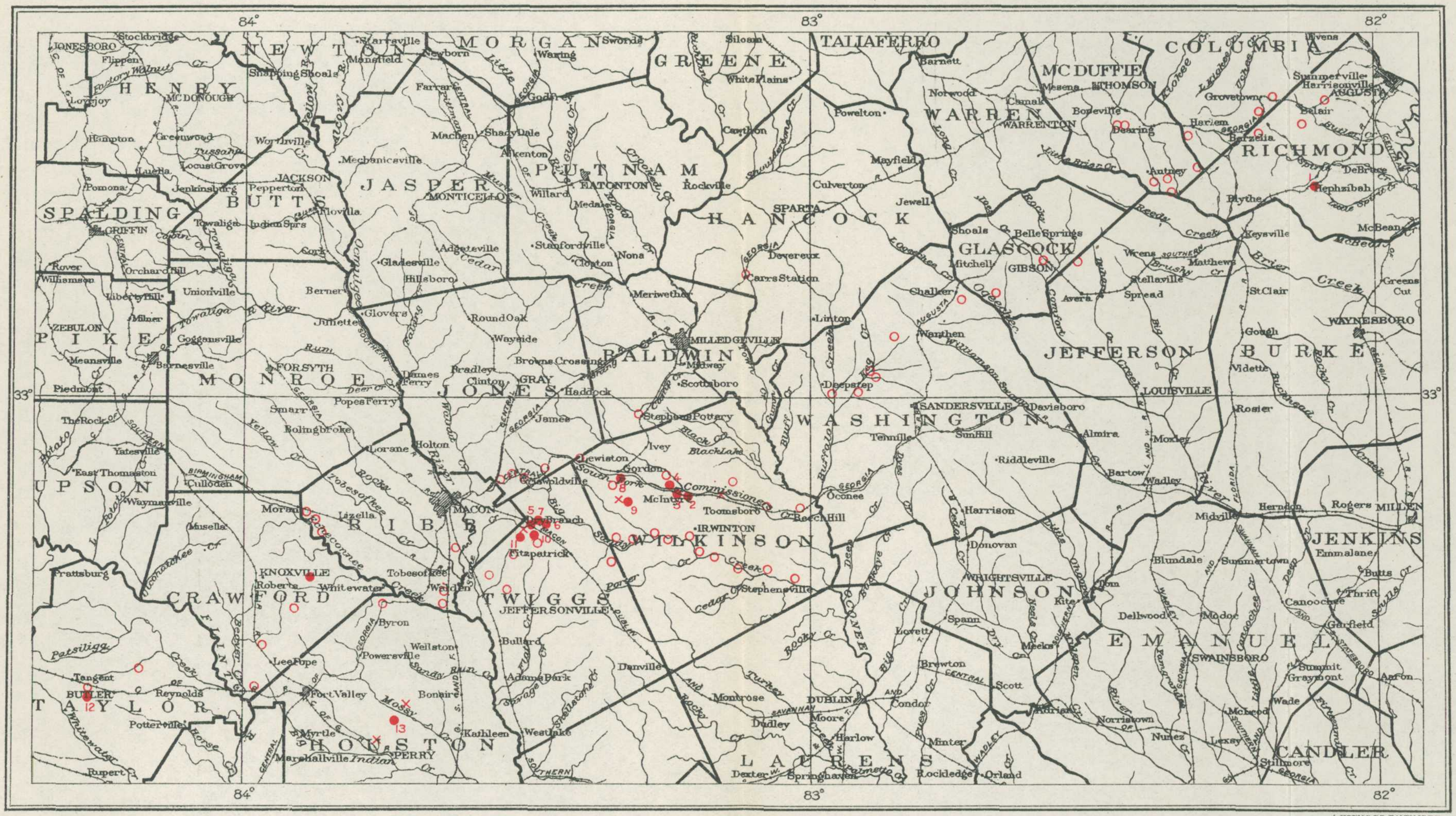
[a] Estimated.

GEORGIA.

DISTRIBUTION.

The Lower Cretaceous deposits of Georgia contain the most extensive and valuable beds of clay in that State. Veatch[77] classes the Lower Cretaceous as Tuscaloosa, but it is no longer so regarded. It

[77] Veatch, Otto, Second report on the clay deposits of Georgia: Georgia Geol. Survey Bull. 18, 1909. Many of the data regarding Georgia have been obtained from this report, supplemented somewhat by a brief visit to the area.



EXPLANATION

Worked pit of white-burning clay (*Number refers to that in list below*)

White-burning clay prospect

Refractory clay, white color but not in the burning.

LIST OF MINES

1 Albion Kaolin Co.
2 Edgar Bros. Co.
3 Edgar Bros. Co.
4 Kaolin Mining Co.
5 American Kaolin Co.
6 Georgia Kaolin Co.
7 R. H. Jones & Co.
8 Savannah Kaolin Co.
9 Columbia Kaolin & Aluminum Co.
10 Atlantic Mining & Clay Co.
11 John Sant & Sons Co.
12 Golding Sons Co.
13 Houston Kaolin Co.

MAP OF A PART OF GEORGIA

Showing location of white clay mines and prospects, the latter from Georgia Geological Survey

Scale $\frac{1}{1,000,000}$

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

1922

forms a belt that extends entirely across the State on the northwestern margin of the Coastal Plain, where it is in contact with the crystalline rocks. (See Pl. XIII.)

The belt of Lower Cretaceous deposits has a maximum breadth of 50 miles along Chattahoochee River, but to the east, at Ocmulgee River, it measures only 20 to 25 miles. East of this river its maximum width is 15 miles, and in places, where it is more or less covered by later formations, it disappears.

The irregular width of the belt is due to the uneven nature of the surface on which the Lower Cretaceous beds were deposited, in places to the overlap or covering by later-deposited formations, and to the deep erosion of valleys along certain lines, which have uncovered the clays. This explanation accounts for the very irregular southeastern border and the tonguelike extensions southeastward, which are chiefly along the stream valleys.

In the eastern part of the State the outcrop of the Lower Cretaceous is very much narrower.

East of Ocmulgee River the Lower Cretaceous is in places obscured by the overlying Claiborne sands (Tertiary), which form the overburden in the clay pits. Other still later formations, of gravelly and loamy character, overlie the clay in places.

The Lower Cretaceous beds consist entirely of sands, gravels, and clays. The thickness of these beds ranges from 500 to 600 feet. In the vicinity of Columbus it is 400 feet, in Crawford and Bibb counties it is 400 to 600 feet, and east of Ocmulgee River it is from 50 to 600 feet. The sand consists chiefly of angular quartz, together with mica and other minerals. It is generally coarse and cross-bedded and makes up about 75 per cent of the deposits.

ORIGIN.

According to Veatch[78] the Lower Cretaceous clays have been derived from the disintegrated and decomposed rocks of the Piedmont Plateau and were laid down in fresh water bodies offshore, as in depressions on the surface of deltas or in inland bodies of water.

MODE OF OCCURRENCE.

The clays occur in lenses inclosed by sand, and though these lenses are of relatively small extent the clay is of high quality.

Individual lenses range from 1 or 2 feet to 35 feet in thickness, and their extent ranges from a hundred yards to several miles. Thus it is difficult to estimate the tonnage unless a number of boring records are available.

[78] Veatch, Otto, op. cit.

The clays are more abundant east of Ocmulgee River, and the deposits are also thicker there than elsewhere.

The larger deposits occur in the upper part of the series, or toward the southeastern margin of the area as mapped, as shown by the developments around Dry Branch, in Twiggs County, and McIntyre, in Wilkinson County.

The upper boundary of the clay as a rule is sharply separated from the overlying Eocene ferruginous sands (Pl. XVI), but the lower part of the clay grades downward into sand.

In Wilkinson County and also in parts of Washington County the white clays in places contain bodies of bauxite, chiefly in the upper part of the deposit (Pl. XIV, *A*.)

In some of the deposits also a nodular clay in beds, lenses, or irregular masses is associated with the massive white clay. This nodular material resembles the clay and not the bauxite in composition.[79]

STRUCTURE.

The white clays are all massive, and show little stratification. Jointing is prominent in some places (Pl. XIV, *B*), but the joints follow no well-defined system and may be simply shrinkage cracks. In places they are a disadvantage, because they permit the infiltration of iron from the overburden.

Although to the eye the clays may appear equally dense, there is nevertheless some variation in this respect, so that some of them slake more easily than others.

VARIATION IN THE CLAY.

The white clays appear remarkably uniform, although closer inspection may bring out local variations in any one deposit, or even reveal impurities of undesirable character.

The impurities include iron stains along the joints, chiefly in the upper part of the deposit; grains or nodules of pyrite, which by their decay may give rise to purplish or red mottlings in the clay; and quartz sand, generally in the form of scattered grains, thin layers or streaks, but some of it in pockets or in curious finger-like masses in the upper 2 or 3 feet of the clay.

If the clay is washed before shipment most of these deleterious ingredients can be thus removed, but if the material is sold in its crude form, the foreign matter should if possible be avoided or thrown out in mining.

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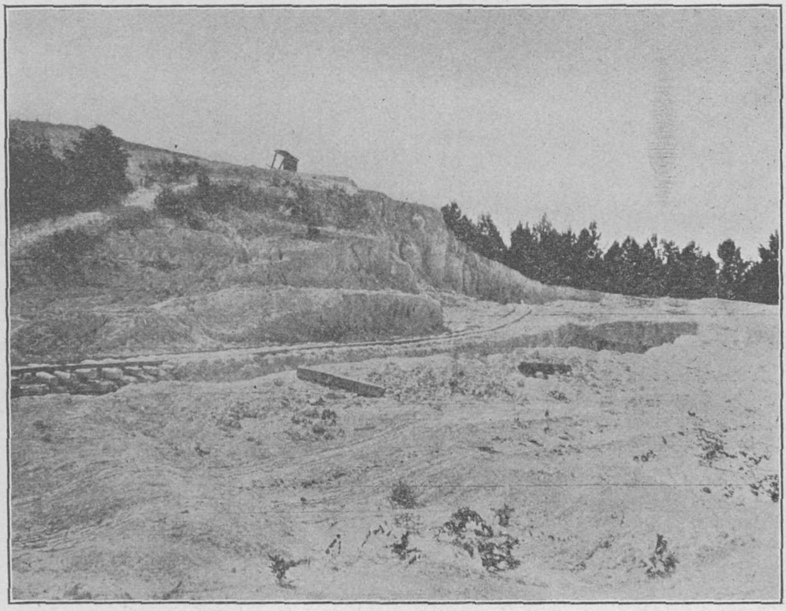
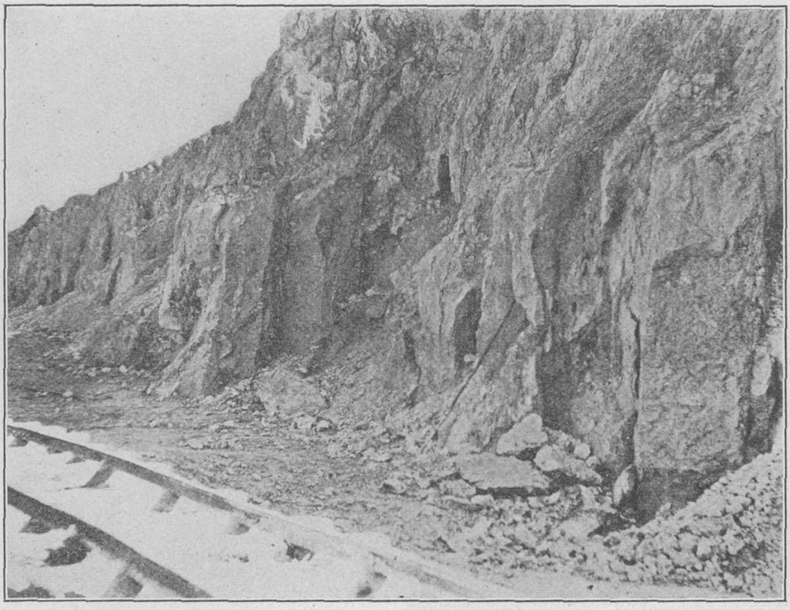
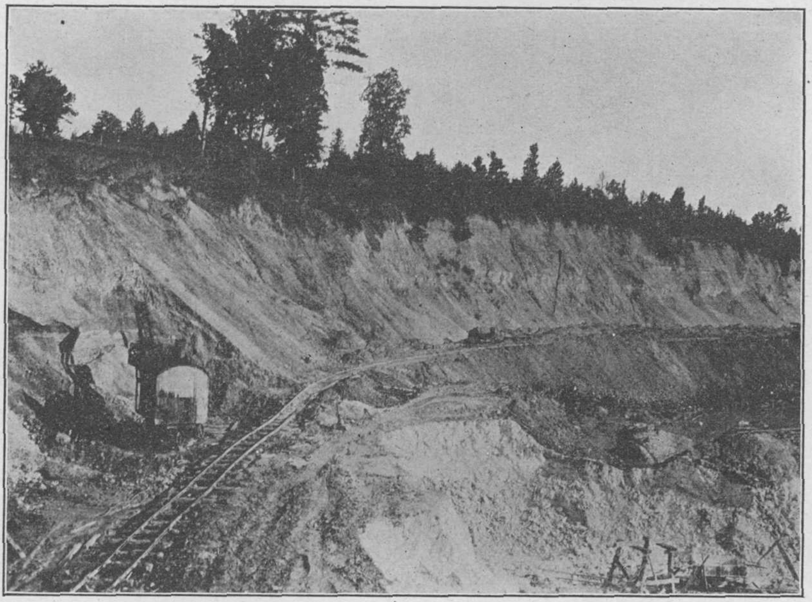
[79] Shearer, H. K., Bauxite and fuller's earth of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 31, 1917.



A. CLAY BANK OF COLUMBIA KAOLIN & ALUMINUM CO., 4 MILES SOUTH OF GORDON, GA.



B. JOINTED STRUCTURE IN CLAY SHOWN ABOVE THE TRACK LEVEL IN *A*.



A. PIT OF GEORGIA KAOLIN CO., NEAR DRY BRANCH, GA.

White clay lies below track level.

B. PIT OF REPUBLIC MINING & MANUFACTURING CO., EAST OF ANDERSONVILLE, GA.

White clay lies above track level and bauxite below it.

CHEMICAL AND PHYSICAL PROPERTIES.

The better grades of clay show the following range in composition, according to Veatch:

Range in composition of better grades of Lower Cretaceous clay from Georgia.

	Per cent.
Silica	40–50
Alumina	34–40
Ferric oxide	0.51–2.11
Titanium oxide	1.5–2

A sieve test showed 5 per cent residue on a 200-mesh sieve. The clays are mostly soft, but flinty material may occur. The air shrinkage is usually low. The fire shrinkage is commonly high, and there is a tendency to check. The tensile strength is low, mostly 10 to 20 pounds to the square inch.

The fusion point is generally from cone 30 to cone 36 (1,730° to 1,850° C.).

MINERALS.

A number of samples of the white clays were examined under the microscope. The minerals noted include hydromica, kaolinite, rutile, quartz, titanite, zircon, and tourmaline.

No detailed petrographic examination was made of the Lower Cretaceous clays of Georgia, but the results obtained from the study of a few samples are worth recording.

Sample No. 1.—Sample No. 1 is a crude clay from Dry Branch, Twiggs County. The clay is fine grained and shows little or no quartz. Hydromica is common, and kaolinite is abundant. Rutile occurs sparingly. The clay that was fired at 1,150° C. yielded a very fine-grained mass in which are some grains that show low interference colors. It showed very little further change at 1,300° C.

Sample No. 2.—Sample No. 2 is a washed clay from Dry Branch, Twiggs County. It is a very fine-grained clay that contains some grains of quartz. Hydromica is common and flocculated, and kaolinite is abundant. A few grains of rutile and zircon are present. The fired clay shows a fine matted mixture of isotropic grains and others that have low interference colors.

Sample No. 3.—Sample No. 3 is a crude clay from the upper bed in a bank 4 miles south of Gordon, Ga. It is fine to medium grained. Quartz grains are fairly common, hydromica is common, and kaolinite is abundant. There are also a number of indeterminable minute dustlike grains. Rutile is scarce.

Sample No. 4.—Sample No. 4 is a clay that underlies the clay of sample No. 3. It is a nodular white clay, which contains an abundance of very fine indeterminable material that may be colloidal. There are a few grains of quartz, some of them sufficiently coarse to be visible to the eye. Kaolinite is scarce, and occurs generally in vermiculites. There are also a few grains of zircon and rutile.

OVERBURDEN.

The thickness of the overburden differs from place to place and may differ even in the same pit. This irregularity is due either to the unevenness of the upper surface of the clay or of the overburden or of both.

As the clay outcrops are most common on the natural slopes, generally in the sides of stream valleys, the overburden may be thinnest where the clay is exposed and increase as one goes into the hill.

In most of the pits the stripping ranges from 10 to 20 feet in thickness, although as much as 30 to 40 feet is sometimes stripped off to work a 20-foot bed of clay. According to some of the sections given by Veatch[80] the overburden on some of the deposits now being worked may increase to as much as 100 feet.

Sections giving the details of the material constituting the overburden are given by Veatch,[81] and by Shearer and Cooke,[82] but as the material is not utilized economically, it is not necessary to repeat them here.

THE WHITE-CLAY INDUSTRY.

When Veatch wrote his report on the Georgia clays in 1909 he remarked that the development of the white clays had hardly begun, but to-day they form the basis of a flourishing clay-mining industry.

The chief developments have been in the vicinity of Dry Branch, Twiggs County (Pl. XV, *A*); Gordon, and McIntyre, Wilkinson County (Pls. XIV, *A*, and XVI); Hephzibah, Richmond County; and Butler, Taylor County. The map (Pl. XIII) shows that these localities form two somewhat widely separated groups.

Veatch in 1909 listed the following operations in the Dry Branch area: Georgia Kaolin Co., Atlanta Mining & Clay Co., American Clay Co., I. Mandle & Co. He also mentioned the Albion Kaolin Co. at Hephzibah.

Since that time there have been extensive developments around McIntyre, where the Edgar Bros. Co., of Metuchen, N. J., operates two plants (see Pl. XVI), and the Kaolin Mining Co., of Philadelphia, Pa., has one at Claymont. Both these companies also have washing plants.

At Gordon the Columbia Kaolin & Aluminum Co., of Washington, D. C., and the Savannah Kaolin Co., of New York, N. Y., are operating clay pits and washing plants.

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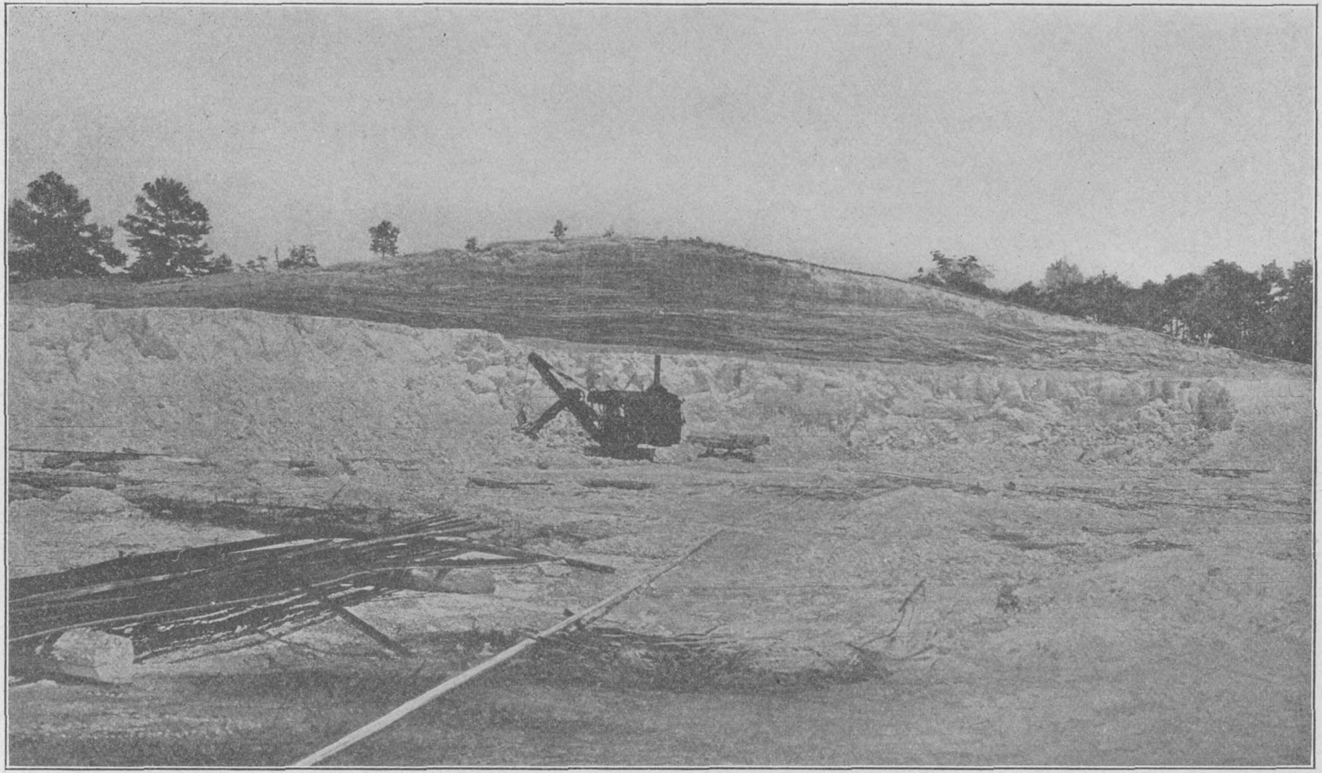
[80] Veatch, Otto, op. cit., p. 127.

[81] Op. cit.

[82] Cooke, C. W., and Shearer, H. K., Deposits of Claiborne and Jackson age in Georgia: U. S. Geol. Survey Prof. Paper 120, pp. 41–81, 1918.



PIT OF EDGAR BROS. CO., NEAR McINTYRE, GA.

Cross-bedded ferruginous Tertiary sands overlie the Cretaceous white clay.

In the Dry Branch district the companies listed by Veatch are still operating, except the firm of I. Mandle & Co., which is now John Sant & Sons Co. A new operation was started in 1918 by R. H. Jones.

At Butler the Golding Sons Co. succeeded the Butler Clay Co., and is now operating.

The following tests of a sample of white clay (Bureau of Mines No. 1.23) from the top bed in the pit of Golding Sons Co., 2½ miles west of Butler, Ga., have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay from pit of Golding Sons Co., near Butler, Ga.

Workability____Plastic; makes good bars.
Water of plasticity, in terms of dry clay____per cent__ 44.3
Air shrinkage by volume____do____ 20.38
Air shrinkage, linear, calculated____do____ 7.3

Fire tests of clay from pit of Golding Sons Co., near Butler, Ga.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	40.20	White	21.45	7.8
1,250	39.30	do	25.60	9.4
1,310	36.70	do	28.08	10.4
1,370	27.97	do	37.15	14.4
1,410	17.80	do	41.80	16.5

Cone of fusion, 33½.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of Golding Sons Co., near Butler, Ga.

Workability_Plastic; makes excellent bars; jiggers well; dries well.
Water of plasticity, in terms of dry clay____per cent__ 31.54
Modulus of rupture____pounds per square inch__ 132.6

Fire tests of porcelain body containing clay from pit of Golding Sons Co., near Butler, Ga.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	27.80	White	18.50	6.6	2,621
1,250	25.54	White; slight buff tint	22.59	8.2	2,418
1,310	23.15	do	22.20	8.1	3,995
1,370	6.09	White	31.10	11.7	4,815
1,410	.18	Pale smoke-gray	35.60	13.7	8,203

For a detailed account of the clay deposits of Georgia the reader is referred to the report by Veatch cited above.

FUTURE EXPANSION.

The clay-mining industry in Georgia may be expanded either by increasing the output of the present plants or by opening new deposits.

With regard to increasing the output of the plants now in operation, it may be said that in 1918 none of the plants were making full production and that all could have increased their output. The total daily capacity of the washing plants, according to figures supplied by the companies, is between 650 and 700 tons.

As regards new deposits the accompanying map (Pl. XIII) shows a number of clay outcrops that are not worked, and no doubt there is a considerable reserve, although it can not be stated in terms of tonnage.

Some of these unworked deposits are likely to lie idle for a time because of remoteness from railway lines.

USES OF THE WHITE CLAYS OF GEORGIA.

All the white clays mined in Georgia are washed before shipment to the market, and the claims of yield of washed product from the crude range from 80 to 95 per cent.

Probably most of the refined clay is sold to paper manufacturers, who use it as a filler for different grades of paper, some of it even in book stock. It is inferior to the English clay in color, but in most other respects it is reported to be as satisfactory, and as a result it has replaced the English clay to some extent during the war. The clay from Georgia does not seem to be regarded as satisfactory for coating, but a not inconsiderable quantity of it is employed by wall-paper manufacturers for coating and as a base for the colors. It is also employed as a filler for shade cloth and has been used to replace part of the English clay formerly employed, but the use of too large a proportion of it is claimed by some to make the cloth too brittle.

In the pottery and tile trades it is used in wall tile, floor tile, sanitary ware, electrical porcelain, semiporcelain tableware, and china. One manufacturer of semiporcelain reports that it replaces 25 per cent of the English clay that he formerly used.

More recently the Bureau of Standards has used it in glass-pot mixtures for making optical glass, and some is being employed by New Jersey potters in sagger mixtures.

The marketed production for 1915 to 1918 of white clays from Houston, Richmond, Taylor, Twiggs, and Wilkinson counties was as follows:

White clay marketed in Georgia, 1915–1918.

Year.	Short tons.	Value.
1915	67,752	$292,943
1916	92,671	417,394
1917	109,222	573,707
1918	[a]75,000	[a]547,000

[a] Estimated.

MARYLAND.

ARUNDEL FORMATION.

The Arundel formation, which is so named because of its great development in Anne Arundel County, Md., carries a large number of lenticular clay deposits, but the clays are of variable character.

Some are refractory,[83] but their occurrence appears to be erratic. In recent years a clay has been obtained from the Arundel formation between Contee and Muirkirk, which resembles a crucible clay in its properties and has been used somewhat in mixtures for that purpose.

Bleininger[84] describes the properties of this clay as follows:

> In appearance this clay resembles very closely the Klingenberg clay. It is black and high in organic matter and exhibits the same characteristic stickiness. It resists slaking in water still more than the Klingenberg clay, though it has a higher pore-shrinkage water ratio. * * * The modulus [of rupture] is 518 [pounds per square inch]. * * * Its porosity at 1,090° [C.] is 21.80 [per cent], * * * and its temperature of complete vitrification * * * is about 1,250° C. The clay, however, reaches a good density at 1,200°. Expansion begins to take place somewhat below 1,350°, and this change becomes accelerated markedly at 1,400°, followed by a stage of quiescence. * * * The softening point is that of cone 31. It would seem that this clay should be valuable for the crucible industry, though less suitable for glass refractories.

Only a few small openings have been made in the clay, and its extent is uncertain. In 1918 it was being shipped to the steel works.

PATAPSCO FORMATION.

This formation, which underlies the Raritan in Maryland, is best developed in the valley of Patapsco River. It is a prominent member of the Cretaceous in that State, however, and extends from the Delaware border to Potomac River.

All the clays found in it are by no means refractory, but in Cecil County at least there are a number of deposits which are quite plastic and whose fusion point lies at cone 27 (1,670° C.) or higher. They are all lenticular and may be of small extent but are worth examination by those searching for refractory bond clays.[85]

[83] Ries, H., Report on the clays of Maryland: Maryland Geol. Survey, vol. 4, p. 431, 1902.

[84] Bleininger, A. V., and Loomis, G. A., Properties of some American bond clays: Am. Ceramic Soc. Trans., vol. 19, p. 621, 1917.

[85] Ries, H., op. cit., p. 413.

UPPER CRETACEOUS CLAYS.

RARITAN FORMATION.

NEW JERSEY.

OCCURRENCE AND DISTRIBUTION.

The high-grade clays of New Jersey occur almost exclusively in the Raritan formation. This formation has been classed as Lower Cretaceous by the New Jersey Geological Survey,[86] but by the United States Geological Survey [87] and the Maryland Geological Survey [88] it is now considered to be the lowest formation of the Upper Cretaceous series as found in the Atlantic Coastal Plain.

The value of the Raritan clays was emphasized in the report by Cook [89] in 1878, and since then the development of the area has been steady.

The Raritan in New Jersey forms a broad belt that extends from Raritan Bay across the State to Trenton and Bordentown, and a much narrower strip extends down Delaware River as far as Salem County, its greatest width being 8 miles. The Raritan beds are in most places covered by later sands and gravels, which may be so thick as not only to conceal them but to prevent mining.

The Raritan consists of a number of beds of clay, sand, and gravel. It is characterized by abrupt transitions in the character of the beds, which commonly occur either vertically or horizontally, so that a bed of clay may pass abruptly into a bed of sand or a bed of sand may pass into a bed of clay. These transitions naturally make the correlation of beds in separated sections rather difficult, and a subdivision of the formation in Middlesex County has been made possible only by the comparison of the numerous sections exposed in pits and cuts.

The beds of the formation dip gently to the southeast. The basal beds rest on Triassic shales in Middlesex County, but from Trenton southwestward the underlying rock is pre-Cambrian gneiss and schist. The Raritan is overlain by the Upper Cretaceous clay and marl series.

New Jersey is one of the three leading States in the ceramic industry. It not only supports a number of ceramic factories of all sorts but is the seat of a thriving clay-mining industry.

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[86] Ries, H., Kümmel, H. B., and Knapp, G. N., The clays and clay industry of New Jersey: New Jersey Geol. Survey Final Rept., vol. 6, p. 161, 1904. Also later New Jersey reports.

[87] Veatch, A. C., Underground water resources of Long Island, N. Y.: U. S. Geol. Survey Prof. Paper 44, pp. 25–26, 1906. Also Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 20, 1914, and other reports.

[88] Clark, W. B., Geol. Soc. America Bull., vol. 20, p. 648, 1910; also Clark, W. B., Bibbins, A. B., and Berry, E. W., Maryland Geol. Survey, Lower Cretaceous, pp. 27, 29, 57, 1911.

[89] Cook, G. H., and Smock, J. C., Report on the clay deposits of Woodbridge, South Amboy, and other places in New Jersey, New Jersey Geol. Survey, 381 pp., 1878.

The State therefore attracted considerable attention during the World War, not only because it maintained industries that were necessary to the prosecution of the war but because it shipped fire clay from deposits in Middlesex County to these industries in other States. New Jersey, however, could supply but small quantities of the types of raw materials that were imported in large quantities from Europe before the war.

USES OF THE CLAYS OF NEW JERSEY.

By G. H. Brown.

The unprecedented demand for fire clay and fire brick during the World War very shortly caused the price of these commodities to rise. The shortage of labor in Middlesex County caused by the activity of munition and other factories seriously handicapped the clay miners in filling orders for their materials. This shortage of labor became more acute as the war progressed, and during 1918 it was the direct cause of the cessation of work at several mines.

In selecting a site for the Raritan depot the Government unfortunately took a part of the property of the Raritan Ridge Clay Co. and other firms near Metuchen, which cut off the production of some of the best grades of clay in that district.

The unprecedented demand and the high prices paid for fire brick caused many companies, such as those commonly engaged in making terra cotta, to engage in the manufacture of refractory products and thus to increase the use of the fire clays of New Jersey.

The electrical-porcelain industry was operated at full capacity, but this industry has never depended largely on the clay of New Jersey, and the same statement applies to the floor and wall-tile and sanitary-ware industries. No clay from New Jersey was used for graphite crucibles at the beginning of the war, but a very good crucible clay mixture has been developed from the clays of Middlesex County and is now being used in the manufacture of graphite crucibles, mostly in plants outside the State.

The clays of New Jersey have proved of great value in the manufacture of the saggers and slabs that are used for containing and supporting abrasive wheels in the kilns during burning, but they have not been found adapted for use in the bond of such wheels.

A small quantity of ball clay from New Jersey is used in the manufacture of sanitary ware, but there is no general use of clays from New Jersey for this purpose, as they are inferior in strength and color after burning to those obtainable from other sources.

Clays from New Jersey are not used either, so far as known, in the manufacture of glass refractories.

The most notable development, recently, because of its relation to foreign material has been the discovery and operation of a deposit of clay which proved to be an excellent substitute for the German Klingenberg clay that was formerly imported and used in the manufacture of pencil leads. The deposit is a surface bed of Recent age, and hence is not a part of the Raritan formation. It is near Metuchen and is owned by Mr. Wm. Dinwiddie. At the present time about 90 per cent of the pencil leads made in the United States are said to contain this clay.

MARYLAND.

The Raritan formation overlies the Patapsco in Maryland, and in places contains large deposits of clay. It occurs in Cecil and Kent counties and extends southwestward on the western shore of Chesapeake Bay along the southeastern border of Harford and Baltimore counties into Anne Arundel County, where it occupies a large area along Severn River. The formation contains a number of deposits of clay, some of which are described by the writer in the report of the Maryland Geological Survey,[90] but none of these clays have so far been used in glass refractories or graphite crucibles. Some of them are refractory, but nothing definite is known regarding their porosity on burning or their firing range.

Some deposits of white clay are found along Severn River, but they are small.

TUSCALOOSA FORMATION.

The Tuscaloosa formation consists of sands, clays, and gravels which are irregularly bedded and have a total thickness of 1,000 feet.[91] The clays range from massive to thinly laminated in structure and are variable in color.

The Tuscaloosa is chiefly restricted to central and western Alabama and northeastern Mississippi. In both these States it carries deposits of white clay. The formation also occurs in Perry County, Tenn., but there it has no clays of economic value, and it is probably also represented as far north as Trigg County, Ky.[92]

ALABAMA.

In northwestern Alabama the white clays of the Tuscaloosa formation at Chalk Bluff, 4½ miles south of Hackleburg, Marion County, are well known but have never been mined to any extent. At this locality the clay is 20 feet thick. The upper 8 feet is somewhat more sandy than the lower 12 feet, but the bed can be traced for several miles, although its thickness is not uniform.

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[90] Ries, H., Report on the clays of Maryland: Maryland Geol. Survey, vol. 4, pt. 3, 1902.

[91] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 20, 1914.

[92] Berry, E. W., U. S. Geol. Survey Prof. Paper 112, pp. 12, 13, 26–29, 1919; Stephenson, L. W., and Wade, Bruce, idem, map, 1919.

The deposit is less than 1 mile from a good macadam road, and water can be obtained within half a mile of the deposit.

The following tests of this clay were made in the laboratory of the Bureau of Mines, at Columbus, Ohio:

General physical tests of clay from Chalk Bluff, Marion County, Ala.

Workability	Fair; chips easily when dry.
Water of plasticity ______ per cent	34.05
Air shrinkage by volume ______ do	15.95
Air shrinkage, linear, calculated ______ do	5.50
Modulus of rupture:	
Raw clay ______ pounds per square inch	53.00
Mixture of clay and sand in proportion of 1 : 1 ______ do	23.56

Fire tests of clay from Chalk Bluff, Marion County, Ala.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage (per cent).
1,190	32.10	Faint creamy white	18.40	7.00
1,250	36.10	do	23.40	8.50
1,310	30.22	do	29.93	11.00
1,370	28.30	do	33.70	13.00
1,410	20.40	Cream	39.10	15.00

Fusion point, cone 33. Steel hard at 1,250° C. Develops minute cracks in firing.

The clay burns sufficiently white to be used in the manufacture of pottery, but its transverse strength and bonding strength are very low. For pottery it would have to be mixed with a more plastic clay. The clay is very fine grained and could probably be used in the manufacture of paper, paint, or rubber. It is similar in many respects to the clay obtained at Cold Spring, Va. (See p. 101.)

Deposits similar in character to the Chalk Bluff clay are found near Pearces Mills in Marion County and Pegram in Colbert County. These deposits have never been developed.

MISSISSIPPI.

DISTRIBUTION AND CHARACTER.

The Tuscaloosa formation occupies a comparatively small area in the northeastern part of Mississippi, and it outcrops in the counties of Lowndes, Monroe, Itawamba, Prentiss, Alcorn, and Tishomingo.

Its clays are said by Logan[93] to be among the most refractory of those found in the State. Chemical analysis shows that most of them run rather high in silica and that they also commonly run under 1 per cent of iron oxide.

[93] Logan, W. N., The pottery clays of Mississippi: Mississippi Geol. Survey Bull. 6, p. 102, 1914.

