CLAYS

THEIR OCCURRENCE, PROPERTIES, AND USES

WITH ESPECIAL REFERENCE TO THOSE OF
THE UNITED STATES

BY

HEINRICH RIES, Ph.D.
Professor of Economic Geology in Cornell University; Fellow Geological Society of America;
Member American Ceramic Society; Member American Institute of Mining Engineers;
Author of "Economic Geology of the United States"

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PREFACE TO SECOND EDITION

Although a comparatively short time has elapsed since the appearance of the first edition, so much new material of importance relating to clay has appeared that it has been deemed advisable to incorporate as much of this as possible in the second edition. These additions occur mainly in the chapters on Occurrence, Properties, and Geographic Distribution. An endeavor has also been made to correct any typographical errors which the first edition contained.

Since the work is not one treating in detail of the manufacture of clay products, this part of the work has not been enlarged; indeed, it was included originally simply for the purpose of giving a brief idea of the processes which clays had to pass through in their conversion into ceramic products.

Acknowledgements are due to Messrs. E. C. Stover, Trenton, N. J.; H. A. Wheeler and L. Parker, St. Louis, Mo.; A. Hottinger, Chicago, Ill.; and W. H. Gorsline, of Rochester, N. Y., for criticisms of portions of the work.

H. R.

Cornell University, Ithaca, N. Y.
July, 1908.

PREFACE TO FIRST EDITION

FEW mineral products have, perhaps, been more extensively treated in the scientific and technical literature than clay, but the published facts are widely scattered, and many of them are not always easily accessible.

It has therefore seemed to the author that there is a demand for a comprehensive work on the subject, which may be of value to geologists, chemists, and others interested in clay and its applications.

As the title of the work indicates, the subject is treated mainly from the American standpoint, and in the preparation of it the author has drawn freely on his own published reports as well as those of others.

The arrangement of the subject-matter of the State descriptions by geologic formations has been selected as permitting the greatest uniformity of treatment, and those desiring to look up the distribution of any one kind of clay can easily do so by reference to the Index.

Credit for information is usually given in foot-notes; but where some particular report has been freely drawn upon, this is indicated by a parenthesis containing the number of the reference in the bibliography following each State.

The author wishes to express his thanks to Dr. G. P. Merrill of the United States National Museum for many helpful suggestions received during the course of his work; and to Mr. S. Geijsbeek of Seattle, Wash., for assistance rendered during the compilation of the manuscript.

Acknowledgments are similarly due to Professors C. S. Prosser and E. Orton, Jr., of Ohio State University; Prof. H. A. Wheeler and Mr. Lemon Parker of St. Louis, Mo.; Prof. I. A. Williams, Iowa Geological Survey; Dr. E. A. Smith, Alabama Geological Survey; Dr. G. P. Grimsley, West Virginia Geological Survey; Dr. W. B. Clark, Maryland Geological Survey; Dr. D. H. Newland, New York Geological Survey; Dr.

H. B. Kummel, New Jersey Geological Survey; and Mr. H. Leighton, Cornell University. Dr. W. B. Phillips, former State Geologist of Texas, has kindly given the author permission to publish the facts relating to that State.

For the loan of cuts the writer is indebted to the American Clay Machinery Co., Bucyrus, Ohio; Chambers Brothers Co., Philadelphia, Pa.; Henry Martin Machine Co., Lancaster, Pa.; and Bergstrom & Bass, Brooklyn, N. Y. Many others have kindly loaned photographs, and to each of these acknowledgment is made under the respective illustrations.

CORNELL UNIVERSITY, ITHACA, N. Y.,
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LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS USED

Amer. Geol. = American Geologist.
Amer. Jour. Sci. = American Journal of Science.
Ann. des Mines = Annales des Mines de Paris.
Böhm. Ges. Wiss. = Böhmische Gesellschaft für Wissenschaften.
Bull. Geol. Soc. Amer. = Bulletin Geological Society of America.
Comptes rend. = Comptes rendus de la Académie des Sciences de Paris.
Dingl. polyt. Jour. = Dingler's Polytechnisches Journal.
Jour. Geol. = Journal of Geology.
Jour. prak. Chem. = Journal für praktische Chemie.
Min. Mag. = Mineralogical Magazine.
Min. Tasch. = Mineralogisches Taschenbuch.
Naturhist. Ver. Bonn = Naturhistorischen Vereins Bonn.
Neues Jahrb. = Neues Jahrbuch für Mineralogie, Geologie und Palæontologie.
Pogg. Ann. = Poggendorfs Annalen.
Phil. Trans. = Philosophical Transactions.
Quart. Jour. Chem. Soc. = Quarterly Journal of the Chemical Society of London.
Royal Agric. Soc. Jour. = Journal of the Royal Agricultural Society of London.
Seger Ges. Schrift. = Seger's Gesammelte Schriften.
Syst. Min. = Dana's System of Mineralogy.
Tscherm. Mitth. = Tschermak's Mineralogische und Petrographische Mittheilungen.
Trans. Amer. Ceram. Soc. = Transactions American Ceramic Society.
Trans. Amer. Inst. Min. Eng. = Transactions American Institute Mining Engineers.
Trans. Eng. Cer. Soc. = Transactions English Ceramic Society.
Trans. N. Y. Acad. Sci. = Transactions New York Academy of Sciences.
Zeitschr. anorg. Chem. = Zeitschrift für anorganische Chemie.
Zeitschr. d. d. Geol. Ges. = Zeitschrift der deutschen Geologischen Gesellschaft.
Zeitschr. f. Kryst. u. Min. = Zeitschrift für Krystallographie und Mineralogie.
Zeitschr. prak. Geol. = Zeitschrift für praktische Geologie.

CLAYS

THEIR OCCURRENCE, PROPERTIES, AND USES

CHAPTER I

ORIGIN OF CLAY

Definition.—Clay is the term applied to those earthy materials occurring in nature whose most prominent property is that of plasticity when wet. On this account they can be molded into almost any desired shape, which is retained when dry. Furthermore, if heated to redness, or higher, the material becomes hard and rock-like. Physically, clay is made up of a number of small particles mostly of mineral character, ranging from grains of coarse sand to those which are of microscopic size, or under one one-thousandth of a millimeter in diameter. Mineralogically, it consists (1) of many different mineral fragments, some of them fresh, but others in all stages of decay, and representing chemically many different compounds, such as oxides, carbonates, silicates, hydroxides, etc.; (2) of colloidal material which might be of either organic or mineral character.[1]

These points are discussed in more detail, however, on a later page (see Minerals in Clays, Physical properties and Chemical composition).

Weathering processes involved.—Clays are always of secondary origin and result primarily from the decomposition of other rocks, very frequently from rocks containing feldspar, so that for this reason many writers have intimated that it was always derived from feldspathic rocks. There are some rock species, however, that contain no feldspar (such as serpentine), and others with very little (as some gabbros), which, on weathering, produce some of the most plastic clays known.

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[1] H. Ries, Md. Geol. Surv., IV, 251, 1902; A. S. Cushman, Jour. Amer. Chem. Soc., XXV, 5.

In order to trace the changes occurring in the formation of clay we may take the case of a rock like granite.

When such a mass of rock is exposed to the weather, minute cracks are formed in it, due to the rock expanding when heated by the sun and contracting when cooled at night, or they may be joint planes formed by the contraction of the rock as it cooled from a molten condition. Into these cracks the rain-water percolates and, when it freezes in cold weather, it expands, thereby exerting a prying action, which further opens the fissures, or may even wedge off fragments of the rock. Plant-roots force their way into these cracks, and, as they expand, supplement the action of the frost, thus further aiding in the breaking up of the mass. This process alone, if kept up, may reduce the rock to a mass of small angular fragments, or even a mass of sand.

The rock having been opened up by disintegrative forces, the silicates are next attacked by the surface-waters, although those exposed on the surface of the stone may already have begun to change.

It has usually been supposed that the decomposition of the silicates in the rock, such as feldspar, is caused chiefly by the dissolved carbon dioxide, which is probably always present in the percolating waters, and this view was advanced by Forschammer as early as 1835,[1] as well as by other writers later;[2] but, as pointed out by Cameron and Bell,[3] this is very doubtful, in view of the fact that many of the minerals found in rocks are known to be soluble in water alone, although their solution may take place but slowly. The water, moreover, is believed to react with or hydrolyze them, as is shown by the fact that an alkaline reaction can be obtained with phenolphthalein, after treating powdered minerals with water free from dissolved carbon dioxide.

The rate of solubility varies, of course, with the different minerals, the magnesium-bearing micas being more soluble than muscovite, and albite more so than orthoclase, with oligoclase between.[4] Clarke [5] found that muscovite, lepidolite, phlogopite, orthoclase, oligoclase, albite, leucite nephelite, cancrinite spodumene, scapolite, and many zeolites, all dissolve in water, giving an alkaline reaction, and the same has been shown of others.[6]

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[1] Pogg. Ann., XXXV, p. 331, 1835.

[2] Rogers, Amer. Jour. Sci., V, p. 404, 1848; Bischof, Naturhist. Ver. Bonn, XII, p. 308, 1855; Daubrée, Compt. ren., LXIV, p. 339, 1867; Miller, Tscherm. Mitth., 1877, p 31.

[3] Bur. of Soils, Bull. 30, p. 16, 1905; also Cushman and Hubbard, Bull. 28, Office of Public Roads, Washington.

[4] Merrill, Rocks, Rock-weathering and Soils, p. 234, 1897.

[5] U. S. Geol. Surv., Bull., 167, p. 156, 1900.

[6] See Bull. 30, Bur. of Soils, for numerous references on this subject; also H. Stremme, Zeitschr. prak. Geol., XVI, p. 122.

The action of water on orthoclase is assumed to be somewhat according to the following formula[1]:

$$KAlSi_3O_8 + HOH = KOH + HAlSi_3O_8.$$

The potassium hydrate thus formed may unite with carbon dioxide to form either a carbonate or bicarbonate of potash, or it is possible that it may unite with other acids, forming salts more soluble than the orthoclase in the hydrolyzed acid.

The $HAlSi_3O_8$ formed is apparently unstable, and may lose some of its quartz, resulting in the formation of kaolinite, pyrophyllite, or diaspore, but the first of these appears to be more commonly formed in the weathering of feldspar.

Kaolinization.—This alteration of the feldspar is termed *kaolinization*, and the mineral kaolinite is always of secondary character. The changes which take place in the alteration of several species of feldspar may be given as follows:

	SiO_2	Al_2O_3	K_2O	H_2O	%
Orthoclase	64.86	18.29	16.85	.....	100.00
Lost	43.24	.....	16.85	.....	60.09
Taken up	.....	.....	.....	6.45	6.45
Kaolinite	21.62	18.29	.....	6.45	46.36

	SiO_2	Al_2O_3	Na_2O	H_2O	%
Albite	68.81	19.40	11.79	.....	100.00
Lost	45.87	.....	11.79	.....	57.66
Taken up	.....	.....	.....	6.85	6.85
Kaolinite	22.94	19.40	.....	6.85	49.10

	SiO_2	Al_2O_3	CaO	H_2O	%
Anorthite	43.30	36.63	20.07	.....	100.00
Lost	.....	.....	20 07	.....	20.07
Taken up	.....	.....	.....	12.92	12.92
Kaolinite	43.30	36.63	.....	12.92	92.85

It will be seen from this that both the orthoclase and plagioclase might yield kaolinite; in fact the plagioclase varieties decompose more readily than orthoclase.[2]

Vogt[3] has recorded an occurrence of kaolin near Jösingfjord, at Eker-

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[1] Cameron and Bell, l. c., p. 18.

[2] Ries, Kaolins and fire-clays of Europe, U. S. Geol. Surv., 19th Ann. Rept., pt. VI (ctd.), p. 377, 1898; Leimberg, Zeitsch, d. d. Geol. Ges., Vol. 35, 1883; Rösler, Neues Jahr., Beil. Bd. XV, 2d Heft, p. 231.

[3] Amer. Inst. Min. Eng., Trans., XXXI, p. 151, 1902.

sund-Soggendal, Norway, which is formed from labradorite, the different stages in the change being indicated by the following analyses:

	Labradorite.	Labradorite partly kaolinized.		Massive kaolin, more or less pure.					Kaolinite.
		I	II	I	II	III	IV	V	
Silica (SiO_2)	54.5	50.03	49.16	48.61	48.06	47.83	47.72	46.85	46.50
Alumina (Al_2O_3)	27.0	28.60	29.60	29.45	38.57	34.53	37.40	37.56	39.56
Iron oxide (Fe_2O_3)	2.5	1.62	1.88	3.40		1.70	1.59	1.00	
Lime (CaO)	9.0	4.21	3.47	.68	undet	.48	.23	tr.	
Magnesia (MgO)	1.0	2.95	1.67	.49		.59	.11	tr.	
Potash (K_2O)	1.0	1.00	undet.	undet.		undet	.44	undet	
Soda (Na_2O)	5.0						.76		
Water (H_2O)	....	11.90	13.63	16.38	12.95	13.76	11.66	14.44	13.94
Total	100.0	100.31	(99.41)	(99.01)	(99.58)	(98.89)	99.91	(99.85)	100.00

Prof. Vogt believes that the kaolinization here is due to the action of carbonic-acid waters, because calcite occasionally occurs with the kaolin. However, from what has been said on page 2, the presence of this mineral would not necessarily show that the acid above mentioned had assisted in the decomposition of the feldspar, but simply that it had united with the lime set free during the breaking up of the labradorite.

While it is probable that other silicates, such as hornblende or augite, yield a hydrous aluminum silicate, it is not known that it is kaolinite,[1] but their decomposition no doubt proceeds in a manner similar to that of feldspar.

Vogt,[2] on the other hand, states that hornblende, augite, beryl, topaz, etc., are known to be occasionally converted into kaolinite, but gives no evidence.

Quartz, although apparently resistent, is not left untouched, for it too is slightly soluble, but, aside from that originally present in the rock, silica may have been liberated during the decomposition of some of the silicates, such as feldspar.

It has been found that in soils, and the same may be said of clays, quartz has accumulated in relatively large proportions. It may be present as quartz, amygdaloidal silica, or perhaps other forms. There is, however, a tendency for it to be gradually changed over into other forms of quartz through solution and redeposition.[3]

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[1] Merrill, Rocks, Rock-weathering and Soils, p. 21, 1897.

[2] Problems in the Geology of Ore Deposits, Trans. Amer. Inst. Min. Eng., XXXI, p. 151, 1902.

[3] Hayes, Bull. Geol. Soc. Amer., VIII, p. 213, 1897, and Jour. Geol., V, p. 319, 1897.

While there is undoubtedly lack of absolute proof that other silicates than feldspar yield kaolinite, all clays appear to contain a variable amount of some hydrated silicate of aluminum, which may be present in some quantity, since it is a highly insoluble natural compound; and even though the statement is frequently made that this silicate is the mineral kaolinite, the fact is at times somewhat difficult of proof; indeed the evidence is clearly against it in some cases.

This hydrated aluminum silicate is sometimes referred to as the clay substance or clay base.[1]

Kaolinization by pneumatolysis.—Aside from the kaolinization of feldspar by the ordinary processes of weathering it seems possible, and even probable, that its decomposition may have been brought about by the action of mineralizing vapors, as at Cornwall, Eng., where it was found that the feldspar of the granite on both sides of the tin veins had been kaolinized. This change is attributed to the action of fluoric vapors, whose presence is pretty clearly indicated by the finding of such minerals as tourmaline and topaz.

That such a process is possible is shown by J. H. Collins,[2] who exposed feldspar to the action of hydrofluoric acid. The feldspar, according to Mr. Collins, was converted into hydrated silicate of alumina, mixed with soluble fluoride of potassium, while pure silica was deposited on the sides of the tube.

With such treatment the orthoclase yielded more readily than either albite or oligoclase. The following analyses show the effect of 96 hours' treatment of orthoclase with hydrofluoric acid at 60° F.:

	I.	II.	III.
Silica (SiO_2)	63.70	49.20	44.10
Alumina (Al_2O_3)	19.76	35.12	40.25
Potash (K_2O)	13.61	.12	.25
Soda (Na_2O)	2.26	tr.	tr.
Ferric oxide (Fe_2O_3)	.71	tr.	tr.
Water (H_2O)	tr.	14.20	15.01
	100.04	98.64	99.61

I is the original feldspar.
II is inner layer of altered feldspar.
III is outer layer of altered feldspar.

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[1] The term is now rather loosely used, however, and in impure clays includes practically all of the very finest particles.

[2] Min. Mag., 1887, VII, p. 213.

From the analysis it will be seen that the composition of the outer layer simply approximates that of kaolinite.

The artificial clay thus produced, when examined under the microscope, resembled washed kaolin. It showed no hexagonal scales, but contained a number of minute colorless cubes which are supposed to be fluorspar.

The theory advanced by Mr. Collins was earlier suggested by Von Buch and Daubrée.[1]

The former early observed the constant occurrence of kaolin with minerals containing fluorin, and suggested that the kaolin of Halle, Germany, owed its origin to hydrofluoric acid.[2]

Daubrée considered that the kaolin near St. Austell in Cornwall,[3] Central France, and the Erzgebirge must have had a similar origin.

The formation of kaolin by other causes than surface agencies has been referred to by B. von Inkey and Semper as a product of propylitization in some cases.[4] Cross and Penrose [5] have sought to suggest a pneumatolytic origin for the kaolin found in some of the Cripple Creek, Colo., mines, but Ransome and Lindgren [6] have rather disputed this.

If Mr. Collins' theory be correct, the kaolin deposits should extend to great depths, but if the kaolinization be due to weathering, then we should encounter undecomposed feldspar at the limit to which weathering has reached. In Cornwall the kaolin mines, which are probably the largest in the world, have reached a depth of over 400 feet without the kaolin giving out, while at Zettlitz in Bohemia a similar depth has been proven with the same result. The latter locality is one of thermal activity. In these two instances the theory just mentioned seems to be very reasonable. There are many localities, however, where the kaolin decreases with the depth, passing into the undecomposed feldspar, as is the case, for example, in North Carolina, where the fresh feldspar is met at a depth of 60 to 120 feet, in Pennsylvania, and also in Delaware. More recently Rösler [7] has advanced the view, on what seems to the writer rather insufficient evidence, that the kaolinization of feldspars is never

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[1] Annales des mines, XX, 1841.

[2] Min. Tasch., 1824. The writer can state from personal examination that the Halle kaolins were formed by ordinary weathering. E. Wüst, Zeitschr. prak. Geol., XV, p. 19, believes humic acid has played the main role in the kaolinization.

[3] Études synthétiques de Geologie Expérimentale, 1879.

[4] Nagyag u. seine Lagerstätten, Budapest, 1885.

[5] U. S. Geol. Surv., 16th Ann. Rept., Pt. II, p. 160.

[6] U. S. Geol. Surv., Bull. 254, p. 21, 1904.

[7] H. Rösler, Beiträge zur kenntniss der Kaolinlagerstätten, Neues Jahrb. f. Min., Geol. u. Pal., XV. Beilage-Band, 2d Heft, pp. 231–393.

due to atmospheric action, but to post-volcanic pneumatolytic and pneumato-hydatogenic processes.[1]

The very fact that many of our kaolins pass into undecomposed feldspar or feldspathic rock when the limit of weathering is reached shows the incorrectness of such a broad statement.[2]

Residual Clay

Where the clay is thus found overlying the rock from which it was formed, it is termed a residual clay, because it represents the residue of rock decay, and its grains are more or less insoluble.

If now a granite which is composed chiefly of feldspar decays under weathering action, the rock will be converted into a clayey mass, with quartz and mica scattered through it. Remembering that the weathering began at the surface and has been going on there for a longer period than in deeper portions of the rock, we should expect to find, on digging downward from the surface, (*A*) a layer of fully formed clay, (*B*) below this a poorly defined zone containing clay and some partially decomposed rock fragments, (*C*) a third zone, with some clay and many rock fragments, grading downward into the solid bed-rock. (Fig. 1.) In other words, there is usually a gradual transition from the fully formed clay at the surface into the parent rock beneath. The only exception to this is found in clays derived from limestone, where the passage from clay to rock is

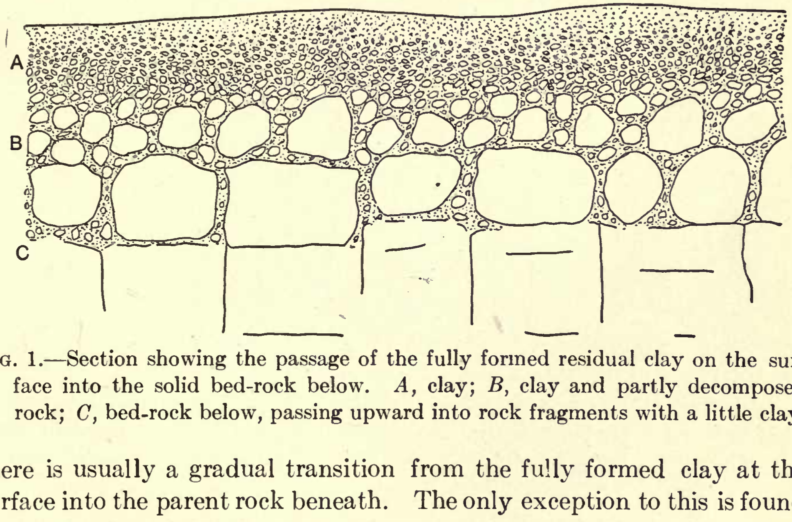

FIG. 1.—Section showing the passage of the fully formed residual clay on the surface into the solid bed-rock below. *A*, clay; *B*, clay and partly decomposed rock; *C*, bed-rock below, passing upward into rock fragments with a little clay.

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[1] See also E. Zalinski on the kaolinization of the granite of the turquoise deposits in New Mexico; Econ. Geol., II, p. 479, 1907; Stütze, Zeitschr. prak. Geol., XIII., p. 333, 1905.

[2] In this connection, see G. P. Merrill, What Constitutes a Clay, Amer. Geol. XXX, Nov. 1902, and H. Ries, Origin of Kaolin, Trans. Amer. Ceramic Soc., II, p. 93, 1900.

sudden. The reason for this is that the change from limestone into clay does not take place in the same manner as granite. Limestone consists of carbonate of lime, or carbonate of lime and magnesia, with a variable quantity of clay impurities, so that when the weathering agents attack the rock, the carbonates are dissolved out by the surface-waters, and the insoluble clay impurities are left behind as a mantle on the undissolved rock, the change from rock to clay being, therefore, a sudden one, and not due to a gradual breaking down of the minerals in the rock, as in the case of granite.

Kaolin.—A residual clay derived from a rock composed entirely of feldspar, or one containing little or no iron oxide, is usually white and therefore termed a *kaolin;* deposits of this type may contain a high percentage of the mineral *kaolinite,*[1] this being assumed because, after washing the sand out of such materials, the silica, alumina, and water in the remaining portion are in much the same ratios as in kaolinite, although, as previously mentioned, other aluminous silicates may at times be present.

A clay made up entirely of kaolinite is sometimes termed a "pure" clay, but since the term clay refers to a physical condition and not a definite chemical composition, it would perhaps be more correct to term kaolin the simplest form of clay.

There are clays made up almost entirely of other hydrous aluminum silicates than kaolinite, which are also termed kaolins, as the indianaite of Indiana, or the halloysite of Alabama.

A deposit of pure kaolinite has not thus far been found in nature though some very nearly pure occurrences are known. While the term kaolin is sometimes applied to any residual clay, the writer believes that this designation should be restricted to white-burning residual clays, a usage which is wide-spread but has not become universal. The name *kaolin* is a corruption of the Chinese *Kauling,* which means *high ridge,* and is the name of a hill near Jauchau Fu, where the mineral is obtained.[2]

In this connection it is interesting to note that, according to Richthofen,[3] the rock from which the King-te-chin porcelain is made is not true kaolin, but a hard jade-like greenish rock which occurs between beds of slate. He states: "This rock is reduced, by stamping, to a white powder, of which the finest portion is ingeniously and repeatedly sep-

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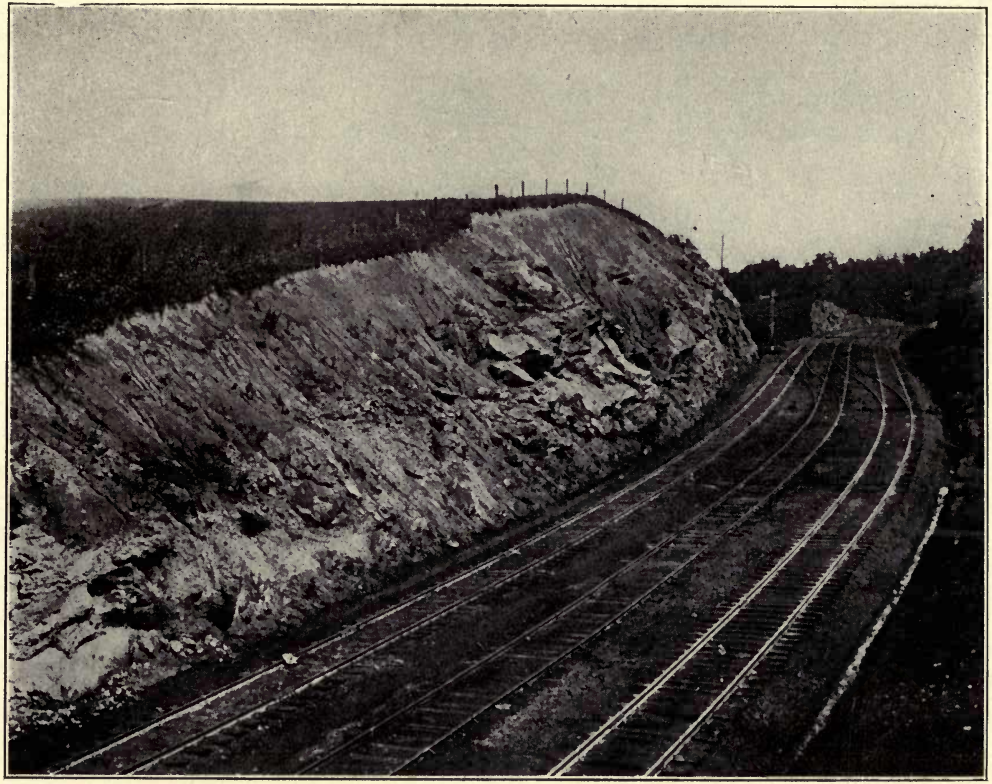
[1] The terms *kaolinite,* referring to the mineral, and *kaolin,* referring to the rock mass, are often carelessly confused even by scientific writers, although there seems to be little excuse for so doing.

[2] Dana, System of Min., 1892, p. 687.

[3] Amer. Jour. Sci., 1871, p. 180.