The lenses of white clay seem to be rather abundant, but no systematic attempt seems to have been made to determine the available quantity of material in them. Some of the best deposits are said to occur north and south of Iuka, in the northeastern corner of the State.

UNDEVELOPED PROPERTIES IN TISHOMINGO COUNTY.

By E. N. Lowe.

The following undeveloped deposits have been examined by the Mississippi Geological Survey:

Tishomingo.—There is clay on the land of James Starkey, 6 miles northeast of Tishomingo on the Birmingham branch of the Illinois Central Railroad. No pits have been opened on the deposit, but the clay is exposed in washes 200 or 300 yards from the public road. At the point where the examination was made and the sample was taken the clay is highly plastic, free of all grit and sand, and light bluish-gray, though near the exposed surface slight yellowish discolorations due to iron oxide appear. This stain was especially noticeable on joint surfaces. The clay has no other observable impurities. Where it is not exposed to the weather it is firm and shows conchoidal fracture.

The exposed thickness of this clay is 6 feet, but its actual thickness is perhaps much greater. It is exposed in most slopes and is probably continuous with a deposit at a negro house half a mile to the south and possibly also with that which was struck in a well at the old Clingscale residence 1 mile south of Starkey's.

The clay fuses at cone 29 (1,650° C.) and has a transverse strength of only 76.7 pounds to the square inch.

Hilgard [94] mentions a fine white clay that was struck in a well on the Clingscale place at a depth of 30 feet. The well was dug 30 feet deeper, but it stopped in the clay.

Iuka.—On the land of John Castlebury, 4 miles southeast of Iuka and three-fourths of a mile from Gravel siding, on the Southern Railway, there is a large deposit of white clay from which small shipments have been made. A pit 75 feet long has been opened, and the clay has been prospected also by small pits and borings along the hillside for a distance of 250 feet. It undoubtedly extends farther. Outcrops of a similar clay occur 1 mile east of this pit. Further prospecting may prove the clay to be continuous between the two points.

The face of the Castlebury pit shows 15 feet of massive white joint clay to the bottom of the pit. The clay extends for an unknown depth below the bottom of pit. Dark-gray laminated sandy clay 4 to 6 feet thick lies unconformably upon the massive white clay. Above this dark-gray clay lies 5 to 7 feet of gravelly soil.

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[94] Hilgard, E. W., Geology and agriculture of Mississippi, p. 35, 1860.

The clay in this pit is not high in plasticity, owing to the appreciable content of very fine white silica that is intimately mixed with it. This silica seems to be identical with that contained in the deposits of tripolite, which are interbedded with Carboniferous chert beds a few miles farther north and east. No other visible impurities exist.

The following tests of this clay, made by C. W. Parmelee, of the University of Illinois, have been furnished by the Mississippi Geological Survey:

General physical tests of clay from Castlebury pit, 4 miles southeast of Iuka, Tishomingo County, Miss.

Kind of material	White plastic clay of medium hardness.
Working properties	Good.
Conduct when flowing through die	Good.
Water of plasticity ... per cent	28.8
Plasticity	Low.
Shrinkage water, in terms of volume of true clay ... per cent	7.25
Pore water, in terms of volume of true clay ... do	20.54
Modulus of rupture (average):	
Raw clay ... pounds per square inch	80
Mixture of clay and sand, in proportion of 1:1 ... do	33.1
Fineness test:	
Residue, 20-mesh sieve ... per cent	0.29
Residue, 40-mesh sieve ... do	.19
Residue, 60-mesh sieve ... do	.20
Residue, 120-mesh sieve ... do	.93
Residue, 200-mesh sieve ... do	.52
Linear drying shrinkage ... do	6.11
Drying conduct	Fair; small cracks appear on surface during drying.

Fire tests of clay from Castlebury pit, 4 miles southeast of Iuka, Tishomingo County, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	38.7	Yellow-white	Nearly steel hard	1.0
03	1,090	39.2	do	do	1.32
2	1,170	39.0	do	do	1.51
5	1,230	37.8	do	do	1.71
9	1,310	36.2	do	do	4.20
12	1,370	30.5	do	do	4.11
14	1,410	32.6	Cream-white; red spots	Steel hard	3.16
15	1,430	30.8	do	do	

Fusion test: Deformed at cone 31 (1,750° C.).

The following general conclusions have been reached regarding this clay: Plasticity, low; drying shrinkage, normal; strength of unburned clay, low; bonding strength, low; fire shrinkage, normal; porosity, high at all temperatures; color, good except for small reddish specks.

The clay is classed as an open-burning refractory clay, having low plasticity and strength. Its color might possibly be improved by washing. Its high fusion point makes it available for the manufacture of refractory wares, such as fire brick and saggers.

Another outcrop of clay occurs on the Iuka and Alsboro road, 4 miles south of Iuka, at Pennywinkle Hill, on the land of George Martin, in sec. 5, T. 4 S., R. 11 E.

The thickness of the visible deposit is 18 feet. Above this clay lies 5 feet of thickly bedded, dark-gray sandy clay that contains thin laminae of lignite, which locally include small masses of amber. Above this laminated clay there is 10 feet of yellowish-red sand.

A well dug 200 yards south of this outcrop exposed clay that was apparently the same in quality, but the thickness exposed in the well is unknown. All wells in this vicinity enter similar clay.

This material is a bluish-gray joint clay, which becomes lighter in color toward the base of the exposure.

The following tests of this clay, made by C. W. Parmelee, of the University of Illinois, have been furnished by the Mississippi Geological Survey:

General physical tests of clay from Pennywinkle Hill, near Iuka, Miss.

Kind of material	Nearly white, plastic clay of medium hardness.
Working properties	Good.
Conduct when flowing through die	Fair.
Water of plasticity ... per cent	30.9
Plasticity	Good.
Shrinkage water, in terms of volume of true clay ... per cent	8.3
Pore water, in terms of volume of true clay ... do	22.6
Modulus of rupture (average):	
Raw clay ... pounds per square inch	164
Mixture of clay and sand, in proportion of 1:1 ... do	52
Fineness test:	
Residue, 20-mesh sieve ... per cent	0.26
Residue, 40-mesh sieve ... do	.15
Residue, 60-mesh sieve ... do	.15
Residue, 80-mesh sieve ... do	.03
Residue, 120-mesh sieve ... do	.32
Residue, 200-mesh sieve ... do	.33
Linear drying shrinkage ... do	5.54
Drying conduct	Surface cracks form during drying.

Fire tests of clay from Pennywinkle Hill, near Iuka, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	40.7	Yellow-white	Nearly steel hard	2.26
03	1,090	38.8	do	do	2.50
2	1,170	37.0	do	do	4.16
5	1,230	35.4	Cream-white	Steel hard	3.95
9	1,310	25.6	do	do	7.57
12	1,370	23.7	do	do	7.58
14	1,410	22.3	do	do	7.75
15	1,430	17.6	do	do	

Fusion test. Deformed at cone 30 (1,730° C.).

The following general conclusions have been reached regarding this clay: Plasticity, good; drying shrinkage, normal; modulus of rupture, low, possibly due to checking in drying; bonding strength, low; porosity after firing, high; fire shrinkage, normal; color after firing, yellowish white, which is slightly intensified at the higher temperatures, with appearance of numerous reddish to brownish specks at temperatures above cone 9 (1,310°C.).

If the clay can be purified by some treatment to remove the specks, it will be of use for pottery, otherwise its high fusion point makes it of value for refractory wares.

Golden.—On the land of Dock Clement, in sec. 16, T. 7 S., R. 10 E., 2 miles southwest of Golden, on the Birmingham branch of the Illinois Central Railroad, there is an outcrop of good clay. The outcrop shows 3 or 4 feet of clay in the banks and bottom of a small creek.

The clay is highly plastic and free from sand or other visible impurities. It is bluish gray while wet, but dry specimens seen in Iuka were creamy white. Neither the depth nor the lateral extent of this deposit could be discovered at the time of examination, but as it occurs continuously along the creek bed for 50 to 75 yards it is probably present in commercial quantities. The Cretaceous clays of this county occur usually in extensive deposits.

No pit has been opened on this clay. The overburden is a thick mass of cherty gravel 25 to 40 feet thick, which if tapped by a spur track from the railroad 2 miles away, would be a commercial product for road material.

The clay is not fused at cone 28 (1,690°C.) and has a transverse strength of 170.6 pounds to the square inch.

Eastport.—At the head of Eastport Hollow, in the bed of a small creek running north, at a point opposite Eastport Church, in sec. 27, T. 2 S., R. 11 E., about 3 miles from Tennessee River, a bed of clay outcrops on the property of C. A. Hill.

The deposit lies on the public road between Eastport and Iuka, 3 miles from the Eastport landing on Tennessee River, and 5 miles from the Southern Railway at Iuka.

The clay is creamy white, with yellowish stains toward the northern end of the outcrop, but toward the southern end this changes to uniform light gray. The only impurity noted was a small proportion of iron oxide discoloring the clay toward the northern end of the outcrop, as before stated.

This clay can be seen to outcrop along the creek bottom for 250 yards, but probably extends much farther under cover. Its depth has not been determined but is not less than 6 feet, perhaps much more. It extends across the creek bottom or flat, 100 yards wide, and passes beneath the hills on each side to unknown distance. In the creek bottom the clay is covered by alluvium 5 to 9 feet thick, and under the hills the overburden consists of gravel deposits 50 to 75 feet thick, excellent for road construction. Both the clay and the gravel are of Cretaceous age.

C. A. Hill has in the past shipped considerable quantities of clay to the Ceramics Department of Sophie Newcomb College, New Orleans.

The following tests of this clay, made by C. W. Parmelee, of the University of Illinois, have been furnished by the Mississippi Geological Survey:

General physical tests of clay from Eastport, Miss.

Kind of material	Light-brown, plastic clay of medium hardness.
Working properties	Good.
Conduct when flowing through die	Fair.
Water of plasticity ... per cent	81.4
Plasticity	Good.
Shrinkage water, in terms of volume of true clay ... per cent	36.15
Pore water, in terms of volume of true clay ... do	45.15
Modulus of rupture (average):	
Raw clay ... pounds per square inch	474
Mixture of clay and sand, in proportion of 1:1 ... do	130
Fineness test:	
Residue, 20-mesh sieve ... per cent	0.25
Residue, 40-mesh sieve ... do	.17
Residue, 60-mesh sieve ... do	.25
Residue, 80-mesh sieve ... do	.12
Residue, 120-mesh sieve ... do	.75
Residue, 200-mesh sieve ... do	.21
Linear drying shrinkage ... do	10.81
Drying conduct	Good.

Fire tests of clay from Eastport, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	72.6	Light buff	Nearly steel hard	3.26
03	1,090	50.1	do	do	4.17
2	1,170	47.0	do	do	5.26
5	1,230	49.8	do	do	5.56
9	1,310	40.1	Brown	Steel hard	9.30
12	1,370	26.0	Chocolate-brown	do	13.9
14	1,410	.127	do	do	7.76

Fusion test. Deforms at cone 28 (1,690° C.).

The following general conclusions have been reached regarding this clay: Plasticity, good; drying shrinkage, normal; strength of unburned clay, good; bonding power, fair; fire shrinkage, rather high with increasing temperature; porosity, high up to cone 12; color after firing, rather dark.

The clay is classed as a low-grade refractory clay, which because of its dark color after firing can not be used for making the better grades of pottery. It can be used in certain classes of wares, such as saggers and second-grade fire brick, which are not expected to meet very severe conditions when in use.

MIDDENDORF ARKOSE MEMBER OF BLACK CREEK FORMATION IN SOUTH CAROLINA.

By W. S. BAYLEY.

The Black Creek formation of the Upper Cretaceous has been recognized in North Carolina and South Carolina. At the base of the formation in South Carolina lies the Middendorf arkose member, which contains extensive deposits of white clay similar to and closely associated with the Lower Cretaceous white clays that are found in the same region.

WARRENVILLE, AIKEN COUNTY.

Property of Parker Kaolin Co.—The Parker Kaolin Co.'s mine is alongside the Southern Railway, 4 miles west of Aiken. Its post office is Warrenville. The property consists of 41 acres, over which borings at irregular intervals indicate the presence of clay everywhere except in narrow valleys or gullies, where it has been removed by erosion.

The place has been worked by several people and contains many large openings, which are on a low plateau intersected by valleys, from which the clay has been cut out completely. However, it outcrops on the slopes of the valleys in such a way as to indicate the essential horizontality of the bed. The overburden consists mainly of yellow sand, which ranges in thickness from 1 to 20 feet. The clay bed measures from 6 to 7 feet in thickness.

A section on the wall of a newly opened pit shows the following sequence:

Section in new pit of Parker Kaolin Co., Warrenville, S. C.

	Feet.
Coarse current-bedded yellow sand, containing still coarser sand at bottom and a few thin layers of clay	18
Pebbly limonite in which nodules of clay are common	$\frac{1}{6}$–$\frac{1}{4}$
Stained yellow clay (ruggage)	2–3
White clay	6–7
White sandy clay	6
White gravelly sand; thickness unknown.	

The clay that is worked is white, compact, and apparently free from grit. It is not quite so dense as that mined at the Interstate pit. The sizes of its components are the same as those of the Interstate clay, but the coarser grains are more numerous. Flakes of mica measuring 0.02 millimeter in diameter are numerous and there are also many black particles that may be rutile. The output consists entirely of crude clay, which is dug by hand and dried before shipment at Parker siding on the Southern Railway.

The following tests of a sample of white clay (Bureau of Mines, No. 1.22) from the pit of the Parker Kaolin Co. have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of sample of clay from the pit of Parker Kaolin Co., near Warrenville, S. C.

Workability	Fairly plastic; makes good bars; cracks slightly.	
Water of plasticity, in terms of dry clay	per cent	43.76
Air shrinkage by volume	do	17.90
Air shrinkage, linear, calculated	do	6.20

Fire tests of sample of clay from pit of Parker Kaolin Co., near Warrenville, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	37.64	White	24.90	9.1
1,250	37.30	do	25.80	9.5
1,310	32.83	do	32.58	12.3
1,370	22.80	do	40.24	15.8
1,410	6.20	do	48.50	17.3

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of Parker Kaolin Co., near Warrenville, S. C.

Workability	Very plastic; makes good bars; jiggers well; dries slowly, but safely.	
Water of plasticity, in terms of dry clay	per cent	32.79
Volume shrinkage	do	18.81
Air shrinkage, linear, calculated	do	6.70
Modulus of rupture	pounds per square inch	166.20

Fire tests of porcelain body containing clay from pit of Parker Kaolin Co., near Warrenville, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	25.60	White	20.10	7.2	3,432
1,250	24.00	do	21.00	7.6	3,978
1,310	18.20	do	24.36	8.9	4,265
1,370	.72	do	35.04	13.4	10,268
1,410	.06	Pale olive-buff	36.34	14.0	9,090

The Parker clay has been used as filler for box and cardboard and for newsprint paper by manufacturers who have never found it necessary to import clay to meet their needs. It is employed as a substitute for imported clays that were formerly used as filler for ticking and is mixed with imported clay for filling window-shade cloth. It is also used for coating and top printing wall paper. In top printing it is mixed with pulp colors and the colored clay is printed on the coated surface. For this purpose the Parker clay seems in general to have the proper physical characters, but some of it is marred by yellow streaks. However, it is being used to a considerable extent in place of English clay.

In addition to its clay the mine has a source of income in the overburden. About 500 tons of sand, grit, and impure clay intermingled have been sold to the city of Aiken for road metal.

RAYFLIN, LEXINGTON COUNTY.

Property of Edisto Kaolin Co.—The pit of the Edisto Kaolin Co. is 2½ miles west of Rayflin, a station between Seivern and Steedman on the branch of the Southern Railway that connects Perry and Batesburg. The post office of the plant is Samaria, and the office of the company is at Bridgeport, Conn.

The property consists of 269¾ acres, of which 135 acres are shown by borings to be underlain by a clay bed from 8 to 16 feet thick. A part of the remainder of the property is a valley from which the clay has been entirely cut out, but the greater part of it is upland, which is underlain by the same bed of clay as that under the bored area. The overburden, which is from 6 to 18 feet thick, is composed of current-bedded sand and interlayered seams of limonite. If the clay is all of commercial quality the available quantity under the bored area is more than 3,000,000 tons. A well on the property 160 feet deep shows that sand underlies the clay to this depth.

The clay is very light cream-colored, almost gritless, and very finely granular. It contains a very little sand and here and there a minute yellow spot. When crumbled and shaken up with water it forms a darker, yellowish suspension that settles rapidly.

Under the microscope the kaolinite is seen to occur in thin scales and grains from 0.002 to 0.01 millimeter in diameter and in small wormlike groupings. Besides the kaolinite a very few tiny grains of quartz, biotite, altered muscovite, zircon, and rutile are present. The quartz occurs in sharp-edged grains a little larger than the grains of kaolinite, but these grains are usually grouped together in little clumps. Few of the little yellow spots are more than 1 millimeter in diameter. Under the microscope they appear as little masses of quartz, mica, and various undeterminable minerals showing stains of iron oxides in the cracks between them and surrounding their peripheries. They thus seem to be grains of some iron-bearing mineral that has entirely broken down under the decomposing agencies.

Formerly the clay was washed, but the process was not successful commercially, possibly because the washer and settling tanks are at a higher elevation than the pit, so that all the clay and water used in the entire process of preparation had to be raised. Until recently only crushed clay was marketed, but there have now been installed two pulverizers, which will crush 10 tons to 150 mesh in 10 hours. The average output of the plant before the pulverizers were operating was 260 tons monthly. This low production was due to lack of labor. With plenty of labor the output will be doubled.

Reports from potters indicate that the clay is very satisfactory in the manufacture of white ware. It is said to burn pure white and to be unusually plastic.

The following tests of a sample of white clay (Bureau of Mines No. 1.53) from the pit of the Edisto Kaolin Co. have been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of sample of clay from pit of Edisto Kaolin Co., Rayflin, S. C.

Workability	Fairly plastic; makes good bars.	
Water of plasticity, in terms of dry clay	per cent	43.80
Air shrinkage by volume	do	33.02
Air shrinkage, linear, calculated	do	12.50

Fire tests of sample of clay from pit of Edisto Kaolin Co., Rayflin, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	32.70	White	28.40	10.5
1,250	30.80	do	31.10	11.7
1,310	23.02	do	38.00	14.7
1,370	16.38	do	43.31	17.3
1,410	2.00	do	46.30	18.7

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of Edisto Kaolin Co., Rayflin, S. C.

Water of plasticity, in terms of dry clay	per cent	28.74
Volume shrinkage	do	18.03
Air shrinkage, linear, calculated	do	6.50
Modulus of rupture	pounds per square inch	171.00

Fire tests of porcelain body containing clay from pit of Edisto Kaolin Co., Rayflin, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	18.40	White	23.31	8.5	2,203
1,250	18.33	....do	23.31	8.5	2,900
1,310	13.24	....do	27.32	10.1	3,546
1,370	.58	Pale gull-gray	32.04	12.1	4,164
1,410	.30	Light pale gull-gray	31.32	11.8	2,004

The overburden is removed by scraper, and the clay loosened by dynamite before digging. It is dried and hauled by mule teams 2½ miles to Rayflin, where it is loaded on a siding of the Southern Railway. When the road is rebuilt the clay will be hauled to the railway by truck.

Perhaps the principal use to which this clay has been put is in the manufacture of wall paper. It is employed both for coating and top printing and also as filler, sometimes alone and sometimes in mixtures with other clays. It is also used as filler for print paper and for coarse textiles, such as wall fabrics, and some of it is blended with washed clay from other States for kalsomine and other cold-water paints. It is mixed with other materials to reduce the color of strong pigments in oil paints and takes the place to some extent of imported china clay. It has also been used to a small extent in semiporcelain and china mixtures, replacing English clay in part. Now that a pulverized product is being furnished, the use of this clay will be greatly extended.

HORRELL HILL, RICHLAND COUNTY.

Property of Interstate Clay Co.—The Interstate Clay Co.'s pit is near Horrell Hill, Richland County, 4 miles northwest of Congaree, on the Atlantic Coast Line, with which it is connected by a standard-gage spur. It is 1½ miles northeast of James Crossing, which is its nearest railroad station. Its administrative office is at Sumter, S. C. The plant has been in operation since 1916.

The land controlled by the company includes 110 acres. Of this area 20 acres has been tested by borings at intervals of 50 feet, and from the data thus obtained an estimate of 700,000 tons in reserve has been reached. This estimate seems a little excessive. A more reasonable estimate, if the average workable thickness of the bed is taken as 9 feet, gives 500,000 tons. The figures have little significance, however, for an enlargement of the area for which the estimate is given would correspondingly increase the size of the reserve.

Messrs. Maynard and Simmons, of Atlanta, Ga., estimate the entire reserve at 1,250,000 tons. In the last analysis the size of the available reserve will probably depend upon the distribution of the overburden, for the cost of the production of the clay is increased by the cost of the removal of a greater thickness of the overburden.

The clay is shipped in four grades, two of which are crude and two washed. Both the crude and the washed clays are divided into No. 1, white, and No. 2, white and pink mixed. The clay of all four grades is very dense and porcelain-like and contains almost no grit. The white clay is very light cream-colored when dug, but almost pure white when dry. When crumbled and shaken with water it forms a smooth creamy suspension. Its components in general measure from 0.003 to 0.02 millimeter in diameter, though a few grains of quartz and shreds of mica are a little larger. No rutile was seen under the microscope, though some grains are no doubt present. All the crude clay is crushed to the size of walnuts. None was pulverized at the time of the writer's visit, but the company planned to install pulverizing machinery in the near future.

At the pit now being worked there is an overburden of 6 to 30 feet of yellow clay and sand. Under this overburden there is a white and pink streaked clay, with little layers of sandy pink clay at the top. Below this clay lies the bed of white clay, from 3 to 13 feet thick. The top layers are sandy. The material of these layers is saved for washing, as is also the best of the white and pink clay above it. Clay that is strongly streaked will not wash white and therefore is rejected. This material and the sandy pink clay above it, known as ruggage, is marketable, but its price is not regarded as profitable and, consequently, it is left in the pit.

The variation in the thickness of the overburden is due almost exclusively to the irregularities of the topography. As the clay bed is nearly horizontal the overburden thins where the surface falls and thickens where it rises. The only structural feature noticed in the beds above the commercial clay is the current bedding in the sandy pink layers. This bedding suggests that this particular layer was deposited in shallow water.

The overburden is removed by steam shovels and a drag machine. The clay is hauled to the washing plant where it is prepared for market.

The plant is provided with a Chambers disintegrator and the usual sand troughs, settling vats, and presses. All the washed clay is passed through a rotating trough of 120 mesh. The plant was built for a daily capacity of 25 tons of crushed clay and 25 tons of washed clay, but this output is not reached because of lack of labor. The present monthly production is about 500 tons of crushed clay and

375 tons of the washed grade. Improvements and enlargements, now being made, will enable the output of washed clay to be increased to 50 tons daily and that of the crude clay to be nearly doubled. The labor problem is being partly solved by the building of comfortable dwellings for tenants.

The following tests of white clays from the pit of the Interstate Clay Co. have been supplied by the laboratory of the Bureau of Mines, at Columbus, Ohio:

General physical tests of sample of clay from pit of Interstate Clay Co., Horrell Hill, S. C. (Bureau of Mines No. 1.45).

Workability	Fairly plastic; makes good bars.	
Water of plasticity, in terms of dry clay	per cent	33.50
Air shrinkage, by volume	do	10.46
Air shrinkage, linear, calculated	do	3.6

Fire tests of sample of clay from pit of Interstate Clay Co., Horrell Hill, S. C. (Bureau of Mines No. 1.45).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	32.86	White	28.38	10.5
1,250	33.20	do	29.30	10.9
1,310	30.87	do	31.26	11.8
1,370	17.41	do	41.80	16.5
1,410	7.60	do	46.7	18.9

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.45.

Water of plasticity, in terms of dry clay	per cent	30.96
Volume shrinkage	do	18.69
Air shrinkage, linear, calculated	do	6.7
Modulus of rupture	pounds per square inch	141.3

Fire tests of porcelain body containing clay of sample No. 1.45.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	23.60	White	19.70	7.1	2,621
1,250	24.53	do	22.00	7.9	2,917
1,310	21.08	do	23.57	8.6	3,594
1,370	2.76	do	33.08	12.5	6,466
1,410	.11	Light pale smoke-gray	34.24	13.1	6,624

General physical tests of sample of clay from pit of Interstate Clay Co., Horrell Hill, S. C. (Bureau of Mines No. 1.7).

Workability	Very plastic; makes good bars; no cracking.	
Water of plasticity, in terms of dry clay	per cent	35.09
Air shrinkage by volume	do	14.02
Air shrinkage, linear, calculated	do	4.9

Fire tests of sample of clay from pit of Interstate Clay Co., Horrell Hill, S. C. (Bureau of Mines No. 1.7).

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	37.00	Light pinkish white	24.60	9.0
1,250	32.60	White	29.20	10.9
1,310	29.17	.....do	31.75	12.0
1,370	11.90	Very light buff	45.10	18.1
1,410	2.00	Pale gull-gray	48.20	19.7

Cone of fusion, 34.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay of sample No. 1.7.

Water of plasticity, in terms of dry clay	per cent	28.49
Volume shrinkage	do	15.35
Air shrinkage, linear, calculated	do	5.4
Modulus of rupture	pounds per square inch	222.8

Fire tests of porcelain body containing clay of sample No. 1.7.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	22.7	White	20.0	7.2	4,073
1,250	24.18	.....do	20.48	7.4	5,240
1,310	19.34	.....do	24.02	8.8	4,241
1,370	1.31	Buff, light-gray spots	33.23	12.6	8,505
1,410	.30	Pale smoke-gray	33.60	12.8	8,492

The washed clay from this mine has been used for chemical and hard porcelain, but only in small quantities in a mixture which is composed mainly of English clay. For semiporcelain it is employed in larger quantities in the mixture. It is also used in making vitreous floor tile and will be used in larger quantity for this purpose when shipments are more regular. It will then replace an equal quantity of English china clay. It is mixed with other domestic clays for a filler for high-grade print papers. The crushed crude clay is employed for filling high-grade book paper, but it would serve the purposes of some manufacturers better if it were finely pulverized, so that it might be better retained within the meshes of the paper stock. The No. 2 clay is used as a filler in oilcloth and linoleum and for other similar purposes.

Property of Columbia Mineral Products Co.—About 300 yards from the pit of the Interstate Co. is the abandoned pit of the Keenan mine of the Columbia Mineral Products Co. The pit is small and there is now no means of determining the extent of the deposit, which is apparently the same as that worked at the Interstate pit. The overburden is about 20 to 25 feet thick and is the same in character as that at the neighboring Interstate pit. The clay also is apparently of the same type, but evidently more of the pink clay was taken out and saved. When examined carefully the pink clay is found to differ from the white clay only in being stained. Some masses are stained throughout, others are stained only superficially, and in others the stain extends irregularly inward, leaving portions of the mass unstained. When the clay is crushed and treated with water its color changes to the characteristic ocher shade, and when boiled with hydrochloric acid it becomes white and the solution gives the usual reactions for iron. The stain is therefore probably produced by ocher. Possibly the red clay might be employed in the manufacture of a cheap red paint.

Near the pit and connected with it by an incline is the drying and storage shed, which is provided with a crusher. The crushed clay was bagged and probably hauled to James Crossing, on the Atlantic Coast Line.

The following tests of a sample of the best white clay (Bureau of Mines No. 169) from the pit of the Columbia Mineral Products Co. of Columbia, S. C., have been supplied by the laboratory of the Bureau of Mines, at Columbus, Ohio.

General physical tests of a sample of clay from the pit of the Columbia Mineral Products Co., of Columbia, S. C.

Workability		Fairly plastic; makes good bars.
Water of plasticity in terms of dry clay	per cent	35.7
Air shrinkage by volume	do	11.78
Air shinkage, linear, calculated	do	4.1

Fire tests of a sample of clay from the pit of the Columbia Mineral Products Co., of Columbia, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	37.20	White	22.4	8.1
1,250	33.10	do	28.2	10.4
1,310	32.10	do	29.88	11.2
1,370	23.00	do	39.30	15.5
1,410	3.90	do	46.00	18.6

Cone of fusion, 33.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from the pit of the Columbia Mineral Products Co., of Columbia, S. C.

Workability		Dries well; no cracks.
Water of plasticity in terms of dry clay	per cent	29.10
Volume shrinkage	do	29.24
Air shrinkage, linear, calculated	do	10.9
Modulus of rupture	pounds per square inch	139.9

Fire tests of porcelain body containing clay from the pit of the Columbia Mineral Products Co., of Columbia, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	24.10	White	19.2	6.9	3,137
1,250	22.90	do	20.5	7.4	3,266
1,310	20.92	do	23.35	8.5	4,181
1,370	2.43	do	32.68	12.4	6,412
1,410	.30	Pale drab-gray	33.10	12.5	6,401

AIKEN, AIKEN COUNTY.

Property of Henderson Bros.—The Henderson Bros. prospect is about 3 miles a little west of north of Aiken, on the west side of the road between Aiken and Edgefield. In all there are 607 acres in the property, but only 40 acres has been tested. The area tested is underlain by a clay bed from 9 to 13 feet in thickness. If the average thickness is assumed to be 12 feet the quantity of clay in the 40 acres is approximately 1,000,000 tons, but the quantity of white clay can not be estimated. The overburden, exclusive of the yellow and pink clay above the white clay, is from 4 to 13 feet thick. If the yellow and pink clays are considered valueless the thickness of the overburden is increased by 10 feet, for there is in most places a layer of yellow clay 7 feet thick and a thinner layer of pink clay above the commercial white clay. Mr. Henderson declares that there is a market for both shades of colored clay, and he considers them to be valuable. Possibly they could be used in colored paints and kalsomine, but so far as is known none have been so used.

The property was worked about 6 years ago by the Pope Clay Products Co., and later for a short time by Mr. J. R. Parker, but very little of the clay was sold. The several small pits on the property are so overgrown that very little can be learned from them. In one pit white clay is directly overlain by sand. In another pit immediately under the sand is a 7-foot bed of yellow clay and beneath this about 1 foot of pink clay which grades down into the white clay. The pink clay apparently is stained white clay, whereas the yellow clay seems to be a distinct deposit. Where the pink clay is thickest the white clay is thinnest and where the white clay is thickest the pink clay is thinnest.

In the old dry shed on the property small quantities of all three varieties of the clay are stored on the racks. The white clay has a very pale pinkish tinge. It is smooth, dense, and extremely brittle and hard. It slakes slowly and imperfectly, forming a cream-colored mixture in which remain many small pieces of the clay that have not disintegrated. From the liquid mixture a flocculent sediment settles very rapidly. Under the microscope the clay shows granules of very fine kaolinite of about 0.003 millimeter in diameter, a fairly large number of flakes about 8 or 10 times as large, some wormlike groupings, many of them 0.05 millimeter in length, numerous tiny shreds of altered mica, a few small grains of quartz. Numerous small black grains, probably of rutile, are present. Tiny masses of limonite are scattered here and there through the clay, and many of the grains of kaolinite are stained with the same substance. The pink tinge of the clay is no doubt due to the limonite.

The yellow clay is also smooth and dense, but it is a little softer than the white variety. It slakes poorly, leaving much unslaked material after several days contact with water. The suspension is chrome-yellow. Under the microscope the yellow clay is seen to differ from the white variety mainly in the darker staining of the kaolinite. There is also a little more mica in this variety and a greater abundance of grains of rutile. Moreover, the rutile is very much coarser, some of the grains measuring 0.05 millimeter in diameter.

The pink clay is also smooth, but is more granular and a little softer than either of the other varieties. When mixed with water it slakes easily and forms a very smooth suspension of a deep old-rose color. When treated with hydrochloric acid the clay bleaches white and the yellow solution produced reacts for iron. Under a low magnifying power the clay is seen to contain many little clumps of red limonite, or some other nearly related compound, some of which measure as much as 0.1 millimeter in diameter. Under high powers the purple clay shows the same structure as the white variety, but many tiny grains of a red mineral which forms the little clumps of limonite referred to above are visible. Moreover, the kaolinite is surface stained. The color of the clay seems, however, to be due largely to the tiny red particles that occur everywhere between the particles of kaolinite.

The property is about 2 miles from Crofts, on the Southern Railway.

SOCIETY HILL, CHESTERFIELD COUNTY.

Coker property.—Mr. T. H. Coker, jr., of Hartsville, reports exposures of white clay in a number of places within a tract of 400 acres, about 5 miles northwest of Society Hill and 4½ miles north of the south line of Chesterfield County, in the area underlain by Middendorf beds. The property is about 2 miles west of the road between Society Hill and Chesterfield and about 3 miles from the Atlantic Coast Line Railroad. Borings indicate that the clay bed is more than 9 feet thick under about 100 acres. Samples sent by Mr. Coker are slightly gritty and of a very pale pinkish gray. The clay separates from the mixture very rapidly, forming a granular precipitate that is rather dense. This precipitate consists of grains of kaolinite 0.003 to 0.005 millimeter in diameter, many particles of partly decomposed feldspar, 0.03 to 0.1 millimeter in diameter, a few tiny grains of quartz and here and there a shred of mica. All the larger particles are stained reddish brown.

EUTAW FORMATION.

The Eutaw formation consists chiefly of more or less glauconitic sand, massive and cross-bedded, in places interbedded with thin layers of clay, some of which are lignitic. Locally the beds are calcareous, especially in the Chattahoochee region of Georgia. The beds are believed to be of shallow-water marine origin, and the total thickness of the formation is 400 to 500 feet.[95]

The Eutaw rests conformably on the Tuscaloosa and is overlain conformably in part by the Selma chalk and in part by the Ripley formation. It forms a narrow belt that extends from central Tennessee to central Georgia and probably is represented at least as far north as Trigg County, Ky.[96] It is possible to subdivide it into two members, the Coffee sand and the Tombigbee sand, but in the present discussion these have no special application.

It is essentially a sand formation, and although in places it contains thin layers of clay, so far as known these have no great value.

SELMA CHALK.

The Selma chalk extends from Tennessee to central Alabama, but it is thinner in Tennessee and northern Mississippi than it is elsewhere.

As it overlies the Eutaw, its area of outcrop is west of that of the Eutaw in Tennessee and south of it in Alabama.

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95 Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 20, 1918.

96 Berry, E. W., U. S. Geol. Survey Prof. Paper 112, pp. 12, 13, 26–29, 1919; Stephenson, L. W., and Wade, Bruce, idem, map, 1919.

It consists in most places of more or less clayey and sandy limestones, which are generally chalky but may contain hard layers.

The chalky beds merge along the strike in either direction into nonchalky deposits, which in northern Mississippi and Tennessee are included in the Eutaw and Ripley formations, whereas in eastern Alabama they are entirely included in the Ripley.[97]

The Selma chalk carries no clays of value, although in Tennessee it contains impure clay. Nelson there refers to it as the Selma clay,[98] but he considers that it does not fully correspond to the Selma chalk as it is known in Mississippi and Alabama but is possibly the equivalent of the beds that form the middle portion in those States. This clay in Tennessee outcrops in a belt 8 or 10 miles wide, which begins at the Mississippi border and extends halfway across the State or nearly as far as the Eutaw formation. It is generally black when wet but leaden-gray or greenish when dry, the greenish color being due to grains of glauconite. The beds may be very sandy and fossiliferous and may also in places contain limestone layers. The clay is well exposed in McNairy County in the Blue cut on the Mobile & Ohio Railway.

The clays of the Selma chalk are not of high grade, and their occurrence in Tennessee is mentioned only so that they may not be mistaken for the higher-grade clays that lie to the west.

RIPLEY FORMATION.

DISTRIBUTION AND CHARACTER.

The Ripley formation, which is the uppermost division of the Cretaceous in the area where it is found, extends from central Georgia through Alabama and Mississippi and then swings northward across Tennessee and Kentucky and into Illinois.

The typical beds of the Ripley in Mississippi, Tennessee, Kentucky, and Illinois consist of

> more or less calcareous and glauconitic sands, sandy clays, impure limestones, and marls of marine origin, reaching an estimated maximum thickness in this region of 250 to 300 feet.
>
> The formation rests * * * in part upon Paleozoic rocks, in part upon the Eutaw (in Tennessee) and in part upon the Selma chalk. From Tennessee and northern Mississippi southward the successively higher beds merge along the strike into the chalky limestones of the Selma formation. Northward the typical beds of the Ripley formation are believed to merge horizontally into a series of sands and clays of shallow-water origin, to which the name McNairy sand member is given.
>
> The formation is overlain unconformably by Tertiary beds of Eocene age.[99]

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[97] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 21, 1914.