PLATE I



Residual clay at Christiansburg, Va.; shows the uneven character of the underlying parent limestone. (Photo by H. Ries.)

arated. This is then molded into small bricks. The Chinese distinguish chiefly two kinds of this material. Either of them is sold in King-te-chin in the shape of bricks, and as either is a white earth, they offer no visible differences. They are made at different places, in the manner described, by pounding hard rock, but the aspect of the rock is nearly alike in both cases. For one of these two kinds of material the place Kaoling ('high ridge') was in ancient times in high repute, and, though it has lost its prestige since centuries, the Chinese still designate by the name 'Kaoling' the kind of earth which was formerly derived from there, but is now prepared in other places. The application of the name by Berzelius to porcelain *earth* was made on the erroneous supposition that the white earth which he received from a member of one of the embassies (I think Lord Amherst) occurred naturally in this state. The second kind of material bears the name Pe-tun-tse ('white clay')."

The following analyses[1] show the average composition of (I) the natural material from King-te-chin, such as is used in the manufacture of the finest porcelain; (II) that from the same locality used in the so-called blue Canton ware; (III) that of the English Cornwall stone; (IV) washed kaolin from St. Yrieux, France; and (V) washed kaolin rom Hockessin, Del.

	I.	II.	III.	IV.	V.
Silica (SiO_2)	73.55	73.55	73.57	48.68	48.73
Alumina (Al_2O_3)	21.09	18.98	16.47	36.92	37.02
Ferric oxide (Fe_2O_3)	.....	.....	.27	.....	.79
Lime (CaO)	2.55	1.58	1.17	.....	.16
Magnesia (MgO)	.15	1.08	.21	.52	.11
Potash (K_2O)	.....	.46	5.84	.58	.41
Soda (Na_2O)	.....	2.09			.04
Water (H_2O)	2.62	1.96	2.45	13.13	12.83
Total	99.62	99.70	99.98	99.83	100.00

The above analyses show a most striking difference between the two washed kaolins and the Chinese clay and Cornwall stone.

Form of residual deposits.—The form of a residual clay deposit, which is also variable, depends on the shape of the parent rock. Where the residual clay has been derived from a great mass of granite or other clay-yielding rock, the deposit may form a mantle covering a considerable area. On the other hand, some rocks, such as pegmatites (feldspar and quartz), occur in veins, that is, in masses having but small width as compared with their length, and in this case the outcrop of residual clay along the surface will form a narrow belt.

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[1] G. P. Merrill, Non-metallic Minerals, p. 224, 1904.

Clay derived from a rock containing much iron oxide will be yellow red, or brown, depending on the iron compounds present. Between the white clays and the brilliantly colored ones others are found representing all intermediate stages, so that residual clays vary widely in their color.

The depth of a deposit of residual clay will depend on climatic conditions, character of the parent rock, topography, and location. Rock decay proceeds very slowly, and in the case of most rocks the rate of decay is not to be measured in months or years, but rather in centuries. Only a few rocks, such as some shales or other soft rocks, change to clay in an easily measurable time. With other things equal, rock decay proceeds more rapidly in a moist climate, and consequently it is in such regions that the greatest thickness of residual materials is to be looked for. The thickness might also be affected by the character of the parent rock, whether composed of easily weathering minerals or not. Where the slope is gentle or the surface flat, much of the residual clay will remain after being formed, but on steep slopes it will soon wash away.

In some cases the residual materials are washed but a short distance and accumulate on a flat or very gentle slope at the foot of the steeper one, forming a deposit not greatly different from the original ones, although they are not, strictly speaking, residual clays.[1]

Distribution of residual clays.—Residual clays, usually of ferruginous character, are found in many portions of the United States, but reach their maximum development in that portion lying east of the Mississippi and south of the southern margin of the ice-sheet of the glacial epoch.

North of the terminal moraine they are found only in protected situations (Fig. 2) or non-glaciated areas. Thus, for example, an important area of residual clay, derived from limestone, is found in the driftless area of Wisconsin.[2] This is a silty clay in its upper part, and a tough jointed clay below, while scattered through it are numerous cherty fragments.

A second type of residual clay occurring in Wisconsin is that found underlying the Potsdam sandstone and has been derived from the pre-Cambrian crystallines. It represents probably the geologically oldest residual clay found in the United States.

The general character of these residuals is much the same whatever the parent rock. Nearly all are ferruginous, and contain angular mineral particles, as well as more or less decomposed ones, from which the more soluble constituents have been leached out. The colors range usually from brown or red to yellow. In the Piedmont and Appalachian areas

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[1] *Colluvial deposits* of G. P. Merrill.

[2] Chamberlin and Salisbury, 6th Ann. Rep. U. S. Geol. Surv., p. 240, 1885.

of the Southern States they often attain great thickness and are widely used for brickmaking.[1] In rare cases they are formed from rocks running low in iron, such as pegmatite veins, and then the clay is whitish in color.

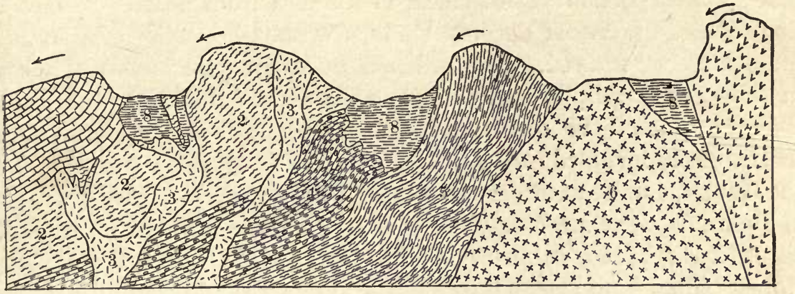

FIG. 2.—Generalized section showing three possible occurrences of kaolin in a glaciated country. 1, limestone; 2, mica schist; 3, pegmatite; 4, feldspathic quartzite; 5, dark gneiss; 6, light granite; 7, dark granite; 8, kaolin, protected from glacial erosion. Arrow indicates direction of ice-movement. (After Laughlin, Conn. Geol. and Nat. Hist. Surv., Bull. 4, p. 70, 1905.)

The following analyses [2] represent the composition of several residual clays:

ANALYSES OF RESIDUAL CLAYS

Constituents	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	71.13	49.90	53.09	49.13	55.42	40.127	39.55	66.27	77.24	55 39
Al_2O_3	12.50	18 64	21.43	20.08	22.17	13.75	28.76	15.25	26.17	20 16
Fe_2O_3	5 52	17.19	8 53	11.04	8.30	12.315	16 80	6.97	7 76	8 79
FeO	.45	.27	.86	.93						
TiO_2	.45	.28	.16	.13	.....	.....	.64	.....	.....	.....
P_2O_5	.02	.03	.03	.04	.....	626	.10	.07	.14	.04
MnO	.04	01	.03	06	.....	.....	.....	.....	.....	.....
CaO	.85	93	95	1 22	.15	3.518	.37	.24	.18	51
MgO	38	.73	1.43	1 92	1.45	.479	.59	43	.38	1 27
Na_2O	2.19	.80	1 45	1.33	17	.006	tr.	.40	.29	79
K_2O	1 61	.93	.83	1.60	2.32	118	tr.	.86	4.41	4 03
H_2O	*4.63	*10 46	*10 79	*11 72	*9.86	†27.441	13.26	8.2	.....	7.38
CO_2	.43	.30	.29	39	.....	2.251	.....	.....	.....	.....
C	.19	.34	22	1 09	.....	.....	.....	.....	.....	.....
	100.39	100 50	100.09	100.68	99 84	100.631	100 07	98.69	99.27	98.30

* Contains hydrogen and organic matter. Dried at 100° C.
† Contains 11.21 per cent of organic matter.

Nos. I, II, III, and IV are limestone residuals from southern Wisconsin. Nos. I and II are from the same vertical section, I being 4½ feet from the surface, and II 8½, and in contact with the underlying lime-

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[1] G. P. Merrill, Rocks, Rock-weathering, and Soils, p. 301; I. C. Russell, U. S. Geol. Surv., Bull. 52, 1884–85; H. Ries, U. S. Geol. Surv., Prof. Pap. 11.

[2] G. P. Merrill, Rocks, Rock-weathering, and Soils, p. 306.

stone. Nos. III and IV are similarly related, III being 3 feet from the surface, and IV 4½ feet, the lower sample lying on the unchanged rock. "The larger percentages of silica, in samples from nearest surface, are due to higher state of decomposition, the soluble portions having been more largely removed. The presence of larger percentages of alkalies in these same samples indicates that these salts existed in the form of silicates which have resisted the decomposing influences, and remain mechanically included in the residues." No. V represents a residual from the Knox dolomite at Morristown, Ala.; VI is a red earth formed by decay of Bermuda coralline limestone; VII is a diabase residual from Wadesboro, N. C.; VIII a gabbro subsoil from Maryland; IX a Trenton limestone residual from Hagerstown, Md.; and X a Triassic limestone residual.

The texture of some of the above residual soils has been determined as follows[1]:

MECHANICAL ANALYSES OF RESIDUAL CLAYS

Diameter of particles, mm.	Name.	I.	II.	III.	IV.	V.
2–1	Fine gravel........	.54	.17	.00	.00	.19
1–.5	Coarse sand.......	.32	.00	.23	.26	1.80
.5 –.25	Medium sand......	.72	.15	1.29	.18	3.12
.25 –.1	Fine sand.........	.62	.25	4.03	.66	6.96
.1 –.05	Very fine sand.....	4.03	2.34	11.57	6.73	8.76
.05 –.01	Silt...............	36.02	19.04	38.97	47.32	34.92
.01 –.005	Fine silt..........	14.99	20.88	8.84	10.04	12.14
.005–.0001	Clay..............	41.24	51.77	32.70	34.90	28.82
	Total mineral matter	88.48	94.60	97.63	94.44	96.71
	Org. matter, water, loss............	1.52	5.40	2.37	5.56	3.29
		100.	100.	100.	100.	100.

TRANSPORTED CLAYS

Sedimentary clays

Origin.—As mentioned above, residual clays rarely remain on steep slopes, but are washed away by rain-storms into streams and carried off by these to lower and sometimes distant areas. By this means residual clays possibly of different character may be washed down into the same stream and become mixed together. This process of wash and transportation can be seen in any abandoned clay bank, where the clay of the slopes is washed down and spread out over the bottom of the pit.

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[1] M. Whitney, Maryland Agricult. Exper. Sta., Bull. 21, 1893.

PLATE II

FIG. 1.—Section showing beds of stratified clay overlain by glacial drift. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 440.)

FIG. 2.—Bank of clay showing white sand on right, passing into a black clay on the left. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 12, 1904.)

As long as the stream maintains its velocity it will carry the clay in suspension, but if its velocity be checked, so that the water becomes quiet and free from currents, the particles begin to settle on the bottom, forming a clay layer of variable extent and thickness. This may be added to from time to time, and to such a deposit the name of sedimentary clay is applied. All sedimentary clays are stratified or made up of layers, this being due to the fact that one layer of sediment is laid down on top of another (Plate II, Fig. 1). If there were absolutely no difference in the character of the material deposited, it would form one thick homogeneous bed, but there is usually more or less variation, a layer of very fine material being laid down at one time and a layer of coarser material on top of it, or vice versa. These layers may also vary in thickness, and since there is less cohesion between unlike particles, the two layers will tend to separate along their line of contact.

As the finer material can only be deposited in quiet water, and coarse material in disturbed waters, so from the character of the deposit we can read much regarding the conditions under which it was formed. If, therefore, in the same bank alternating layers of sand, clay, and gravel are found, it indicates a change from disturbed to quiet water, and still later rapid currents over the spot in which these materials were deposited. The commonest evidence of current deposition is seen in the cross-bedded structure of some sand beds where the layers dip in many different directions, due to shifting currents which have deposited the sand in inclined layers. The beds of thinly stratified or laminated sands and clays found in many of the Cretaceous and Tertiary deposits of the coastal plain are another example of rapid changes in the conditions of deposition.

Sedimentary clays can be distinguished from residual clays chiefly by their stratification, and also by the fact that they commonly bear no direct relation to the underlying rock on which they may rest.

Structural irregularities in sedimentary clays.—All sedimentary clays resemble each other in being stratified, but, aside from this, they may show marked irregularities in structure.

Thus, any one bed, if followed from point to point, may show variations in thickness, pinching or narrowing in one place and thickening or swelling in others, as shown in Fig. 3.

In digging clay the miner often finds streaks of sand extending through the deposit and cutting through several different layers, these having been caused by the filling of channels cut in the clay deposits by streams after the elevation of the former to dry land. Occasionally a bed of clay may be extensively worn away or corraded by currents subsequent to its deposition, leaving its upper surface very uneven, and on this an entirely different kind of material may be deposited, covering the earlier bed, and filling the depressions in its surface. If the erosion has been deep, adjoining pits dug at the same level may find clay in one case and sand in the other (Fig. 4). Such irregularities are known to occur in both clays and shales.

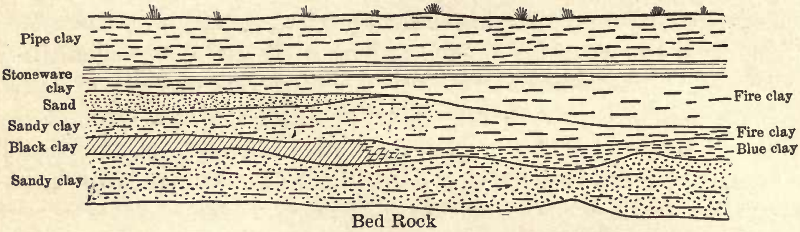

FIG. 3.—Generalized section showing how beds may vary both horizontally and vertically.

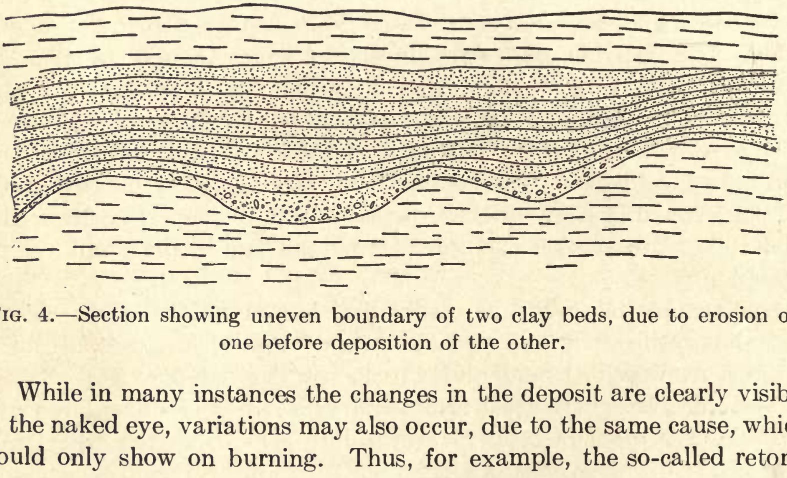

FIG. 4.—Section showing uneven boundary of two clay beds, due to erosion of one before deposition of the other.

While in many instances the changes in the deposit are clearly visible to the naked eye, variations may also occur, due to the same cause, which would only show on burning. Thus, for example, the so-called retort-clay, found in the Woodbridge region of New Jersey, is similar in its plastic qualities wherever found, but the shrinkage of that found in the different pits is not always the same, because it varies in fineness from place to place. It may also vary in color.

CLASSIFICATION OF SEDIMENTARY CLAYS

The general character of sedimentary clays is more or less influenced by the locality and conditions of deposition, which enables us, therefore, to divide them into the following classes:

Marine clays.—This class includes those sedimentary clays deposited on the ocean bottom, where the water is quiet. They have, therefore, been laid down at some distance from the shore, since nearer the land, where the water is shallower and disturbed, only coarser materials can be deposited. Beds of clay of this type may be of vast extent and great thickness, but will naturally show some variation, horizontally at least, because the different rivers flowing into the sea usually bring down different classes of material.

Thus, one stream may carry the wash from an area of iron-stained clay, and another the drainage from an area of white or light-colored clay. As a sediment spread out over the bottom, the areas of deposition might overlap, and there would thus be formed an intermediate zone made up of a mixture of the two sediments. This would show itself later as horizontal transition from one kind of clay to another. These changes may occur gradually, or at other times within the distance of a few feet (Plate II, Fig. 2).

The laminations produced by vertical changes are shown in Plate II, Fig. 1.

The most persistent beds of this class are found in the rocks of the Silurian, Devonian, and Carboniferous systems, but beds of considerable horizontal extent are at times found in the Mesozoic formations.[1]

Estuarine clays.—These form a second type of some importance in certain areas. They represent bodies of clay laid down in shallow arms of the sea, and are consequently found in areas that are comparatively long and narrow, with the deposits showing a tendency towards basin shapes. If strong currents enter the estuary from its upper end, the settling of the clay mud may be prevented, except in areas of quiet water in recesses of the bay shore. Or, if the estuary is supplied by one stream at its head, and this of low velocity, the finer clays will be found at a point most distant from the mouth of the river. In such cases we should anticipate an increase in coarseness of the clay bed or series of beds as they are followed from what was formerly the old shore line up to the mouth of the former river that brought down the sediment.

Estuarine clays often show sandy laminations, and are not infrequently associated with shore marshes, due to the gradual filling up of the estuary and the growth of plants on the mud flats thus formed. The clays of the Hackensack region of New Jersey and those of the Hudson

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[1] A peculiar type of marine deposit, which covers many square miles of the deeper lying portions of the ocean floor, is the so-called *Red Clay*. It is of no economic value.

The composite analysis of a number of samples, recalculated so as to omit adsorbed sea-salts, calcium carbonate, and a little gypsum, is given by Clarke (Jour. Geol., XV, p. 787) as follows: SiO_2, 54.48; TiO_2, 0.98; Al_2O_3, 15.94; Cr_2O_3, 0.012, Fe_2O_3, 8.66; FeO, 0.84; NiO,CoO, 0.039; MnO_2, 1.21; MgO, 3.31; CaO, 1.96; SrO, 0.056; BaO, 0.20; K_2O, 2.85; Na_2O, 2.05; V_2O_3, 0.035; As_2O_3, 0.001; MoO_3, tr., P_2O_5, 0.30; CuO, 0.024; PbO, 0.008: ZnO, 0.005; H_2O, 7.04; 100.00.

Valley of New York are good examples of estuarine deposits, formed at the close of the glacial period, when the region around the Palisades stood somewhat lower in respect to sea-level than at present.[1]

Swamp and lake clays.—Swamp and lake clays constitute a third class of deposits, which have been formed in basin-shaped depressions occupied by lakes or swamps. They represent a common type, of variable extent and thickness, but all agree in being more or less basin-shaped. They not infrequently show alternating beds of clay and sand, the latter in such thin laminæ as to be readily overlooked, but causing the clay layers to split apart easily. Many of the lake clays are directly or indirectly of glacial origin, having been laid down in basins or hollows along the margin of the continental ice-sheet, or else in valleys that have been dammed up by the accumulation of a mass of drift across them. This wall of drift serves to obstruct the drainage in the valley, thus giving rise to a lake, in which the clay has been deposited. Clay beds of this type are extremely abundant in all glaciated regions. They are usually surface deposits,[2] of variable thickness, often highly plastic, and more or less impure. Their chief use is for common brick and earthenware, and they are rarely of refractory character

Flood-plain and terrace clays.—Many rivers, especially in broad valleys, are bordered by a terrace or plain, there being sometimes two or more, extending like a series of shelves, or steps, up the valley side. The lowest of these is often covered by the river during periods of high water, and is consequently termed the flood-plain. In such times much clayey sediment is added to the surface of this flood-terrace, and thus a flood-plain clay deposit may be built up.

Owing to the fact that there is usually some current setting along over the plain when it is overflowed, the finest sediments cannot settle down, except in protected spots, and consequently most terrace clays are rather sandy, with here and there pockets of fine, plastic clay. They also frequently contain more or less organic matter. Along its inner edge the terrace may be covered by a mixture of clay, sand, and stones, washed down from neighboring slopes.

Where several terraces are found it indicates that the stream was formerly at the higher levels, and has cut down its bed, each terrace representing a former flood-plain. Even along the same stream, however, the clays of the several terraces may vary widely in their character, those of one terrace being perhaps suitable for pottery, and those of the sec-

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[1] Report on Glacial Geology, N. J. Geol. Survey, Vol. V, p. 196; and N. Y. State Museum, Bull. 35, p. 576.

[2] Those formed at earlier geologic periods may have become subsequently covered by other sediments, as may of the coal under clays of the Carboniferous. These sometimes show the upright stumps of trees that grew in the swamp in which the clay was deposited.

PLATE III

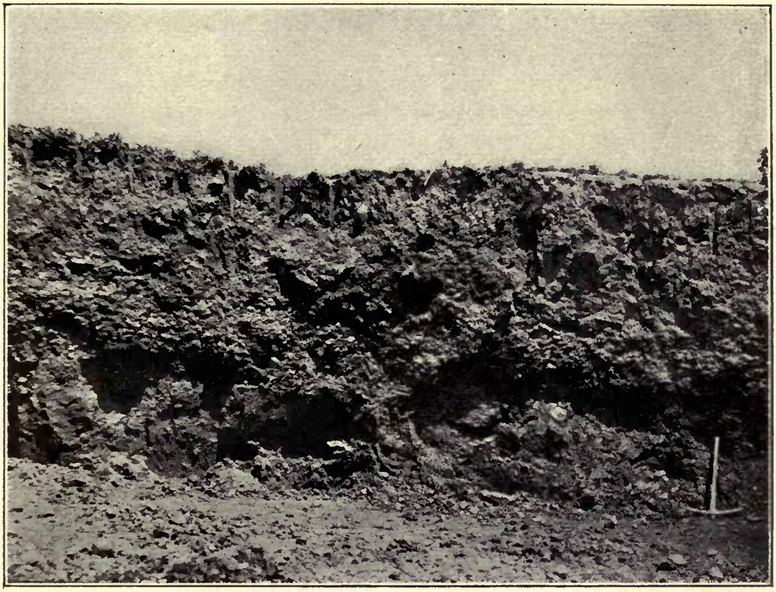

Fig. 1.—Deposit of stony glacial clay. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 128.)

Fig. 2.—Clay pit in Lignitic Tertiary formation, Athens, Tex. Shows gently dipping layers. (Photo by H. Ries, 1903.)

ond being available only for common brick and tile. Examples of such clays are to be found in most regions.

Drift or bowlder clays.—In that portion of the United States formerly covered by the continental ice-sheet there are occasional deposits of clay formed directly by the glacier. These are usually tough, dense, gritty clays, often containing many stones (Pl. III, Fig. 1). The material deposited by the ice (till) was usually too stony and sandy to serve as clay, although often known as bowlder clay. Locally, however, although the ice-transported material has been largely ground to a fine rock flour, the bowlder clay is plastic enough and not too full of stones for use. Such deposits are mostly of limited extent, impure, and of little value.

In addition to this type of clay formed directly by the ice, there were clays deposited in lakes or along flood-plains by the streams issuing from the glacier. These were composed of material derived from the ice, but since they were deposited by water they were stratified, and may properly be classed as lacustrine, estuarine, or flood-plain clays of glacial age. Bowlder clays, although abundantly distributed, are often too stony to be of much value for the manufacture of clay products.

Æolian clays.—In many parts of the West there is found a silty, often calcareous clay, termed the loess. This, although commonly a water deposit, may at times have been formed by wind action. It could therefore properly be classed as transported clay, and would also show a stratified structure.

CLASSIFICATION OF CLAY DEPOSITS

Clays may be classified according to their origin, chemical and physical properties, or uses. To the geologist the first is, perhaps, the most important, to the technologist the second and third are of more interest.

Several such classifications have appeared in the United States in the last few years, most of them based primarily on genetic features, and sometimes secondarily on the properties of the clay. They include the following:

Orton's classification.[1]

High-grade clays. (50 per cent or more kaolin) with silica.	1. Kaolin. 2. China-clay. 3. Porcelain-clay. 4. Fire-clay (hard). 5. Fire-clay (plastic). 6. Potter's clay.
Low-grade clays. (10 to 70 per cent kaolin with notable per cent fluxing elements.	1. Argillaceous shale—Paving-block. 2. Ferruginous shale—Pressed brick. 3. Siliceous clays—Sewer-pipe and paving-block. 4. Tile-clays. 5. Brick-clays. 6. Calcareous shales—Brick.

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[1] Ohio Geol. Survey, VII, p. 52.

Quality is made the basis of division in the above. Nos. 1, 2, and 4 of the first group are practically the same, and the subdivisions of group 2 are not always distinct. The term kaolin is used incorrectly, kaolinite being intended instead.

Wheeler's classification.[1]

1. Whiteware clays.
    - Kaolin.
    - China-clay.
    - Ball-clay.
2. Refractory clays.
    - Plastic fire-clay.
    - Flint-clay.
    - Refractory shale.
3. Pottery-clays.
4. Vitrifying clays.
    - Paving-brick clay and shale.
    - Sewer-pipe clay and shale.
    - Roofing-tile clay and shale.
5. Brick-clays.
    - Common-brick clay and shale.
    - Terra-cotta clay and shale.
    - Drain-tile clay and shale.
6. Gumbo clays—Burnt-ballast clay.
7. Slip-clays.

The qualities or uses of the materials are here again employed as bases for subdivision.

Such a classification is somewhat unsatisfactory, for the reason that one kind of clay might be used for several purposes.

Ladd's classification.[2]

Indigenous.
  A. Kaolins.
    (*a*) Superficial sheets.
    (*b*) Pockets.
    (*c*) Veins.
Foreign or transported.
  A. Sedimentary.

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[1] Mo. Geol. Surv., XI, p. 25, 1897.

[2] Ga. Geol. Surv., Bull. 6 A, p. 12, 1898.

- (*a*) Marine.
  - 1. Pelagic (deposited in deeper water).
  - 2. Littoral (deposited near shore).
- (*b*) Lacustrine (deposited in fresh-water lakes).
- (*c*) Stream.
  - 1. Flood-plain.
  - 2. Delta.

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

Under the Indigenous are included those clays formed by the decay of feldspar and other aluminous silicates in place. The Foreign or transported embrace all sedimentary deposits. The meta-sedimentary clays are chemical products resulting from the decomposition of other transported materials, such as volcanic tuffs, pumice, etc. The residual clays include the insoluble residue left by the dissolving of limestones, while under unassorted are included the glacial ones.

The term kaolin, as here used, includes all residual clays, except those derived from limestones, and, since it is not restricted to white-burning ones, its use is unfortunate. Furthermore, the placing of limestone residuals in a separate class seems a rather fine distinction. Delta clays hardly seem of sufficient importance to warrant being placed in a separate class, and are rare.

Buckley's classification.[1]

I. Residual derived from
  A. Granitic or Gneissoid Rocks.
  B. Basic igneous rocks.
  C. Limestone or dolomite.
  D. Slate or shale.
  E. Sandstone.
II. Transported by
  A. Gravity assisted by water.
    Deposits near the heads and along the slopes of ravines.
  B. Ice.
    Deposits resulting mainly from the melting of the ice of the glacial epoch.
  C. Water.
    Marine.
    Lacustrine.
    Stream.