[98] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, 1911.

[99] Stephenson, L. W., Cretaceous deposits of the eastern Gulf region: U. S. Geol. Survey Prof. Paper 81, p. 21, 1914.

In Alabama and in the Chattahoochee region in Georgia the Ripley resembles that of the type region in northern Mississippi. The thickness in the Chattahooche region is 950 feet. In Alabama and Georgia the Ripley rests conformably on the Eutaw, but along the strike westward in Alabama the successively higher beds merge into the Selma chalk. The formation is overlain conformably by Eocene beds.

On the whole the Ripley does not offer a promising field for the discovery of high-grade clay. Some clays of refractory character have been found in it in Georgia and Tennessee and are mentioned below.

GEORGIA.

Veatch[1] states that the lower part of the Ripley formation, known as the Cusseta sand member, contains deposits of white refractory clay. These deposits occur in pockets that are comparatively small in area and may contain sand partings or grade into sand. Some of the pockets may be as much as 20 feet in thickness.

Occurrences have been described from Fort Valley, Perry, and Bonaire, in Houston County, and Marshallville and Maverick, in Macon County.

These clays, although refractory, do not burn white, nor can they be considered as refractory bond clays because of their low tensile strength. Most of them show mottlings of purplish or reddish color. The best known development is at a locality 3 miles north of Perry, Houston County, where the Houston Kaolin Co. has started operations. The clay outcrops in the side of a ravine and the section in the face of the excavation shows the following beds:

Section in pit of Houston Kaolin Co., north of Perry, Ga.

	Feet.
Ferruginous sands	8–10
Mottled clay	8
Whitish clay	10

As the hillside rises steeply the thickness of the overburden increases to a marked extent in a short distance. Grains of pyrite are visible in the mottled clay, and even the lower clay may show them.

The clay is very dense and breaks with a conchoidal fracture. The texture is quite uniform. A microscopic examination of the mottled clay showed very little difference between the red and the white parts. On the whole the clay is composed chiefly of exceedingly fine grained, mostly unidentifiable particles, and the red material is stained with hematite. A few grains of quartz were present, some of them being much larger than the other mineral grains.

[1] Veatch, Otto, Second report of the clay deposits of Georgia: Georgia Geol. Survey Bull. 18, 1909.

There were a few grains of hydromica and kaolinite. The red material showed a few grains of rutile, but the white material showed numerous tiny grains of this mineral as well as some zircon.

Tests by the Georgia Geological Survey show that the clay burns a faint cream color at cone 9 (1,310° C.) and has 11.8 per cent fire shrinkage. Its fusion point lies above cone 33 (1,790° C.). This deposit was not operated in 1918 and had apparently been idle for some time.

TENNESSEE.

The Ripley formation extends across the State of Tennessee in a belt which ranges from 15 miles in width on the southern boundary to 6 or 8 miles on the northern boundary. It crosses the counties of Hardeman, McNairy, Chester, Henderson, Carroll, Benton, and Henry. (See Pl. XVII.)

The formation consists mostly of stratified sands of different colors, between which occur beds of gray lignitic or yellow sandy micaceous clay. The sands are somewhat extensively stained with iron, and on this account commonly resemble those of the overlying so-called "Lafayette formation." This iron in many places cements the sands and causes the development of curious pipelike forms.

Two occurrences of refractory bond clays have been located in the Ripley formation, one of them near Hollow Rock, in Carroll County, and the other near India, in Henry County.

HOLLOW ROCK, CARROLL COUNTY.

All the clays worked around Hollow Rock are in the Ripley formation and are mostly of the sagger and wad type, although some ball clay is also dug. The pits are rather small. Two of them were visited.

One of these pits is operated by the National Sales Co. and A. Nunnelly on the land of Harvey Hodge, 1½ miles northeast of Hollow Rock station. The pit shows a circular working face about 200 feet long and 15 feet high. The clay, whose section is shown in figure 33 (No. 1), is mostly dark gray, but the upper 5 feet is much lighter in color and is not so clean as the lower part.

This lighter color is due to weathering, which has also caused the development of mottlings of limonite in the joint fractures.

There are no visible streaks of sand, but grains and small lumps of lignite are scattered through the clay. These particles, however, would burn out in the kiln. Certain layers also contain impressions of leaves, but these are not harmful.

In the hand specimen the clay appears gritty and shows tiny scattered scales of mica. Under the microscope this clay is seen to be medium to coarse grained.

Quartz is common; hydromica abundant; kaolinite common; rutile is abundant in small needles and grains; tourmaline is present but rare.

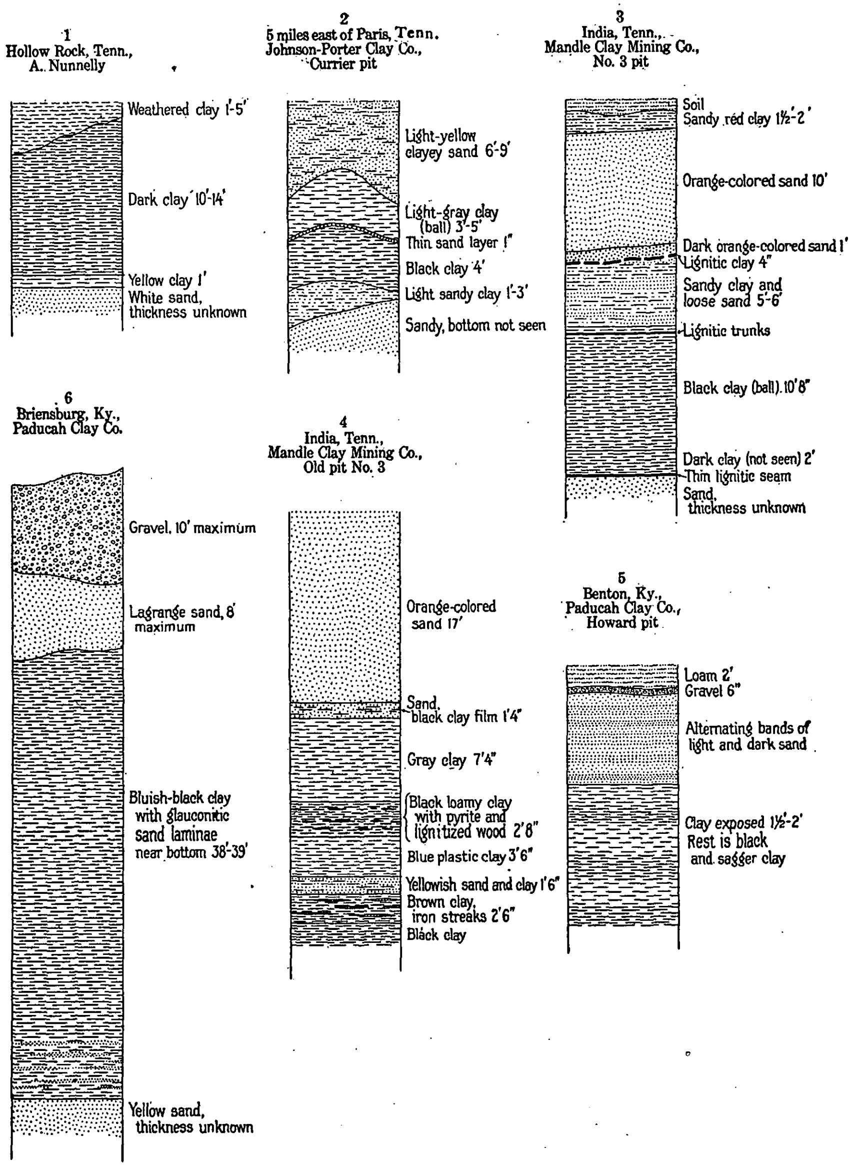


FIGURE 33.—Columnar sections in the Ripley and Porters Creek formations of western Tennessee and Kentucky.

The light and dark grades of clay are separated for shipment, and the pit supplies sagger clay and ball clay that is known as No. 291.

The following tests of clay from the Nunnelly pit, commercially known as No. 291, were supplied by the Tennessee Geological Survey:

LIST OF LOCALITIES.

(The active pits from field notes of H. Ries and C. W. Parmelee.

The prospects and abandoned pits chiefly from Tennessee Geological Survey.)

1. Cooley Ball & Sagger Clay Co., pits Nos. 9, 10, and 11.
2. Dixie Brick & Tile Co.
3. Dixie Brick & Tile Co.
4. Mandle Clay Mining Co., Monroe pit.
5. Sanders & Nealy, Bradlee pit.
6. Mandle Clay Mining Co., Cole pit.
7. Mandle Clay Mining Co.
8. Johnson-Porter Clay Co.
9. Mandle Clay Mining Co., Wade or No. 4 pit.
10. Jackson pit.
11. Calloway County Clay Co.
12. United States Clay Co.
13. H. C. Spinks, Hilltop mine.
14. H. C. Spinks Clay Co. and W. Allison, Mill pit.
15. Mandle Clay Mining Co., No. 3 pit
16. S. & J. Jackson.
17. Mandle Clay Mining Co., Barbee pit.
18. Johnson-Porter Clay Co., Jackson or Porter's pit.
19. H. C. Spinks Clay Co., Jernigan pit.
20. J. C. Strop.
21. H. C. Spinks Clay Co., Atkins pit.
22. C. Sparks.
23. H. C. Spinks Clay Co., Grable pit.
24. H. C. Spinks Clay Co.
25. Johnson-Porter Clay Co., Dalton pit.
26. Johnson-Porter Clay Co., Williams pit.
27. Scates-Reynolds Clay Co. Breedlove pit.
28. McNanee pit.
29. A. P. Diggs pit.
30. A. Nunnelly & National Sales Co., Hodge pit.
31. G. M. Bennett pit.
32. H. M. Cooper.
33. Johnson-Porter Clay Co., wad mine.
34. J. F. Dale, sand pit.
35. Colonial Clay Co.
36. Paducah Clay Co., Lofton pit.
37. Kentucky Construction & Improvement Co.
38. Mayfield Clay Co.
39. Old Hickory Clay & Talc Co.
40. American Clay Co.
41. St. Louis Clay Co.
42. Paducah Clay Co., Howard pit.
43. Paducah Clay Co., Briensburg pit.
44. Excelsior Clay Co.

General physical tests of clay from Nunnelly pit, Hollow Rock, Tenn.

Working property	Good, somewhat sticky.	
Water of plasticity	per cent	31.6
Modulus of rupture:		
Raw clay	pounds per square inch	112.0
Mixture of clay and sand in proportion of 1:1	do	112.0
Slaking test	minutes	5.0
Fineness test:		
20-mesh sieve	No residue.	
40-mesh sieve	No residue.	
60-mesh sieve	Trace.	
80-mesh sieve	Trace.	
Residue, 120-mesh sieve, mica and sand	per cent	0.46
Residue, 150-mesh sieve, mica and sand	do	.50
Residue, 200-mesh sieve, mica and sand	do	.60
Drying shrinkage, linear	do	6.8

Fire tests of clay from Nunnelly pit, Hollow Rock, Tenn.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	White	Steel hard	16.5	28.0
Cone 5 (1,230° C.)	do	do	13.7	28.0
Cone 9 (1,310° C.)	Light cream	do	14.7	22.1
Cone 12 (1,370° C.)	do	do	15.8	8.5
Cone 13 (1,390° C.)		do	16.2	11.4

Fusion test: Deforms at cone 31 (1,750° C.).

This clay burns to a good color at the temperatures indicated in the table. It is rather open burning for a ball clay, and the strength of the unburned clay is only fair. It is more of a semiball clay in nature than a ball clay. It will doubtless be of service in the manufacture of certain grades of chemical stoneware, sanitary ware, terra cotta, face brick, and saggers, and possibly it will find some use as a bonding material in the manufacture of certain refractories which are not expected to stand exceedingly high temperatures.

The pit of H. N. Cooper lies about 1½ miles south of Hollow Rock and one-fourth of a mile east of the Nashville, Chattanooga & St. Louis Railway. It covers about an acre and has a diameter of about 200 feet.

According to Mr. Cooper the clay underlies 30 to 40 acres, and a boring made about 1,000 feet to the east of the pit penetrated it to a depth of 16 feet under 8 feet of overburden, but definite evidence that the clay extends continuously from this point to the pit is not at hand.

The section in the pit shows a maximum of 18 feet of clay overlain by 4 to 5 feet of loamy overburden and underlain by sand. Scattered nodules of pyrite are found in the lower part of the clay.

The clay is dark gray-brown and stratified. The hand specimens show a faint banding. It runs fairly uniform in texture, although on the south side of the pit there are narrow vertical cracks that are filled with limonite.

A microscopic examination of the clay revealed a medium texture. Quartz was common, and both hydromica and kaolinite were abundant. Rutile in tiny grains was very common, but only two or three grains of tourmaline were observed.

A section of the burned clay showed that, although the micaceous texture remains, all the interference colors of the hydromica had disappeared, the grains showing instead a low interference color similar to that of kaolinite. Very little of the groundmass was isotropic. The grains of quartz were still visible, although some of them showed corrosion.

When wet the clay is very plastic and feels smooth.

One sample fired at 1,180° C. had 14.5 per cent absorption, and a second fired at 1,300° C. had 4.4 per cent absorption and 9.1 per cent porosity. The burned product was steel hard and buff.

The clay is hauled by wagon to a siding 250 yards distant and shipped to Nashville, Tenn., and Atlanta, Ga., for use in brick and terra cotta. It could probably be utilized also for saggers. The pit has been in operation about six years.

The following tests of H. N. Cooper's clay were supplied by the Tennessee Geological Survey:

General physical tests of sagger clay from H. N. Cooper's pit, Hollow Rock, Tenn.

Working properties	Good.
Water of plasticity ..... per cent	33.9
Modulus of rupture:	
Unburned clay ..... pounds per square inch	115
Mixture of clay and sand in proportion of 1 : 1 ..... do	86.2
Slaking test ..... minutes	6
Fineness test:	
20-mesh sieve	No residue.
40-mesh sieve	No residue.
60-mesh sieve	No residue.
80-mesh sieve	No residue.
Residue 120-mesh sieve	Trace, chiefly mica.
Residue 150-mesh sieve ..... per cent	0.04
Drying shrinkage, linear ..... do	5.8

Fire tests of sagger clay from H. N. Cooper's pit, Hollow Rock, Tenn.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Pinkish	Steel hard	10.0	29.1
Cone 5 (1,230° C.)	do	do	11.5	25.0
Cone 9 (1,310° C.)	Dark gray	do	13.5	6.1
Cone 12 (1,370° C.)	do	do	13.7	5.1
Cone 13 (1,390° C.)		do		11.4

Fusion test: Deforms at cone 30 (1,730° C.).

The clay shows a good vitrification at cone 9 (1,310° C.). The color is fair and the strength is fairly good. It will probably be of service in the manufacture of terra cotta, sanitary ware, face brick, and saggers. It is doubtful if the color is satisfactory for use as a ball clay.

INDIA, HENRY COUNTY.

About 1½ miles east of India the Mandle Clay Mining Co. has two active pits, known as the No. 3 and the Barbee. They lie on the western edge of the Ripley formation and hence are in its upper part, because the beds dip westward.

Several other pits have been opened here in close proximity to each other, as new pits were opened when the old ones were worked out.

The section in pit No. 3, which was being worked in 1918, is shown in figure 33 (No. 3). About 20 feet is stripped off before the best black ball clay is reached. These two pits yield several grades of clay, known as "Tennessee Ball Nos. 3 and 6," "Glasspots," "Barbee special," and "Special sagger clay."

The black clay consists chiefly of kaolinite and hydromica, all stained dark with very fine grained organic matter.

A neighboring worked-out pit, shown in figure 33 (No. 4), illustrates how the section may change in a distance of a few hundred feet.[2] The blue clay is the best in the pit and contains the least amount of sand. It changes gradually into the brown bed beneath it, which represents a fairly good ball clay.

All the clays dug in this locality for commercial use have a high content of organic matter.

A sample of the ball clay No. 3, as tested by Nelson, gave 10 to 15 per cent residue, mainly silica, on a No. 12 sieve. The clay is very plastic and carries 72 per cent of flint. At cone 1 (1,150° C.) its shrinkage is 12.5 per cent, and at cone 8 (1,290° C.) it is 18 per cent, the body being of a grayish-white color.

Another pit in the Ripley formation is that operated by the Johnson-Porter Clay Co., 5 miles east of Paris, Tenn., which is known as the Jackson or Currier pit. A generalized section in this pit is shown in figure 33 (No. 2). The beds, however, are not uniform throughout the pit, which is about 350 feet long and 50 feet wide. The thickness of the clay ranges from 7 to 16 feet, although the maximum exposed at the time of the writer's visit was 10 feet. The upper 3 to 5 feet of light-gray clay, known as J1, is sold as ball clay, and the black clay, which shows yellow and red stains and which is of the ball-clay type, is said to be sold as sagger clay. The best clay occurs in the center of the pit.

[2] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, p. 89, 1911.

Two samples of the clay were examined microscopically. One of these samples is a specimen of the clay known as the black clay. It is medium grained, and in it grains of quartz and kaolinite are common and hydromica is abundant and commonly coagulated. Rutile is scarce. The hand specimen shows a few grains of lignitic material and also a few scattered flakes of mica.

In the brown sandy bottom clay also quartz is common but fine grained. Kaolinite is abundant, and hydromica a little less so. Rutile is present in numerous needles and grains, but tourmaline and titanite though present are rare.

It is claimed that this deposit contains 140,000 tons of clay.

TERTIARY CLAYS.

DISTRIBUTION.

Formations of Tertiary age are distributed throughout the Coastal Plain and Embayment Area from New Jersey to Illinois, but those that contain clays of the types discussed in this report have been found only in South Carolina, Georgia, Florida, Mississippi, Tennessee, Kentucky, Illinois, and Arkansas. In these States refractory clays occur at a number of places. Some of them are of value because of their whiteness in either the raw or the burned condition, and others belong to the class of refractory bond clay.

Occurrences of the white-burning clays are, however, of little importance in the present discussion, except those in Florida. The clay from the Tertiary deposits of Georgia is white only in its unburned condition. That from the other States burns cream-white or bluff but has high bonding qualities.

The high-grade clays do not occur in the same division of the Tertiary in every State, although the majority are found in the Wilcox.

The deposits will be described by formations, where these are known.

EOCENE (?) CLAY.

SOUTH CAROLINA.

By W. S. Bayley.

Abbeville, Abbeville County.—No high-grade clays of undoubted Tertiary age are known in South Carolina, and the following clay, which may be of Eocene age, is placed here provisionally. It lies within the area of crystalline rocks west of the fall line, on the property of J. A. and W. E. Hill, 2½ miles south of Abbeville. This property has already been referred to in connection with the occurrence of kaolin (p. 80).

The Tertiary clay is exposed on the east side of the road, in gullies cut in the fields. The best exposure is about 300 yards southeast of the pit on the road, where there is a gully cut 4 or 5 feet into a sticky granular, very gritty whitish clay overlain by alternating thin layers of limonite and sandy clay. Farther south in a branch of the same gully is another exposure, where the clay is several feet thick. The clay is grayish pink and putty-like, resembling "fuller's earth" in many respects. It overlies a coarse sandstone or granite but is not a product of its decomposition. Plainly both of the deposits east of the road are sedimentary, and both are Eocene or Recent. The composition of the whitish clay as determined by Brackett is as follows:

Analysis of white clay from Hill property, 2½ miles south of Abbeville, S. C.

Silica (SiO_2)	72.10
Alumina (Al_2O_3)	16.12
Ferric oxide (Fe_2O_3)	2.48
Lime (CaO)	1.20
Magnesia (MgO)	.21
Soda (Na_2O)	.96
Potash (K_2O)	1.85
Manganese oxide (MnO)	Trace.
Titanium oxide (TiO_2)	Trace.
Water (H_2O)	5.30
	100.22

The composition shown in the table corresponds to 36.75 per cent of quartz, 29.25 per cent of feldspar, and 34.22 per cent of clay substance.

When mixed with water the clay works up into a grayish-white mass from which a fine sand separates. When examined under the microscope its components show that they have been subjected to sorting. The grains of quartz are clear and colorless and are much more uniform in size than those of the clay from the pit on the road. They range in general from 0.05 to 0.1 milimeter in diameter, though there are a few grains above or below these limits. Most of them are irregular in shape, but by no means so ragged as those in the kaolin at the road. Moreover, very few grains of white feldspar are present and only here and there a grain that is colored brown. The mica is white and colorless, and its grains are abundant. The kaolinite presents no peculiar features. The proportion of large plates and of aggregates of plates is much smaller than in the residual kaolin in the road, and the average size of the plates is less. Only a very few broken wormlike and rosette aggregates are noticeable.

The microscopic features of the clay are those that might be expected in one that originated in the transportation for a short distance of the constituents of a residual clay, like that at the road.

The "fuller's earth" was tested on cottonseed oil by Mr. J. H. Mallory, of Columbia, who reports that it filters as rapidly or only slightly more slowly than English fuller's earth and produces a clearer and whiter oil. Burning tests made by the Norton Co. in 1917 gave the following results: Shrinkage on drying, 10 per cent; on burning, 13 per cent. Plasticity, good. The clay burned at cone 13 (1,390°C.) gives a product that is dense and so hard that it can not be scratched; bending strength, 53.8 pounds to the square inch.

The following tests of a sample of white clay (Bureau of Mines No. 1.57) from this pit has been supplied by the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of sample of clay from pit of J. R. & W. Hill Co., Abbeville, S. C.

Workability	Plasticity low; gritty; corners tear; dries well.	
Water of plasticity, in terms of dry clay	per cent	32.50
Air shrinkage by volume	do	11.46
Air shrinkage, linear, calculated	do	4.00

Fire tests of sample of clay from pit of J. R. & W. Hill Co., Abbeville, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).
1,190	30.90	Pale pink-buff	8.00	2.7
1,250	29.20	Cartridge-buff	12.20	4.6
1,310	26.58	do	17.24	6.1
1,370	.20	do	30.50	11.4
1,410	.00	Olive-buff	30.90	11.6

Cone of fusion, 27.

A sample of this clay was used in a porcelain body and gave the results noted below:

General physical tests of porcelain body containing clay from pit of J. R. & W. Hill Co., Abbeville, S. C.

Water of plasticity, in terms of dry clay	per cent	31.34
Volume shrinkage	do	13.59
Air shrinkage, linear, calculated	do	4.8
Modulus of rupture	pounds per square inch	197.6

Fire tests of porcelain body containing clay from pit of J. R. & W. Hill Co., Abbeville, S. C.

Temperature (°C.).	Porosity (per cent in terms of volume of burned clay).	Color.	Volume shrinkage (per cent in terms of volume of dry clay).	Linear shrinkage, calculated (per cent).	Modulus of rupture (pounds per square inch).
1,190	14.60	Pale buff	16.90	6.0	2,946
1,250	11.07	Ivory-yellow	20.76	7.5	4,489
1,310	1.82	Pale olive-buff	27.58	10.2	5,228
1,370	2.49	Gray	17.49	6.2	4,047
1,410	25.90	Ivory-yellow	10.50	3.6	1,973

The location is convenient for mining. Water would have to be pumped 90 feet, but water from the mine would flow to Abbeville, 2½ miles distant, where shipment could be made either by the Southern Railway or the Seaboard Air Line. The refined clay might also be trucked three-fourths of a mile to the Seaboard Air Line, south of Abbeville.

MIDWAY GROUP.

GEORGIA.

Of the several divisions of the Tertiary deposits that underlie the Coastal Plain of Georgia, the Midway[3] and Wilcox are the only divisions that contain high-grade clays of promise. In Georgia these deposits form a belt 10 to 15 miles in width, which extends from Fort Gaines, on Chattahoochee River, northeastward to Montezuma, on Flint River, and perhaps even northward into Houston County. They rest in contact with the underlying Upper Cretaceous sands and marls and occupy parts of Clay, Quitman, Randolph, Stewart, Webster, Schley, Sumter, and Macon counties.

Spencer estimates their thickness along Chattahoochee River as 618 feet, but it probably diminishes northward.

These deposits as a whole carry clays of varying quality, sands, and limestones. The deposits of white clay are not widely distributed, but where present they may be extensive. Large beds occur at Kelly Mill and Copperas Bluff in Sumter County, and in Stewart, Randolph, and Quitman counties white clays occur in the sands, but these deposits are in the form of lenses or irregular pockets which are not very persistent, although some of the pockets reach a thickness of 12 to 15 feet or even more.

The white clays are massive and not as pure as those of the Lower Cretaceous. The plasticity is good, the fire shrinkage and the refractoriness high, and the tensile strength low.

These clays have not been used much if at all. They do not burn as white as the Lower Cretaceous clays of Georgia, but as they are white in their unburned condition they might possibly serve in the manufacture of paper, paint, linoleum, or rubber. In their burned form they might be used in electrical porcelain.

The following table gives the tests made by Veatch on some of these clays in Georgia.

[3] Veatch, Otto, Second report on the clay deposits of Georgia: Georgia Geol. Survey Bull. 18, 1909. Most of the data here given are from this report, in which Veatch included both the Wilcox and the Midway in what he described as "Midway formation."

Physical tests of Midway and Wilcox clays from Georgia.

	1	2	3
Slakes	Slowly and incompletely	Incompletely	
Per cent of material passes 150 mesh	90		
Plasticity	Moderate	Medium	Excellent.
Tensile strength in pounds per square inch	14	37	Low.
Air shrinkage, per cent	5.7	6.2	6.
Water required	42	43	52.
Burning tests:			
Cone 4 (1,210°C.):			
Fire shrinkage, per cent	9.1	11.9	10.8.
Color	Light cream	Cream	Nearly white.
Cone 9 (1,310°C.):			
Fire shrinkage, per cent	11.1		22.2.
Color	Bluish gray		Dark gray.
Cone 13 (1,390°C.):			
Fire shrinkage, per cent	13.4		
Color	Dark gray		
Fusion cone		30+	

1. Kelly Mill, Sumter County. 2. Copperas Bluff, Sumter County. 3. Moye property, 5½ miles north of Cuthbert, Randolph County. Checks badly. Almost impervious at cone 9. This clay is now classed as Wilcox, but as it is similar in many respects to Nos. 1 and 2, it is included in the table.

An interesting deposit of white clay, according to Shearer,[4] overlies the bauxite at the Sweetwater bauxite mine, of the Republic Mining & Manufacturing Co., 5½ miles east of Andersonville. The clay has a maximum thickness of 20 feet and tapers down to a thin edge. It is overlain unconformably by sand, which is as much as 30 feet thick in places. Here and there the upper 2 feet or more of the clay is stained and mottled red and purple, but the rest is pure white. The mottled clay contains grains of pyrite.

At the time of the writer's visit the clay was exposed for a distance of about 400 feet. It was 8 feet thick at the southeast end of the pit and 20 feet at the north end. No attempt is made to utilize it, and it is stripped off to get at the bauxite. (See Pl. XV, *B*, p. 197.)

The white clay is dense, fine grained, and brittle. When thoroughly slaked down and mixed with water it has very fair plasticity.

Under the microscope it is seen to be very fine grained. Kaolinite is abundant, and hydromica is common, but its interference colors are a little lower than usual. A few tiny prisms of rutile and tourmaline are present.

The red clay is also very fine grained and contains much fine-grained indeterminable material which is stained with iron. There are numerous small grains of a mineral that is probably kaolinite, but hydromica is scarce. A few grains of chlorite, zircon, and rutile were seen.

Two samples were fired with the following results:

[4] Shearer, H. K., A report on the bauxite and fuller's earth of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 31, p. 66, 1917.

Fire tests of white clay, Sweetwater mine, east of Andersonville, Ga.

Temperature (°C.).	Absorption (per cent).	Porosity (per cent).	Color.
1,150	26.9	43.7	Faint cream white.
1,300	16.4	33.1	Cream white.

A section of the clay which was fired at the lower temperature showed a very fine granular aggregate that consisted half of isotropic material and half of grains that showed the interference color of kaolinite. Another section which was fired at the higher temperature was similar to the first but was beginning to develop matted patches that had low interference colors.

The clay could be shipped as well as the bauxite.

MISSISSIPPI.

The Midway group forms a narrow belt which extends across northeastern Mississippi. It enters the State in Kemper County and passes out in Tippah County. The upper formation of the group is the Tippah sandstone of Lowe,[5] and the underlying formation is known as the Porters Creek ("Flatwoods") clay. These clays are gray, laminated, and somewhat shaly, commonly micaceous, and bear abundant iron-stone concretions in their upper part. They form lens-shaped deposits.

The analyses given by Logan all indicate a high content of iron, and no high-grade clays have been found, although the same formation farther north has much better-grade materials.

There is a possibility, however, that the Porters Creek may carry some clays similar to those found near Benton and Briensburg, Ky. (pp. 236–238).

One sample collected from Flatwoods, near Ripley, Tippah County, fuses at cone 28 (1,690° C.) and has a transverse strength of 469 pounds to the square inch.

E. N. Lowe communicates the following notes regarding this deposit:

One and one-half miles north of Ripley, on the west side of the Gulf, Mobile & Northern Railroad, an outcrop of gray clay occurs in the public road 40 rods west of J. F. Conner's sawmill. The surface formation here is the heavy, sticky gray clay soil of the Porters Creek formation of the Midway, which outcrops over a zone of low flat country 4 to 6 miles wide. On slopes the soil is removed and the unweathered gray Porters Creek clay is exposed.

This clay is light gray and very plastic and has no visible impurities except slight yellowish mottlings of iron where it is weathered; locally the clay, owing to its content of lignitic matter, becomes darker. The typical clay, as at the exposure where the sample was taken, shows jointing into small concretionary-

[5] Lowe, E. M., Mississippi Geol. Survey Bull. 12, p. 64, 1915.

like nodular masses, and these on drying show distinct conchoidal or concentric fracture, which is very characteristic.

The exposure of this clay just west of the Conner sawmill is 12 to 15 feet thick in washes in the slopes west of the road, but the depth below the road level is unknown, though it is probably at least twice the visible thickness. Laterally clay of apparently identical quality is exposed for miles across the country. This exposure is 250 yards from the Gulf, Mobile & Northern Railroad and 1½ miles north of Ripley. No pit has been opened here.

TENNESSEE, KENTUCKY, AND ILLINOIS.

DISTRIBUTION AND CHARACTER.

The Porters Creek clay of the Midway group crosses Tennessee[6] and Kentucky[7] in a belt that averages about 8 miles wide across southern Tennessee, but widens out to 10 or 12 miles in Calloway County, Ky. Then as it curves westward beyond Paducah the outcrop narrows and the formation is concealed by alluvial deposits of Ohio River before it crosses into Illinois. In Illinois it outcrops only along the bank of the Ohio at Caledonia Landing and for some distance to the north of Grand Chain. (See Pl. XVII.)

In Tennessee the Porters Creek carries a fine-grained gray clay, locally known as soapstone, which gets very black when wet. In the lower part of the formation the clay may be interbedded with a very fine micaceous sand, and in places it also carries beds of green sand or glauconite. No clays of high grade are found in the Porters Creek in Tennessee.

In Kentucky the Porters Creek carries clay which has been opened up at several localities in Marshall County, and though not of the best pottery grade it is nevertheless of better quality than anything which has been developed in Tennessee, much of it being sold as wad and sagger clay. The pits seen were located chiefly near Benton and Briensburg.

BENTON, MARSHALL COUNTY, KY.

Of the several pits in the vicinity of Benton none were in continuous operation during 1918. The clay was dug as local needs demanded and most of the product was sent to the stoneware factory at Paducah.

One opening, the Howard pit, which is 1 mile northwest of Benton, is a shallow excavation that covers about half an acre and is not steadily in operation.

The total thickness of the clay is 12 feet, of which 5 to 7 feet is a black laminated clay and the rest is a bluish-gray sagger clay. (See fig. 33 (No. 5), p. 226.) The clay appears to thin out to the south.

[6] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, 1911.
[7] Glenn, L. C., Water-Supply Paper 164, p. 29, 1906.

The wad clay from the Howard pit is of fair plasticity but rough textured and shows a few mica scales and some finely divided organic matter.

Under the microscope grains of quartz are seen to be fairly common, and both hydromica and kaolinite abundant. Rutile is present in numerous tiny grains and needles. A little epidote was also noticed.

A sample that was fired to 1,300° C. showed 12 per cent absorption and 24.5 per cent porosity and was buff.

A thin section of the burned clay showed many grains of quartz in a groundmass that was mostly isotropic, but wherever it showed any interference colors these were very low. The hydromica, however, has all disappeared, but the grains of rutile appeared to be unaffected.

A sample of the lower-grade clay from the Howard pit is medium to fine grained. It contains thin sheets of sand along the bedding planes and scales of mica that are visible to the naked eye. This sample was also examined under the microscope and showed quartz grains, abundant and rather coarse hydromica, and abundant kaolinite. Rutile again was common in tiny grains and needles.

About one-fourth of a mile west of the Howard pit and along the highway leading north from Benton clay again outcrops in a high bank. There is nothing to show that it is part of the same mass that is exposed in the Howard pit, but if it is a part of that mass it indicates that the level of the clay surface rises considerably. If it is a separate deposit it must lie at a higher level than the Howard lens.

The section exposed along the highway shows the following beds:

Section along highway north of Benton, Ky.

	Feet.
Sand, ash-colored and buff	2½
Dark chocolate-colored laminated clay, of sandy and micaceous character, with small lenses of white sand	16
Talus to road	17
	41

As the surface of the hill rises away from the road and the conglomerate extends to the top, then if the surface of the clay remains level the overburden must reach a maximum thickness of 70 feet.

About 3½ miles north of Benton are two other pits, on the Lofton property, both leased by the Paducah Clay Co. The clay is said to underlie an area of 40 acres. It is sandy, about 15 feet thick, and is underlain by sand. Above it lies a gravelly conglomerate and hardpan, whose thickness is not less than 8 or 10 feet. The pits were idle in June, 1918.

BRIENSBURG, MARSHALL COUNTY, KY.

The Paducah Clay Co. has opened a deposit 2 miles east of Briensburg to supply clay for making pottery.

On one side of the excavation there is a square pit which shows 39 feet of clay. This material is black, dense, and plastic but contains sandy laminae from 2 to 6 inches apart. Flat concretions of pyrite are scattered along the bedding planes through the deposit, but these are thrown out in mining. Near the bottom the clay contains thin layers of glauconitic sand. (See Pl. XVIII, *A*, and fig. 33 (No. 6), p. 226.)

Where the clay was being dug in June, 1918, it had but 4 feet of overburden, but in the 10 acres that have been tested the overburden increases in places to 15 feet.

On the south side of the pit the section shows Lagrange sand on the top of the clay, which in turn is overlain by terrace gravels. (See fig. 34.) The clay is used in stoneware and saggers.

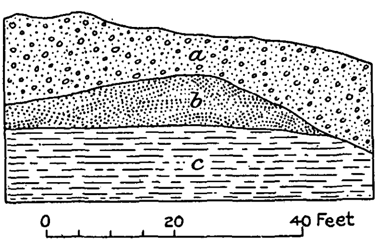


FIGURE 34.—Section on south side of pit of Paducah Clay Co., east of Briensburg, Ky. Porters Creek clay (*c*) is overlain by Lagrange sands (*b*) and these in turn are overlain by terrace gravels (*a*).

The wad clay has fair plasticity but is rather coarse textured and contains visible scattered grains of mica.

Under the microscope quartz is quite common, and hydromica and kaolinite are abundant. The hydromica appears to be iron stained. Rutile is not very abundant, and there are a few grains of zircon.

At 1,300° C. the clay burns gray-brown and has 5.6 per cent absorption and 12.9 per cent porosity. It is steel hard.

A thin section of the fired clay showed abundant grains of quartz, but the hydromica had all disappeared and the groundmass appeared to be fused.

MURRAY, CALLOWAY COUNTY, KY.

The United States Clay Co., whose office is at Indianapolis, Ind., owns clay pits 10 miles north of Murray, but they have not been regularly operated. The deposits worked at this locality are probably in the Porters Creek formation.

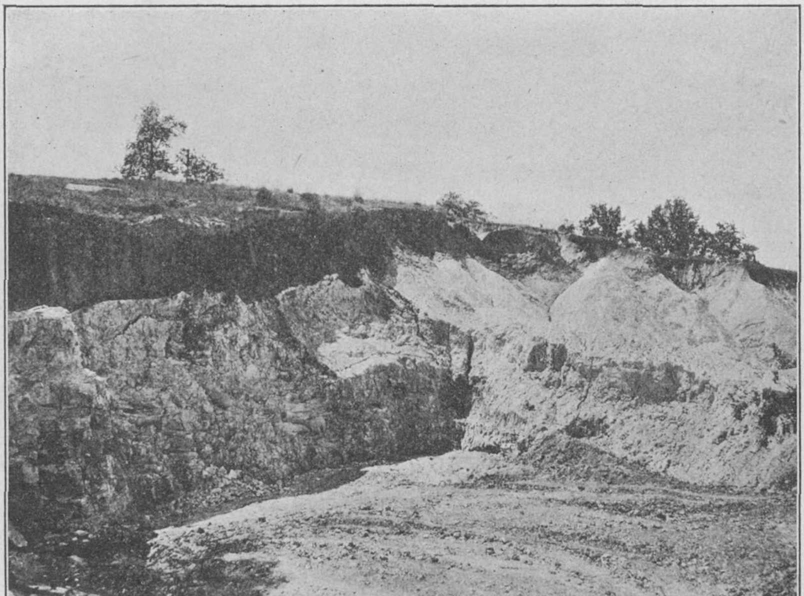
WILCOX GROUP.

DISTRIBUTION.

The Wilcox group is one of the most extensive clay-bearing divisions in the Southern States. It contains clays of high grade in Arkansas and Mississippi and in its northward extension in Ten-

A. SECTION IN PIT OF PADUCAH CLAY CO., BRIENSBURG, KY.

(See fig. 34, p. 238.)



B. CLAY PIT OF J. T. BRAMLETT, 10 MILES WEST OF ENID, MISS.

A. GULLIES NEAR HUNTINGTON, TENN., SHOWING NATURAL EXPOSURES OF LAGRANGE CLAYS.

B. TYPICAL SECTION OF GRAVELLY OVERBURDEN, OFTEN CALLED "LAFAYETTE."

This material overlies the Lagrange clays in many places in Tennessee.

nessee, Kentucky, and Illinois (Pl. X, p. 162), where it is represented in the Lagrange formation, of which it composes the major part.

The deposits comprise littoral and estuarine sediments over a wide area and contain many impressions of plants.[8] They consist in general of more or less extensive lenticular beds of sands and clays. The sands are commonly cross-bedded and ferruginous and contain lenses of clay, which in places are of sufficient size and purity to form the basis of an important clay-mining industry.

Their occurrence in the several States is referred to below.

GEORGIA.

The clays of Wilcox age in Georgia are not extensively worked. One is referred to on page 234.

MISSISSIPPI.

DISTRIBUTION AND CHARACTER.

The outcrops of the Wilcox group extend across Mississippi in a northwesterly direction from the eastern border of Lauderdale County to the northern boundary of the State, where the deposits cross into Tennessee (Pl. X, p. 162) and form the major part of the Lagrange formation.

The Wilcox in Mississippi is subdivided into three formations—the Grenada formation, the Holly Springs sand, and the Ackerman formation—in descending order.[9]

From the Alabama line to the southern border of Webster County,[10] the outcrop maintains a fairly uniform width of about 30 miles, but beyond this point northward to the State line its width is about twice as great. There are also two detached belts to the west of the main area, in northwestern Mississippi.

These boundaries delineate the area within which clays of the Wilcox deposits may be sought. However, in many places a mantle of loam or even gravel covers the Wilcox beds, so that unless the clays outcrop either in the sides of gullies or road embankments the deposits have to be located by boring. Some good natural exposures are seen in the bluffs that border the Mississippi bottoms in Tallahatchie County.

The Wilcox consists in general of beds of sand, clay, and lignite. The sands may be of different colors, cross-bedded in structure, and in places contain layers of lignite.

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[8] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, 1916.

[9] Lowe, E. N., Mississippi Geol. Survey Bull. 10, p. 23, 1913. Logan, W. N., The pottery clays of Mississippi: Mississippi Geol. Survey Bull. 6, 1909.

[10] Logan, W. N., op. cit., p. 136.

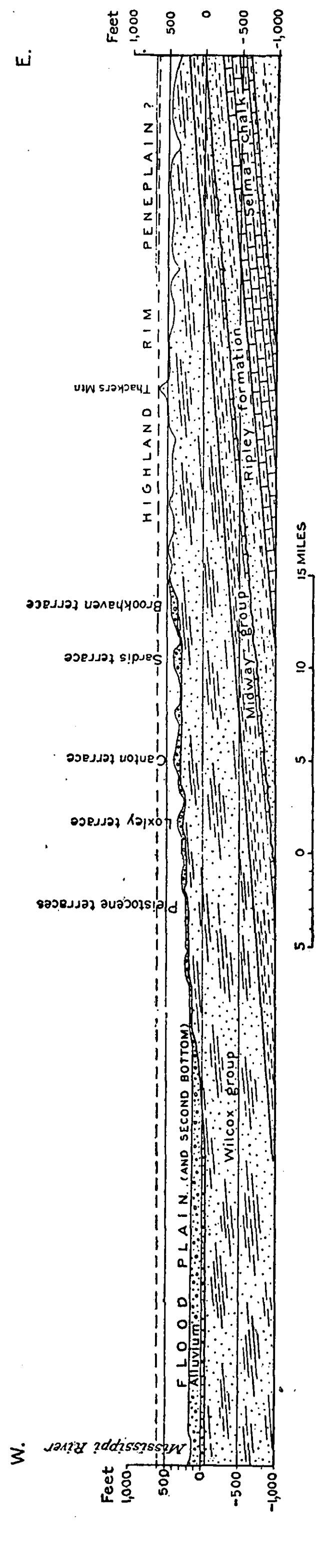

FIGURE 35.—Section through Wilcox clays and sands in northwestern Mississippi. (After E. W. Shaw, U. S. Geol. Survey Prof. Paper 108, pl. 45, A, 1918.)

The clays differ in character from place to place and show considerable range in their content of silica. They differ also in their other properties.

The Wilcox beds dip gently westward (fig. 35) and southwestward; consequently those beds along the western side of the belt lie higher in the group than those along the eastern edge.

CLAYS OF ACKERMAN FORMATION.

The basal formation of the Wilcox group, the Ackerman,[11] consists of about 300 feet of dark-gray lignitic and ferruginous clays, lignite, iron carbonate, and sandstone. Little is known regarding the quality of the clay.

CLAYS OF HOLLY SPRINGS SAND.

The middle formation of the Wilcox group, the Holly Springs, is prevailingly sandy. It is about 350 feet thick and consists chiefly of cross-bedded, mostly coarse, micaceous, white to yellow, red, and purple sands, hardened in places. It contains lenses, more or less extensive, of pink and white, rarely chocolate-colored, generally sandy clays. These clay lenses seem to be very abundant, however, for Logan[12] has described many occurrences in Marshall, Benton, Lafayette, Calhoun, Webster, Choctaw, Winston, Noxubee, and Lauderdale counties.

Some of the lenses have a thickness of 15 to 18 feet. The clays in general seem to burn to a cream color, but they do not fire to a very dense body on account of their siliceous character.

[11] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, 1916.

[12] Logan, W. N., The pottery clays of Mississippi: Mississippi Geol. Survey Bull. 6, 1909.

All show fair to good plasticity, and the content of iron oxide ranges from 1.26 up to 3 per cent, or even more. It is probable that some of them could be improved by washing.

Up to the present time they have been only utilized locally by potteries. Their quantity is unknown. Their thickness, however, in places is considerable, to judge from the following record of the city well at Oxford, Miss.:[13]

Section of city well, Oxford, Miss.

	Feet.
Clay and sand	90
Sand	15
Clay	67
Soapstone (clay)	78
Hard sandstone	50

Nothing is known regarding the quality of the clay, but it occurs in the Holly Springs sand of the Wilcox group.

The most extensive operation is at Holly Springs, Marshall County, where a stoneware factory has been running for some years. A number of clay lenses have been noted around this locality,[14] but it is doubtful if any of them are of large dimensions. They all pass into or are surrounded by sand.

A fairly typical occurrence is seen in a pit about half a mile east of Holly Springs and worked by the Holly Springs Stoneware & Firebrick Co. In the north end of this pit a mass of clay about 15 feet thick and 50 feet long and covered with 3 to 5 feet of loamy overburden is exposed. Not more than 30 feet south of this face the bank shows 10 feet of cross-bedded sand capped by crusts of limonite and over this, in turn, 8 feet of very sandy clay. This section shows how abruptly the character of the material may change horizontally. The clay in the west half of the pit contains thin sheets of sand and scattered light stains of iron along both the joint cracks and the bedding planes.

The clay is used in its crude condition for making common Albany-glazed stoneware, the body of which is steel hard but not vitrified.

The following tests of this clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay from Holly Springs, Miss.

Workability		Very plastic; works well; smooth.
Water of plasticity	per cent	31.25
Air shrinkage by volume	do	26.65
Air shrinkage, linear, calculated	do	8.00
Modulus of rupture: Raw clay	pounds per square inch	381.9

[13] Crider, A. F., and Johnson, L. C., U. S. Geol. Survey Water-Supply Paper 139, p. 65, 1906.

[14] Logan, W. N., The pottery clays of Mississippi: Mississippi Geol. Survey Bull. 6, p. 138, 1909.

Fire tests of clay from Holly Springs, Miss.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	17.60	Light buff	20.40	7.4
1,250	19.21	Cream color	19.06	6.8
1,310	11.34	Light buff	22.34	8.2
1,370	.60	Pale buff	29.20	10.9
1,410	.10	....do	27.00	9.9

Fused at cone 32. Residue left on 150-mesh sieve, 0.065 per cent. Steel hard at 1,190° C. At 1,250° C. the body develops small rusty iron spots.

This clay has good bonding strength. It does not burn white enough for the best grades of pottery. Its refractoriness is good, but it does not fire to a dense body until the temperature reaches 1,370° C. Air and fire shrinkage are moderate. It resembles some of the refractory bond clays, but for the best results it should be mixed with a denser-burning material. Its bonding strength and refractoriness are better than those of a sample tested from the same formation at Oxford, Miss. It can be used in stoneware and face brick or for other uses where this type of clay is needed.

Under the microscope the crude clay shows small grains of quartz to be rather common, and abundant hydromica and kaolinite, both of which occur in places in bunches. Rutile in minute grains and needles is common.

Thin sections of the clay that were fired at the two temperatures noted above showed that even at 1,150° C. the hydromica had largely disappeared, yielding a dense groundmass, which in part was isotropic and in part carried patches that showed low interference colors, scattered through which were grains of quartz. There was not much further change in the section when it was fired to 1,300° C.

As the sandy clays of the Holly Springs type dip westward they occur only at a considerable depth in Tallahatchie County.

CLAYS OF GRENADA FORMATION.

Distribution and character.—The clays of the Grenada or upper formation of the Wilcox group, as already mentioned, form a belt that extends northward across Tallahatchie County. The exposures lie mainly west of the Illinois Central Railroad.

Natural outcrops are not very abundant, for the clays are capped by loam, which conceals them and may even wash down the slopes of gullies, thus hiding fresh sections. A good series of natural exposures occurs in the bluffs that border the Mississippi bottoms about 10 miles west of Enid. In this locality and at several others that will be mentioned in a little more detail the clays have been dug for the ceramic industry.

These Grenada clays are in general very dense, sticky plastic clays, chiefly of refractory character. They are mostly light gray, although some beds are dark gray, owing to their content of finely divided lignitic material. Scattered thin beds of lignite also occur, as well as some thin beds of oolitic limonite. Very little pyrite is found in the clay, but in some of the pits a thin film of crystalline gypsum lines the joint cracks. As this material is undesirable it is usually trimmed off.

The following notes give some information regarding the industry in this region:

Pits of J. T. Bramlett.—The pits of J. T. Bramlett form a series of openings in the face of the bluff 10 miles west of Enid. The property is said to include 35 acres of clay land.

The most southern of several pits, known as No. 15, shows a maximum of 20 feet of clay, covered by 4 feet of gravelly loam. The clay extends at least 20 feet below the bottom of the pit.

The clay is very tough and plastic. It contains scattered light stains of limonite and in places small grains of lignite. The joints in at least the upper part of the deposit show thin films of gypsum, but an effort is made to throw these out in mining. About 6 feet above the bottom of the pit occurs a 1-foot layer of oolitic limonite, which shows in the north face of the excavation. Just north of this pit the clay appears to be quite sandy.

Pit No. 5 (Pl. XVIII, *B*) lies about 600 feet north of No. 15. This pit opens northward on a west facing slope and shows the following section:

Section in pit No. 5, of J. T. Bramlett, west of Enid, Miss.

	Feet.
Loess and gravel	10
Whitish sandy clay	15
Lignitic clay	2
Clay (bored)	12
Bottom not reached.	

In this pit also the layer of oolitic ore is present in the lower portion at about the same level as that in pit No. 15.

The top sandy clay is very plastic and smooth, but under the microscope it shows fairly abundant fine grains of quartz. Hydromica is exceedingly abundant, but kaolinite occurs sparingly. Rutile and tourmaline grains occur only in small quantity.

The following tests of this clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay from Bramlett pit No. 5, Enid, Miss.

Workability	Plastic; works well.
Water of plasticity ......per cent..	34.01
Air shrinkage, by volume ......do....	38.54
Air shrinkage, linear, calculated ......do....	15.00
Modulus of rupture:	
Raw clay ......pounds per square inch..	525.8
Mixture of clay and sand in proportion of 1:1....do....	289.2

Fire tests of clay from Bramlett pit No. 5, Enid, Miss.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of dry clay).
1,130	10.60	Brown	22.90
1,190	.5	.....do	24.7
1,250	2.09	.....do	24.45
1,310	1.26	.....do	28.45
1,370	.07	Yellow brown	24.90

Fusion point, cone 30 (1,730° C.). Steel hard at 1,190° C.

This clay shows good strength in the unfired condition and has fair bonding stregnth. Its refractoriness is fair. It burns to a dense body at 1,190° C., but is not white enough to be used as a ball clay. It is a refractory bond clay and should be of value for uses requiring this type of clay, such as the manufacture of glass refractories, crucibles, abrasives, and stoneware. For all these purposes it would be used in a mixture and not alone.

Because of its fine grain and abundance of hydromica the thin section of the clay after firing shows a very dense mass, which seems to consist of a very fine felty aggregate.

The lower clay in pit No. 5 is less gritty, but is also exceedingly plastic.

Three-quarters of a mile farther north along the bluff is another natural exposure, known as pit No. 21, which had not been developed. This exposure shows 15 to 18 feet of gray and pink clay above the road level and is said to extend 26 feet below it, giving a total thickness of over 40 feet at this point. Below the clay there is lignite, and on top of it there is a 9-inch layer of lignitic clay. The overburden, which appears farther up the hillside, is the usual gravelly loam.

The following tests of this clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay from Bramlett pit No. 21, Enid, Miss.

Workability___Plastic; smooth; works well in molding; dries well.
Water of plasticity________per cent__ 35.20
Air shrinkage, by volume________do____ 30.48
Air shrinkage, linear, calculated________do____ 11.0
Modulus of rupture:
Raw clay________pounds per square inch__ 533.6
Mixture of clay and sand in proportion of 1:1__do____ 404.5

Fire tests of clay from Bramlett pit No. 21, Enid, Miss.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	2.5	Light brown	22.80	8.3
1,250	2.02	Deep cream	25.49	9.4
1,310	2.37	Brown	26.00	9.5
1,370	2.00	Buff	25.20	9.3
1,410	14.40	Deep buff	Overburned.	

Fusion point cone 30 (1,730° C.). Steel hard at 1,900° C.

This clay has good bonding strength and good firing range, but is overfired at 1,410° C., or even lower, and though it may be classed as a refractory bond clay it is not of the highest type, and according to Bleininger's classification it is not adapted for graphite crucibles. It does not burn white enough for ball clay. It is also somewhat less refractory than the clay from pit No. 5, described above. It could be used for pottery, face brick, terra cotta, or other uses which demand this type of clay.

A clay similar to that in pit 21 outcrops up the creek about one-fourth of a mile eastward.

The clay in the main exposure is light gray, dense, and even-textured. It feels smooth and is very plastic, but contains some fine grit.

At 1,150° C. the clay is steel hard and has 5.6 per cent absorption. At 1,300° C. it shows no absorption and but 0.4 per cent porosity. It is steel hard and buff.

A microscopic examination of the raw clay showed some quartz, very abundant hydromica, and rather numerous grains of kaolinite. Rutile and tourmaline were very scarce.

A thin section of the burned clay showed a very fine-grained, felty-looking mass similar to that of the burned clay from pit No. 15.

Property of McLendon Clay Co.—The McLendon Clay Co. has a property on Deese Creek, 3 miles southeast of Crevi, or 6½ miles west of Enid. Only some trial shipments have been taken out.

The clay is exposed near the base of a high bluff that borders the creek. The bed is 6 to 10 feet thick and is covered by a maximum thickness of 50 feet of the gravelly loam overburden.

It is claimed that the clay has been determined by boring to extend 18 feet below the creek level and that it underlies the low ground north of the bluff, but no natural outcrops occur there.

The following tests of samples taken from the foot of the bluff along the creek were furnished by Mr. McLendon:

Tests by Norton Emery Co.: Color of clay, gray. Structure, massive. Hard, tough. Sand, fine grained. Coarse impurities, none. Drying properties, good. Plasticity, very good; water of plasticity, 32.3 per cent. Drying shrinkage, 8.05 per cent; fire shrinkage, 7.48 per cent; total shrinkage, 15.93 per cent.

The burned clay has dense structure and shows bluestoning. Color after burning, brownish buff. Steel hard. The material is rated as a good grade of fire clay and is recommended as a bond clay if the strength is high enough.

Test by the Bureau of Standards: Linear shrinkage, 6.25 per cent. Dries without difficulty. Burns dark buff and vitrifies at cone 13½ (1,400° C.). Modulus of rupture, 1,168 pounds to the square inch. Fusion point, cone 29 (1,710° C.). The clay is recommended for crucibles.

Tests by A. S. Watts: Sample No. 1 fuses at cone 26 (1,650° C.).

Sample No. 2: Air shrinkage, 10 to 10.2 per cent. Fire shrinkage, 18 per cent at cone 12 (1,370° C.) at which it is vitrified. Suggested as useful for glass pots.

Sample No. 3: Air shrinkage, 7 per cent; total shrinkage, at cone 2 (1,170° C.), 14 per cent, and at cone 8 (1,290° C.), 15 per cent. Below 1,200° C. it burns buff, but at this temperature it is gray-brown and remains so to 1,250° C. Gray above 1,250° C. Almost completely vitrified at cone 8 (1,290° C.). Recommended as base for terra cotta, bricks, or fire brick.

The following analysis was furnished by the Mississippi Agricultural College:

Analysis of McLendon Clay Co.'s clay.

Silica (SiO_2)	57.28
Alumina (Al_2O_3)	28.54
Ferric oxide (Fe_2O_3)	2.68
Lime (CaO)	.36
Moisture	.86
Organic and volatile matter	9.40
	99.12

Pits of Mitchell Clay Co.—The Mitchell Clay Co. has operated several pits in the slope of the bluffs that overlook the bottoms 10 miles west of Enid.

Property of Southern Ball Clay Co.—The Southern Ball Clay Co. owns several deposits of clay in the territory west of Enid and claims to have 80 acres of clay land.

Pit No. 1 is 7 miles west of Enid, on Shelton Creek. A pit has been dug on the east side of the creek and on the west base of a low wooded ridge. The clay outcrops also on the east side of the ridge.

After the gravelly loam overburden 7 to 8 feet thick was stripped off, the pit was carried to a depth of 9 feet in clay, and a boring in the bottom of the excavation showed 31 feet more of clay, at which depth lignitic clay was struck. As the creek showed some outcrops of clay in its channel, which was cut to a depth of 6 feet in its flood plain, a series of bore holes was made in the flat several hundred yards to the south. All of these bore holes struck clay.

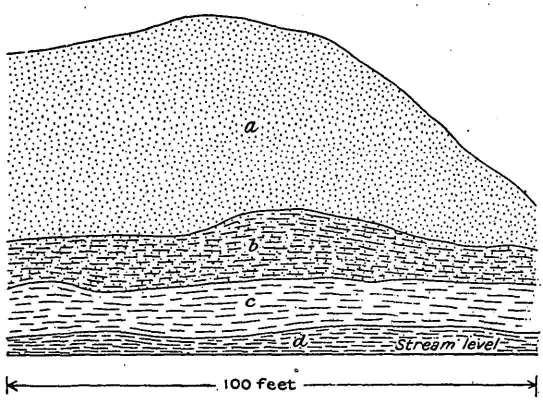

FIGURE 36.—Section along Sherman Creek, 4 miles south of Crevi, Miss., on the property of the Southern Ball Clay Co. *a*, Ferruginous sand; *b*, whitish sand and clay; *c*, lignitic clay; *d*, grayish-white clay.

Pit No. 2 of the same company is on Sherman Creek 4 miles south of Crevi. At this place clay is exposed in the bluff (fig. 36) in several beds of varying character. It is claimed that the lower bed was proved to a depth of 35 feet by boring, and the tests of the samples obtained in this manner are given in column 2 in the table on page 248. If the clay continues under the depression to the north of the bluff, this area would be a much better place for an opening, as there would be less overburden to remove.

The deposit was not being worked and had not been opened in June, 1918.

The following tests represent a series made by E. Lovejoy for the Southern Ball Clay Co. on samples supplied by them.

General physical tests of clays from property of Southern Ball Clay Co.

	1	2	3	4	5
Plasticity, stickiness considered	Good	Good	Good	Good	
Strength: Length of bar flowing from die unsupported (inches)	8½	8	7.6	a 33.5	a 49.
Water required (per cent)	25.4	27.4	31.6	33	33.5.
Quantity of material that passes through 200 mesh	99.89	98.5	98.45	99.31	99.45.
Deleterious material	Quartz, muscovite mica.	Pyrite, quartz, or feldspar.	Some FeS_2; chiefly quartz; some black mineral; magnetite.	Chiefly quartz.	Mostly quartz.
Behavior in machine	Tears	Tears and laminates.	Tears	Tears	Tears.
Behavior in drying	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory.
Shrinkage in drying	5.3	6.3	6.4	6.5	6.6.
Scum	Develops	Trace	Trace	Trace	Trace.
Efflorescence after firing	Yellow-green	None	None	None	Bad.
Color when burned	Cream	Yellow	Cream to yellow.	Yellow; blue at cone 10.	Cream; blue at cone 10.
Hardness	Steel hard	Steel hard	Steel hard	Steel hard	Steel hard.
Refractoriness, cone	31		31-32	31	32.

a Suspended.
1, 5. Light-gray clay. 2. Dark-gray clay. 3, 4. Gray clay.

Fire tests of clays from property of Southern Ball Clay Co.

	1		2		3		4		5	
	Fire shrinkage (per cent).	Absorption (per cent).	Fire shrinkage (per cent).	Absorption (per cent).	Fire shrinkage (per cent).	Absorption (per cent).	Fire shrinkage (per cent).	Absorption (per cent).	Fire shrinkage (per cent).	Absorption (per cent).
Cone 01 (1,130° C.)	6.9	3.0	6.2	3.6	8.2	4.9	7.2	1.7	7.7	5.0
Cone 2 (1,170° C.)	6.9	1.4	6.5	2.9	8.2	2.9	7.2	1.6	8.3	2.1
Cone 4 (1,210° C.)	7.0	1.4	6.6	3.3	8.2	2.3	7.3	3.3	8.3	5.1
Cone 6 (1,250° C.)	7.2	1.4	6.6	2.2	8.3	1.6	7.4	0.0	8.7	2.5
Cone 8 (1,290° C.)	7.3	1.4	6.9	1.3	8.6	.7	7.9	0.6	9.0	.3
Cone 10 (1,330° C.)	7.6	0.0	7.2	0.0	9.0	1.3	8.0	0.0	9.4	.3

Samples bear same numbers as in preceding table.

Lovejoy recommends these clays for a wide range of wares, including: Buff face brick, especially No. 5; fireproofing, stoneware, and refractory products; as bond clay for high-grade fire brick, bauxite bricks, glass pots, and crucibles. He states that they all burn to a very dense body; in fact, too dense to be used alone.

Charleston, Tallahatchie County.—Among the recent developments in this region is one begun by the French Clay Blending Co., 5½ miles north of Charleston, Miss. The clays from this pit are being utilized for glass refractories, crucibles, and enameling.

Future of the clays of the Grenada formation.—These clays have been known for some time, but their real development is of comparatively recent date. In view of their value as refractory bond clays, it is probable that there will be a continued demand for them as long as the supply lasts. Owing to the poor character of the roads in much of this region, deposits should be worked as near the railroad as possible. Clays from the bluffs along the Mississippi bottoms have to be hauled 10 miles to Enid on the Illinois Central Railroad, although there is a railroad only 4 miles distant across the bottoms.

UNDEVELOPED PROPERTIES.

By E. N. Lowe.

The following undeveloped properties have been examined by the Mississippi Geological Survey. The tests were made by C. W. Parmelee, of the University of Illinois.

CLAYS OF GRENADA FORMATION.

Tocowa, Panola County.—A small exploratory pit has been opened at the residence of Samuel Elmore, 3 miles south of Tocowa, Panola County, sec. 15, T. 27 N., R. 2 W. At this pit the clay is light gray and is 8 to 12 feet thick. The overburden consists of 12 to 18 feet of gravel and sand that might be useful for road building. The clay presents no visible impurities, except at the bottom, where it becomes sandy and passes below into a bed of fine white sand. The gravelly overburden contains concretions of brown iron oxide in considerable quantities.

North of the pit the face of the hill is covered with slope wash, and the clay is covered. In a ravine 300 yards north of the pit the clay overlies a bed of good lignite 5 to 5½ feet thick. The clay is here a gray, slightly lignitic joint clay that has a horizontal stratification. In places on the joint surfaces a white deposit of gypsum is noticeable. Otherwise the clay is apparently pure and is darker gray than at the pit. It passes above into a bluish-purple clay, which is very sandy. The gray clay is very plastic and has a thickness of 10 to 15 feet. The overlying sandy, purplish clay is 15 to 18 feet thick. The overburden here consists of 12 to 15 feet of loose sand and silt.

General physical tests of clay from Tocowa, Panola County, Miss.

Kind of material	Light-gray, medium hard, plastic clay.
Working properties	Good.
Conduct in flowing through die	On the whole works well but shows tendency to laminate.
Water of plasticity per cent	33.2
Plasticity	Good.
Shrinkage water, in terms of volume of pure clay per cent	20.2
Pore water, in terms of volume of pure clay do	13.0
Modulus of rupture (average):	
Raw clay pounds per square inch	674
Mixture of clay and sand in proportion of 1:1	461

Fineness test:
Residue, 20-mesh sieve .... per cent .. 0.17
Residue, 40-mesh sieve .... do .... .00
Residue, 60-mesh sieve .... do .... .07
Residue, 80-mesh sieve .... do .... .00
Residue, 120-mesh sieve .... do .... .18
Residue, 200-mesh sieve (white sand and mica) ... do 1.05
Linear drying shrinkage .... do 8.9
Drying conduct .... Good.

Fire tests of clay from Tocowa, Panola County, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	25.6	Cream	Near steel hard	1.24
03	1,090	18.7	do	do	2.51
2	1,170	19.8	do	Steel hard	3.45
5	1,230	13.9	do	do	3.93
9	1,310	2.1	Grayish	do	4.79
12	1,370	6.6	do	do	3.33
14	1,410	14.5	do	do	4.07
15	1,430	17.5	do	do	4.79
30	1,760	Fused.			

The following conclusions have been reached in regard to this clay: Plasticity, good; drying shrinkage, normal; strength of unburned clay, high; bonding strength, high; warpage, none; porosities, very low at cone 9, slight overburning at cone 12, more marked at cone 14; color sufficiently good for a ball clay; fusibility high, but overburning at cone 12 bars it from the refractory class.

The clay conforms quite closely to the type of the refractory bond clay, which should make it of value wherever a plastic, strong, dense-burning clay is required. Its color makes it available for use in making pottery.

The nearest railroad is the Batesville Southwestern, 5 miles to the west, which connects with the main line of the Illinois Central at Batesville.

Charleston, Tallahatchie County.—There is a promising looking clay on the G. I. Otott place, 4½ miles from Charleston. The clay is reported to be 15 feet thick and has 6 to 8 feet of overburden.

Carrollton, Carroll County.—Clay outcrops on the slope of the hill 150 yards south of the old Dr. Vassar residence in Carrollton, now owned by Dr. T. H. Somerville, of Oxford, Miss. No pit has been opened on this clay, but the outcrop extends along a hill slope half a mile south of the Southern Railway at Carrollton.

The best outcrops of the clay are in an old roadbed and in deep washes on the roadside. It is a good firm massive light-gray clay, and shows no stratification planes, though, taken as a whole, the outcrop exhibits somewhat different characters at different levels. Joint planes are well marked; indistinct and fragmentary impressions of leaves occur in the clay, more noticeably toward the bottom of the section. This clay is remarkably free from impurities that can be detected by the eye. In the lower third of the deposit an appreciable proportion of fine white sand is intimately mixed with the clay. A little stain of iron also occurs here and there.

The deposit is 25 feet thick and is covered with 15 to 25 feet of soft sand and loess silt. The sand appears to be suitable for building. The clay passes down into a whitish-gray clayey sand. Over an acre or more the overburden would not average more than 15 feet. The clay outcrops in the hill slopes and stream bluffs for a mile or more east and west and half a mile north and south.

Should the clay need washing, Big Sandy Creek is less than one-quarter of a mile away, and the city standpipe, supplied by strong artesian wells, is on the hill within 150 yards of the outcrop. The clay could be trammed down the natural incline from the hill to the Southern Railway.

This deposit is half a mile south of the railroad station at Carrollton, Carroll County.

General physical tests of clay from Carrollton, Carroll County, Miss.

Kind of material		Light gray, medium hard, plastic clay.
Working properties		Good.
Conduct when flowing through die		Shows tendency to laminate.
Water of plasticity	per cent	37.9
Plasticity		Good.
Shrinkage water, in terms of volume of true clay	per cent	25.0
Pore water, in terms of volume of true clay	do	12.9
Modulus of rupture (average):		
Raw clay	pounds per square inch	1,093
Mixture of clay and sand in proportion of 1:1	do	385.6
Fineness test:		
Residue, 20-mesh sieve	per cent	0.28
Residue, 40-mesh sieve	do	.00
Residue, 60-mesh sieve	do	.00
Residue, 80-mesh sieve	do	.00
Residue, 120-mesh sieve	do	1.07
Residue, 200-mesh sieve	do	4.25
Linear drying shrinkage	do	11.2
Drying conduct		Pieces warp badly.

Fire tests of clay from Carrollton, Carroll County, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear fire shrinkage (per cent).
05	1,050	22.8	Light buff	Steel hard	0.8
03	1,090	20.9	do	do	2.0
2	1,170	19.5	Light chocolate-brown	do	2.4
5	1,230	18.7	do	do	2.7
9	1,310	11.4	Light gray	do	3.9
12	1,370	10.5	do	do	4.2
28	1,690	Fused.			

The following conclusions have been reached in regard to this clay: Plasticity, good; drying shrinkage, high; strength of unburned clay, very high; bonding strength, high; fire shrinkage, low; porosity, moderate; color too dark for a ball clay. It is to be classed as a bond clay for certain types of refractories and other wares, as face brick and terra cotta.

CLAYS OF HOLLY SPRINGS SAND.

Hudsonville, Marshall County.—Clay occurs in a lens exposed in a deep wash near the residence of S. B. Gibbons, in sec. 16, T. 2 S., R. 2 W., 5 miles northwest of Hudsonville, Marshall County.

The clay is highly plastic and is light gray but near the surface is appreciably mottled with iron stains that give it a pinkish discoloration. Locally very fine white sand forms thin partings in the clay one-fourth to one-half an inch thick.

The full extent of this lens can not be made out, but the clay is exposed in the bottom and sides of the ravine beneath an overburden of 8 to 10 feet of variegated sands, which in turn are overlain by 6 to 8 feet of brown loamy soil. It is probably not more than 200 to 250 feet in lateral extent. The owner, Mr. Gibbons, stated that he had dug a pit 15 feet deep and found the same quality of clay to the bottom. He further stated that a boring was made in the bottom of this pit, and the same quality of clay was found to the full depth of 60 feet in one place; in another place, a few rods away, the drill passed into dry sand beneath the clay at a depth of 40 feet, but above the sand the clay was of uniform quality, free from sand and other impurities.

General physical tests of clay from property of S. B. Gibbons, Hudsonville, Marshall County, Miss.

Kind of material	Light-pink plastic clay of medium hardness.
Working properties	Good.
Conduct when flowing through die	Fair; tends to laminate.
Water of plasticity ... per cent	32.5
Plasticity	Good.
Shrinkage water, in terms of true clay volume ... per cent	15.5
Pore water ... do	17.0
Modulus of rupture (average):	
Raw clay ... pounds per square inch	395
Mixture of clay and sand, in proportion of 1:1 ... do	172
Fineness test:	
Residue, 20-mesh sieve ... per cent	0.0
Residue, 40-mesh sieve ... do	Trace.
Residue, 60-mesh sieve ... do	0.08
Residue, 80-mesh sieve ... do	.07
Residue, 120-mesh sieve ... do	.22
Residue, 200-mesh sieve ... do	.12
Linear drying shrinkage ... do	7.97
Drying conduct	Good.

Fire tests of clay from property of S. B. Gibbons, Hudsonville, Marshall County, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	63.9	Pinkish	Nearly steel hard	1.42
03	1,090	30.4	Light buff	do	2.89
2	1,110	25.0	do	Steel hard	4.79
5	1,230	22.5	do	do	6.04
9	1,310	7.2	do	do	7.58
12	1,370	7.1	do	do	8.57
13	1,390	2.9	do	do	9.32
14	1,410	2.8	do	do	10.05
15	1,430	1.4	do	do	8.40
30	1,730	Fused.			

The following conclusions have been reached in regard to this clay: Plasticity, good; drying shrinkage, normal; strength of unburned clay, good; bonding strength, fair; fire shrinkage, normal; warpage, none; attains low porosity at cone 9 and is not overfired at cone 15, hence shows long heat range; color, sufficiently good to serve as a ball clay. It can be used as a bond clay in the manufacture of pottery, abrasives, or refractories.

Lamar, Benton County.—An outcrop of white clay occurs on the old Judge A. M. Clayton place, 2 miles south of Lamar. The clay is exposed in a deep ravine washed out of the hill 200 yards south of the residence, at a spring. This clay occurs in thin beds interstratified with sandy clay, all light gray to white. A very thin stratum of the clay is pure white and entirely free from grit.

The clay beds are 18 feet thick, but in part are rather sandy. The deposit appears to be rather small in area, and is undoubtedly a lens 60 to 70 yards from north to south, and perhaps about the same from east to west. Except for a little stain of iron in places and the alternating beds of sandy clay, the clay of this deposit appears quite pure.

The overburden consists of 6 to 15 feet of sand and loam. The deposit is one-fourth of a mile east of the Illinois Central Railroad.

The transverse strength of this clay is 173.6 pounds to the square inch.

Oxford, Lafayette County.—In the Isom Ravine, a deep ravine that faces eastward, thick deposits of clay are exposed a few rods north of the high-school building in the town of Oxford.

The deposit is undoubtedly a lens, for the ravine cuts through the clay into underlying sands. This clay is very firm, almost a shale, and is light pinkish gray to dark gray, the darker color being due to lignitic material. It is highly fossiliferous, and some very fine specimens of fossil plants have been collected by E. W. Berry from this ravine. The clay is highly plastic when weathered. Its visible impurities include a little iron oxide, the lignitic matter, and a noticeable sprinkling of scales of mica.

In the lower half of the ravine the clay is massive or heavy-bedded, and becomes distinctly stratified above. This lower phase of the clay is 12 feet thick. Above this lower bed, and conformable with it, is 10 feet of lighter pinkish clay, less fine, which becomes thin-bedded and somewhat siliceous. These clay beds are overlain by 15 feet of yellowish sands that contain thin pale-pinkish sandy clay laminae, above which lies 4 to 12 feet of red sands.

The extent of this deposit has not been made out satisfactorily, but an outcrop of similar clay one-quarter of a mile to the south is probably an extension of this lens.

General physical tests of clay from Isom Ravine, Oxford, Lafayette County, Miss.