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[1] Wis. Geol. Surv., Bull. VII, Pt. I, p. 14.

- D. Wind.
    - Loess.

E. Orton Jr.'s classification.[1]

- A. Primary or residual clays.
    - I. Entirely decomposed feldspathic rock.
        - Kaolin or china clay.
    - II. Partially decomposed feldspathic rock.
        - English Cornwall stone.
        - Porzellanerde of the Germans.
- B. Secondary or transported clays.
    - I. Deposited in still water.
        - (*a*) Fire-clays.
            - Highly refractory.
                - Flint fire-clay.
                - Plastic fire-clay.
            - Moderately refractory.
                - No. 2 fire-clay.
                - Stoneware-clay.
                - Sewer-pipe clay.
        - (*b*) Shales.
            - Slaty shales.
            - Bituminous shales.
            - Clay shales.
    - II. Deposited from running water.
        - Alluvium.
        - Sandy clay.
        - Loam.
    - III. Deposited by glacial action.
        - Leached—Whitish or red bowlder clay.
        - Unleached—Blue bowlder clay.
    - IV. Deposited by winds.
        - Loess.

Grimsley and Grout's classification.[2]

- I. Residual clays.
    - 1. Kaolin.
    - 2. China- or porcelain-clay.

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[1] Quoted by Beyer and Williams, Ia. Geol. Surv., XIV, p. 40, 1904.

[2] W. Va. Geol. Surv., Vol. III, p. 70, 1906.

- II. Transported clays.
    - A. Refractory (fluxing impurities low).
        - 3. Flint fire-clay.
        - 4. Plastic fire-clay.
    - B. Semi-refractory clay (fluxing impurities medium).
        - 5. Paving-brick clay and shale.
        - 6. Sewer-pipe clay and shale.
        - 7. Roofing-tile clay and shale.
        - 8. Stoneware-clay and shale.
    - C. Non-refractory (fluxing impurities high).
        - 9. Pottery clay.
            - (*a*) Ball-clay.
            - (*b*) Flower-pot clay.
        - 10. Brick- and tile-clay and shale.
            - (*a*) Ornamental brick-clay and shale.
            - (*b*) Terra-cotta clay and shale.
            - (*c*) Ornamental tile-clay and shale.
            - (*d*) Common-brick and tile clay and shale.
        - 11. Gumbo ballast-clay.
        - 12. Slip-clay.

Ries' classification.—The following classification suggested by the author is an amplification of one proposed by him some years ago[1]:

- A. Residual clays. (By decomposition of rocks in situ.)
    - I. Kaolins or china-clays. (White-burning.)
        - (*a*) Veins, derived from pegmatite.
        - (*b*) Blanket deposits, derived from extensive areas of igneous or metamorphic rocks.
        - (*c*) Pockets in limestone, as indianaite.
    - II. Red-burning residuals, derived from different kinds of rocks.
- B. Colluvial clays, representing deposits formed by wash from the foregoing and of either refractory or non-refractory character.
- C. Transported clays.
    - I. Deposited in water.
        - (*a*) Marine clays or shales. Deposits often of great extent.
            - White-burning clays. Ball-clays.
            - Fire-clays or shales. Buff burning.
            - Impure clays or shales. { Calcareous. / Non-calcareous.

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[1] Md. Geol. Surv., IV.

(*b*) Lacustrine clays. (Deposited in lakes or swamps.)
  Fire-clays or shales.
  Impure clays or shales, red-burning.
  Calcareous clays, usually of surface character.
(*c*) Flood-plain clays.
  Usually impure and sandy.
(*d*) Estuarine clays. (Deposited in estuaries.)
  Mostly impure and finely laminated.
II. Glacial clays, found in the drift, and often stony.
  May be either red- or cream-burning.
III. Wind-formed deposits (some loess).
IV. Chemical deposits. (Some flint-clays.)

SECONDARY CHANGES IN CLAY DEPOSITS

Changes often take place in clays subsequent to their deposition. These may be local or wide-spread, and in many cases either greatly improve the deposit or render it worthless. The marked effect of some of these changes is often well seen in some clay beds of which only a portion has been altered. These secondary changes are of two kinds, viz., mechanical and chemical.

MECHANICAL CHANGES

Tilting, folding, faulting.—In the uplifting of beds of clay or shale, subsequent to their deposition, the amount of elevation is rarely the same at all points over a large area, so that the beds frequently show a variable degree of tilting. If the uplift is accompanied by folding of the rocks, the dip of the beds may be quite steep. Thus, for example, the Cretaceous and Tertiary clay-bearing formations of the Atlantic and Gulf coastal plain show a gentle dip to the southeast and south (Pl. III, Fig. 2), while the Devonian shales of southern New York dip to the south. At Golden, Colo. (Pl. XXIV, Fig. 2), the Cretaceous fire-clays often have a dip of as much as 90°. Beds of clay and shale sometimes show folds or undulations. In the case of consolidated, or hard beds these may be due to lateral pressure, caused by movements in the earth's crust, while in soft beds the cause is frequently local. Many clay deposits in the Northern States show a local folding caused by the shoving action of the ice-sheet during the glacial period.[1] Such folds, however, are of minor account and affect only a few beds.

Where beds of clay are gently folded into arches (anticlinal folds)

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[1] See Hollick, Trans. N. Y. Acad. Sci., XIV, p. 8, 1894; Clapp, Bull. Geol. Soc. Amer., XVIII, p. 505, 1908; Meinegk sheet, Prussian Geol. Surv., 1906.

and troughs (synclinal folds) each bed slopes or dips away from the axis of an anticlinal fold and towards the axis of a synclinal fold, but if followed parallel to the axis it will remain at the same level, provided the axis itself is horizontal.

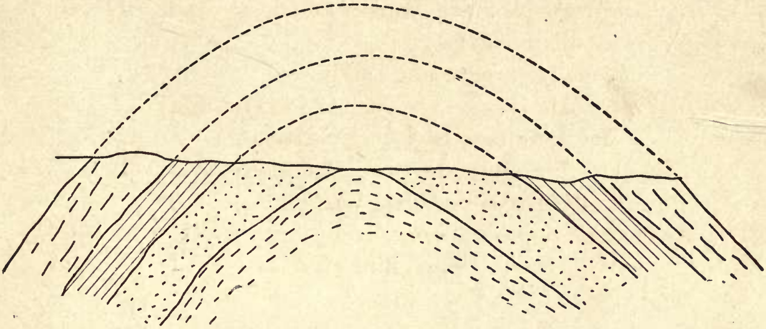

Fig. 5.—Section of folded beds, with crest worn away, exposing different layers. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 18, 1904.)

Where a bed is not sufficiently elastic to bend under pressure it breaks, and if, at the same time, the beds on opposite sides of the break slip past each other, faulting is said to occur. When the breaking surface or fault-plane is at a low angle one portion of the bed may be thrust over the other for some distance. In other cases the displacement may amount to but a few inches. Figs. 6 and 7 represent sections in faulted strata, and in these it will be noticed that every bed terminates abruptly

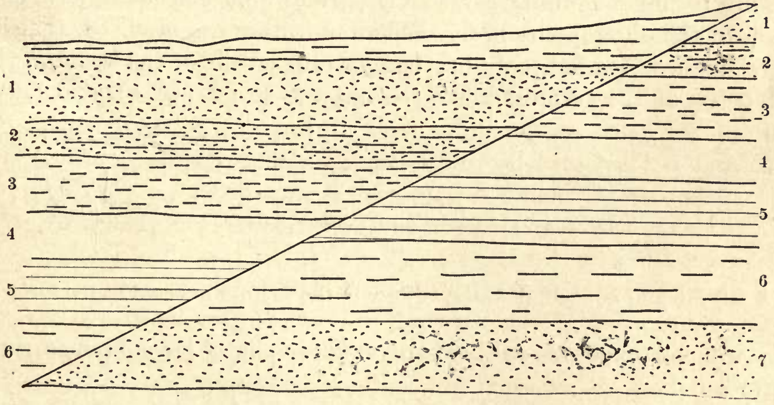

Fig. 6.—Section showing strata broken by fault-planes of low inclination. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 15, 1904.)

at the fault-plane, its continuation on the other side being at a higher or lower level. Displacements of this type are somewhat rare in surface clays, and if occurring, the throw is not apt to exceed a few feet. In the shales of pre-Pleistocene age the amount of displacement is sometimes much greater.

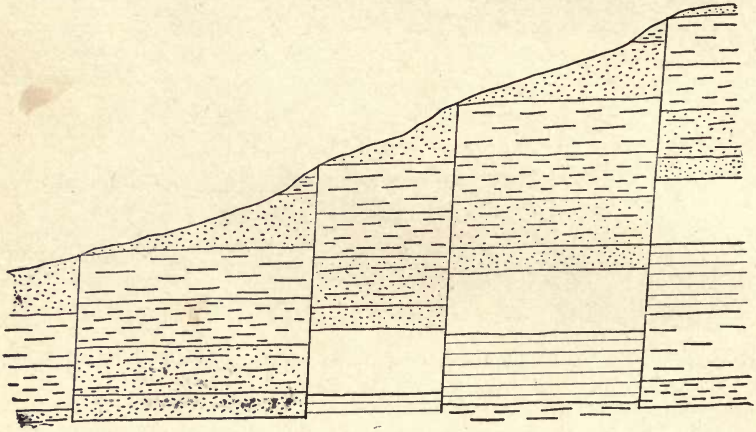

FIG. 7.—Strata broken by parallel fault-planes. (After Ries, N. J. Geol. Surv., Fin. Rept., VI., p. 15, 1904.)

Both tilting and folding exert an important influence on the form and extent of the outcropping beds. Where no tilting has occurred, that is, where the beds are flat, only one bed, the upper one of the section, will be exposed at the surface, where the latter is level (Fig. 8), and lower beds will be exposed only where stream-valleys have been carved (Fig. 9).

FIG. 8.—Section of horizontal strata, with only the top one exposed at the surface.

If the beds are tilted (Figs. 10 and 11) or folded, and the crests of the folds worn off (Fig. 5), then the different beds will outcrop on the surface as parallel bands, whose width of outcrop will decrease with an increase in the amount of dip (Figs. 10 and 11).

Erosion.—All land areas are being constantly attacked by the weathering agents (frost, rain, etc.). The effect of this is to disintegrate the surface rocks and wash away the loose fragments and grains. This brings about a general sculpturing of the surface, forming hills and valleys, the former representing those parts of the rock formations which have not yet been worn away. The effect of this is to cause phenomena or conditions which may at first sight appear puzzling, but are nevertheless quite simple when the cause of them is understood.

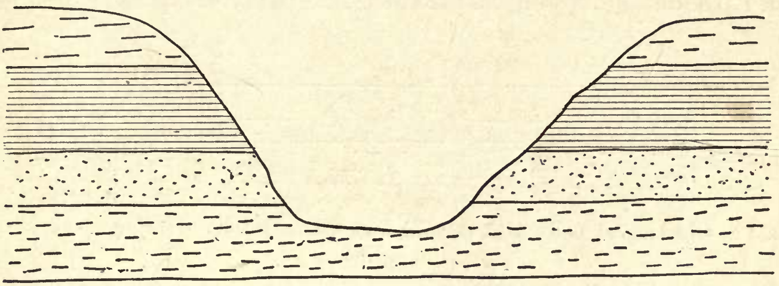

Fig. 9.—Horizontal beds, with several layers exposed by wearing down of the land surface. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 18, 1904.)

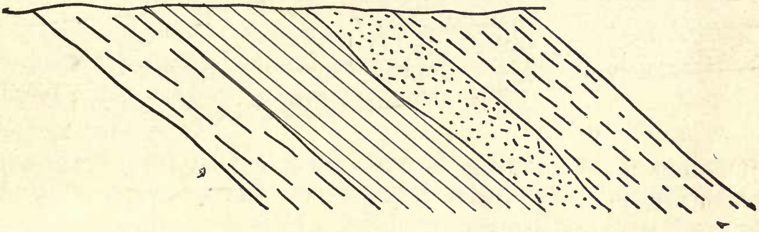

Fig. 10.—Section showing outcropping of tilted strata.

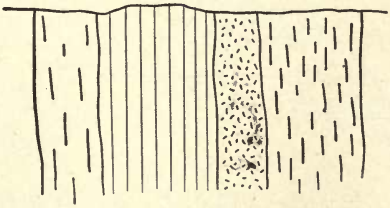

Fig. 11.—Section of vertical beds. The width of outcrop is the same as the actual width of the bed. (See also Pl. XXIV, Fig. 2.)

Let us take, for example, a section of horizontal clay beds which originally covered an extensive area and were interstratified with sand beds. In Figs. 8 and 12, beds 1 and 3 may be taken to represent the clays. In Fig. 8 we have indicated the surface as it originally was, and in Fig. 12 the outline as it appears after the land has been exposed to weathering and erosion for an extended period. Here we see that the upper bed is left only on the highest hills and has been removed over a large area, while No. 2 caps the smaller knolls, and No. 3 outcrops in the sides of the deeper valleys. Many small areas of clay thus represent all that is left of a formerly extensive bed.

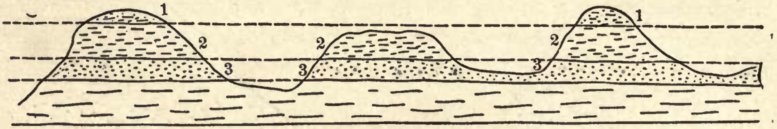

FIG. 12.—Horizontal beds with several layers exposed by wearing down of the land surface.