Kind of material		Light-gray, medium hard, plastic clay.
Working properties		Good.
Conduct when flowing through a die		Good.
Water of plasticity	per cent	64.1
Plasticity		Good.
Shrinkage water, in terms of volume of true clay	per cent	19.7
Pore water	do	44.4
Modulus of rupture (average):		
Raw clay	pounds per square inch	149
Mixture of sand and clay in proportion of 1:1	do	62
Screen test:		
Residue, 20-mesh sieve	per cent	10.0
Residue, 40-mesh sieve	do	5.2
Residue, 60-mesh sieve	do	4.69
Residue, 80-mesh sieve	do	.42
Residue, 120-mesh sieve	do	1.52
Residue, 200-mesh sieve	do	1.57
Linear air shrinkage	do	5.82
Drying conduct		Good.

Fire tests of clay from Isom Ravine, Oxford, Lafayette County, Miss.

Cone.	Temperature (°C.).	Porosity (per cent).	Color.	Hardness.	Linear shrinkage (per cent).
05	1,050	56.0	Cream-white	Nearly steel hard	0.72
03	1,090	55.4	do	do	2.38
2	1,170	53.9	do	do	2.72
5	1,230	55.4	do	do	3.50
9	1,310	32.5	do	do	12.30
12	1,370	17.0	do	Steel hard	16.80
14	1,410	6.2	Gray	do	
15	1,430	.7	do	do	15.0
27	1,670	Fused.			

The following conclusions have been reached in regard to this clay: Plasticity, good; drying shrinkage, normal; strength of unburned clay, low; bonding strength of unburned clay, very low; color after firing, fairly good, white; bluestoned badly above cone 12; warpage, none; porosity, high up to cone 12; fire shrinkage, high above cone 9.

The clay may be used where a low-grade refractory clay is suitable, but because of its lack of strength it will ordinarily be mixed with stronger clays. It is slightly stained with iron and hence unsuited for white pottery; could be used in manufacture of face brick.

The deposit is one-quarter of a mile east of the Illinois Central Railroad.

ARKANSAS.

DISTRIBUTION AND CHARACTER.

Branner,[15] in his report on Arkansas clays, states:

> The Tertiary clays are the most important in the State of Arkansas. As already stated, they, with their accompanying sands, marls, and organic deposits, underlie a large part of the State east and south of the St. Louis, Iron Mountain & Southern Railway south of Arkansas River. North of this and east of the Paleozoic hills the sediments are chiefly Quaternary deposits, except Crowleys Ridge, the lowest part of which is Tertiary. * * * The sediments laid down during Tertiary time vary from place to place in thickness and in character, just as any marine sediments of the present time vary. Some of the beds are clays and some of them are sands and gravels. * * *
>
> The fire clays of the Crowleys Ridge region are everywhere associated with beds of Tertiary lignites, which outcrop in the basins of several of the larger streams. Lignites and fire clays occur in the NE. ¼ NE. ¼ sec. 26, T. 4 N., R. 4 E.; NW. ¼ SW. ¼ sec. 8, T. 11 N., R. 4 E.; NE. ¼ NE. ¼ sec. 20, T. 10 N., R. 4 E.; sec. 30, T. 16 N., R. 5 E.; and in sec. 36, T. 19 N., R. 6 E.

Many of these deposits have to be worked by underground methods, as the overburden is heavy, but in many places the beds are 3 to 4 feet thick.

All the analyses given by Branner show a high content of silica.

The Wilcox formation underlies the surface of the whole State south and east of the Cretaceous and Midway outcrops and extends southward into Louisiana. Little is known, however, regarding the value of its clays for making ceramic products.

Berry[16] states that they have a total thickness of 400 to 800 feet and are predominatingly dark carbonaceous sands and brown laminated, commonly selenitic clays. The latter character does not indicate a high-grade material. However, little has been published regarding the quality of the Arkansas clays, except a few chemical analyses.

In Ouachita County, Branner[17] gives the following localities: S. ½ SE. ¼ sec. 2, T. 12 S., R. 18 W.; NW. ¼ SW. ¼ sec. 2, T. 12 S., R. 18 W.; SW. ¼ NW. ¼ sec. 36, T. 11 S., R. 18 W.; NW. ¼ NE. ¼ sec. 12, T. 12 S., R. 18 W.

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[15] Branner, J. C., The clays of Arkansas: U. S. Geol. Survey Bull. 351, p. 39, 1908.

[16] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 36, 1916.

[17] Branner, J. C., op. cit., p. 138.

Some analyses of the clays of Ouachita County show a low content of ferric oxide, but as a rule high silica. If otherwise satisfactory the material might be improved by washing.

MINES.

Lester, Ouachita County.—The only clay deposits that have attracted any attention seem to be those in the vicinity of Lester, Ouachita County.

Owen [18] gives a section at the mine of the Camden Coal & Clay Co., in sec. 12, T. 12 S., R. 18 W., as follows:

Section at mine of Camden Coal & Clay Co., Lester, Ark.

	Feet.
Sand and ferruginous sandstone	20–30
Ash-colored clay	6–7
Lignite	6
Pipe clay with segregations of limonite Light-gray sandy clay, somewhat ferruginous	10–18

Harris [19] later gives the following section, presumably at the same locality or near it:

Section near mine of Camden Coal & Clay Co., Lester, Ark.

	Feet.
Sandy materials, poorly exposed.	
Light-pink clay	6
White sand	6
Bluish clay	8
Lignite	6

The Camden Coal & Clay Co., of Hot Springs, Ark., has opened up a mine northwest of Lester, in Ouachita County, in the SE. ¼ sec. 15, T. 12 S., R. 18 W. (See fig. 37.) The section at the mine is poorly exposed, but a bed of clay, which ranges from 4½ to 8 feet in thickness, underlies the lignite. It is dense, plastic, and commonly smooth but contains here and there streaks of sand.

A similar clay outcrops 4 miles north of the mine in the bank of Ouachita River.

About 4½ miles northwest of Lester, the lignite, which is exposed in an abandoned tunnel, is overlain by a smooth plastic clay, which grades upward into a sandy clay. Below the lignite is a plastic clay similar in appearance to that at the Camden Coal & Clay Co.'s mine.

At the Camden Coal & Clay Co.'s mine a tunnel was run east into the hill for a distance of 200 feet. At the end of this tunnel a drift was run north and south, and every 100 feet on this drift rooms 12

[18] Owen, D. D., Second report of a geological reconnaissance of the middle and southern counties of Arkansas in 1859 and 1860, pp. 128–133, 1860.

[19] Harris, G. D., Arkansas Geol. Survey Ann. Rept. for 1892, vol. 2, p. 65, 1894.

feet wide and 6 feet high were opened, all of them in the clay under the lignite.

The mine is connected by a branch road with the St. Louis, Iron Mountain & Southern Railway about 2 miles to the south.

As the clay in the mine is not sufficiently uniform to be shipped crude, the company has constructed a washing plant along its branch road about 1½ miles northwest of Lester.

The mine and mill have been idle for some months.

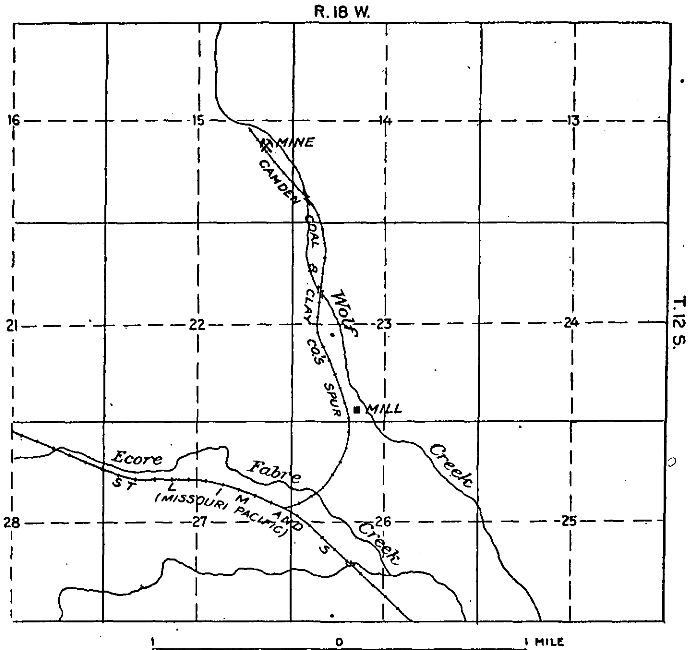


FIGURE 37.—Map of region northwest of Lester, Ark., showing location of clay mines.

The following physical tests were made by A. V. Bleininger, of the Bureau of Standards, on a sample of the clay from the Camden Coal & Clay Co.'s mine: [20]

General physical tests of clay from vicinity of Lester, Ark.

Water in terms of dry weight .... per cent..	29.02
Ratio of pore water to shrinkage water	.72
Apparent specific gravity of dried clay	1.89
Volume shrinkage, in terms of dry volume .... per cent..	32.32
Time of slaking .... minutes..	128
Modulus of rupture:	
Dried clay .... pounds per square inch..	817
Mixture of clay and sand in proportion of 1:1 ....do....	466

[20] Bleininger, A. V., and Loomis, G. A., The properties of some American bond clays: Am. Ceramic Soc. Trans., vol. 19, p. 601, 1917.

Fire tests of clay from vicinity of Lester, Ark.

Temperature (° C.).	Porosity (per cent).	Volume shrinkage (per cent).
1,050	28.95	....
1,125	26.92	0.92
1,150	26.82	2.13
1,200	25.45	2.18
1,290	25.60	1.60
1,350	25.05	1.81
1,400	25.02	1.94
1,450	23.90	2.24
1,475	22.55	2.69

Softens at cone 29 (1,710° C.). Does not overfire at 1,475° C.

This clay is of the Gross Almerode type, and the plasticity and bonding power of the sample tested was superior to that clay.

Bleininger classes it as an excellent glass-pot material but not adapted for crucibles except in mixture with more dense-burning clay.

The following tests of the washed clay were made at the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of washed clay, Lester, Ark.

Workability	Very plastic, smooth.
Water of plasticity ....per cent..	29.73
Air shrinkage, by volume ....do....	26.19
Air shrinkage, linear, calculated ....do....	9.5
Modulus of rupture:	
Raw clay ....pounds per square inch..	1,068.6
Mixture of clay and sand in proportion of 1:1..do....	405.1

Fire tests of clay from Lester, Ark.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	18.70	Light buff	3.20	1.20
1,250	19.19	Deep cream	4.52	1.80
1,310	20.45	Light buff	4.11	1.61
1,370	17.50	Deep buff	2.90	1.01
1,410	13.90	.....do	3.50	1.33

Fusion point, cone 26—. Steel hard, 1,190° C. Small spots of iron develop at 1,250° C.

This clay has high bonding strength and low fire shrinkage. It does not fire to a very dense body and is not white enough after firing for a ball clay. It is classed as a bond clay of rather low refractoriness. Comparison with another clay from the same mine tested by Bleininger shows that its porosity is lower after firing and that its fusion point is several cones lower.

A microscopic examination of the washed clay showed it to be coarse grained. Quartz and hydromica were abundant and kaolinite common. Grains of tourmaline and rutile were sparingly present. The crude clay was similar in appearance, the chief difference being that it contained a few grains of other less common minerals, such as titanite and zircon.

Before the operations ceased, several companies had tried this clay in making glass pots, with good results.

There are probably other beds of clay in this district, but their qualities are not known and all are not likely to be of high-grade character. Exposures are not abundant, and prospecting by drilling would be necessary in many localities. Some of the clays are known to be gypsiferous.

Benton, Saline County.—Berry[21] gives a section near Benton, Saline County, Ark., which shows appreciable clay, but nothing is known regarding its quality. The section is as follows:

Section near Benton, Saline County, Ark.

	Feet.
Heavy gravel	0–8
Sand and gravel, brick-red	0–5
Gray sandy mottled clay	0–6
Plastic gray to brown heavily bedded clay	2–6
Gray sand	4–6

Half a mile to the west a small pottery pit shows a few feet of brownish sandy clay which grades upward into grayish and pinkish clays.

Half a mile to the north of the pit just mentioned, at the Such place on the Pine Bluff road, the following section is exposed:

Section at Such place near Benton, Saline County, Ark.

	Feet.
Reddish sand	6–8
Massive brown plastic clay that contains bits of lignite	6

LAGRANGE FORMATION.

CORRELATION AND CHARACTER.

The Wilcox deposits extend northward across western Tennessee and Kentucky, but there they are included in the Lagrange formation, of which they form the major part. The upper part of the Lagrange, however, includes beds of Jackson and possibly of Claiborne age; and the Lagrange formation does not include all of the Wilcox group as represented in Mississippi, because the Ackerman formation is

[21] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 52, 1916.

absent in Tennessee and Kentucky. In fact, most of the Lagrange probably corresponds to the Holly Springs sand,[22] but in many places it differs greatly from the Holly Springs in lithologic characters.

In general, the Lagrange of Tennessee and Kentucky consists of interbedded sands, clays, and lignites, but the lignites are less developed than those in the basal Wilcox of Alabama and Mississippi. The sections in the clay pits differ from place to place. Moreover, owing to the lenticular character of the deposits, careful boring is necessary to accurately determine their extent and content of clay.

TENNESSEE.

DISTRIBUTION AND CHARACTER.

In western Tennessee the Lagrange is the thickest formation present and covers a larger area than any of the others, but it has the fewest surface exposures. (See Pl. XIX, *A*.)

The best clays occur along its eastern outcrop, which extends from the southwestern part of Hardeman County north-northeastward through Chester, Madison, Henderson, Carroll, and Henry counties. (See Pl. X, p. 162.) Along this whole line the Lagrange occurs at no great depth. Plate XVII (p. 226) shows the location of active pits and prospects on this clay in Tennessee.

Nearly everywhere in the foothills the eastern portion of the Lagrange is covered to a slight depth by the terrace gravels (see Pl. XIX, *B*), the loess, or the loam; in the river bottoms it is covered by alluvial deposits.

The Lagrange consists of interbedded sands, clays, and lignitic material. The largest part is sand, generally fine but some of it gravelly. The color of the sand is light yellow or cream, but in places it contains streaks of brown and purple. Lignitic material darkens the sand here and there.

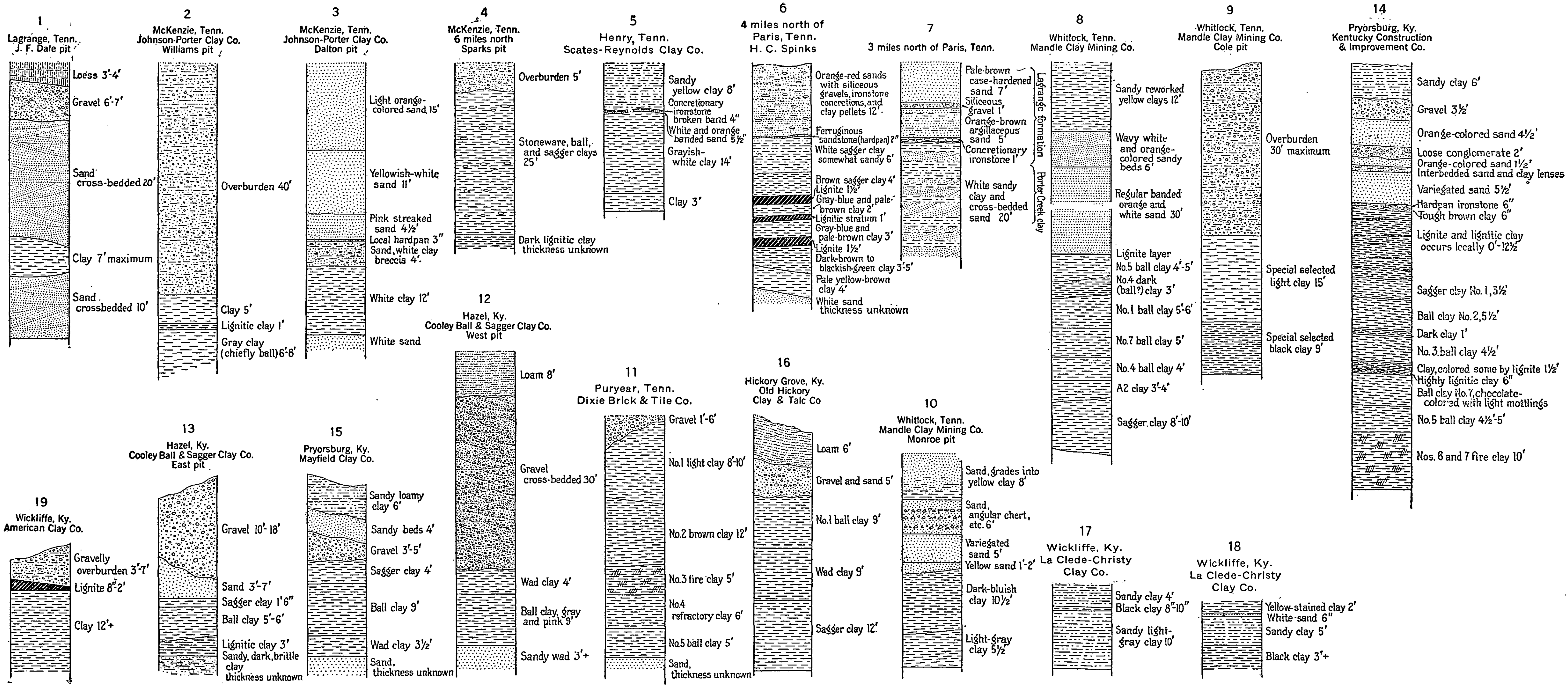
The clays range from a fine grade of ball clay to common brick clay. Some of them are lignitic, and even beds or layers of pure lignite occur. The clay deposits are in the form of lenses, whose central portion may be purer than the edges. These lenses as a rule cover several acres.

Nelson [23] says that in Henry and Carroll counties their longer axes trend several degrees west of north, whereas in Madison and Hardeman counties they extend east of north, and that this statement applies to workable deposits in both the Ripley and Lagrange formations.

The clay is mined chiefly in Henry and Hardeman counties, but there are small pits in Carroll and Madison counties.

[22] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, p. 37, 1916.

[23] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, p. 15, 1911.



COLUMNAR SECTIONS OF LAGRANGE FORMATION OF WESTERN TENNESSEE AND KENTUCKY.

The upper part of the Lagrange formation carries beds of dark lignitic clays, which are penetrated in wells in this region. At Memphis there is 200 feet of blue clay, but it is not known whether the bed is continuous.

One of the best sections of the Wilcox portion of the Lagrange formation is exposed at the town of La Grange, in southeastern Fayette County, where the clay lenses can be seen completely surrounded by sand (Pl. XXI, *B*).

The amount of overburden covering the clays differs in different localities, and in some places as much as 40 feet is stripped off to recover 12 or 15 feet of ball clay. Unless the deposit is extensive and the covering can be cheaply removed this overburden may prevent successful mining.

LOCALITIES.

GENERAL FEATURES OF THE MINES.

A number of the working pits were visited by the writer in the month of June, 1918, in company with W. A. Nelson, State geologist of Tennessee, and the following brief notes were then collected. Some of these pits were in operation in 1911 when the State Geological Survey issued a report on the clays of western Tennessee,[24] but others have been opened since.

These descriptions and the sections given in Plate XX show that the grades of clay mined include ball, sagger, and wad clays, but these terms do not really indicate the variety of uses to which they are put.

The deposits are all lenticular and are covered by 3 to 40 feet of overburden in the pits that are worked. Much of this overburden is cherty gravel. (See Pl. XIX, *B*.)

Few deposits yield only one kind of clay; indeed, three or four different grades are commonly obtained from the same lens.

Most of the clays are massively bedded. The individual beds are commonly differentiated by color, although they may differ in other physical properties such as texture, plasticity, shrinkage, refractoriness, and color-burning qualities.

The thickness of the several grades or beds in a pit may also differ from place to place, the difference being sometimes marked even within a distance of 50 or 100 feet.

The clay is worked by open pits and dug by hand. Steam shovels or other mechanical diggers as a rule are used only to remove the overburden. This overburden consists in most places of terrace

[24] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, 1911. Additional descriptions, including those of many unworked deposits, are given in a later report by R. A. Schraeder in The resources of Tennessee, vol. 9, No. 2, 1919.

gravels or loam but in few places of sand of the Lagrange formation and is commonly thrown on the dump.

The different grades of clay in the deposit are separated in digging and either loaded diıectly on the cars, or, at a few pits, placed in storage bins.

Two companies have constructed narrow-gage branch roads to the railway line, but generally the clay is hauled by teams.

As is but natural, most of the deposits which have been opened are fairly close to the railroad, but as these are worked out others more remote from rail lines will be developed. Indeed, some of those now being worked are 3 to 4 miles from the railway.

Several of the companies operating in Tennessee have been prospecting the territory quite actively so as to be assured of a reserve supply, and the results indicate that there is much good clay still in the ground.

The map (Pl. XVII, p. 226) shows both the worked pits and also the outcrops or prospects noted by the Tennessee Geological Survey and visited in part by the writer.

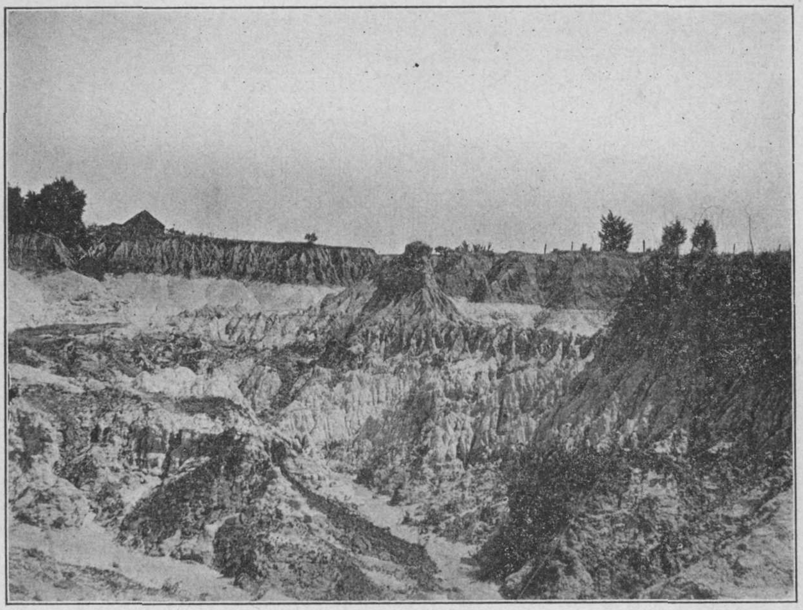
The localities are here described in general from south to north.

LA GRANGE, FAYETTE COUNTY.

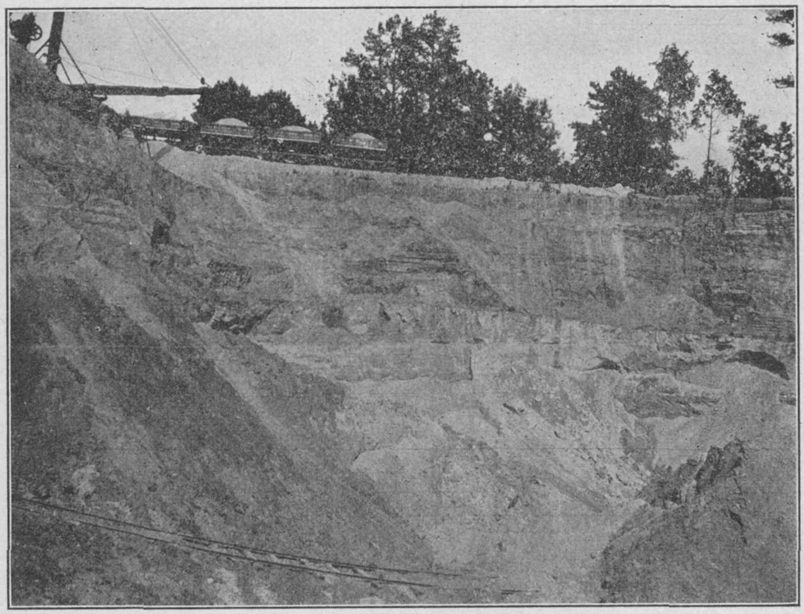
J. F. Dale sand pit.—The pit of J. F. Dale, which is 1 mile south of La Grange, is worked only for sand but is interesting because its section shows the typical occurrence of the clay in lenses surrounded by sand.

In this excavation, which covers 3 to 4 acres, the lens of clay shown in Plate XXI, *B*, has a maximum thickness of 7 feet and tapers out to a knife edge in both directions. Its length as exposed is about 100 feet. A second lens occurs at a lower level on the south side of the pit. The upper surface of the clay lens is sharply defined and has evidently been eroded somewhat, for the basal part of the overlying sand contains clay pellets, the largest of which are 3 inches in diameter. The base is more irregular than the top and is marked by a thin streak of limonite.

This pit shows on a small scale the relationships that exist in most of the clay deposits. The chief difference is that the overburden at most of the clay pits consists of gravel and loam, and not of sand as at this pit. A columnar section at this pit is shown in Plate XX, No. 1. A microscopic examination was made of the clay forming the lens mentioned above, of the sandy clay at the bottom of the lens, and of the sand underlying the clay lens. The results of these determinations are tabulated below.



A. McNANEE CLAY PIT, LAGRANGE, TENN.



B. J. F. DALE SAND PIT, LAGRANGE, TENN.

SAGGER CLAY PIT OF SCATES-REYNOLDS CLAY CO., SOUTH OF HENRY, TENN.

Minerals in clay and sand of Dale pit, La Grange, Tenn.

	1	2	
Texture	Medium to coarse	Coarse	Very coarse.
Quartz	Abundant	Abundant	Very abundant.
Hydromica	Not common	A little	Scarce.
Kaolinite	Abundant	do	Do.
Rutile	Common in small grains.	Common in needles and grains.	Do.
Titanite	A few grains	A few grains	
Tourmaline	Scarce	do	
Zircon	do	Scarce	
Epidote		A few grains	

1. Clay forming main part of lens.
2. Sandy clay at bottom of lens.
3. Sand underlying clay lens.

McNanee pit.—A shallow pit one-fourth of a mile west of La Grange, from which clay was formerly dug by J. Davenport,[25] is known as the McNanee pit. (See Pl. XXI, *A*.)

It is somewhat difficult to give a section representative of the entire pit, as the materials differ widely in different parts of the excavation, but the general sequence is as follows:

Section in McNanee pit, La Grange, Tenn.

	Feet.
Overburden, consisting of loam, underlain by gravel	8–25
White and pinkish clay	6– 8
Layer of limonite	¼
Sand	1– 3
Whitish clay.	

The clay is coarse textured and lies in lenses. It bears laminae of sand, and in this respect it resembles that worked at Holly Springs, Miss. (p. 241), from which it differs in that the sand contains more mica.

On the whole the deposit is similar to the deposits found in the Holly Springs sand of the Wilcox group in Mississippi.

Very little clay is being dug at this pit, and that which is excavated has to be hauled but a short distance to the railroad. The use is not known, but it has been shipped to potteries.

The mineral composition of this clay is somewhat similar to that from the Dale pit, described above. It is medium grained and shows abundant quartz. Hydromica and kaolinite are also abundant, and the hydromica is much more abundant than it is in the clay from the Dale pit. Rutile is present in numerous small grains, and there are a few grains of zircon and chlorite. The clay therefore resembles that from Holly Springs in its mineral composition.

PINSON, MADISON COUNTY.

Light-colored sandy clays of Wilcox age outcrop in this county, but very little use has been made of them except at Pinson, where

[25] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, p. 61, 1911.

pottery was manufactured for some years. The clays in this county probably resemble those from La Grange already described.

M'KENZIE, CARROLL COUNTY.

Johnson-Porter Clay Co.—In 1911 the Johnson-Porter Clay Co. was operating two pits about three-quarters of a mile northeast of Henry, but these have been abandoned, and in the summer of 1918 the company was operating two others, 4½ miles northeast of McKenzie. They were connected by a narrow-gage road with the Nashville, Chattanooga & St. Louis Railway.

The two pits which are known, respectively, as the Williams (Pl. XXIV, *B*) and the Dalton, are about 500 feet apart.

The first pit covers several acres and shows about 40 feet of overburden under which there is from 5 to 12 feet of clay. (See Pl. XX, No. 2.) The three grades of ball clay which are dug, are known as No. 9, a dark-gray clay, chiefly from the lower part of the bed; No. 10, a light grayish-white clay; and No. 11, a pink and brown clay.

Clays Nos. 10 and 11 are more or less mixed in the deposit and have to be separated after digging. The waste is sold for saggers.

Clay No. 10 is a very plastic clay of fine grain, which, under the microscope, shows a few grains of quartz, abundant hydromica, and a little less kaolinite. Aside from these minerals a little rutile and tourmaline was noticed.

Clay No. 11 is also very plastic and fine grained and shows practically the same mineral composition, with the exception of tourmaline, which occurs in amounts so small that it may or may not be present in a sample.

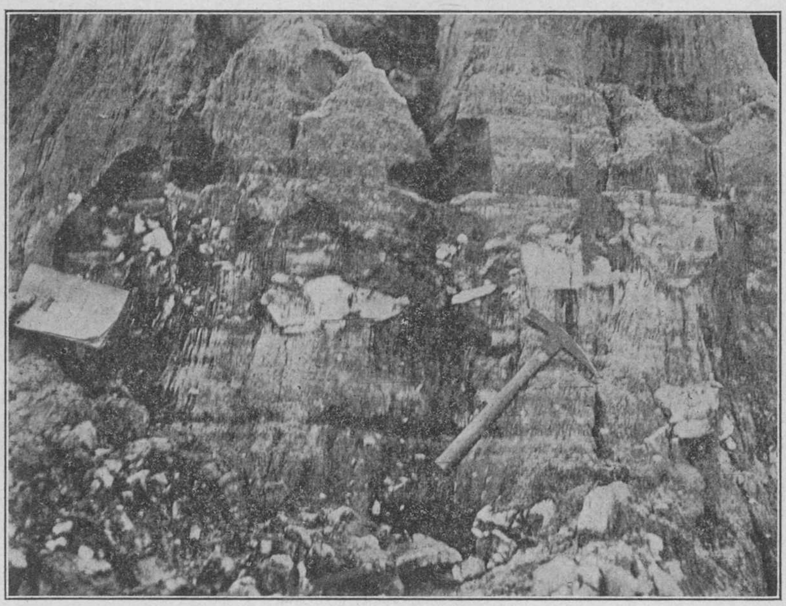
This clay burns cream-white at 1,150° C. and is steel hard. At this temperature it has 10.1 per cent absorption and 25.3 per cent porosity; at 1,300° C. it has but 5.4 per cent absorption and 14.2 per cent porosity.

The clay is dug with pick and shovel, but the overburden is removed by steam shovel.

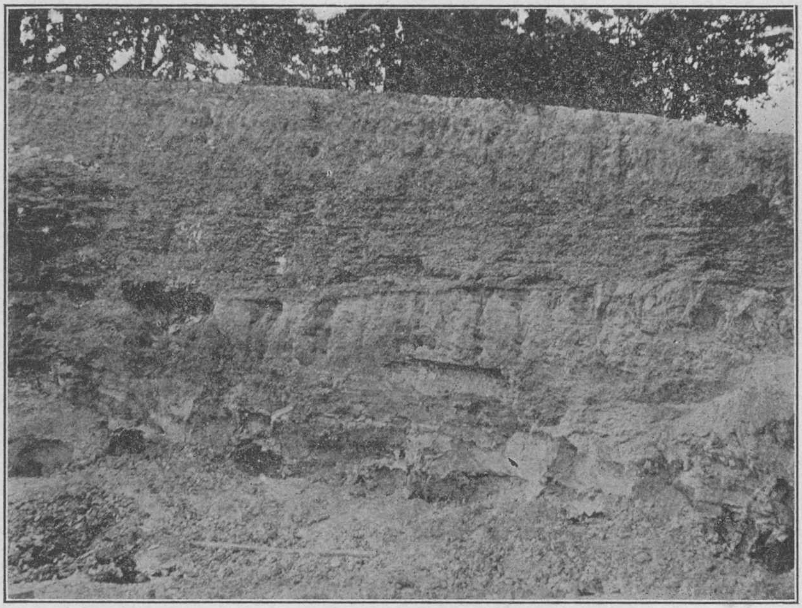
The clays from this pit are used in pottery, electrical porcelain, and grass pots. Some of clay No. 10 is used for steel enamels.

The Dalton pit was opened in 1918. It showed about 36 feet of overburden over about 12 feet of clay. (See Pl. XX, No. 3.) The upper part of the clay is open textured and sandy and ranges from a thin film to 2 feet in thickness. The lower part is a ball clay similar to clay No. 10. It is claimed that clay No. 10 can be used as a substitute for the Vallendar clay if washed. White sand underlies the clay. Plate XXIII, *A*, shows the contact of the clay and the overlying sand, which contains lumps of the clay that were evidently loosened by erosion.

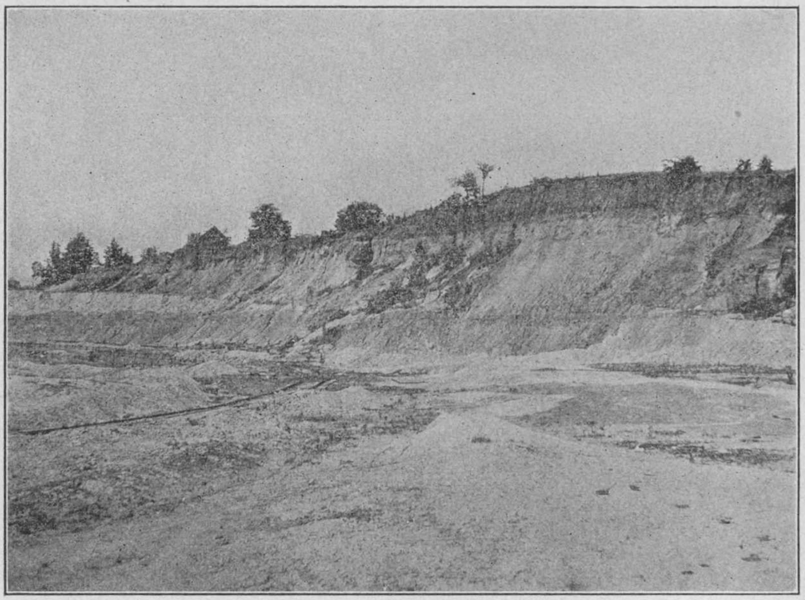
The following tests of the Johnson-Porter ball clays Nos. 9 and 11 were supplied by the Tennessee Geological Survey:



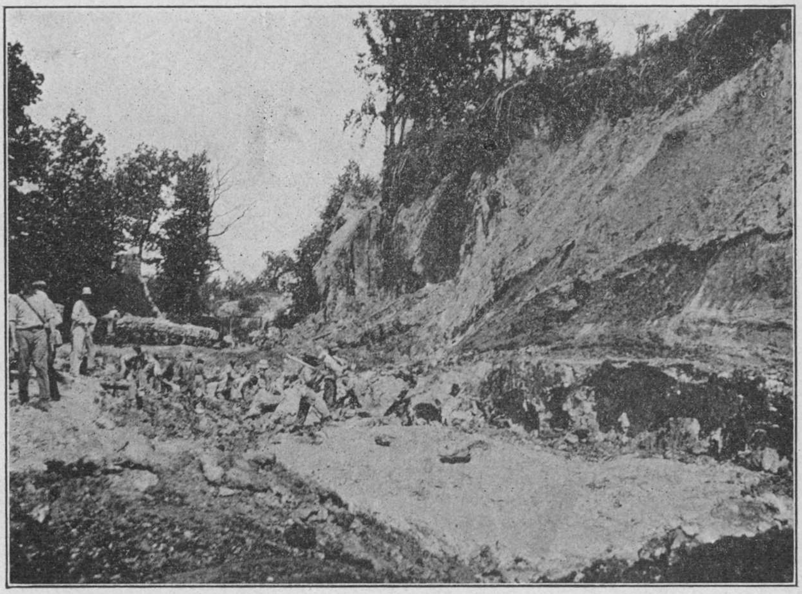
A. NEAR VIEW OF FACE IN DALTON PIT OF JOHNSON-PORTER CLAY CO., NEAR McKENZIE, TENN.



B. VIEW IN PIT OF COOLEY BALL & SAGGER CLAY CO., IN HENRY COUNTY, TENN., 8 MILES NORTHWEST OF PURYEAR.



A. PIT OF MANDLE CLAY MINING CO., WHITLOCK, TENN.



B. WILLIAMS PIT OF JOHNSON-PORTER CLAY CO., NEAR McKENZIE, TENN.

General physical tests of Tennessee ball clay No. 9.

Working property		Very sticky.
Water of plasticity	per cent	35.5
Modulus of rupture:		
Unburned clay	pounds per square inch	240
Mixture of clay and sand in proportion of 1:1	do	138.9
Slaking test	minutes	12
Fineness test:		
Residue, 20-mesh sieve		None.
Residue, 40-mesh sieve		None.
Residue, 60-mesh sieve		None.
Residue, 80-mesh sieve		None.
Residue, 120-mesh sieve (white sand)	per cent	0.08
Residue, 200-mesh sieve (white sand)	do	.67
Drying shrinkage, linear	do	8.82
Drying conduct		Poor.

Fire tests of Tennessee ball clay No. 9.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Dark tan	Steel hard	6.0	0.78
Cone 5 (1,230° C.)		do	16.2	
Cone 9 (1,310° C.)	Light brown	do	13.3	1.8
Cone 12 (1,370° C.)	do	do	11.7	6.2
Cone 13 (1,390° C.)	do	do	13.0	15.0

Fusion test: Deformed at cones 32–33 (1,770°–1,790° C.).

The color of the clay when fired is dark, and hence it is not ranked with the best ball clays. It is strong and refractory and will serve for purposes where a plastic refractory clay is required as a bond clay. It may be used in the manufacture of chemical and other stoneware, face brick, and saggers, and possibly in the manufacture of abrasives. The clay will have to be burned carefully because of the apparent tendency to overburn at cone 13 (1,390° C.).

General physical tests of Tennessee ball clay No. 11.

Working property		Good; sticky.
Water of plasticity	per cent	42.5
Modulus of rupture:		
Raw clay	pounds per square inch	95.3
Mixture of clay and sand in proportion of 1:1	do	118.6
Slaking test	minutes	9
Fineness test:		
Residue, 20-mesh sieve		None.
Residue, 40-mesh sieve		None.
Residue, 60-mesh sieve		None.
Residue, 80-mesh sieve		None.
Residue, 120-mesh sieve		Trace.
Residue, 150-mesh sieve		Trace.
Residue, 200-mesh sieve		Trace.
Drying shrinkage, linear	per cent	5.75

Fire tests of Tennessee ball clay No. 11.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent)
Cone 2 (1,170° C.)	White	Steel hard	21.5	21.15
Cone 5 (1,230° C.)	do	do	16.3	19.6
Cone 9 (1,310° C.)	Gray-white	do	17.2	17.7
Cone 12 (1,370° C.)	Gray	do	17.8	2.2
Cone 13 (1,390° C.)		do	17.5	3.4

Fusion test: Deformed at cones 32–33 (1,770°–1,790° C.).

The strength of this clay appears to be rather low. The color is very good and it is fairly well vitrified at cone 9 (1,310° C.). It is fairly representative of the ball-clay type and will find use as a ball clay. It will also be useful in the manufacture of sanitary ware, chemical and other stoneware, face brick, terra cotta, and saggers. Its rather high fusion point is likely to make it of service in the manufacture of refractories, where a plastic clay of good strength is desired.

C. S. Sparks pit.—A small pit, known as the C. S. Sparks pit, lies 6 miles north of McKenzie on the east side of the road to Henry. (See Pl. XX, No. 4.) It has been opened in a slope, so that the overburden increases to the west.

About 2 acres of clay have been proved by boring, and the lens may not be very extensive. The sandy overburden on the property ranges from 1 to 15 feet.

Although the clay in the face is somewhat uniform in appearance it nevertheless differs a little in its character. The clay from the main part of the bed is sold as sagger clay, whereas that from the lower part is a low-grade ball clay.

The ball clay is medium to fine grained, gray, and of uniform texture. It contains some fine grit or grains of quartz. The microscopic examination shows that hydromica and kaolinite are equally abundant. Tiny grains of rutile are also rather numerous. Tourmaline and epidote are present in very small amounts. The clay burns to a cream color.

Some of the output is sent to the Sparks stoneware factory at McKenzie.

The pit is operated by Chrisman & Reynolds, of Henry, and the clay has to be hauled there for shipment.

The following tests of the Sparks clay were supplied by the Tennessee Geological Survey:

General physical tests of clay from the Sparks pit, near McKenzie, Tenn.

Working property	Good.
Water of plasticity ... per cent	31.8
Modulus of rupture:	
Raw clay ... pounds per square inch	101.2
Mixture of clay and sand in proportion of 1 : 1 ... do	108
Slaking test ... minutes	5
Fineness tests:	
Residue, 40-mesh sieve	None.
Residue, 60-mesh sieve	None.
Residue, 80-mesh sieve	None.
Residue, 120-mesh sieve (white sand)	Trace.
Residue, 150-mesh sieve (white sand)	Trace.
Residue, 200-mesh sieve (white sand)	Trace.
Drying shrinkage, linear ... per cent	5.2

General physical tests of clay from the Sparks pit, near McKenzie, Tenn.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Cream	Steel hard	11.2	2.1
Cone 5 (1,230° C)	Tan	do	12.1	2.1
Cone 9 (1,310° C.)	Gray	do	14.3	1.6
Cone 12 (1,370° C.)	do	do	14.0	1.5
Cone 13 (1,390° C.)		do	11.9	4.5

Fusion test: Deformed at cone 28 (1,690° C.).

The color of the burned sample is not quite satisfactory, possibly because of reducing conditions in the kiln, and it seems doubtful that the clay will be available in the manufacture of white wares because of its evidently high content of iron. The strength of the clay is fair. It fuses at too low a temperature to permit its use in the manufacture of refractories which are to withstand high temperatures. It is likely that this clay will be more serviceable in the manufacture of chemical and other stoneware, face brick, and terra cotta.

HENRY, HENRY COUNTY.

Several pits are in operation at this locality as shown on the map (Pl. XVII, p. 226), but the largest is that known as the Breedlove pit, 1½ miles south of Henry, which is operated by the Scates-Reynolds Clay Co. (Pl. XXII).

This opening is a large shallow pit about 400 feet in diameter, the section of which is shown in Plate XX (No. 5).

The clay lens, according to Nelson,[26] is about 500 by 1,200 feet in area, and its longer axis extends N. 30° W.

[26] Nelson, W. A., Clay deposits of west Tennessee: Tennessee Geol. Survey Bull. 5, p. 87, 1911.

Some of the clay is fine grained in places, but most of it shows thin laminae of sand.

The overburden, which is in part sand of Wilcox age and in part of later age, is not utilized.

The clay possesses good plasticity but is not so fat as the ball clays and contains much fine grit.

Under the microscope it appears to be of medium grain. Quartz and hydromica are abundant, and kaolinite is common. Tiny grains of rutile are numerous, and a few crystals of tourmaline and zircon were noted.

The clay when fired to 1,300° C. is light buff and steel hard. Its absorption is 4.9 per cent and its porosity 11.9 per cent. A section of the clay burned to this temperature showed numerous grains of quartz, but no traces of hydromica remained, the groundmass being in part isotropic and in part composed of grains that showed low interference colors.

The following tests of this clay were supplied by the Tennessee Geological Survey:

Tests of Scates-Reynolds sagger clay from Henry, Tenn.

Working property		Good.
Water of plasticity	per cent	27.2
Modulus of rupture:		
Unburned clay	pounds per square inch	69.3
Mixture of clay and sand in proportion of 1:1	do	112
Slaking time	minutes	8
Fineness test:		
Residue, 20-mesh sieve		None.
Residue, 40-mesh sieve		None.
Residue, 60-mesh sieve		None.
Residue, 80-mesh sieve		None.
Residue, 120-mesh sieve		None.
Residue, 150-mesh sieve		None.
Residue, 200-mesh sieve		None.
Drying shrinkage, linear	per cent	5.6

Fire tests of Scates-Reynolds sagger clay from Henry, Tenn.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Light cream	Steel hard		24.8
Cone 5 (1,230° C.)	do	do	10.3	25.3
Cone 9 (1,310° C.)	do	do	13.2	8.8
Cone 12 (1,370° C.)	Light gray		10.0	5.5

Fusion test: Deforms at cone 28 (1,690° C.).

The clay has good color when burned, and shows fair vitrification at cone 9 (1,310° C.). The strength of the unburned clay is low, and it is not sufficiently refractory to be regarded as a plastic refractory bond clay. It is likely to be of service in the manufacture of sanitary ware, chemical stoneware, stoneware, face brick, and saggers.

All the clay dug here is sold for saggers.

The clay has to be hauled 1½ miles to Henry station on the Louisville & Nashville Railroad.

The section shown in Plate XX (No. 6) is exposed at the Hilltop mine or the McClure pit of the H. C. Spinks Clay Co. The section shown in Plate XX (No. 7) is exposed at a point 3 miles north of Paris, Tenn., and is interesting as showing the occurrence of the Lagrange formation at a point where there are no thick beds of clay in it.

WHITLOCK, HENRY COUNTY.

Pits of Mandle Clay Mining Co.—A number of pits are clustered around Whitlock, but the largest are those operated by the Mandle Clay Mining Co., of St. Louis, Mo.

The principal pit, No. 4, is 4½ miles northwest of Whitlock, on the Nashville, Chattanooga & St. Louis Railway, and one-half mile northeast of the Spring Hill road. It covers about 20 acres and is connected with the main line by a narrow-gage steam road.

A long north-south face (Pl. XXIV, *A*), in which the clay thins out in both directions, is exposed in the pit.

At the north end of the pit there is an east-west face about 350 feet long, where clay was being dug in 1918.

As shown in the section (Pl. XX, No. 8) the overburden has a maximum thickness of about 50 feet. A number of different grades of clay occur, the thickness and types of which are given in the section as well as the special letter or mark by which each is designated.

The following notes indicate in a little more detail the character of some of the beds.

Tennessee ball clay No. 5: Utilized in manufacture of white ware, electrical porcelain, and glass pots.

Tennessee ball clay No. 4, dark: This clay is used in saggers, but the better selected portions of it are sold to the glass-pot trade.

Tennessee ball clay No. 1, known as S. G. P.: This layer is absent in the central part of the deposit. It is used in making floor and wall tile, white ware, and electrical porcelain.

Tennessee ball clay No. 7, known as W. W. C.: This clay has similar uses to No. 1 but is said to burn a little denser.

Tennessee ball clay A2: Selected material of this type is used for stilson pins and other wares, and some of it is used in the bond of abrasive wheels.

Sagger clay: This clay is siliceous, short, and hard clay. The bed ranges in thickness from 6 to 20 feet in different parts of the deposit, but the entire thickness is not invariably used for saggers. The greatest thickness is found in the south end of the pit.

The mineral composition of these grades of clay is given in the following table:

Mineral composition of Mandle clays from pit No. 4, near Whitlock, Tenn.

	No. 1 S. G. P.	No. 5 ball clay.	No. 7 ball clay.	No. 4 white ball clay.	No. 4 dark ball clay.
Texture	Fine grained	Medium grained	Medium grained	Medium to fine grained.	Very fine grained.
Quartz	Very fine	Very little	Very little	Very little	Very little.
Hydromica	Abundant, coagulated.	Abundant, stained.	Abundant	Abundant, coagulated.	Abundant, coagulated, very fine.
Kaolinite	Common	Common	Common	Common	Common.
Rutile	Fairly numerous, very minute needles.	Scarce	Very few, small	Abundant, tiny grains.	Scarce.
Tourmaline	One or two crystals.	....	....	One or two crystals.	

All these samples run low in quartz and high in hydromica and carry kaolinite in lesser amounts. Rutile is abundant only in No. 1.

The Cole pit is about 2 miles north of Whitlock and three-fourths of a mile west of the Nashville, Chattanooga & St. Louis Railway. It covers about 15 acres, and additional ground is leased but undeveloped.

This pit supplies but two grades of clay (Pl. XX, No. 9), known respectively as light and black selected, tests of which are given on page 271.

The clays from this pit are utilized in making glass pots and electrical porcelain, but some of the material is sold as wad clay.

An old pit, known as the Scott or Monroe pit, which was also worked formerly by the Mandle-Sant Clay Co. is 2 miles north of Whitlock, on the west side of the Nashville, Chattanooga & St. Louis Railway. The pit covered between 2 and 3 acres. The overburden was 12 to 20 feet thick and the sides of the excavation show as much as 20 feet of clay in places.

The new pit, which is not very large, is 4½ miles north of Whitlock and 1 mile west of the Nashville, Chattanooga & St. Louis Railway. The section in this pit is shown in Plate XX (No. 10).

The upper dark-bluish clay is gritty and rough textured. It weathers to a much lighter color, but the lower light-gray clay has a finer texture.

Some glass-pot and crucible clay is obtained from this pit, but the inferior siliceous grades are sold for sagger and wad clays.

The various clays produced in the Mandle pits, around Whitlock, may obviously be used in a number of different kinds of work. In general these clays are used in mixtures for white ware, glass pots, and crucibles, and in the bond of abrasive wheels and saggers.

The tests given in the following table were supplied by the company:

Chemical analyses of Mandle clays from Whitlock, Tenn.

	Tennessee ball clay No. 5.	Tennessee ball clay No. 5.	Tennessee ball clay No. 4, dark.	Tennessee ball clay No. 1, S.G.P.	Tennessee ball clay No. 7, W.W.C.	Barbee special.	Tennessee ball clay No. 3.	Tennessee ball clay No. 6.	Special selected black clay.	Special selected light clay.
Silica	46.85	44.85	44.50	53.13	47.26	63.54	48.50	51.57	65.43	64.30
Alumina	33.15	33.15	35.43	32.82	35.85	24.42	32.57	30.40	22.65	24.60
Ferric oxide	2.04	2.04	3.25	1.31	1.01	1.22	2.26	2.10	2.00	1.56
Lime	.35	.30	.34	.82	.58	.60	.60	.60	.50	.43
Magnesia	.40	.42	.42	.38	.68	.63	.63	1.25	.70	.55
Potash	.61	.66	.62	.59	.74	1.00	.98	.68	.55	.42
Soda	.10	.10	.10	.21	.45	.15	.14	.14	.14	.10
Sulphur	.03	.03	.04	.02	.00	.06	.15	.10	.03	.04
Ignition	16.45	18.45	15.30	10.92	13.43	8.38	14.16	13.16	8.00	8.00
	99.98	100.00	100.00	100.00	100.00	100.00	99.99	100.00	100.00	100.00
Mineral composition:										
Clay substance	94.03	....	93.05	90.01	93.04	62.94	89.04	....	49.67	50.47
Silica	4.65	....	5.70	9.01	6.17	34.36	9.64	....	45.79	45.00
Feldspar	1.32	....	1.25	.98	.79	2.70	1.32	....	4.54	4.53

Physical tests of Mandle clays from Whitlock, Tenn.

	Porosity (per cent).								
	No. 5 ball clay.	No. 4 ball clay.	No. 1 ball S. G. P. clay.	No. 7 ball W. W. C. clay.	Barbee special clay.	No. 3 ball clay.	No. 6 ball clay.	Special selected black clay.	Special selected light clay.
Fired to a temperature (° C.):									
1,050	38.00	42.80	....	....	33.86	40.65	....	38.60	34.89
1,075	35.15	41.85	....	....	32.55	38.60	....	36.10	35.46
1,100	17.98	38.75	....	....	29.84	35.50	....	35.07	31.32
1,125	13.80	36.00	....	....	27.88	18.65	....	32.08	30.55
1,150	13.32	18.83	....	....	24.67	14.05	....	29.95	25.76
1,175	8.53	14.65	....	....	22.30	13.74	....	27.40	23.99
1,200	2.94	14.17	....	....	20.13	8.62	....	27.04	22.25
1,230	.03	9.38	....	....	19.07	1.79	....	23.18	19.71
1,260	.06	3.79	....	....	18.10	.40	....	22.12	18.28
1,290	.15	.33	....	....	17.92	.35	....	21.22	16.67
1,320	.69	.32	....	....	15.09	.20	....	18.60	13.94
1,350	.60	1.52	....	....	10.72	.45	....	....	11.93
1,375	.46	1.61	....	....	4.92	.60	0.35	17.59	8.81
1,400	.02	1.45	....	....	3.10	.81	....	16.93	4.95
1,425	.64	1.31	....	....	1.25	.76	....	6.39	1.04
1,450	.86	.82	....	....	17.40	.97	....	1.11	.74
1,475	.52	1.49	....	....	17.72	1.04	....	.66	.65
1,500	1.05	5.27	....	....	22.21	4.53	....	12.60	6.55
Cone of fusion	33½	35½	32	33	30	33	34½	31	31
Cone of vitrification	2¼	2¼	5	6	....	3½	....	....	....
Modulus of rupture (pounds to the square inch)	466	344	303	279	407	380	360	466	285
Slacking of ½-inch cube (minutes)	14	12½	12.6	14	12	14	12½	12½	8.6
Water of plasticity	42.9	42.9	44	45	29.02	43	40	30.75	30.27
Linear shrinkage	5.57	5.57	5.5	5.5	5.48	5.55	5.5	5.93	5.46
Maximum fire shrinkage	14.57	14.57	12.0	11.58	4.82	13.5	13.5	4.63	4.74

PURYEAR, HENRY COUNTY.

Property of Dixie Brick & Tile Co.—The Dixie Brick & Tile Co. has a pit one-fourth of a mile south of Puryear, on the west side of the Nashville, Chattanooga & St. Louis Railway. The section exposed at the time of the writer's visit is that shown in Plate XX (No. 11).

The overburden is somewhat irregular, and though the terrace gravel that caps the clay averages 6 feet in thickness, it becomes thinner where the bed of No. 1 light clay and some of the overlying sands rise. The upper limit of the sands in places is 8 feet higher than the base of the gravel at other places. There is also in places a bed of sandstone 1 foot thick between the gravel and the clay. At present the pit does not expose the full thickness of the clay. Beds 2, 3, and 4 are all low in ferric oxide.

The pit at present is being worked for brick clay, although some of the material is graded as ball clay.

Nelson in 1911 estimated that the lens underlies 5 or 6 acres. The deposit at that time was worked by the Mandle-Sant Clay Co., and the product was shipped as ball and sagger clay.

The two following analyses made by K. Langenbeck were supplied by the company:

Analyses of clay from Puryear, Tenn.

	1	2
Combined silica	68.29	59.83
Free silica	.19	0
Alumina	22.99	27.80
Ferric oxide	1.43	.83
Lime	.40	.15
Magnesia	.42	.24
Alkalies	.22	.82
Loss on ignition	6.42	10.42
	100.36	100.09

The upper part of the section in the pit shows a laminated clay, which although of good plasticity contains considerable fine grit. It burns to a buff color and is steel hard at 1,150° C. At this temperature its absorption is 19.0 per cent and its porosity 28 per cent, whereas at 1,300° C. its absorption is only 7.2 per cent and its porosity 16.3 per cent.

This clay contains a large number of minerals as compared with the other clays examined. Quartz and hydromica are common, kaolinite is very abundant, and a few grains of tourmaline, titanite, rutile, and zircon were noted.

Property of Cooley Ball & Sagger Clay Co.—The Cooley Ball & Sagger Clay Co., whose office is at Hazel, Ky., has three pits in operation in Henry County, Tenn., just south of the Kentucky boundary and about 8 miles northwest of Puryear. These pits are known as Nos. 9, 10, and 11.

Pit No. 9 is 5½ miles a little south of west from Hazel, Ky. The overburden in the pit is about 17 feet thick and under it lies 7 to 14 feet of ball clay, which in turn is underlain by 2 feet of sagger clay.[27]

C. W. Parmelee, who tested the clay, says of it:[28]

This clay burns to a good color, has good strength in the unburned state, and is quite refractory. It is rather open burning at cone 9 and is a typical ball clay. It is suggested that it may be useful for the many purposes for which ball clay is used and also in the manufacture of special refractories, chemical stoneware, terra cotta, face brick, abrasives, and saggers.

Pits Nos. 10 and 11 are about half a mile south of pit No. 9 and are about 600 feet from each other on the west and east sides of a hill. Detailed sections are shown in Plate XX (Nos. 12 and 13), and a view of the pits is shown in Plate XXIII, *B*.

The two openings are so close together that they may represent different sections of the same deposit and therefore show the amount of variation that may occur from place to place in the same clay mass. In both pits the overburden, already heavy, will increase greatly if the two pits are worked toward the crest of the hill.

Pit No. 11 supplies two grades of ball clay, both from the same bed, the upper part of which is known as light ball and the lower part as dark ball. The following tests of the light ball clay, made by C. W. Parmelee, were supplied by the Tennessee Geological Survey:

General physical tests of light ball clay from pit No. 11, 8 miles northwest of Puryear, Tenn.

Working property	Good.
Water of plasticity ……per cent	41
Modulus of rupture:	
Raw clay ……pounds per square inch	167.3
Mixture of clay in proportion of 1:1 ……do	61.4
Slaking test ……minutes	8
Fineness test:	
Residue, 20-mesh sieve	None.
Residue, 60-mesh sieve	None.
Residue, 80-mesh sieve	None.
Residue, 120-mesh sieve	None.
Residue, 200-mesh sieve (white sand) ……per cent	0.09
Drying shrinkage, linear ……do	7.5

Fire tests of light ball clay from pit No. 11, 8 miles northwest of Puryear, Tenn.

	Color.	Hardness.	Shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Gray-white	Steel hard	11.4	28.9
Cone 5 (1,230° C.)	do	do	15.7	19.2
Cone 9 (1,310° C.)	do	do	16.3	11.1
Cone 12 (1,370° C.)	do	do	17.5	.86

Fusion test: Deforms at cone 33 (1,790° C.).

[27] Schroeder, R. A., Ball clays of Tennessee: The resources of Tennessee, vol. 9, No. 2, p. 125, 1919.

[28] Idem, pp. 125–126.

This clay burns to a good color, has good strength in the unburned state, and is quite refractory. It is rather open burning at cone 9. It is suggested that it will be useful for the many purposes to which ball clay is put, and also for the manufacture of special refractories, terra cotta, chemical stoneware, face brick, abrasives, and saggers.

A sample of the dark ball clay, when examined under the microscope, showed some grains of quartz. Hydromica was abundant and somewhat coagulated. Kaolinite was common. Rutile was present in numerous tiny grains and needles, and a few grains of zircon and chlorite were noted.

The following tests of the dark ball clay, made by C. W. Parmelee, were supplied by the Tennessee Geological Survey:

General physical tests of dark ball clay from pit No. 11, near Puryear, Tenn.

Working property	Good, slightly sticky.
Water of plasticity .... per cent	41.8
Modulus of rupture:	
Raw clay .... pounds per square inch	199
Mixture of clay and sand in the proportion 1:1 .... do	232
Slaking test .... minutes	7
Fineness test:	
Residue, 20-mesh sieve	None.
Residue, 40-mesh sieve	None.
Residue, 60-mesh sieve	Trace.
Residue, 80-mesh sieve	Trace.
Residue, 120-mesh sieve (chiefly white sand) .... per cent	0.03
Residue, 200-mesh sieve .... do	.11
Drying shrinkage, linear .... do	6.3

Fire tests of dark ball clay from pit No. 11, 8 miles northwest of Puryear, Tenn.

	Color.	Hardness.	Shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Gray-white	Steel hard	10.3	33.7
Cone 5 (1,230° C.)	do	do	14.1	18.5
Cone 9 (1,310° C.)	do	do	14.7	16.0
Cone 12 (1,370° C.)	do	do	16.6	4.0

Fusion test: Deforms at cone 32 (1,770° C.).

The clay burns to a good color and has good strength in the unburned state. It burns rather open at cone 9 (1,310° C.), has good refractoriness, and will be useful for the many purposes to which ball clay is put. It may be used in the manufacture of special refractories, chemical stoneware, terra cotta, face brick, abrasives, and saggers.

The clay mined in pit No. 10 is regarded as somewhat inferior to that obtained from the other two pits. Both ball and wad clay are dug.

The following tests of the ball clay, made by C. W. Parmelee, were supplied by the Tennessee Geological Survey:

General physical tests of ball clay from pit No. 10, 8 miles northwest of Puryear, Tenn.

Working property		Good.
Water of plasticity	per cent	35
Modulus of rupture:		
Raw clay	pounds per square inch	225
Mixture of clay and sand in proportion 1:1	do	164.6
Slaking test	minutes	7
Fineness test:		
Residue, 20-mesh sieve		None.
Residue, 60-mesh sieve		None.
Residue, 80-mesh sieve		None.
Residue, 120-mesh sieve (white sand)	per cent	0.01
Residue, 200-mesh sieve (white sand)	do	.04
Drying shrinkage, linear	do	5.7

Fire tests of ball clay from pit No. 10, 8 miles northwest of Puryear, Tenn.

	Color.	Hardness.	Total shrinkage (per cent).	Porosity (per cent).
Cone 2 (1,170° C.)	Gray-white	Steel hard	11.0	25.4
Cone 5 (1,230° C.)	do	do	12.6	10.4
Cone 9 (1,310° C.)	do	do	13.1	2.2
Cone 12 (1,370° C.)	do	do	14.0	.26

Fusion test: Deforms at cone 31 (1,750° C.).

This clay burns to a good color and has good strength in the unburned state. It has a good degree of vitrification at cone 9 (1,310° C.) and is refractory. It may be used as a ball clay or in the manufacture of special refractories, chemical stoneware, terra cotta, face brick, abrasives, and saggers.

The wad clay is grittier and burns more open than the ball clay. A sample of it, when examined under the microscope, showed that grains of quartz and scales of hydromica were fairly common and kaolinite was abundant. Rutile was common in tiny grains and needles, and there were also a few grains of tourmaline.

At 1,150° C. the clay showed 28.5 per cent porosity and was cream-white. After firing at 1,300° C. it had 14.8 per cent porosity and was light buff.

USES OF LAGRANGE CLAYS OF TENNESSEE.

The clays of the Lagrange formation in Tennessee are used for many purposes, as indicated in the foregoing descriptions.

In general, the clays may be subdivided into ball clays, refractory bond clays, sagger clays, and wad clays, although the ball clay is really a high-grade subtype of the refractory bond clay.

More specifically, the first two grades are used in mixtures for different grades of table and toilet ware, sanitary ware, wet and dry pressed electrical porcelain, art pottery, smoking pipes, glass pots, and graphite crucibles, abrasive wheels, and enamels.

The ball clays have been and are being used successfully as substitutes for the English clays, but care should invariably be taken to see that the shipments run uniform, as neglect to do so has sometimes caused dissatisfaction.

All the clay is shipped crude.

None of the clay miners report the use of their clay in the unburned form, as for paper, paint, etc.

The production of ball clay in Tennessee for the period 1915–1918 was as follows:

Ball clays marketed in Tennessee, 1915–1918.

Year.	Short tons.	Value.
1915	27,257	$78,497
1916	33,230	110,756
1917	40,282	166,589
1918 [a]	33,000	200,000

[a] Estimated.

KENTUCKY.

OCCURRENCE AND DISTRIBUTION.

The eastern border of the Lagrange formation (see p. 259) in Kentucky passes through southwestern Calloway, northeastern Graves, middle McCracken, and northern Ballard counties. It then swings westward into Pulaski County, Ill., not far south of Caledonia Landing, but can not be traced westward across Pulaski and Alexander counties because of the covering of later deposits.

The deposits of ball clay in Henry County, Tenn., extend beyond the State line into Kentucky.

The number of developed localities is not so great as in Tennessee, nor have the clays been studied in great detail. It seems probable, however, that the Lagrange formation will continue to furnish clay of good quality. The largest pits are those at Pryorsburg, south of Mayfield, but several firms are operating in the area west of Hickory and north of Mayfield.

PRYORSBURG, GRAVES COUNTY.

In the summer of 1918 two companies were operating at Pryorsburg, the Kentucky Construction & Improvement Co., and the Mayfield Clay Co., but the Mayfield Clay Co. has not operated steadily since that time.

Property of Kentucky Construction & Improvement Co.—The Kentucky Construction & Improvement Co., whose main office is in Mayfield, Ky., has been in operation for some years and has rather extensive pits on the east side of the Illinois Central Railroad near Pryorsburg station. The deposits are said to underlie about 50 acres.

The clay lens, which is evidently large, appears to trend in a direction N. 20° W., and its upper surface, within the limits of the excavation, is fairly level. The overburden, because of surface irregularities, ranges from 36 to 60 feet.

The section, measured in 1918, as shown in Plate XX, No. 14, is quite varied; indeed it probably exhibits a greater number of beds than any other section measured in Kentucky or Tennessee.

These different beds, exclusive of the overburden, have a total thickness of about 37 feet. Immediately under the overburden at the north end of the pit occurs a lens of lignite, which is 12½ feet thick in the center, and tapers out to a thin edge in both directions. It is mostly fine grained and shows comparatively few woody fragments.

The sagger clay, which is light gray and has a dark seam in the center, seems to be missing in the old pit.

The No. 3 ball clay corresponds to No. 4 of the old mine, where it lay directly below the lignite. This clay is used in the manufacture of crucibles, tiles, and white ware. It is also said to have been employed as an ingredient of steel enamels.

The following tests of this clay were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay No. 3, Kentucky Construction & Improvement Co., Pryorsburg, Ky.

Workability	Very plastic, sticky; pulls under spatula.	
Water of plasticity	per cent	41.72
Air shrinkage, by volume	do	31.92
Air shrinkage, linear, calculated	do	12.00
Modulus of rupture:		
Raw clay	pounds per square inch	25.55
Mixture of clay and sand in proportion 1:1	do	196.30

Fire tests of clay No. 3, Kentucky Construction & Improvement Co., Pryorsburg, Ky.

Temperature (°C.).	Porosity (per cent).	Color.	Volumetric shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	16.70	Cream-colored	32.00	12.00
1,250	16.79	do	29.89	11.20
1,310	1.59	do	37.52	14.50
1,370	.90	Brown-buff	40.00	15.60
1,410	.30	do	38.00	14.70

Fuses at cone 32+ (1,770° C.+). Steel hard at 1,190° C. At 1,310° C. the clay shows small yellowish specks.

This clay shows only moderate bonding strength. It fires to a dense body at 1,310° C., and the color is fair but not equal to that of the best ball clay. It can be used as an ingredient of pottery, tile, and other bodies where this type of clay is desired.

The following tests of clay No. 5 were made in the laboratory of the Bureau of Mines at Columbus, Ohio:

General physical tests of clay No. 5, Kentucky Construction & Improvement Co., Pryorsburg, Ky.

Workability	Plastic, tough; molds well; warped in drying.	
Water of plasticity	per cent	34.47
Air shrinkage, by volume	do	26.34
Air shrinkage, linear, calculated	do	5.82
Modulus of rupture:		
Raw clay	pounds per square inch	189.1
Mixture of clay and sand in proportion 1:1	do	167.5
Fineness test:		
Residue on 150-mesh sieve	per cent	1.27

Fire tests of clay No. 5, Kentucky Construction & Improvement Co., Pryorsburg, Ky.

Temperature (°C.).	Porosity (per cent).	Color.	Volumetric shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	18.33	Cream-white	28.30	10.4
1,250	18.33	do	29.64	11.0
1,310	10.84	do	33.41	12.7
1,370	.60	Buff	38.20	14.8
1,410	.40	do	37.50	14.5

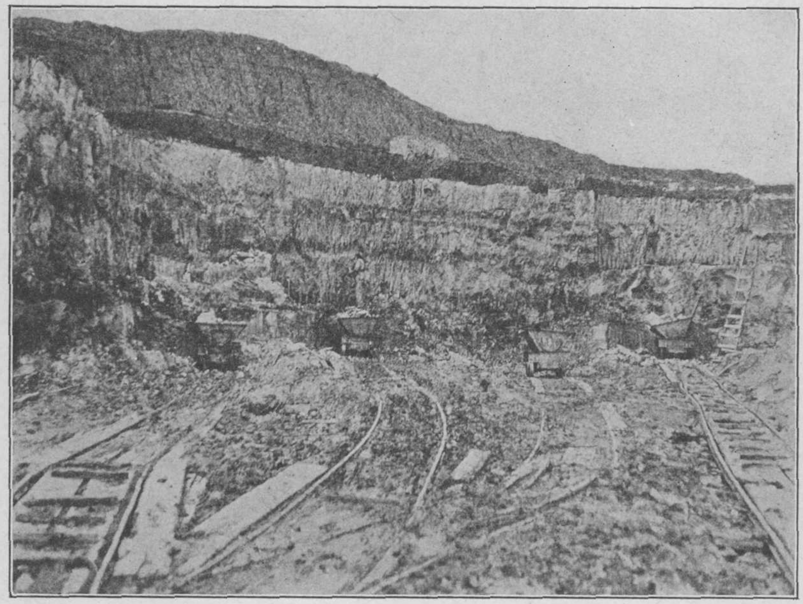
Fusion point, cone 31 (1,750° C.). Steel hard at 1,190° C.

This clay shows moderate bonding strength and fair refractoriness. It fires to a dense body of creamy-white color at 1,370° C. If mixed with other clays it could be employed in pottery and tile bodies, abrasives, sanitary ware, chemical stoneware, and similar products.

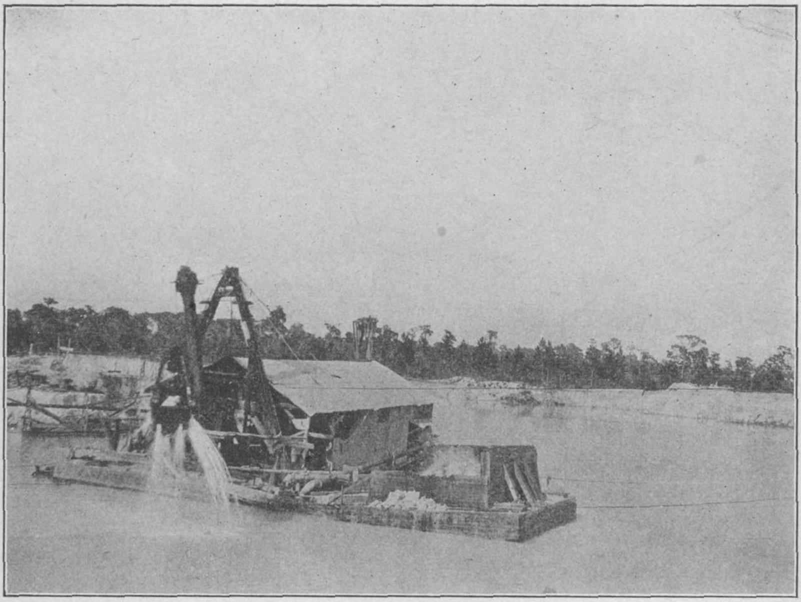
The highly lignitic clay between the No. 3 clay and the next lower ball clay is thrown out.

Ball clay No. 7 is chocolate-colored above and lighter below. The whole bed shows somewhat bright colorings. It is of value for glass pots.

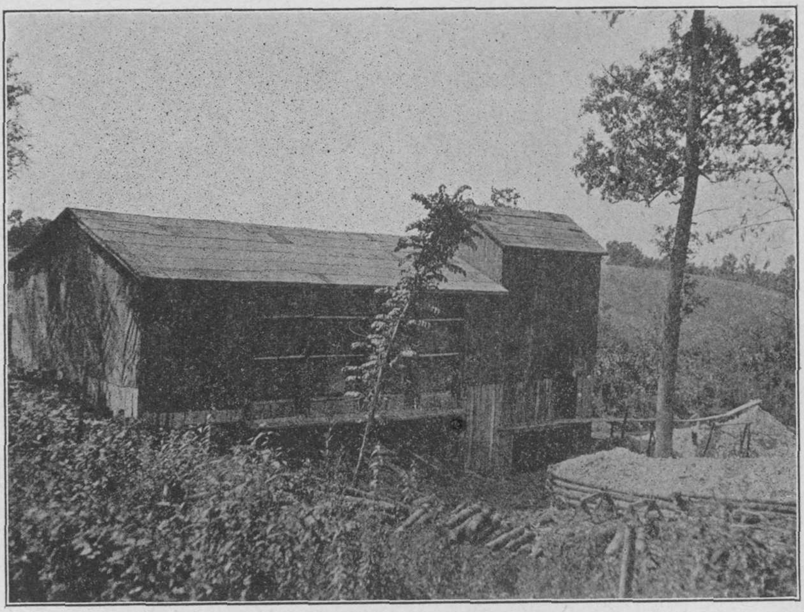
Underneath the ball clay come several beds usually called fire clays, which have been opened at a lower level. They appear to be somewhat similar to each other but are separable into several grades. The upper clay, known as No. 5 ball, is mixed with the lower fire clay and is of use in the clay bond of abrasive wheels.