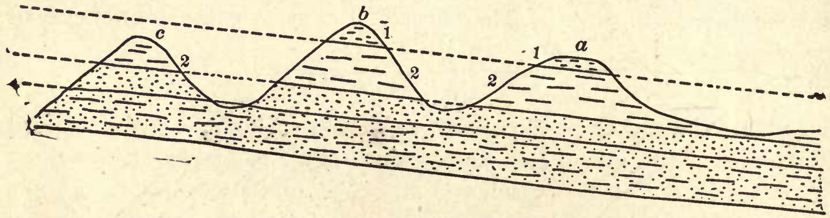

FIG. 13.—Inclined strata, showing rise of the bed above sea-level, when followed up the slope or dip. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 19, 1904.)

If the beds had a uniform dip, the conditions may be as indicated in Fig. 13. Here bed 1 appears at the summit of two hills, *a* and *b*, but its rise carries it, if extended, above the summit of hill *c*, which is capped by bed 2. If one did not know that the beds rose in that direction, it might

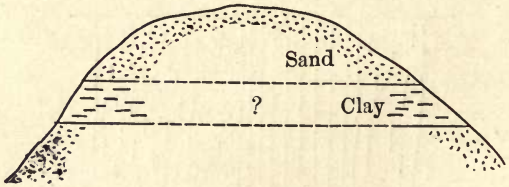

FIG. 14.—Outcrops of a clay bed on two sides of a hill and its probable extension into the same. (After Ries, N. J. Geol. Surv. Fin. Rept., VI.)

be assumed that bed 1 passed into bed 2, because they are at the same level. This dipping of the layers, or beds, sometimes accounts for the great dissimilarity of beds at the same level in adjoining pits.

Where a bed of clay is found outcropping at the same level on two sides of a hill it is reasonable to assume that it probably extends from one side to the other, but it is not safe to predict it with certainty, for, as has been mentioned above, clay beds may thin out within a short distance. Furthermore, the overlying material, or overburden, will become thicker towards the center or summit of the hill, so that even if present the clay may be economically unworkable (Fig. 14).

CHEMICAL CHANGES

Nearly all clay deposits are frequently changed superficially, at least, by the weather or by percolating surface-waters. The changes are chiefly chemical and can be grouped under the following heads:

Change of color.
Leaching.
Softening.
Consolidation.

Change of color.—Most clay outcrops which have been exposed to the weather for some time show various tints of yellow or brown. This coloration, or rather discoloration, is due to the oxidation, or rusting, of the iron oxide which the clay contains. This iron compound is usually found in the clay as an original constituent of some mineral, and rusts out as the result of weathering, so that the depth to which the weathering has penetrated the material can often be told by the color. The lower limit of this is commonly not only irregular, but the distance to which it extends from the surface depends on the character of the deposits, sandy open clays being affected to a greater depth than dense ones. The discoloration of a clay due to weathering does not always originate within the material itself, for in many instances, especially where the clay is open and porous, the water seeping into the clay may bring in the iron oxide from another layer, and distribute it irregularly through the lower clay.

The changes of color noticed in clay are not in every case to be taken as evidence of weathering, for in many instances the difference in color is due to differences in chemical composition. Many clays are colored black at one point by carbonaceous matter, whereas a short distance off the same bed may be white or light gray, due to a smaller quantity of carbonaceous material. In many of the Lower Cretaceous clays of New Jersey, for example, there is often a change from blue to red and white mottled, and from this into red clay. This is not the result of weathering, but is due to local variations in the iron-oxide contents of the different layers.

Discoloration caused by weathering can usually be distinguished from differences in color of a primary character in that the former begins at the surface and works its way into the clay, penetrating to a greater distance along planes of stratification or fissures, and even following plant-roots as shown in Fig. 15.

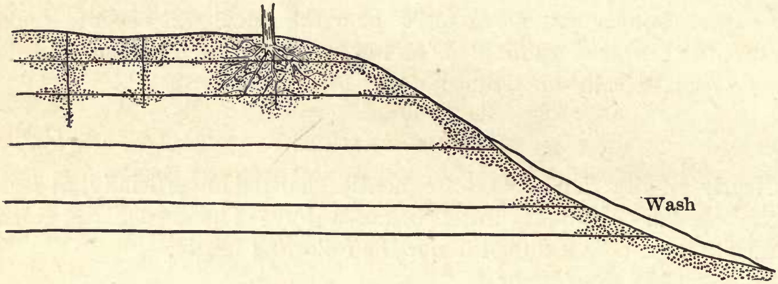

Fig. 15.—Section showing how weathering penetrates a clay bed, particularly along roots, cracks, and joint-planes. (After Ries.)

Where the clay deposit outcrops on the top and side of a hill it does not follow that, because the whole cliff face is discolored, the weather will have penetrated to this level from the surface, but indicates simply that the weathering is working inward from all exposed surfaces. The overburden often plays an important rôle in the weathering of clay, for the greater its thickness the less will the clay under it be affected. This fact is one which the clay-worker probably often overlooks, and therefore does not appreciate the important bearing which it may have on the behavior of his material. Some unweathered clays crack badly in drying or burning, but weathering seems to mellow and loosen them, as well

as to increase their plasticity, so that the tendency to crack is sometimes either diminished or destroyed. If a clay which is being worked shows this tendency, it will be advisable to search for some part of the deposit which is weathered, and if the clay is covered by a variable thickness of overburden, the most weathered part will be found usually under the thinnest stripping, as shown in Fig. 16.

Leaching.—More or less surface-water seeps into all clays, and in some cases drains off at lower levels. Such waters contain small quantities of carbonic acid which readily dissolves some minerals, most prominent among them carbonate of lime. In some areas, therefore, where calcareous clays occur, it is not uncommon to find that the upper layers of the deposit contain less lime carbonate than the lower ones, due to this solvent action of the percolating waters, and residual clays from limestone contain little or no lime carbonate.

Softening.—Most weathering processes break up the clay deposits, either by disintegration or by leaching out some soluble constituents that served as a bonding or cementing material, thus mellowing the outcrop, and many manufacturers recognize the beneficial effect which weathering has on their clay. They consequently sometimes spread it on the ground after it is mined and allow it to slake for several months or, in some cases, several years. The effect of this is to disintegrate thoroughly the clay, render it more plastic, and break up many injurious minerals, such as pyrite. Although mentioned under Chemical Changes, it will be seen that the process of softening is partly a physical one.

Consolidation.—This change is found to have taken place in a few deposits, and is due to the formation of limonite crusts in the clay. At times these may form at a few points in the deposit, or only along certain layers, but in other instances they have originated in all parts of the mass, both along the stratification-planes, as well as in every joint or crack. They thus permeate the clay deposit with such a network of rusty, sandstone-like chunks, nodules, and strips as to seriously interfere with the digging of the clay, and requiring powerful machinery to break up the hard parts.

Concretions.—In some deposits the limonite or siderite (carbonate of iron) collects around nuclei,[1] such as pebbles or grains of sand, and grows into more or less symmetrical ball-like concretions, which, if large, can be avoided or thrown out in mining. These are most abundant in the weathered portions of the clay (Fig. 17). They are not to be con-

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[1] The way in which natural physical forces act to bring about this segregation of chemical compounds of the same kind is not yet satisfactorily explained, although it is a common phenomenon.

fused, however, with the nodules and lumps of pyrite that are found throughout some clay beds, and are of yellow color and glistening metallic lustre. These latter, although of secondary origin, are not necessarily due to weathering.

In many calcareous clays concretions (Pl. IV, Fig. 2) are specially abundant, being found not uncommonly along lines of stratification. Many of the drift-clays, though free from lime, show concretionary lumps, and in some deposits they have been formed by the deposition of lime carbonate around tree-roots. In this case they would be closely associated with weathering.

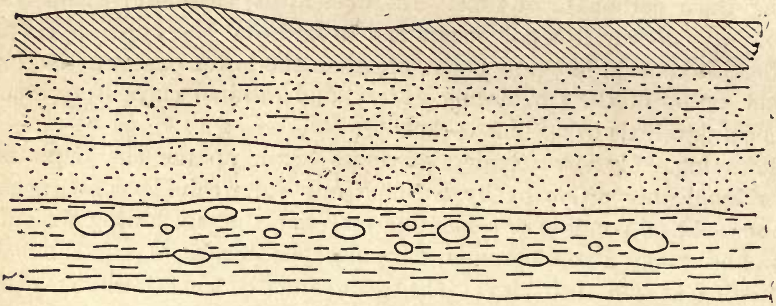


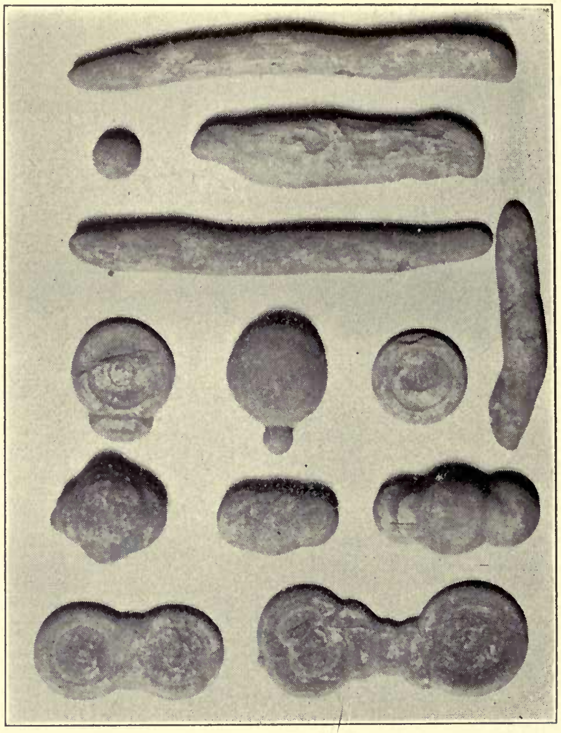
Fig. 17.—Section showing occurrence of concretions in certain layers.

Formation of shale.—Many sedimentary clays, specially those of marine origin, after their formation are covered up by many hundred feet of other sediments, due to continued deposition on a sinking ocean bottom. It will be easily understood that the weight of this great thickness of overlying sediment will tend to consolidate the clay by pressure, converting it into a firm rock-like mass, termed shale. That the cohesion of the particles is due mostly to pressure alone is evidenced by the fact that grinding the shale and mixing it with water will develop as much plasticity as is found in many surface clays. An additional hardening has, however, taken place in many shales, due to the deposition of mineral matter around the grains, as a result of which they become more firmly bound together.

In regions where mountain-making processes have been active and folding of the rocks has taken place, heat and pressure have been developed, and the effect of this has sometimes been to transform or metamorphose the shale into slate or even mica-schist (when the metamorphism is intense), both of which are devoid of any plasticity when ground. The shales utilized for clay products in different parts of the

PLATE IV

Fɪɢ. 1.—Clay bank showing carbonate of iron concretions, Reynolds ore bank, Anne Arundel County, Md. (Md. Geol. Surv., Vol. IV, p. 222, 1902.)



Fɪɢ. 2.—Clay concretions. (From N. J. Geol. Surv., Fin. Rept., VI, p. 24, 1904.)

country show a wide variation in their plasticity. Those of the Carboniferous, much used in the Central States, are often highly plastic, while the red shales of the Triassic formation of New Jersey are in most cases consolidated sandy clay, but, with one exception, all those examined are of poor plasticity and very low fusibility. The Hudson River slates, found over a large area of New Jersey, New York, and Pennsylvania, owe their low plasticity partly to a slight metamorphism, and partly to the deposition of cement around the grains.

Geologic age cannot be used as a guide towards determining whether the beds of a formation are hard or soft. The Cretaceous of the Atlantic coastal plain contains soft plastic clays, while that of the Rocky Mountain district carries shales which are hard and sometimes flinty in their character.

Dehydration.—The dehydration of a clay is produced in several ways, of which the following may be noted:

1. Clay or shale when changed to slate or schist, lose the chemically combined water, in which event most of the hydrous aluminum silicates should break down into $Al_2 SiO_5$ and SiO_2. The former represents the three minerals and andalusite, kyanite and sillimanite.[1] The formation of these anhydrous silicates is further referred to under changes in Burning, Chap. III.

2. Dehydration of a clay or shale is often caused by the burning out of adjacent coal seams, the argillaceous beds being either baked to the condition of bricks, or sometimes still more to a viscous or slag-like mass. Such occurrences are not uncommon in the Western States, having been described by Bastin[2] and Allen[3] from Eastern Wyoming, and by Leonard from North Dakota.[4]

At the Wyoming locality there have been developed in the more slag-like portions, minerals recognizable as cordierite, oligoclase, pyroxene, magnetite and hematite.

These baked clays have been described by a number of German geologists under the names of *Porzellanit* and *Porzellanjaspis*.[5]

3. Igneous intrusions, such as dikes, may also bake and fuse clay.

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[1] F. W. Clarke, U. S. Geol. Surv., Bull. 330, p. 527, 1908.

[2] E. S. Bastin, Notes on Baked Clays and Natural Slags in Eastern Wyoming, Jour. Geol., XIII, p. 408, 1905.

[3] J. A. Allen, Proc. Bos. Soc. Nat. Hist., XVI, p. 246, 1874.

[4] A. G. Leonard, N. Dak. Geol. Surv., 4th Bien. Rep., p. 79, 1906.

[5] Zirkel, Lehrbuch der Petrographie, III, p. 775, 1894.

CHAPTER II

CHEMICAL PROPERTIES OF CLAY

MINERALS IN CLAY

THE complex mineralogical character of clay has been referred to on an earlier page, and a microscopic examination or chemical analysis of a few impure clays will convince one of this fact.