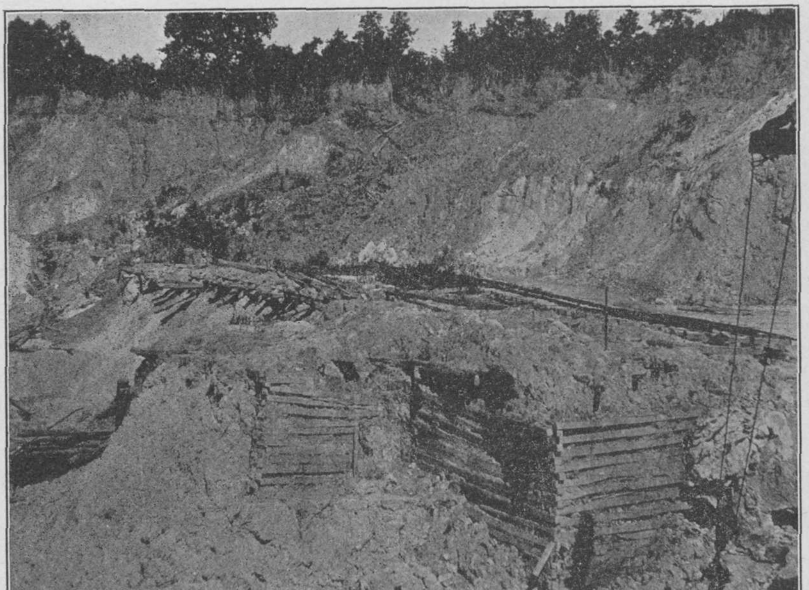
A. WORKING FACE OF PIT OF KENTUCKY CONSTRUCTION & IMPROVEMENT CO., PRYORSBURG, KY.



B. PIT OF EDGAR PLASTIC KAOLIN CO., EDGAR, FLA.



A. SHAFT HOUSE AND STORAGE SHED AT GANTS MINE, NEAR MOUNTAIN GLEN, UNION COUNTY, ILL.



B. OLD PIT OF ILLINOIS KAOLIN CO., NEAR MOUNTAIN GLEN, UNION COUNTY, ILL.

Clay No. 6, which underlies clay No. 5, is used to some extent in glass-pot mixtures and also for bats in making abrasive wheels. Clay No. 7 lies next below and is not quite as short as clay No. 6.

The clay deposit is underlain by sand.

The pit is a large opening, but at the time of the writer's visit a rather small face was being worked. (See Pl. XXV, *A*.)

After the overburden is removed with a steam shovel the clay is dug with mattock and shovel. It is then loaded on small dump cars that hold a ton, hauled to the foot of an incline, and drawn up to the storage bins.

A microscopic examination and also a few fire tests were made of several clays from this pit, with the following results:

No. 3 ball clay is of nonlignitic character and is highly plastic, smooth, and fine-grained. It contains very little quartz but a great abundance of hydromica. Kaolinite is common, but rutile is scarce. At 1,300 C. it burns light cream and has 0.8 per cent absorption and 1.4 per cent porosity. A thin section of the burned clay, when examined under the microscope, shows an exceedingly fine-grained feltlike mass that has low interference colors.

Old No. 4 ball clay is also a smooth plastic clay that carries very little quartz. Hydromica is abundant and much coagulated. Kaolinite is common, and rutile occurs in numerous tiny grains. At 1,300° C. the clay burns cream-white and has 1.8 per cent absorption and 2.5 per cent porosity.

No. 5 clay is medium to fine grained but is very plastic and smooth. Under the microscope it shows little quartz. Hydromica is common and kaolinite is much more abundant. Rutile occurs sparingly. At 1,300° C. it burns cream-white and has 14 per cent absorption and 28.7 per cent porosity.

Pit of Mayfield Clay Co.—The pit of the Mayfield Clay Co. is on the east side of the Illinois Central Railroad, near Pryorsburg station, and in June, 1918, had been in operation about a year. It lies at a slightly lower level than the other pit, and the clay is totally different in appearance from the clay in the pit of the Kentucky Construction & Improvement Co. It is nearly all grayish black.

The overburden in the pit is from 12 to 15 feet thick and under this occurs a mass of clay which is almost black but becomes light colored as it dries. (See Pl. XX, No. 15.)

About 7 acres had been tested, and this area contained 18 to 23 feet of clay.

Although the clay at first appears somewhat similar from top to bottom, close examination shows a variation in the texture and plasticity. The bed is therefore separated into an upper part, which is a sagger clay that contains fine laminae of sand, and a lower part, which is smoother and is classed as ball clay.

A specimen of the No. 3 ball clay, which is very plastic and smooth, was found on microscopic examination to be fine grained. Quartz was common, and hydromica was very abundant and coagulated. Kaolinite was common but less abundant than the hydromica. A few grains of tourmaline and rutile were present. When fired at cone 10 (1,330° C.) the clay burned a light buff, and its absorption was 1.2 per cent and its porosity 3.6 per cent. The material when dry is gray. It contains some fine grit but forms a very smooth plastic mass when wet.

A sample of sagger clay, which is very plastic, was medium to fine grained. Quartz was common. Hydromica was abundant and commonly coagulated, and kaolinite was likewise abundant. Rutile was present in numerous tiny grains, and there were a few grains of tourmaline. At 1,150° C. the clay showed 14.1 per cent absorption, but at 1,300° C. it showed 11.9 per cent absorption and was cream-white. It was steel hard at the lower temperature. A thin section of the burned clay showed a compact mass, of the type commonly developed when hydromica is abundant. Quartz was moderately abundant and was embedded in a groundmass which is partly isotropic and partly composed of material that shows a low interference color. The isotropic material was more abundant in the clay that was fired to the higher temperature. At this higher heat the grains of rutile still preserved their identity.

The output is used chiefly in the manufacture of whiteware.

HICKORY GROVE, GRAVES COUNTY.

Pit of Old Hickory Clay & Talc Co.—A new development, started by the Old Hickory Clay & Talc Co., is 2½ miles northeast of Hickory Grove. Only a small pit had been opened in June, 1918, but about 6 acres has been tested and is underlain by clay, whose maximum thickness, as determined partly by boring, was about 40 feet.

The section given in Plate XX (No. 16) is compiled partly from the pit and partly from drill records. It shows 3 grades of clay—No. 1 ball, wad, and sagger.

The ball clay, which is very smooth and plastic, is very fine grained. Under the microscope it showed a few small grains of quartz. Hydromica, fine grained and coagulated, is abundant. Kaolinite is common and rutile scarce. A sample that was fired at two temperatures gave the following results:

Since June, 1918, this property has changed hands and has been developed much more. The section now shows sagger clay at the top and several grades of ball clay below. The following tests have been supplied by the present operators:

Physical tests of clays of Old Hickory Clay & Talc Co., Hickory, Ky.

	Sagger clay A.	Ball clay B.	Ball clay C.	Ball clay D.
Plasticity	Very good.	Very good.	Very good.	Very good.
Water of plasticity per cent	25	37.7	40	31.5
Air shrinkage, linear do	7	6.7	6.5	5.25
Air shrinkage by volume in terms of volume of dry clay per cent	25	25	30	26.8
Modulus of rupture pounds per square inch	280	249	401	263
Modulus of rupture for mixture of clay and sand in proportion of 1:1 pounds per square inch	137	137	143	102
Slaking time of mixture of clay and flint in proportion of 1:1 minutes	9	8	7	5
Temperature when burned steel hard (° C.)	1,150	1,150	1,150	1,150
Linear fire shrinkage when burned to following temperatures (° C.):				
1,230 per cent	7.25	11.75	11.0	8.7
1,270 do	10.00	12.50	12.5	11.0
1,310 do	9.00	13.00	12.5	11.0
1,370 do	10.50	14.00	15.0	11.0
1,450 do	11.50	13.50	16.00	10.5
Porosity when burned to following temperatures (° C.):				
1,150 per cent	27.30	27.90	30.1	24.4
1,230 do	23.76	20.10	19.4	16.9
1,270 do	21.70	19.00	17.9	14.0
1,310 do	17.80	9.60	16.0	5.1
1,370 do	9.00	3.00	3.8	1.1
1,450 do	9.40	3.30	2.5	.4
Color after firing	Cream-white.	Cream-white.	Cream-white.	Cream-white.

Pit of Colonial Clay Co.—Recently Mr. C. E. Jennings, of Paducah, Ky., has started the development of another clay property just west of the property of the Old Hickory Clay & Talc Co. He has 200 acres under lease on the Wyatt and Moses farms, which he claims is underlain by a white ball clay that ranges from 22 to 38 feet in thickness.

The following analysis of a sample from this property was furnished by Mr. Jennings:

Analysis of clay from Jennings pit, Hickory Grove, Ky.

Silica	58.6
Alumina	22.7
Magnesia	Trace.
Loss on ignition	15.2
Alkalies by difference	3.5
	100.0

Pit of National Sales Co.—The National Sales Co., whose main office is at Cincinnati, Ohio, has a pit 2 miles west of Hickory Grove. On the west side this pit shows the following section:

Section in west side of pit of National Sales Co., Hickory Grove, Ky.

	Feet.
Overburden of gravel	9–12
Sagger clay	15–16

On the east side of the pit, about 50 feet distant from the west side, the section is as follows:

Section in east side of pit of National Sales Co., Hickory Grove, Ky.

	Feet.
Overburden	10
Light bluish-white ball clay	6
Sagger clay, gray; has red mottlings	2

The company controls 30 acres. The clay is hauled by wagon to Hickory Grove.

Other firms which have begun to mine clay in the region west of Hickory Grove since the field work for this report was done are the Kentucky Clay Mining Co., the West Kentucky Clay Co., and the M. B. Cooley Clay Co.

WICKLIFFE, BALLARD COUNTY.

The occurrence of high-grade bond clays in the vicinity of Wickliffe was mentioned by the Kentucky Geological Survey in 1888, and the clays have been worked in a small way for some years. All the excavations are small and are close to town.

La Clede-Christy Clay Co.—The main office of the La Clede-Christy Clay Co. is in St. Louis, Mo. The company has opened two pits about two-fifths of a mile south of Wickliffe. Both of them lie within an area of about 2 acres, and one is at a slightly higher level than the other. (See Pl. XX, Nos. 17 and 18.) Neither pit shows a very thick section or a great variety of clay types.

The sandy clay and the black clay are sold to glass-pot manufacturers, but five different grades in all are sorted out. One grade is used in the manufacture of lead pencils.

American Clay Co.—The American Clay Co., whose office is at Muncie, Ind., operates a pit half a mile northeast of Wickliffe. The section is given in Plate XX, No. 19. The deposit was worked for about three years prior to June, 1918.

The clay is sorted into two grades. Clay No. 2, which ranges from 5 to 8 feet in thickness, lies on top and is underlain by clay No. 1, a fine-grained fat clay that has a similar range of thickness.

The clays are dried by heating before shipment, a practice that is not followed at any other pits in Kentucky or Tennessee.

Some of the clay from this pit has a composition similar to the Gross Almerode glass-pot clay but shows a higher shrinkage than that clay and is softer when burned. It can be used to mix with other clays in the manufacture of glass refractories.

UNDEVELOPED LAGRANGE CLAYS IN KENTUCKY.

There may still be many undeveloped deposits of clay in the Lagrange formation in Kentucky.

Two properties which have not been producers are those of the Calloway County Clay Co., 6 miles east of Murray, Calloway County, and the United States Clay Co., near Wiatts schoolhouse, 10 miles from Murray. Other deposits are known, but most of them are too far from the railroad to permit their present development.

Berry[29] gives the following section in the Illinois Central Railroad cut near Wickliffe, Ky.:

Section near Wickliffe, Ky.

	Feet.
Heavy gravel, all sizes	10
Fine to coarse, yellowish or reddish ferruginous sand	8–13
Iron crusts and water-bearing horizon—	
Gray plastic clay with scattered lignite	12
Concealed to track level	7

The section 100 yards north of the section just given is as follows:

Section 100 yards north of preceding section.

	Feet.
Mostly concealed, loamy loess	25
Gravel and sand	20
Argillaceous lignite	4
Clay or sand	8
Lignite, about	4
Clay or sand, about	10

This section is not as promising as the one preceding it.

Prospecting will no doubt develop additional deposits in the Lagrange beds, and there are others which are being held in reserve.

USES OF LAGRANGE CLAYS OF KENTUCKY.

In general the Lagrange clays mined in Kentucky are utilized as ball clays in white ware and high-voltage insulators; in mixtures with other clays for glass refractories, graphite crucibles, and the bond for abrasive wheels; and in saggers. One pit has supplied clay for lead pencils. Of course, the same grade of clay is not employed for all these purposes. The ball clays have an excellent reputation.

Mixtures of clays from Kentucky, St. Louis, and Mississippi should work well for glass refractories.

The production of ball clays in Kentucky for the years 1917–1918 is reported as follows:

Ball clays marketed in Kentucky, 1915–1918.

Year.	Short tons.	Value.
1915	13,677	$45,199
1916	15,282	50,831
1917	17,858	98,736
1918 [a]	20,000	113,000

[a] Estimated.

[29] Berry, E. W., The lower Eocene floras of southeastern North America: U. S. Geol. Survey Prof. Paper 91, 1916.

ILLINOIS.[30]

DISTRIBUTION AND OCCURRENCE.

Deposits of fire clay near Mountain Glen, Union County, Ill., have been known for many years, but there was no serious development until the European war cut off the importations of high-grade German refractory clays.

These clays occur in the northwestern part of Union County, near Mountain Glen, on the Mobile & Ohio Railroad.

The bedrock includes Devonian, Mississippian, and Pennsylvanian shales and limestones, but these bear no genetic relation to the clays. Above the clays there is a general covering of loess, which ranges from a few feet to 15 feet or more in thickness, and this is underlain by a gravel bed whose thickness ranges from 3 inches to 2 feet in the hillside deposits up to 8 feet in the deposits in the lowland along the east branch of Clear Creek.

In typical exposures white and pale-red fine-grained micaceous sands underlie the gravel bed. These sands have a maximum thickness of 20 feet in some places but are absent in other places. Below all these beds lies the fire clay.

The large pit of the Illinois Kaolin Co., no longer worked, shows the following section:

Section in pit of Illinois Kaolin Co. near Mountain Glen, Ill.

	Feet.
Fire clay, pink	15
White clay	1–10
Bluish-white clay containing lignite in some places; maximum	40
Clay and lignite; maximum	17
White and red water-bearing sand.	

A view of this pit is shown in Plate XXVI, *B*, and sections exposed in it are given in figure 38.

Sand lenses occur in places in the clay, especially near the edge of the deposit.

At a few small prospects, which are well up on the hillsides, the conditions of occurrence are similar to those found in the main deposits, but the clay is apparently of different quality.

The bedrock is probably limestone, and the clays appear to occupy depressions within it.

One deposit of the pink clay showed a thickness of 93 feet. The highest elevation of the bluish-white and white clay seems to be from 470 to 475 feet above sea level. Other clays in the vicinity extend about 100 feet higher, but they are of different grade.

[30] St. Clair, Stuart, Clay deposits near Mountain Glen, Union County, Ill.: Illinois Geol. Survey Bull. 36 (extract), 1917.

The clays are undoubtedly of sedimentary origin, although as there are several large faults in the district, some of the smaller deposits might be due to the alteration of rock along fault planes. Some difficulty has been found in correlating these clays with those of Kentucky and Tennessee, but the Illinois Geological Survey regards them as probably of Wilcox age. This correlation is also applied to the refractory clays elsewhere in southern Illinois. It is based on their distribution and their resemblance to the clays at Hickory and north of Mayfield, Ky. These resemblances include a similar content of lignite; similarity in texture and color; a rather conspicuous uniformity of elevation; and, so far as the tests have progressed, a striking similarity in refractoriness and other qualities.

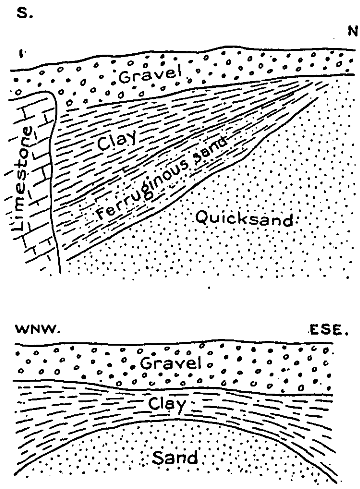


FIGURE 38.—Sections of deposit of Illinois Kaolin Co., near Mountain Glen, Ill.

According to St. Clair the clays were laid down in depressions of the old land surface within the limits of the embayment area. If this view of their origin is correct then we may expect to find clay bodies only where there were depressions in the land surface over which the waters of these early times extended. St. Clair says:[31]

The favorable places for deposition would be in small embayments, where the movement of the water would be so slight as to allow the fine clay material held in suspension to settle, yet where fresh supplies could be continually introduced. Such conditions as these would probably not obtain along the main arm of the sea. Therefore in the smaller reentrants we should expect to find clay deposits commensurate with the size of the surface depressions in which the clay could settle.

The clays are worked in the region around and to the north of Mountain Glen. One company, the Illinois Kaolin Co., worked its deposit with steam shovels in a large open cut, but at the time of the writer's visit in June, 1918, this pit had been abandoned. The other operators in that district, including the French Clay Blending Co., F. E. Bausch, Dr. Goodman, and others, were mining the clay with shafts. (See Pl. XXVI, *A*.)

CHARACTER AND USES OF THE CLAYS.

Much of the clay mined in this area is satisfactory in the manufacture of glass pots and graphite crucibles and as an ingredient of the bond for abrasive wheels.

[31] St. Clair, Stuart, op. cit., p. 80.

The better grades of the clay are refractory, are of excellent plasticity, and show a low porosity from cones 5 to 9 (1,230° to 1,310° C.).

One sample of white clay from the Goodman shaft, which was examined under the microscope, showed much quartz and hydromica. Kaolinite was abundant in bunches, and rutile in tiny grains was common. This clay had a porosity of 33.4 per cent at 1,150° C.

The following tests were made by C. W. Parmelee, of the University of Illinois:

Sample 1 is a bluish-white clay from a depth of 58 feet below the surface or 50 feet below the top of the clay bed. Sample 2 is a bluish-white clay taken 30 feet below the top of the pink clay and 15 feet below the top of the bluish-white clay. Sample 3 is a pink clay taken from the pit and was about 10 feet from the top of the clay bed.

Sample 1, bluish-white clay from Union County, Ill.

Color	Bluish white.
Plasticity	Very good.
Water content required .... per cent	32.8
Molding properties	Formed readily by hand and flowed easily through a die.
Tensile strength of dry briquets .... pounds per square inch	124
Bonding strength (tensile strength of a mixture of equal parts of clay and standard Ottawa sand) .... pounds per square inch	95.3
Slaking test (time required for a mixture of equal parts of potter's flint and clay formed into ¾-inch cubes to disintegrate when submerged in water at room temperature) .... minutes	21
Fineness test of clay deflocculated by use of an appropriate amount of sodium carbonate:	
Residue, 20-mesh sieve .... per cent	0.00
Residue, 40-mesh sieve .... do	.04
Residue, 80-mesh sieve .... do	.24
Residue, 100-mesh sieve .... do	.21
Residue, 200-mesh sieve .... do	.53
Total residue	1.02
Drying shrinkage of the clay formed into bars by forcing the plastic body through a die .... per cent	6.7

Fire tests of sample 1, bluish-white clay from Union County, Ill.

	Color.	Hardness.	Porosity (per cent).	Shrinkage (per cent).
Cone 08 (990° C.)	White	Scratched with knife.	37.0	2.75
Cone 06 (1,030° C.)	do	do	36.7	3.25
Cone 04 (1,070° C.)	do	do	36.9	3.25
Cone 02 (1,110° C.)	do	Steel hard	33.7	4.0
Cone 1 (1,150° C.)	do	do	33.7	4.0
Cone 3 (1,190° C.)	do	do	23.0	7.7
Cone 5 (1,230° C.)	Bluestone	do	3.25	11.0
Cone 7 (1,270° C.)	do	do	3.25	11.5
Cone 9 (1,310° C.)	do	do	3.5	11.25

Showed much checking during the burning.

Fusion test: Small cones tested in gas-and-oil burning furnaces deformed (fused) between cones 32 and 33 (1,770° and 1,790° C.).

Sample 2, bluish-white clay from Union County, Ill.

Color	Bluish white.
Plasticity	Very good.
Water content required ... per cent	34.6
Molding properties	Formed readily by hand and flowed easily through a die.
Tensile strength of dry briquets ... pounds per square inch	132
Bonding strength ... do	89
Slaking test ... minutes	29
Fineness test:	
Residue, 20-mesh sieve ... per cent	0.00
Residue, 40-mesh sieve ... do	.02
Residue, 80-mesh sieve ... do	.11
Residue, 100-mesh sieve ... do	.09
Residue, 200-mesh sieve ... do	.20
Total residue	.42
Drying shrinkage	7.2

Fire tests of sample 2, bluish-white clay from Union County, Ill.

	Color.	Hardness.	Porosity (per cent).	Shrinkage (per cent).
Cone 08 (990° C.)	White	Scratched with knife.	36.2	3.0
Cone 06 (1,030° C.)	do	do	36.0	3.2
Cone 04 (1,070° C.)	do	do	36.0	3.2
Cone 02 (1,110° C.)	do	Steel hard	32.2	5.0
Cone 1 (1,150° C.)	do	do	32.5	4.5
Cone 3 (1,190° C.)	Light buff	do	21.2	8.2
Cone 5 (1,230° C.)	Bluestone	Vitreous	2.5	11.0
Cone 7 (1,270° C.)	do	do	3.2	11.2
Cone 9 (1,310° C.)	do	do	3.0	11.2

Fusion test: Deforms between cones 33 and 34 (1,790° and 1,810° C.).

Sample 3, pink clay from Union County, Ill.

Color	Dark rose-pink.
Plasticity	Very good.
Molding properties	Soft, easily crushed; formed readily by hand.
Tensile strength of dry briquets ... pounds per square inch	95.5
Drying shrinkage ... per cent	5.9
Slaking test ... minutes	30
Fineness test:	
Residue, 40-mesh sieve ... per cent	0.00
Residue, 60-mesh sieve ... do	.10
Residue, 100-mesh sieve ... do	.14
Residue, 200-mesh sieve ... do	.16
Total residue	.40

Fire tests of sample 3, pink clay from Union County, Ill.

	Color.	Hardness.	Porosity (per cent).	Shrinkage (per cent).
08 (990° C.)	Pink		35.5	3.0
06 (1,030° C.)	do	Steel hard	35.5	3.0
04 (1,070° C.)	do	do	34.2	3.5
02 (1,110° C.)	do	do	31.8	4.7
1 (1,150° C.)	do	do	28.0	6.5
3 (1,190° C.)	do	do	12.5	10.0
5 (1,230° C.)	Faint pink	do	6.5	10.0
7 (1,270° C.)	Grayish white	do	2.8	10.0
9 (1,310° C.)	do	do	3.6	10.0
10 (1,330° C.)	do	do	3.6	10.0

Fusion test: Deforms between cones 33 and 34 (1,790° and 1,810° C.).

These tests show similar pyrometric qualities as those which have already been reported for samples of clay which were taken from pits in the Mountain Glen district many years ago.[32] Chemical analyses of the old samples are tabulated below. Sample D10 was taken at a depth greater than 50 feet; sample D11, at a depth of 40 to 44 feet; sample D12, at a depth of 35 to 40 feet; samples D13 and D14 were taken from the stock crib and represent the beds from the top of the deposit to a depth of 20 feet.

Analyses of clays from Mountain Glen district, Ill.

	D10	D11	D12	D13	D14
Silica (SiO_2)	43.90	48.30	56.55	47.95	52.65
Alumina (Al_2O_3)	40.79	31.14	29.97	37.86	33.98
Ferric oxide (Fe_2O_3)	1.76	1.02	1.23	1.23	.97
Titanium oxide (TiO_2)	2.40	3.20	2.75	3.01	2.92
Moisture (H_2O)	1.25	.97	.86	.90	.87
Volatile matter	9.90	15.37	8.64	9.05	10.61
	100.00	100.00	100.00	100.00	102.00

Prof. C. W. Parmelee, of the Department of Ceramic Engineering of the University of Illinois, makes the following statement in regard to the uses and commercial qualities of the bluish-white clay as indicated by mechanical and pyrometric tests of samples 1 and 2:

This material is a very fine grained, plastic, strong, highly refractory clay, well suited for use as a bond clay in the manufacture of high-grade refractories. Although its properties are not quite the same as those that characterize the European bond clays heretofore extensively imported for use in the manufacture of graphite crucibles, crucibles for melting brass, and other purposes, yet this clay approaches so nearly to the European clays as to warrant the belief that it may be used for the same purposes.

The clay may be used also where a good bond clay is required, as in the manufacture of chemical stoneware. Possibly further experiments may show that this clay may be substituted in certain products for ball clays, providing that the dark color developed by these clays at the higher temperatures is not objectionable.

[32] Purdy, R. C., and De Wolf, F. W., Preliminary investigations of Illinois fire clays: Illinois Geol. Survey Bull. 4, p. 175, 1907.

As already stated (p. 285), these clays are being satisfactorily used in place of the European clays in the manufacture of graphite crucibles and glass pots.

In regard to the commercial qualities of the pink clay, sample 3, Prof. Parmelee says:

This clay is similar to clays 1 and 2 (bluish-white) in that it is a highly refractory bond clay and is suited to the purposes previously mentioned. This clay differs slightly with respect to the cone temperature at which it first attains its minimum porosity. Clays 1 (1,150° C., and 2 (1,170° C.) show a minimum porosity attained at two cones lower than clay 3. This characteristic is likely to render clays 1 and 2 better suited to use for graphite crucibles.

An unusual feature of this clay is the retention of a pink color (lilac at the higher temperatures) up to cone 5 (1,230° C.). This is most unusual, and a chemical analysis of the clay would be of much interest.

It is our opinion that the color of the clay does not affect its intrinsic value for the purposes mentioned and that any method of decolorizing the clay would be prohibitively expensive and of no real advantage.

OLIGOCENE CLAYS.

FLORIDA.

DISTRIBUTION AND CHARACTER.

The white clays of Florida, "plastic kaolins," as they are usually called, form a unique type of material. Their use was recognized more than 20 years ago, and they have been mined ever since by a few companies.[33]

The formation in which the clay occurs is of Tertiary age, but its exact position in the beds laid down in this period is not known. Sellards says that it overlies the Oligocene limestones, but that there is also some reason for "believing that it lies at a stratigraphic level higher than the beds of fuller's earth and hence is not older than the Miocene." However, as no one of the later fossiliferous formations overlies the clay, its age can not be fixed more definitely. The clay is probably coextensive with the "lake region" of Florida—that is, it probably extends from Clay County on the north to the middle of De Soto County on the south. Its length, therefore, is about 150 miles and its width from 10 to 40 miles.

According to Sellards, an area which has a similar type of topography and is underlain probably by the same formation occurs in several counties of western Florida, between Suwannee and Choctawhatchee rivers.

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[33] Ries, H., The clays of the United States east of the Mississippi River: U. S. Geol. Survey Prof. Paper 11, p. 83, 1903. Matson, G. C., Notes on the clays of Florida: U. S. Geol. Survey Bull. 380, pp. 346–357, 1909. Sellards, E. H., Mineral industries and resources of Florida: Florida Geol. Survey Sixth Ann. Rept., p. 23, 1914; Clays of Florida: Am. Ceramic Soc. Jour., vol. 1, p. 313, 1918.

The clays are sedimentary and consist of a mixture of particles of clay, grains and pebbles of quartz, and mica. The overburden as a rule is composed of loose sand, and at the localities worked it ranges from 4 to 10 feet in thickness.

The sandy clay is gray, some of it iron-stained in its upper part, and has a maximum thickness of 30 feet. It is underlain by a sticky blue clay, which is left alone in mining.

The clay is dug at Edgar, Putnam County, by the Edgar Plastic Kaolin Co., and at Okahumpka, Lake County, by the Lake County Clay Co. and the Florida China Clay Corporation.

The material as excavated is very sandy and has to be washed to eliminate the sand, so that the washed product probably does not average over 15 per cent of the material excavated. The sand is usually coarse and sharp and affords an excellent building material.

The method of excavating the clay is unique. It consists in floating a dredge in the pit (Pl. XXV, *B*) and in forcing the dredged clay with water through a pipe to the washing plant.

The clay from this region is plastic, burns white, and is refractory but has a rather strong shrinkage. It is utilized almost exclusively in making pottery and decorative tile.

There are probably abundant reserves, so that production could be greatly increased.

In mineral composition the clay does not differ materially from many of the other clays examined.

In the crude material quartz is very abundant and coarse, a fact that is easily seen with the naked eye. Hydromica does not appear to be very common, but kaolinite is abundant in large and small flakes and also in fan-shaped masses. Rutile is very scarce, and there are a few grains of chlorite and zircon.

The washed clay is medium to fine grained. It shows very little quartz. Hydromica is fairly abundant and commonly coagulated, although there are some large single grains. Kaolinite is abundant, mostly in fine grains, though there are a few large ones. There are a few grains of rutile and zircon.

Thin sections were cut of pieces that had been fired to 1,150° C. and 1,300° C., respectively. These sections (Plate XXX, *B*) showed very little quartz and consisted of a fine groundmass, which in the specimen that was fired to the lower temperature showed considerable isotropic material together with small flakes of low interference color. In the piece that was fired at 1,300° the groundmass showed a distinctly felty appearance, with more material of low interference color.

The raw clay contains a few slivers of material, either kaolinite or a low grade of hydromica, which are larger than the other flakes.

On firing these slivers, or some of them, retain their shape and simply lose a little of their interference color, but others are converted to sillimanite.

The following tests of the washed clay from Okahumpka, Fla., were made in the laboratory of the Bureau of Mines, at Columbus, Ohio:

General physical tests of washed clay from Okahumpka, Fla.

Workability	Very plastic; molds well.
Water of plasticity, in terms of dry clay ..... per cent	49.78
Air shrinkage by volume ..... do	32.15
Air shrinkage, linear, calculated ..... do	12.20
Modulus of rupture ..... pounds per square inch	181.00

Fire tests of clay from Okahumpka, Fla.

Temperature (°C.).	Porosity (per cent).	Color.	Volume shrinkage (per cent in terms of dry clay).	Linear shrinkage (per cent in terms of dry clay).
1,190	28.3	White	32.1	12.1
1,250	27.05	Faint cream-white	33.11	12.5
1,310	23.41	.....do	37.33	14.4
1,370	7.4	Cream	46.3	18.7
1,410	2.2	Buff	49.4	20.3

Deformation temperature, cone 31+ (1,750° C.). Steel hard at 1,190° C. Develops small cracks in firing.

The clay fires to a good color and shows moderate strength in its unfired condition. It is not to be classed as a bond clay. It is extensively used in different kinds of white ware.

USES OF CLAYS OF FLORIDA.

The white clay of Florida is extensively used in the manufacture of white ware, electrical porcelain, and floor and wall tile. It is not usually regarded as a paper clay. It has also been used in manufacture of porcelain, glass pots, fine optical glass, and in the making of certain classes of munitions.

MICROSCOPIC STUDY OF CLAYS.

By R. E. Somers.

Most of the clays considered in this report were examined microscopically in order to determine the minerals they contained, and in addition thin sections of some of the burned samples were studied, so far as time would permit, in order to ascertain the changes that took place in burning.

This investigation is not to be regarded as exhaustive, for much work of this kind still remains to be done, but the results are believed to be of interest and are therefore here presented.

METHOD OF EXAMINATION.

The samples examined were obtained by gently crushing the crude clay and mounting it in balsam dissolved in xylene. The specimens were then allowed to stand 24 hours before they were studied, in order to permit the balsam to harden.

It was not considered necessary to use liquids of special indices of refraction for most of the work, as the greatest value of the examination seems to be derived from a general study of the more common minerals rather than from a close determination of the rarer grains, and the minerals that are most abundant have indices near that of balsam.

The following table shows the minerals that were noted in the specimens examined and their approximate abundance. Most of the clays examined probably contain colloid matter that is not visible under an ordinary microscope. The minerals listed include only those that were identifiable. The following letters are used to indicate relative abundance: S, scarce; C, common; M, moderate amounts; A, abundant; VA, very abundant.

Minerals in residual and sedimentary clays.

Residual clays.

Formation and locality.	Quartz.	Hydromica.	Kaolinite.	Rutile.	Zircon.	Tourmaline.	Epidote.	Titanite.	Diaspore.	Halloysite.	Colloid matter.
GRANITE.											
English china clay, washed	S	M	VA	......	......	......	......	......	......	......	......
CAMBRIAN SANDSTONE (CHICKIES QUARTZITE).											
Frazer, Pa	A	M	A	C	......	......	......	......	......	......	......

Minerals in residual and sedimentary clays—Continued.

Residual clays—Continued.

Formation and locality.	Quartz.	Hydromica.	Kaolinite.	Rutile.	Zircon.	Tourmaline.	Epidote.	Titanite.	Diaspore.	Halloysite.	Colloid matter.
CAMBRIAN SCHIST.											
Mount Holly Springs, Pa.:											
Unidentified sample	C	A	VA	C	......	S	......	......	......	......	......
Sandusky Portland Cement Co.	C	C	A	C	......	......	......	......	......	......	......
Philadelphia Clay Co., crude	A	A	A	C	......	S	......	......	......	......	......
Philadelphia Clay Co., washed	C	C	A	S	......	S	......	......	......	......	......
Holly Clay Corporation, crude	C	C	A	S	S	S	......	......	......	......	......
Holly Clay Corporation, washed	M	C	VA	C	......	......	S	......	......	......	......
Beavertown, Pa	C	S	VA	......	S	......	......	......	......	......	......
Narvon, Pa.:											
Whittaker pit	S	A	A	S	S	C	......	......	......	......	......
Diller pit	A	A	A	C	S	S	S	S	......	......	......
CAMBRIAN (CHICKIES) QUARTZITE.											
Honeybrook, Pa	VA	C	S	C	......	S	......	......	......	......	......
CAMBRIAN (GATESBURG) CLAYEY SANDSTONE.											
Scotia, Pa	S	A?	C?	S	S	S	......	......	......	......	......
Warriorsmark, Pa	A	S	VA	A	......	S	......	C?	......	......	......
Furnace Road, Pa.: Colonial Clay Co	A	S	A	C	S	......	......	......	......	......	......
CAMBRIAN SHALE.											
Cold Spring, Va	......	S	A	A	S	S	......	......	......	......	......
CAMBRIAN LIMESTONE.											
Lutesville, Mo.:											
Unidentified sample	A	A	A	S	......	......	......	......	......	......	......
Clay No. 1	C	A	A	S	......	......	S	......	......	......	......
Clay No. 2	C	C	A	A	......	S	S	......	......	......	......
ORISKANY GROUP (SHALES, LIMESTONES, AND SANDSTONES).											
Kunkletown, Pa.: Disintegrated quartzite	A	......	S	S	......	......	......	......	......	......	......
Kunkletown, Pa.:											
Clay with quartzite, crude	C	C	A	A	......	S	S	......	......	......	......
Clay with quartzite, washed	C	C	A	C	......	......	S	......	......	......	......
Saylorsburg, Pa.:											
Crude No. 1	A	A	A	A	......	S	......	S	......	......	......
Crude No. 2	C	A	A	S	......	......	......	......	......	......	......
Washed	C	A	A	A	......	......	......	......	......	......	......
Crude, Cement Co.'s mine	C	C	A	A	S	S	......	......	......	......	......
Shirleysburg, Pa	S	C	A	A	S	......	......	......	......	......	......
MISCELLANEOUS.											
Bauxite, Ark.:											
Banded clay under bauxite [a]	......	S	VA	A	......	......	S	S	......	......	......
White clay under bauxite [a]	......	S	VA	S	S	......	......	......	......	......	......
Oreana, Nev.: Pitt-Rowland deposit	A	[b]A	A	S	......	......	S	......	......	......	......
Lovelocks, Nev.: Adamson-Dickson deposit	A	......	A	S	......	......	......	......	......	......	......
Beatty, Nev.: Bond-Marks deposit	......	......	S	S	......	......	......	......	......	VA	......
Antioch, Calif	S	S	VA	S	......	S	......	......	......	......	M?
Fort Payne, Ala.:											
Brower mine	C	A	A	A	......	S	......	......	......	......	......
Cochrane pit, siliceous bauxite	S	C	......	A	S	S	......	......	......	......	A
Cochrane pit; bauxite	......	S	M	A	S	......	......	......	......	......	VA
Bynum, Ala.:											
Kraus pit, white clay	......	A	A	S	......	S	......	......	......	......	......
Kraus pit, black clay	......	C	......	C	S	......	......	......	......	......	A

[a] Contains some large flakes of mica.
[b] Probably mostly sericite.