Nevertheless the statement is often made in print that clay is a hydrated silicate of alumina of the formula $Al_2O_3,2SiO_2+2H_2O$, consequently of definite chemical composition and with a formula corresponding to that of the mineral kaolinite.

That this explanation is clearly improbable can be seen by examining any series of clay analyses, few of which will reduce to such a formula.

Equally sweeping and incorrect is the statement that kaolinite is the basis of *all* clays, and that they are therefore to be regarded as a mixture of kaolinite with other minerals

Many clays no doubt contain a variable amount of kaolinite,[1] but there are others, consisting almost entirely of silica, alumina, and water, which clearly do not correspond to the formula of the mineral above mentioned (see Halloysite and Pholerite), and in impure clays it becomes a matter of some difficulty to prove beyond a doubt whether the hydrous aluminum silicate present is kaolinite or some other mineral.[2] We may even express reasonable doubt regarding the necessary presence of kaolinite for the development of plastic qualities in the mass.

The flint-clays of Missouri (many of which correspond closely to pholerite in composition) when finely ground possess some plasticity. The Edwards County, Texas, kaolin has even more plasticity, a tensile strength of 159 lbs. per sq. in., and an air shrinkage of 6.2, and yet it

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[1] Kaolins of commerce and ball clays.

[2] This fact has also been emphasized by G. P. Merrill, Non-metallic Minerals, p. 217, 1904.

does not correspond exactly to the formula of kaolinite, but stands intermediate between halloysite and kaolinite.

Wheeler has described an halloysite from Missouri[1] which is slightly plastic even when ground to pass 20 mesh, and has an average tensile strength of 38 lbs. per sq. in.

The number of different minerals present in a clay is often no doubt large and depends partly on the mineralogical composition of the rock or rocks from which the clay has been derived, and partly on the extent to which the mineral grains in the clay have been destroyed by weathering; but in any case the identification of mineral species is rendered rather difficult, chiefly because of the extreme fineness of the grains, and partly because these are often surrounded by decomposition products.

More attention has been given to the mineralogy of soils than of clays, but since the former are in many cases nothing more than surface clays, what is true of the one is more or less so of the other.

Chamberlin and Salisbury,[2] in studying the residuals of the Wisconsin driftless area, were able to identify such minerals as plagioclase, orthoclase, biotite, muscovite, hornblende, augite, magnetite, and quartz, while Ladd, in studying the Georgia Cretaceous clays,[3] has noted kaolinite, feldspar, quartz, muscovite, biotite, magnetite, titanite, limonite, calcite, and prochlorite. In the Wisconsin materials Buckley[4] records finding quartz, feldspar, mica, calcite, dolomite, and iron oxide. The Leda clays of Canada[5] show quartz, orthoclase, plagioclase, mica, tourmaline, pyroxene, chlorite, and hornblende.

In the study of soils perhaps the largest number of species have been determined by Delage and Lagatu,[6] who include in their list calcite, quartz, biotite, muscovite, sericite, orthoclase, oligoclase, zircon, tourmaline, amphibole, apatite, andalusite, titanite, microcline, limonite, hematite, chlorite, augite, etc.

The more important of these may be referred to in more than a passing manner.

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[1] Mo. Geol. Surv., XI, p. 186, 1896.

[2] U. S. Geol. Surv., 6th Ann. Rept., 245.

[3] Amer. Geol., XXIII, p. 240, 1899.

[4] Wis. Geol. and Nat. Hist. Surv., Bull. VII, Pt. I.

[5] Merrill, Rocks, Rock-weathering, and Soils, p. 335.

[6] Ann. de l'école nationale d'agriculture de Montpellier, VI, pp. 200–220, 1905; also Comptes rend., CXXXIX, p. 1044, 1904. See also F. Steinriede, Anleitung zur mineralogischen Bodenanalyse, Halle, 1889; Dumont, Comp. rend., CXL, p. 1111, 1905; Tebier, *ibid.*, CVIII, p. 1071, 1889; and Cameron and Bell, Bur. of Soils, Bull. 30, p. 11, 1905, and Bull. 22, p. 12, 1903.

Hydrous Aluminum Silicates

Kaolinite.—This mineral is a hydrated silicate of alumina, represented by the formula $Al_2O_3,2SiO_2,2H_2O$, which corresponds to a composition of Silica (SiO_2), 46.3 per cent; Alumina (Al_2O_3), 39.8 per cent; Water (H_2O), 13.9 per cent. It is sometimes referred to as clay substance, and is that portion of the clay which is soluble in hot sulphuric acid and sodium carbonate. It is a white, pearly mineral, crystallizing in the monoclinic system, the crystals presenting the form of small hexagonal plates (Pl. V, Fig. 1) with a hardness of 2–2.5 and a specific gravity of 2.2–2.6. It is naturally white in color, and a mass of it is plastic when wet, but very slightly so.

According to Rosenbusch[1] its index of refraction is the same as that of Canada balsam; the double refraction is strong. A negative bisectrix emerges from the face of the plate, and the axial plane bisects the acute prism angle. The optical behavior is therefore very similar to that of muscovite, and it can only be distinguished with certainty from colorless mica by chemical reaction to prove the absence of alkali; its specific gravity cannot be used to advantage because of the micaceous form of both minerals.

It has naturally been assumed by most writers that kaolinite was a widely distributed mineral in clays, but when we come to sift the evidence of its presence comparatively little is to be found.

A microscopic examination even of the white clays free from impurities rarely reveals the presence of the hexagonal kaolinite scales, although the little vermiculite-like bunches of plates of this mineral may be present (Fig. 26); but still even these are rarely seen in the more impure clays, and the theory of the universal presence of kaolinite in clay is probably traceable to the fact that many white clays, after having the sand washed out, often approach kaolinite in composition.[2]

The occurrence of kaolinite in crystals has been noted from the National Belle mine, Red Mountain, Colo.,[3] by Dick from Anglesey,[4] as well as by several other writers.[5]

Many kaolins show the bunches of kaolinite plates referred to above,

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[1] Physiography of Rock-making Minerals, Iddings' translation, 1889, p. 320.

[2] H. Ries, Ala. Geol. Survey, Bull. 6, p. 41, 1900.

[3] H. Reusch, Jahrb. f. Min., 1887, II, p. 70; L. Milch, Centralb. Min. Geol., 1908, 1–3.

[4] A. Dick, Min. Mag., 1876, VIII, p. 15.

[5] Safarik, Böhm, Ges. Wiss., 16th Feb., 1870; Knop, Neues Jahr. Min., etc., 1859, p. 595; Johnson and Blake, Amer. Jour. Sci., ii, XLII, pp. 351 and 867; Ehrenberg, Pogg. Annal, XXXIX, p. 104; v. Fritsch, Tonindus.-Zeit., 1881, p. 371.

PLATE V

FIG. 1.—Photo-micrograph of kaolinite. (After Merrill, Non-metallic Minerals.)

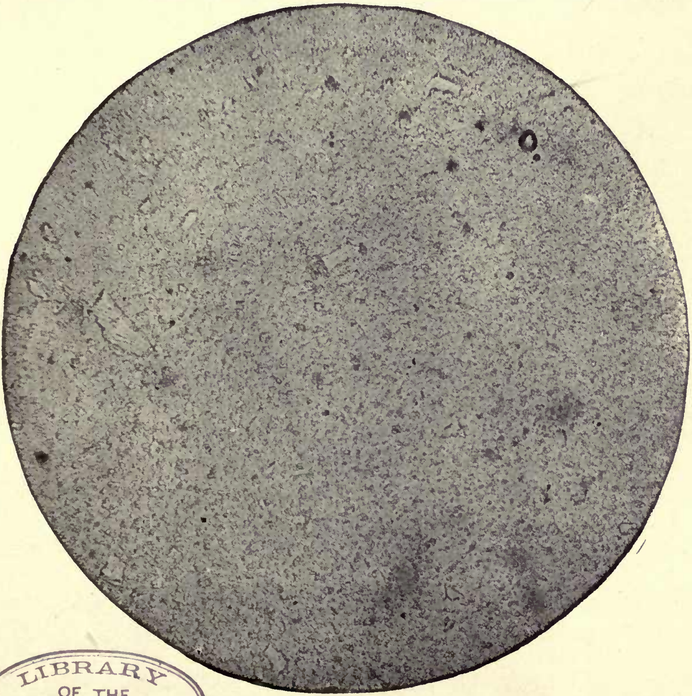

FIG. 2.—Washed kaolin. (After Merrill.)

PLATE VI

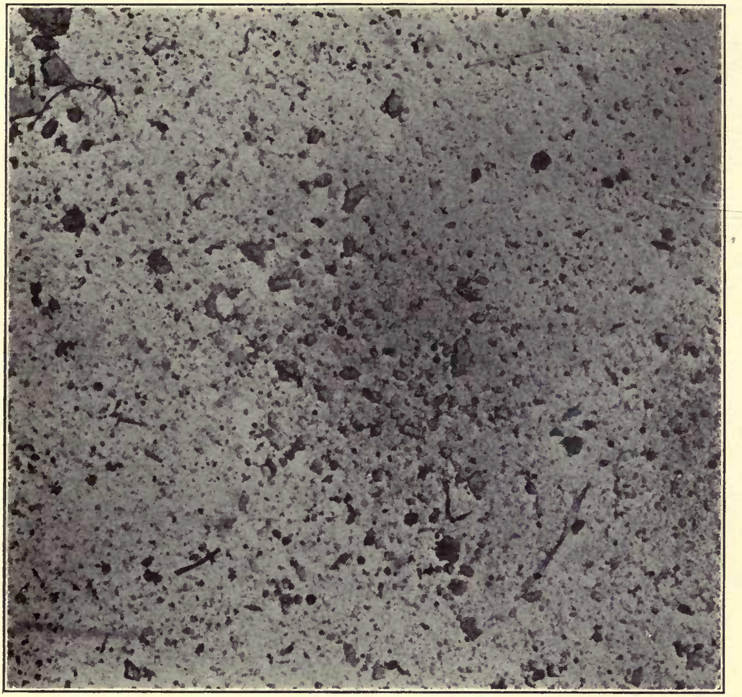

FIG. 1.—Photo-micrograph of indianaite, showing coarseness of grain.

FIG. 2.—Photo-micrograph of particles of washed kaolin. (After Rieke, Sprechsaal, XL, p. 33, 1907.)

and the separation of these by grinding was said by Cook[1] to increase the plasticity.

Staining appears in some cases to have more clearly shown the structure of the kaolinite plates, for Rieke,[2] in describing some crystalline kaolinite from Hirschau, Bavaria, showed that the crystals stained with methylene blue, are lamellar and exhibit a zonal structure parallel to the edges. Very thin flakes were also found as well as fragments of spherical particles. The former showed distinctly a porous structure, and analysis proved them to be practically identical with kaolinite.

Kaolinite is always of secondary origin, and although in most cases it has probably been derived from feldspar, its derivation from numerous other minerals has been recorded, although unaccompanied by proof.

Thus Rösler[3] states that the formation of kaolinite from scapolite, leucite, nepheline, sodalite, hauyne, analcite, topaz, etc., is chemically possible, but not proven.

The same may be said in part regarding the statements of Van Hise,[4] who lists andalusite, anorthoclase, biotite, cyanite, epidote, leucite, microcline, nephelite, orthoclase, plagioclase, scapolite, sillimanite, sodalite, topaz, zoisite, and garnet as the primary mineral. He gives the formula for the kaolinization of feldspar as follows:

$$2KAlSi_3O_8 + 2H_2O + CO_2 = H_4Al_2Si_2O_9 + 4SiO_2 + K_2CO_3.$$

Van Hise calculates that the decrease in volume, supposing the freed silica as quartz, and the potassium carbonate dissolved, is 12.57%. If all the silica were dissolved (which is unlikely), then the volume decrease would be 54.44%.

Pure kaolin is highly refractory, but a slight addition of fusible impurities lowers its refractoriness.

Many kaolins contain very minute scales of white mica which it would be difficult to distinguish under the microscope from kaolinite; and since white mica in a very finely divided condition is not unlike kaolinite in its plasticity, as shown by the experiments of Vogt, its presence may be thought by some to exert no influence, unless there is an appreciable amount of it. The following quotation[5] exhibits those experiments:

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[1] Clays of New Jersey, N. J. Geol. Surv., 1878.

[2] Sprechsaal, XL, p. 33.

[3] l.c. See also Fiebelkorn, Baumaterialienkunde, IV, p. 280.

[4] Treatise on Metamorphism, p. 352.

[5] Quotation from U. S. Geol. Surv., 19th Ann. Rept., Pt. VI, p. 20, 1898. Original ref. Tonindustrie-Zeitung, 1893, p. 140; also Compt. rend., Acad. Sci., Paris, CX, p. 1199, 1890.

"Mr. Vogt considers that the plasticity which clays have is chiefly due to the hydrated silicate of alumina or kaolinite. Experiments which he made show that the kaolinite is not the only substance which remains in suspension for a long period. For his trials he took quartz from Limousin, orthoclase from Norway, and a potash mica. All three were ground very fine, and then washed in a current of slightly ammoniacal water. The washed materials were then allowed to stand. After 24 hours each of the liquids was as opalescent as if it had washed clay in suspension. After nine days the turbidity still remained, but was less marked. At the end of this time the supernatant liquid was ladled off of each, and a few drops of hydrochloric acid added to it. The suspended materials coagulated and settled, and the precipitate was collected, dried, and weighed. The mica which had remained in suspension during the nine days was very fine; still the particles glittered in the light. The addition of hydrochloric acid caused the instant settling of the particles, which was also noted by the cessation of the glittering. The settlings of mica from 1 liter of water amounted to 0.15 gram. This fine-grained mica possessed a plasticity almost equal to that of the kaolin.