Minerals in residual and sedimentary clays—Continued.

Residual clays—Continued.

Formation and locality.	Quartz.	Hydromica.	Kaolinite.	Rutile.	Zircon.	Tourmaline.	Epidote.	Titanite.	Diaspore.	Halloysite.	Colloid matter.
CARBONIFEROUS ROCKS.											
Cheltenham clay, St. Louis district, Mo.:											
La Clede-Christy, raw washed pot clay	C	A	A	S	......	......	......	......	......	......	......
La Clede-Christy, weathered pot clay	C	A	C	A	S	S	......	......	......	......	......
La Clede-Christy, fire-brick clay	C	A	S	S	......	......	......	S	......	......	......
La Clede-Christy, selected crude clay	C	A	S	S	......	......	......	......	......	......	......
Highland Clay Co., weathered pot clay	S	A	A	S	S	......	......	......	......	......	......
Highland Clay Co., washed pot clay	C	A	C	A	......	......	S	......	......	......	......
Flint clay district, central Missouri:											
Bland, Mo.: Plastic clay	A	C	S	......	......	......	......	......	......	......	......
Owensville, Mo.—											
Sassman pit, white clay	......	S	S	S	......	......	......	......	......	......	C
Sassman pit, red clay	......	......	S	C	......	......	......	......	......	......	C
Sassman pit, flint clay	......	......	S	C	......	......	......	......	......	......	C
Sassman pit, diaspore clay	S	......	A	A	......	S	......	......	C	......	......
Connell pit, flint clay	......	C	A	S	......	......	......	......	C	......	......
Connell pit, diaspore clay	......	......	C	S	......	......	......	......	C	......	C
Connell pit, diaspore clay	......	......	A	S	S	......	......	......	A	......	......
Hofflin, Mo.—											
Cox pit, flint clay	......	S	......	S	S	S	......	......	......	......	C
Cox pit, flint clay	......	S	VA	A	S	S	......	......	S	......	......
Rosebud, Mo.—											
Toelke & Heidel pit, flint clay	......	......	C	A	......	......	......	......	A	......	......
Brown pit, diaspore clay	......	......	......	S	S	......	......	......	VA	......	C?
Brown pit, diaspore clay	......	......	C	S	......	......	......	......	VA	......	......
Huron district, Ind.:											
Indianaite (earthy white clay)	......	A	A	S	......	......	......	......	......	[c] C?	......
Indianaite (massive white clay)	......	S	C	C	......	......	......	......	......	[c] A?	......
Sedimentary clays.											
LOWER CRETACEOUS DEPOSITS.											
Gordon, Ga.:											
Columbia Kaolin & Aluminum Co., white clay of upper bed	C	C	A	S	......	......	......	......	......	......	M
Columbia Kaolin & Aluminum Co., nodular clay of upper bed	S	......	S	S	S	......	......	......	......	......	VA
Dry Branch, Ga.:											
American Clay Co., crude white clay	S	C	VA	S	......	......	......	......	......	......	......
American Clay Co., washed white clay	S	C	A	S	S	......	......	......	......	......	......
UPPER CRETACEOUS DEPOSITS.											
Allendale, S. C.: J. L. Box pit	A	S	A	S	S	......	S	......	......	......	......
Rayflin, S. C.: Edisto Kaolin Co.	S	S	A	C	S	......	......	......	......	......	......
Abbeville, S. C: Hill pit	A	C	A	S	......	......	......	......	......	......	......
Trenton, S. C: White clay	C	S	VA	A	......	......	S	......	......	......	......
Bath, S. C.:											
McNamee Kaolin Co., clay No. 1	......	M	A	A	S	S	......	......	......	......	......
McNamee Kaolin Co., clay No. 2	......	C	A	A	S	S	......	......	......	......	......
Langley, S. C.: White clay	S	C	VA	A	......	......	......	......	......	......	......
Do	S	C	A	A	S	......	......	C	......	......	......
Aiken, S. C.: White clay	S	S	A	A	......	......	......	......	......	......	......
Ripley formation.											
Perry, Ga.: Houston Kaolin Co., white clay	S	S	S	C	S	......	......	S	......	......	A
Houston Kaolin Co., white part of mottled clay	......	S	S	S	S	S	......	S	......	......	A

[c] This mineral may be allophane and not halloysite.

Minerals in residual and sedimentary clays—Continued.

Sedimentary clays—Continued.

Formation and locality.	Quartz.	Hydromica.	Kaolinite.	Rutile.	Zircon.	Tourmaline.	Epidote.	Titanite.	Diaspore.	Halloysite.	Colloid matter.
UPPER CRETACEOUS DEPOSITS—continued.											
Ripley formation—Continued.											
Houston Kaolin Co., red part of mottled clay	S	S	S	S	S	S					[d] A
Hollow Rock, Tenn.:											
Sagger clay	C	A	C	C		S					
Do	C	A	A	A	S						
India, Tenn.: Lignitic clay	S	A	C	S							
Paris, Tenn.:											
Currier pit, brown sandy clay	C	A	A	A		S		S			
Currier pit, dark clay	C	A	C	S							
Porters Creek clay.											
Benton, Ky.:											
Howard pit, wad clay	C	A	A	A			S				
Howard pit, wad clay	C	A	A	A							
Briensburg, Ky.: Wad clay	C	A	A	S	S						
Wilcox group.											
Andersonville, Ga.:											
Sweetwater mine, white clay		C	A	S							
Sweetwater mine, mottled clay		S	A	S	S						
Enid, Miss.:											
Bramlett No. 5 pit	C	VA	S	S		S					
Bramlett No. 21 pit	S	A	A	S		S					
Holly Springs, Miss., stoneware clay	C	A	A	C							
Lester, Ark.:											
Camden Coal & Clay Co., crude clay	C	A	A	A	S	S		S			
Camden Coal & Clay Co., washed clay, Camden	A	A	C	S		S					
Lagrange formation.											
La Grange, Tenn.:											
Dale sand pit, clay lens	A	S	A	M	S	S		S			
McNanee pit	C	A	A	A	S						
McKenzie, Tenn.:											
Johnson-Porter No. 10 ball	S	A	A	S		S					
Johnson-Porter No. 11 ball	S	A	A	S							
Sparks pit	S	A	A	M		S	S				
Henry, Tenn.: Scates-Reynolds Clay Co., sagger clay	A	A	C	C	S	S					
Whitlock, Tenn.:											
Mandle No. 1 S. G. P. clay	S	A	C	C		S					
Mandle No. 5 ball clay	S	A	C	S							
Mandle No. 7 ball clay	S	A	C	S							
Mandle No. 4 white ball clay	S	A	C	A		S					
Mandle No. 4 dark ball clay	S	A	C	S							
Puryear, Tenn.: Dixie Brick & Tile Co	C	C	VA	S	S	S		S			
Hazel, Ky.:											
Cooley Ball & Sagger Clay Co., wad clay	C	C	A	C		S					
Cooley Ball & Sagger Clay Co., dark ball clay	S	A	C	A	S						
Pryorsburg, Ky.:											
Kentucky Construction & Improvement Co., No. 4 ball clay	S	VA	A	S							
Do	S	VA	C	A							
Kentucky Construction & Improvement Co., No. 5 clay	S	C	A	M							
Mayfield Clay Co., No. 3 ball clay	C	VA	A	S		S					
Mayfield Clay Co., ball clay	C	A	A	A		S					
Hickory, Ky.: Old Hickory Clay & Talc Co., No. 1 ball clay	S	VA	C	S							
TERTIARY DEPOSITS.											
Edgar, Fla.:											
Crude clay	A	S	A	S	S						
Washed clay	S	A	A	S	S						

[d] Stained with hematite.

IDENTIFICATION AND CHARACTER OF MINERALS.

QUARTZ.

If it occurs in medium-sized or large grains, quartz can readily be discriminated by its index of refraction, low interference color, and lack of cleavage, for in such grains it resembles no other mineral found in clays. If, however, it occurs in small grains, it greatly resembles kaolinite. Its index of refraction is then of little assistance, the interference color is lowered nearly to that of the kaolinite, and it must be identified by its more angular shape and its more rapid extinction or "quicker wink." Such grains are generally so small that the difference in optical character is useless for their identification.

Quartz was noted in many of the clays examined and was particularly abundant in the residual clays. Most of the Wilcox clays from the embayment area contained but little quartz.

KAOLINITE.

Kaolinite can be distinguished by its orthodox characters where the particles are large and by its flaky appearance and its common tendency to combine in fan or worm-shaped bunches. (See Pl. XXVII, *A*.) Its low index of refraction and low birefringence distinguish it from the other micaceous minerals. Where it is fine, it can merely be noted as minute transparent plates, whose index of refraction is close to that of balsam, and whose interference color is very low.

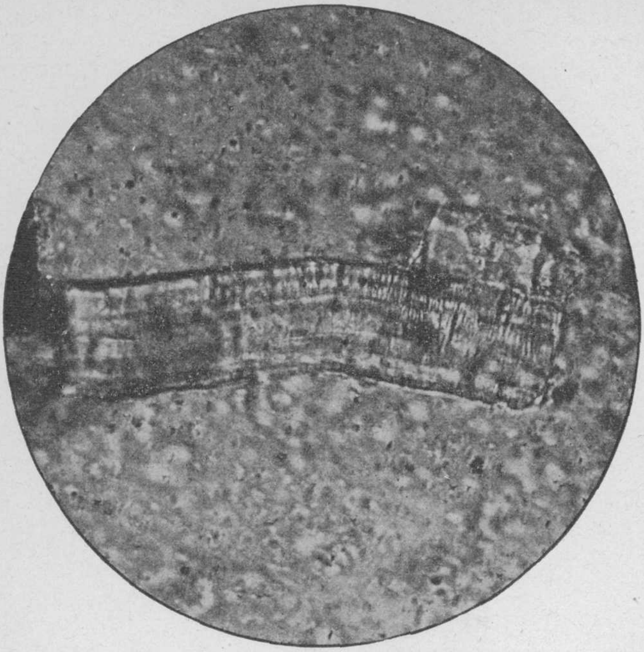
Kaolinite occurs in the clays examined as single scales or plates, some of them in fan-shaped bunches, and also as vermiculites. In one clay, the indianaite from Lawrence County, Ind., spherulite-like bodies were also found, but these are rare. Especially fine examples of "fans" were noted in the clay from Perry, Ga.; Bynum, Ala.; Bauxite, Ark.; and Antioch, Calif. Good examples of vermiculites were seen in the clay from South Carolina; Perry, Ga.; Bauxite, Ark.; Antioch, Calif.; and the nodular white clay from Gordon, Ga.

The clay from Okahumpka and Edgar, Fla., as well as that from Langley and Aiken, S. C., contained large single flakes of kaolinite. Many clays that contain considerable kaolinite show but few of the fans.

HYDROMICA.[34]

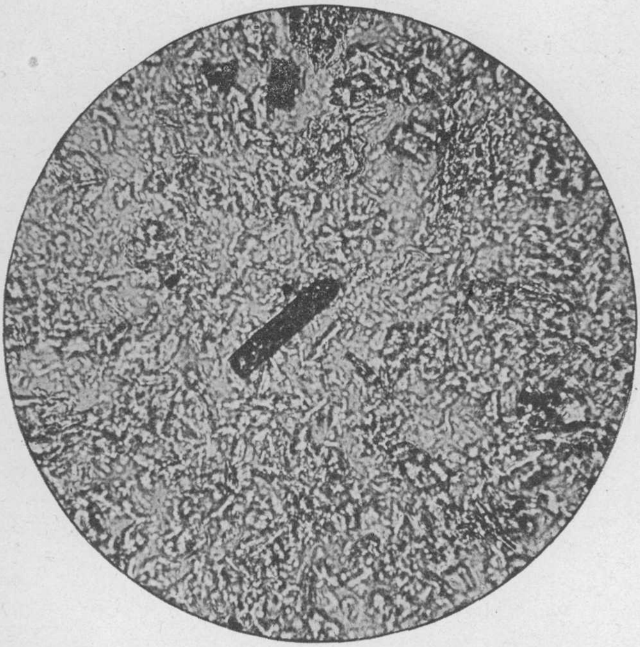
Hydromica is a distinctly micaceous mineral whose single and double refractions are higher than those of kaolinite, yet not so high

[34] Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, pp. 306, 338, 1912.



A. "WORM" OF KAOLINITE, FROM BAUXITE, ARK.

Ordinary light. × 405.



B. GRAIN OF TOURMALINE SURROUNDED BY GRAINS OF KAOLINITE AND HYDROMICA, FROM NARVON, PA.

Ordinary light. × 180.

PHOTOMICROGRAPHS OF SPECIMENS OF CLAY.

A. OOLITE OF DIASPORE FROM FLINT CLAY AT ROSEBUD, MO.

Ordinary light. × 97.

B. SPHERULITE OF KAOLINITE (?) IN WHITE CLAY FROM HURON, IND.

Polarized light. × 110.

PHOTOMICROGRAPHS OF SPECIMENS OF CLAY.

as those of muscovite or sericite. Furthermore, the degree of these refractions differs in different clays. It is therefore assumed that there is an isomorphous gradation between sericite and kaolinite, which is marked by a gradual loss of potash and addition of water, and in products of weathering, such as these, hydromica represents a transition stage of weathering toward kaolinite as the final product.

The fan of the hydromica is similar to that of the kaolinite, but the grains of hydromica may be larger. Radiating bunches and spherulite-like grains were found in the white clay from the vicinity of Huron, Ind. (Pl. XXVIII, *B*), but in none of the other clays examined. A clay that shows considerable sericite of relatively coarse grain is that from the Pitt-Rowland deposit at Oreana, Nev. (Pl. XXIX, *A*.)

COMPARATIVE ABUNDANCE OF KAOLINITE AND HYDROMICAS.

In the reports on microscopic examinations of clays that have been published from time to time frequent reference is made to kaolinite, but the presence of mica is less often mentioned, yet the clays described in this report contain abundant mica.

The same inference might possibly be made from the chemical composition of many kaolins that show a small percentage of potash, for as feldspar seems to be very scarce the potash is probably contained in mica. Vogt, for example, in 1906, concluded that china clay consisted of kaolinite, muscovite, and quartz, although he based his conclusions on the chemical composition of the material.[35]

Later Hickling,[36] after studying the china clay of Cornwall, says that the finest washed clays contain kaolinite, mica, quartz, and tourmaline, but that kaolinite and mica make up 90 per cent of the mass. He adds, however, that the relative amounts of kaolinite and muscovite are difficult to estimate. He differentiates the mica into two classes—primary mica and secondary mica derived from feldspar.

According to Hickling the kaolinite occurs in irregularly hexagonal prisms, with rough faces, which show strong transverse striations that correspond to the basal cleavage. Most of these prisms are curved and some of them are vermiculiform. The shorter prisms commonly present a fanlike arrangement and resemble the similar forms of mica so closely that they can be distinguished only by their lower interference tint. Isolated plates or very short prisms may

[35] Vogt, G., De la composition des argiles: Mémoires publiés par la Société d'encouragement pour l'industrie nationale, Paris, pp. 193–218, 1906.

[36] Hickling, G., China clay; its nature and origin: Inst. Min. Eng. [England] Trans., vol. 36, 1908–9.

occur, and then, even with convergent polarized light, it is not easy to judge the amount of birefringence and consequently to decide to which mineral a given fragment belongs; hence the difficulty of estimating the relative proportions of kaolinite and mica. Both minerals show the same irregular form (due probably to development within decaying feldspar) and the same evidence of corrosion on the edges.

The low interference tint and low index of refraction definitely distinguish these crystals from mica. The identification of kaolinite rests on the following evidence: (1) The index of birefringence is distinctly low, nearly that of quartz but variable; (2) the index of refraction is very near to 1.56; (3) the prismatic crystals extinguish parallel to the basal plane; (4) basal flakes show a biaxial interference figure.

Hickling refers to the mica as muscovite, but he notes that it may be hydrated. Indeed, he thinks that the muscovite changes directly to kaolinite in the clay, because he can find mica but no kaolinite in the feldspar or in the granite, because there is no difference in form between the mica and the kaolinite, and because some prisms are composed of mica at one end and kaolinite at the other.

Hickling also quotes the observations of Johnstone,[37] who found that after muscovite had been immersed in pure water and water saturated with carbon dioxide for twelve months, it had changed to hydromuscovite. This experiment, Hickling believes, shows a conversion in the direction of kaolinite.

In his work on flint clays Galpin[38] found platy masses of a mineral which at first appeared to be kaolinite. These masses commonly show "ribs" or plates of higher index and birefringence intergrown with those of kaolinite, and these ribs show practically every grade of variation between kaolinite and muscovite.

HALLOYSITE.

Two clays—those from the deposit north of Huron, Ind., and those from the Bond-Marks deposit, near Beatty, Nev. (Pl. XXX, *A*)—contain isotropic material in platelike grains, which is probably halloysite. In no other samples could this material be so definitely identified.

RUTILE.

In view of the probable constant occurrence of titanium in high-grade clays the presence of rutile is interesting. Practically every

[37] Johnstone, A., On the action of pure water and of water saturated with carbonic-acid gas on minerals of the mica family: Geol. Soc. London Quart. Jour., vol. 45, p. 363, 1889.

[38] Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, p. 301, 1912.

clay examined contained some rutile. In some clays it occurs in grains or prisms, perhaps 0.015 to 0.020 millimeter in diameter, and in these its color and refractive properties distinguish it at once. Generally, however, it is found on close examination as very minute grains or needles, which are nevertheless so clear-cut that their refractions can be plainly seen. The interference color is of the first order, but the particles are so small that the actual birefringence is thereby shown to be very high. They range from perhaps 0.001 to 0.010 millimeter in diameter, and the length of the needles is five or six times their width. Though these grains are numerous, their actual bulk represents a very small quantity of rutile.

RARE MINERALS.

Tourmaline is well marked by its pleochroism, and its common occurrence is notable. (See Pl. XXVII, *B*.) Epidote appears in some specimens as a slightly greenish mineral of moderate single and double refractions. Grains of zircon and titanite, marked by high index and birefringence, are common though not abundant. A distinction between the two is possible by means of the higher interference color of the titanite. Zircon is much the commoner.

DIASPORE.

Diaspore is easy to determine by its moderately high index and double refraction and its occurrence in irregular grains. It is common in some of the clays examined from Missouri. (See Pl. XXVIII, *A*.) Some of the diaspore in these clays or their associated rocks occurs in grains sufficiently large to be seen with the naked eye and thus may be mistaken for quartz, but the diaspore can be separated from the quartz and the clay by means of bromoform (specific gravity 2.8), in which the diaspore (specific gravity 3.4) sinks and the associated minerals float.[39] The section of a diaspore oolite from the flint clay at Rosebud, Mo., shows the concentric shells composing the grains.

GIBBSITE.

Gibbsite has been noted by Galpin[40] in the flint clays from Olive Hill, Ky., where it occurs in minute oolites similar to the diaspore in the flint clays from Missouri.

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[39] Wherry, E. T., Field identification of diaspore: Am. Mineralogist, vol. 3, p. 154, 1918.

[40] Galpin, S. L., Studies of flint clays and their associates: Am. Ceramic Soc. Trans., vol. 14, p. 301, 1912.

TEXTURE.

No attempt is made in this bulletin to standardize the clays according to size of particle because any clay is apt to be made up of particles of all sizes and because there is no standard to use. However, in the clays examined relatively coarse grains average 0.100 millimeter or more in size, medium grains 0.020 to 0.025 millimeter, and fine grains 0.010 millimeter or less.

MINERALS IN THE BURNED CLAY.

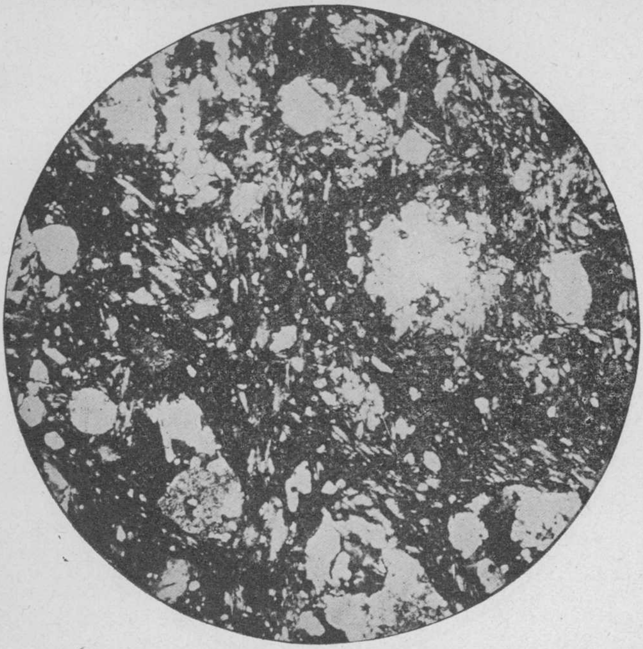
A number of samples of the clays were molded into 1-inch cubes, which were all fired for 8 hours to 950° C. After this firing one set of the cubes was refired for 8 hours to 1,150° C., and a second set was refired for 10 hours to 1,300° C. The cubes were then ground to thin sections and studied under the microscope. (See Pls. XXIX, *B*; XXX, *B*.)

Grains of quartz as a rule stand out with much greater clearness in the burned than in the raw clay, for the hydrous aluminum silicates tend to mat or fuse together to a fine-grained groundmass, which holds the quartz. In some specimens a fluxing action appears to have taken place between the fine-grained material and the silica, which has resulted in corrosion of the quartz, but this condition is comparatively rare in the specimens studied. Plate XXIX, *B*, shows a thin section of kaolin from Mount Holly Springs, Pa., which was fired at 1,150° C. In this section the corroded quartz grains are clearly seen in the groundmass of mostly isotropic character. On heating to 1,150° C. hydromica either practically disappears, forming an isotropic mass (Pl. XXIX, *B*), or else it loses the greater part of its interference color. The only exception to this condition occurred in samples where the grains of hydromica were much larger than usual, and then the central portion of the grains retained usually the original interference color (Pl. XXIX, *A*).

This change of the hydromica on heating suggests that it furnishes some of the flux for the clay, and other things being equal there may be a connection between the degree of density at the temperature mentioned and the quantity of hydromica present.

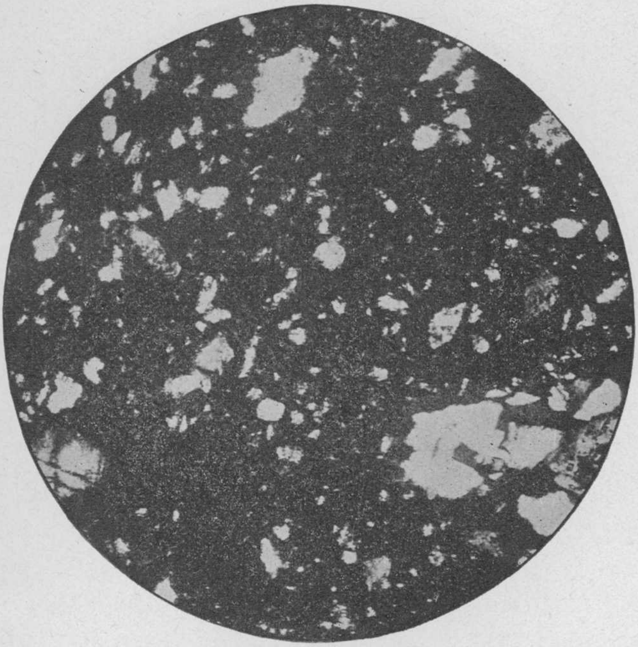
If it is not fluxed, kaolinite appears to retain its shape and at least a part of its original interference color. Tourmaline and probably epidote disappear even at 1,150° C., but rutile, zircon, and probably titanite seem to be unaffected even at 1,300° C. The persistence of the rutile can be plainly seen even though the particles are very small.

Sillimanite was noticed in a white clay from Florida that was fired at 1,150° C. where the conditions happened to be just right for its development. (See Pl. XXX, *B*.) That it has formed from the large flakes of kaolinite or the low-grade hydromica is clearly indicated by one composite flake of the two minerals.



A. CLAY FROM PITT-ROWLAND MINE, OREANA, NEV.

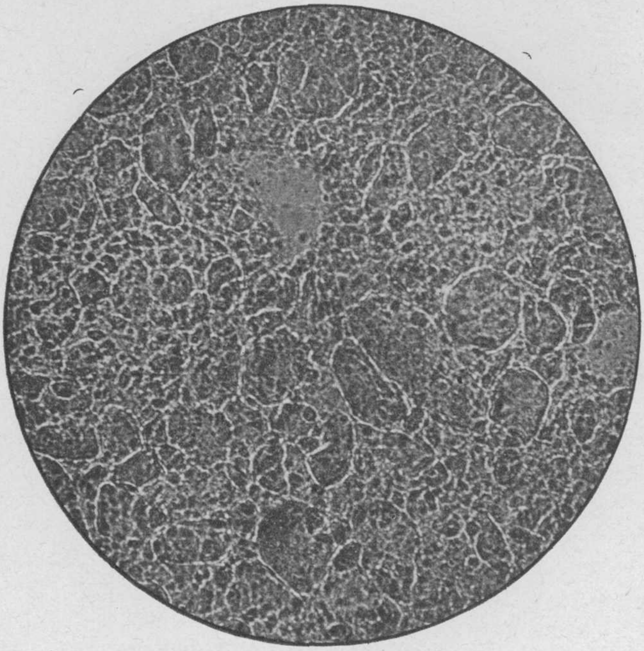
Section cut from a specimen of coarse-grained quartzose and sericitic clay fired at 1,150° C. The structure in the section is due to to numerous grains of sericite that show interference colors of kaolinite. Crossed nicols. × 110.



B. KAOLIN FROM MOUNT HOLLY SPRINGS, PA.

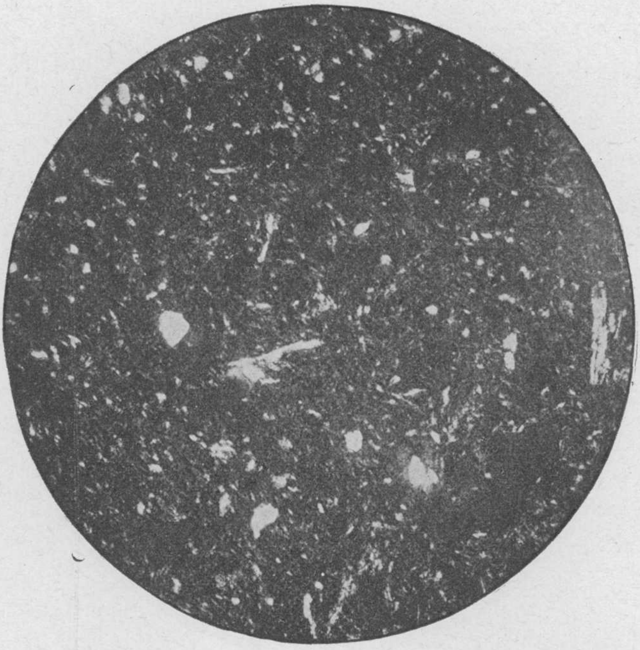
Section cut from a specimen fired at 1,150° C. The groundmass is mostly isotropic, with a few scales of kaolinite and grains of quartz that show corrosion. × 51.

PHOTOMICROGRAPHS OF SPECIMENS OF CLAY.



A. RESIDUAL CLAY FROM BEATTY, NEV.

Shows scales of halloysite (?). × 110.



B. BURNED WHITE SEDIMENTARY CLAY FROM FLORIDA.

Section cut from a specimen fired at 1,150° C. The groundmass is mostly isotropic but shows a few grains of quartz and needles of sillimanite. Crossed nicols. × 110.

PHOTOMICROGRAPHS OF SPECIMENS OF CLAY.

The actual cause of its development is not evident, for other clays that contain similar micaceous flakes and that were burned at the same time do not show the sillimanite in the burned product.

This development of sillimanite by burning and its possible abundance in porcelain[41] may serve to explain a feature that was noted in some of the other clays, when a double refraction was produced in the groundmass of these clays by burning to higher temperatures. This double refraction is very probably caused by particles too minute to be easily recognizable, and the development of the interference color may be due to the formation of sillimanite. The single and double refractions of the material would not be evidence against this supposition, and the only evidence for it is that of analogy.

In the sections where sillimanite was actually determined it is present in the form of slender crystals of fair size and can be distinguished with certainty by its moderate relief, low interference, optical character, and cross fractures.

The following table gives a summary of the features shown by a number of the thin sections. These features are worth recording, although the series is not sufficiently large to warrant definite conclusions. For further comparison the table also gives the texture of the clay, the relative abundance of the chief constituents, and the porosity after burning.

[41] Klein, A. A., The constitution and microstructure of porcelain: Am. Ceramic Soc. Trans., vol. 18, p. 377, 1916.

Petrographic character of burned clays.

[C, common: A, abundant; VA, very abundant; S, scarce.]

Locality.	Texture.	Quartz.	Hydromica.	Kaolinite.	Rutile.	Temperature. 1,150° C. Porosity (percent).	1,150° C. Appearance.	1,300° C. Porosity (percent).	1,300° C. Appearance.
Kaolin from Lutesville, Mo.	Medium	C	A	A	S	14.4	Fine texture; in part isotropic, in part shows interference color of kaolinite.	0.8	Little different from that at 1,150° C.
Saylorsburg, Pa.: Kaolin	Medium	C	A	A	S	21.9	....	.5	Quartz in slightly felted groundmass, some of it isotropic; rutile still visible.
Washed kaolin	Medium to fine	C	A	A	A	5.9	Fine granular aggregate; some hydromica and some isotropic material.	.4	Fine granular aggregate; hydromica gone; more isotropic material.
Crude kaolin	Medium to fine	C	C	A	A	31.2	Granular, slightly matted ground mass; color of hydromica gone; some isotropic material.	2.9	More isotropic material; rutile persists.
Mount Holly Springs, Pa.: Crude kaolin	Medium	C	C	A	S	10	Hydromica gone; groundmass mostly isotropic; shows some interference colors of kaolinite. (See Pl. XXIX, *B*.)	2	More isotropic material.
Washed kaolin	Fine	C	C	VA	A	19.5	Hydromica gone; some isotropic material.	3.4	More isotropic material; rutile persists.
Kaolin from Pitt-Rowland mine, Oreana, Nev.	Coarse	A		A	S	51.1	Most of the mica shows interference color of kaolinite except in center; some isotropic material. (See Pl. XXIX, *A*.)	30.8	Interference color of mica practically all gone; more isotropic material.
Kaolin from Adamson-Dickson property, Lovelocks, Nev.	Medium	A	....	A	S	48.9	Not much different in appearance from unburned clay.	45.2	Not much different in appearance from unburned clay.
Kaolin from Beatty, Nev. (Mostly halloysite).	Fine	....	....	S	S	58.2	Fine fibrous aggregate, interference color just beginning to show.	36.9	Same appearance as that at lower temperature, but interference color has increased.

Sagger clay from Hollow Rock, Tenn.	Medium......	C	A	A	A	....	....	9.1	Micaceous texture remains; interference color of hydromica gone; groundmass shows mostly interference color of kaolinite and very little isotropic material.
White granular sedimentary clay from Andersonville, Ga.	Very fine......	....	C	A	S	43.7	Fine granular aggregate; about half the material is isotropic and half shows interference color of kaolinite.	33.1	Appearance similar to that at the lower temperature except that it is beginning to develop mottled patches of low interference color.
Clay from Benton, Ky........	Medium to fine.	C	A	A	A	....	....	24.5	Hydromica all gone; quartz grains in mostly isotropic groundmass; a few low interference colors.
Clay from Enid, Miss..........	Medium......	C	VA	S	S	....	....	.6	Very fine, dense felty aggregate; shows low interference color; possibly sillimanite.
Clay from Holly Springs, Miss..	Fine..........	C	A	A	C	22.6	Hydromica gone; quartz in fine felty groundmass, composed in part of isotropic material and in part of material that shows low interference color.	13	Similar appearance to that at lower temperature.
Clay from mine of Mayfield Clay Co., Pryorsburg, Ky.	Medium to fine.	C	A	A	A	30	Color of hydromica gone; quartz in fine-grained groundmass, composed in part of isotropic material and in part of material that shows low interference color.	24	Increase in isotropic material; rutile visible.
White clay from Dry Branch, Ga.	Fine.........	S	C	VA	S	40.0	Fine-grained mass.............	27.6	Fine-grained mass; shows low interference color throughout.
Washed white clay from Florida.	Medium to fine.	S	A	A	S	38	Fine-grained groundmass, composed of much isotropic material, and small flakes that show low interference color. (See Pl. XXX, *B*.)	26.1	Felty aggregate; shows more interference color of low order; some of the larger flakes of mica are changed to sillimanite.

PREVIOUS WORK ON BURNED CLAY.

Microscopic studies of burned-clay wares, chiefly porcelains, have been made by a number of investigators, but much less of this work has been done on the clays alone.

After heating a refractory clay at white heat for 72 hours, Vernadsky[42] observed the presence of small crystallites, which were optically positive and showed an extinction parallel to the prismatic axis. They were insoluble in cold concentrated hydrofluoric acid.

After studying the changes in clay on heating, Glasenapp[43] came to the conclusion that all clays dissociate at a sufficiently high temperature into a glassy groundmass and a crystalline portion and that their disassociation increases with increasing temperature and duration of burning. He considered the glassy groundmass to be richer in silica and the crystalline material to be richer in alumina.

Klein[44] experimented with samples of kaolin from North Carolina and from England. The sample from North Carolina showed kaolinitic material as its chief constituent and also much sericite. The sample from England was similar but showed more sericitic mica.

Both samples were heated for five hours at 600°, and for two hours each at 900°, 1,100°, 1,200°, 1,300°, 1,400°, 1,450°, and 1,500° C. Klein reports the results of his microscopic examination after each of these burns as follows:

> As soon as the water of combination was driven off, the kaolinitic material became entirely isotropic, but the index of refraction altered to only a slight extent. Then there was no profound change noted in the optical properties until the temperature of burning reached upward of 1,200°. At this point there was noted a beginning of an incipient dissociation of the kaolinitic material, which became manifest by the formation in very small amounts of two isotropic substances, one of which had an index lower than 1.50 and the other had an index higher than 1.60. They were extremely intergrown and showed no attempt toward crystal form.
>
> The dissociation remained incipient until a burning temperature of 1,400° was reached, when a complete dissociation occurred and the two isotropic compounds noted above were formed. The higher refracting isotropic material showed no crystalline development but occurred as extremely minute, almost submicroscopic, irregular to rounded grains, intimately intergrown with the lower refracting product of dissociation.

There were also a few aggregates of thin prismatic crystals, which were apparently isotropic and of greater index than 1.60.

Between 1,400° and 1,450° C. nearly all the higher refractory isotropic grains showed a prismatic development, an index of about 1.64, biaxial interference figures, and an optically positive character.

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[42] Vernadsky, W., Soc. franç. minéralogie Bull., vol. 13, p. 256, 1890.

[43] Glasenapp, M., Ueber Aenderungen der Mikrostruktur der Tone durch Einwirkung hoher Hitzegrade: Tonindustrie Zeitung, vol. 31, p. 1167, 1907.

[44] Klein, A. A., The constitution and microstructure of porcelain: Am. Ceramic Soc. Trans., vol. 18, p. 377, 1916.

These grains were thought to be sillimanite, and Klein believes that the higher refracting amorphous material previously mentioned is an amorphous phase of sillimanite, which resulted from the dissociation of the kaolinite molecule "before there is sufficient mobility for molecular orientation in any definite crystalline form."

Even in burning mixtures of clay, quartz, and feldspar the needles of sillimanite occurred only to a very slight extent between 1,250° and 1,275° C. and below this temperature not at all.

In commenting on Klein's results, Mellor[45] claims that crystals of sillimanite can develop abundantly in bodies which have not reached 1,200° C., and he considers the time factor an important conditioning variable. In other words, in an extended period of time work can be done which could also be done at a higher temperature in a shorter period of time.

Mellor also states that there is evidence to show that the crystals develop much more freely in some mixtures than in others which contain the same constituents in different proportions and compounded in different ways.

The results obtained by Klein do not agree with those reached by the writer, for in the specimens studied by the writer the hydromica became isotropic at as low a temperature as 1,150° C., but the kaolinite did not.

The writer's results are, however, somewhat in agreement with Klein's, so far as the slight formation of sillimanite is concerned.

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[45] Mellor, J. W., Can the firing temperature of a body be determined from the microscopic appearance?: Eng. Ceramic Soc. Trans., vol. 16, pt. 1, p. 71, 1917.

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