"From the decanted liquid of the feldspar the hydrochloric acid brought down about 0.4 gram of this mineral per liter, while of the quartz only 0.1 gram of sediment was obtained.

"A very plastic clay from Dreux was treated in the same manner, and after nine days a precipitate of 0.56 gram was brought down.

"From these experiments we see that in washing kaolin it is impossible to free it entirely from quartz, feldspar, and mica, if they are present in a finely divided condition."

Minerals related to Kaolinite

These include several species, all hydrated silicates of alumina. Some of these have been found in crystals and are very probably good species, but others are known only in an amorphous condition, which may tend to suggest some doubt as to their validity; in fact Johnson and Blake[1] suggested that the name *kaolinite* should include all the associated species mentioned below, and that the term *kaolin* be retained for the "more or less impure commercial article," but this usage seems too comprehensive, especially since some of those hydrous aluminum silicates mentioned below seem to have a definite formula distinctly

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[1] Amer. Jour. Sci., ii, XLII, p. 351.

different from that of kaolinite proper. These associated species together with their characters are given by Dana as follows:

Halloysite.—A massive, clay-like or earthy mineral with a conchoidal fracture and showing little or no plasticity; hardness 1–2; specific gravity 2.0–2.20; luster somewhat pearly to waxy or dull; color white, grayish, greenish, yellowish, and reddish; translucent to opaque, sometimes becoming translucent or even transparent in water, with an increase of one fifth in weight. It is a hydrous silicate of alumina like kaolinite, but amorphous and containing more water; the amount is somewhat uncertain, but according to Le Chatelier the composition is probably $2H_2O,Al_2O_3,2SiO_2+aq$, or silica 43.5%, alumina 36.9%, water 19.6%=100. It is not uncommon in the kaolin deposits around Valleyhead, Dekalb County, Ala.,[1] where it occurs as veins in the kaolin, but no analysis of the material is available.

A deposit has been described by Wheeler[2] from five miles southwest of Aurora, Mo. The material is a white porcelain-like clay, which is more or less stained or intermixed with yellow clay. It is massive, compact, hard, and of low plasticity. It fuses completely at 2600° F. and has the following composition:

ANALYSIS OF MISSOURI HALLOYSITE

Silica (SiO_2)	44.12
Alumina (Al_2O_3)	37.02
Ferric oxide (Fe_2O_3)	.33
Lime (CaO)	.19
Alkalies (Na_2O,K_2O)	.24
Water (H_2O)	18.48
Total	100.38

This analysis it will be seen agrees closely with the theoretic composition of this mineral given above.

G. P. Merrill[3] has also noted its occurrence in small quantities associated with kaolin, in narrow veins in the decomposing gneissic rock near Stone Mountain, Ga.

The following four analyses[4] represent the composition of halloysite from different localities:

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[1] Gibson, Geol. Surv. of Ala., Report on Murphrees Valley, 1893, p 121.

[2] Mo. Geol. Surv., XI, p. 186, 1896.

[3] Non-metallic Minerals, p. 225.

[4] I–III, ibid.; IV, Zellner, Neues Jahrb. Min., 1835, p. 467

ANALYSES OF HALLOYSITE

	I.	II.	III.	IV
Silica (SiO_2)	39.30	40.70	42.91	42.00
Alumina (Al_2O_3)	38.52	38.40	38.40	20.12
Lime (CaO)	0.75	0.60	0.60	2.81
Magnesia (MgO)	0.83	1.50	1.5	2.01
Ferric oxide (Fe_2O_3)	1.42	......	......	8.53
Manganese	0.25	......	......	......
Water (H_2O)	19.34	18.00	18.00	24.00
Potash ((K_2O)	......	......	......	0.50
	100.41	99.20	101.41	99.97

I. Elgin, Scotland. II. Steinbruck, Styria. III. Detroit Mine, Mono Lake, Calif. IV. Striegau, Silesia.

It will be noticed that none of these agree very closely with the composition given by Dana except III. If No. IV is halloysite, it evidently has considerable impurities.

The kaolin found near Leaky, Edwards County, Tex.,[1] appears to be of intermediate composition between kaolinite and halloysite, and may be a mixture of the two.

Indianaite.—This is a whitish residual clay found in Lawrence County, Ind. (see Indiana clays), which is placed under halloysite by Dana,[2] and called allophane in the Indiana [3] Survey report.

Of the following analyses, No. I is given by Dana, and No. II by the Indiana Survey, Nos. III and IV are for comparison.

ANALYSES OF INDIANAITE, HALLOYSITE, AND KAOLINITE.

	I.*	II.	III.	IV.
Silica (SiO_2)	43.25	44.75	43.5	46.3
Alumina (Al_2O_3)	39.92	38.69	36.9	39.8
Ferric oxide (Fe_2O_3)	.....	.95		
Lime (CaO)	.69	.37		
Magnesia (MgO)		.30		
Potash (K_2O)	.59	.12		
Soda (Na_2O)		.23		
Water (H_2O)	15.52	15.17	19.6	13.9

* The moisture has been left out, and the analysis recalculated to 100 per cent.

While the percentage of combined water in this material is higher than in kaolinite, and the silica lower, still they approach no more closely to those given for halloysite than they differ from similar constituents of kaolinite.

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[1] See description of Texas clays.

[2] System of Mineralogy, 688, 1892.

[3] Ind. Geol. Surv., 29th Ann. Rept.

An interesting type of clay apparently allied to Indianaite has been described by J. H. Gardner from the Subcarboniferous near Brownsville, Edmonson County, Ky.[1] There, underlying the Conglomerate sandstone is a white waxy clay with conchoidal fracture and said to resemble Indianaite. It grades down into a hard brown layer thought to be bauxite (Fig. 17*a*) with admixed wavellite.

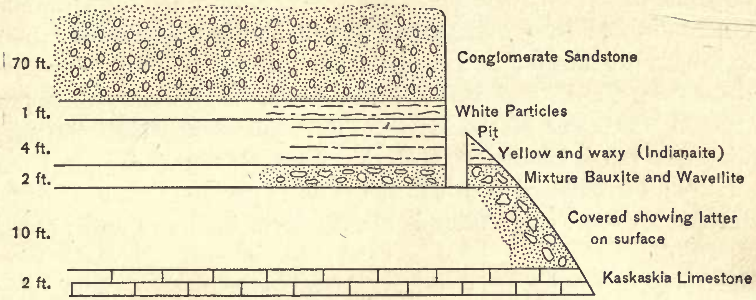

FIG. 17*a*.—Section in sub-carboniferous near Brownsville, Ky., showing occurrence of Indianaite and bauxite. (After Gardner, Ky. Geol. Surv., Bull. 6, 1905.)

The following analyses, which are taken from Gardner, have been recalculated to 100% after subtracting an appreciable percentage of moisture given under each.

ANALYSIS OF CLAYS FROM EDMONSON CO., KY.

	White Clay.	Waxy Clay.	Bauxite-Wavellite Mixture.
Silica (SiO_2)	44.69	45.35	22.81
Alumina (Al_2O_3)	38.17	37.64	46.15
Ferric oxide (Fe_2O_3)	.47	.68	1.41
Lime (CaO)	.40	.36	.41
Magnesia (MgO)	.55	.56	.45
Potash (K_2O)	.09	.24	.35
Soda (Na_2O)	.08	.09	....
Phosphoric acid (P_2O_5)	.21	.23	4.27
Titanic acid (TiO_2)	tr	tr	tr
Sulphur trioxide (SO_3)	tr	tr	.30
Ignition	15.30	14.80	23.82
Total	99.96	99.95	99.97

Pholerite.—This term was first applied by Guillemin in 1825[2] to a pure white pearly substance, occurring in the form of small hexagonal scales, soft and friable to the touch, adherent to the tongue, and giving

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[1] Ky. Geol. Surv., Bull. 6, p. 50, 1905.

[2] Ann. des Mines, XI, p. 489.

a plastic mass with water. Similar occurrences were noted later by J. L. Smith[1] in 1859, by A. Knop,[2] and by L. L. Koninck.[3]

The composition of pholerite is: Silica (SiO_2) 39.3, alumina (Al_2O_3) 45, water (H_2O) 15.7, which corresponds to a chemical formula of $2Al_2O_3,3SiO_3,4H_2O$.

Dana[4] classes this under kaolinite, and gives halloysite as a separate species, but, in view of the fact that the pholerite has been found in crystalline form and the halloysite not, this hardly seems reasonable.

So far as the author is aware no crystallized pholerite has been described from the United States, but Wheeler has pointed to its probable presence in some of the Missouri flint-clays,[5] in which the silica-alumina ratio ranged from 0.94 to 1.15. Now, since this ratio in kaolinite is 1.16 and in pholerite 0.81, it seems quite probable that in some at least of the Missouri clays there is a mixture of kaolinite and pholerite present.

Cook, in his report on the New Jersey clays,[6] gives 32 analyses in which the combined silica has been separated from the sand, and of these 21 seem to indicate the presence of some pholerite, their silica-alumina ratio ranging from 0.94 to 1.15.

If this explanation is correct, then pholerite is no doubt present in many other fire-clays, and perhaps even some kaolins. The writer has questioned whether the presence of bauxite with the kaolinite might not give a mixture with a high alumina percentage similar to that shown by pholerite.

Belonging possibly to this type is the high-alumina flint clay described by Greaves-Walker[7] from Olive Hill, Ky., which has the following composition:

ANALYSIS OF HIGHLY ALUMINOUS FLINT CLAY

Silica (SiO_2)	39.56
Alumina (Al_2O_3)	43.35
Ferricoxide (Fe_2O_3)	2.57
Lime (CaO)	.56
Magnesia (MgO)	.50
Loss on ignition	13.09
	99.63

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[1] Amer. Jour. Sci., ii, XI, p. 58.

[2] Neues Jahrb. Min., 1859; also Johnson and Blake, Amer. Jour. Sci., XLIII, p. 361, 1867.

[3] Zeitschr. f. Kryst. u. Min., II, p. 661.

[4] Syst. Min., 1893, p. 685.

[5] Mo. Geol. Surv., XI, p. 50, 1897.

[6] N. J. Geol. Surv., 1878.

[7] Trans. Amer. Ceram. Soc., VIII, p. 297.

The clay contained small rounded bodies which are nearly pure alumina.

Greaves-Walker states, however, that the matrix surrounding these has the same composition as the No. 1 flint clay. So while the bulk analysis gives a composition resembling pholerite, neither the matrix or nodules alone do, and one might perhaps question whether the material is not a mixture of kaolinite and bauxite. The analysis given above is not the most aluminous one recorded, for one showed 48% Al_2O_3.

Nacrite, according to Johnson and Blake,[1] is identical with pholerite.

Rectorite.[2]—Monoclinic. In leaves or plates resembling mountain-leather; hardness less than that of talc; feels soapy; luster pearly; color pure white, sometimes stained red with iron oxide. Composition: $HAlSiO_4$ or $Al_2O_3,2SiO_2,H_2O =$ silica 50.0, alumina 42.5, water 7.5.

Newtonite.[3]—Rhombohedral. In soft, compact masses, resembling kaolinite. Color white. Its composition is $H_8Al_2Si_2O_{11} +$ water, or $Al_2O_3,2SiO_2,5H_2O =$ silica 38.5, alumina 32.7, water 28.8. Sp. gr. 2.37.

Allophane.—Amorphous. As incrustations which are usually thin, with mammillary surface. Occasionally almost pulverulent. Fracture imperfectly conchoidal and shining to earthy. Very brittle. Color variable. Translucent. Hardness 3. Sp. gr. 1.85–1.89. A hydrous aluminum silicate, $Al_2SiO_5 + 5H_2O =$ silica 23.8, alumina 40.5, water 35.7.

Other species listed by Dana in the kaolinite group are:

Cimolite, $H_6Al_4Si_9O_{27} + 3H_2O$(?)
Montmorillonite, $H_2Al_2Si_4O_{12} + nH_2O$.
Pyrophyllite, $H_2Al_2Si_4O_{12}$.
Collyrite, Al_4SiO_8, $9H_2O$.
Schrötterite, $Al_{16}Si_3O_3$, $30H_2O$.

Le Chatelier's experiments.—H. Le Chatelier,[4] in studying the action of heat on certain clays, emphasized the fact that the hydrated aluminum silicates, in spite of their common occurrence and their industrial import-

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[1] l.c.

[2] Brackett and Williams, Amer. Jour. Sci., XLII, p. 16, 1891.

[3] Ibid.

[4] Compt. rend., CIV, p. 1443, 1887; also Ding. polyt. Jour., CCLXV, p. 94, 1887.

ance, are little known as regards their chemical constitution. They generally form mixtures so complex that analysis alone furnishes no precise data as to their nature, and he suggests that by studying the temperature of dehydration of these bodies, it may be possible to identify a small number of chemical species, and to distinguish the presence of each of them in different mixtures. Le Chatelier states that if a small quantity of clay is rapidly heated there occurs at the moment of dehydration a retardation in the rise of temperature, and this point may be utilized for establishing a distinction between the various hydrated aluminum silicates.

As a result of his experiments he recognized the following groups:

1. Halloysite ($2SiO_2,Al_2O_3,2H_2O+Aq$). Shows a retardation in the rate of rise of the temperature between 150° and 200° C., a second one at 700° C., followed by a sudden acceleration at 1000° C.

2. Allophane (SiO_2,Al_2O_3+Aq). Retardation between 150° and 220° C., and acceleration at 1000° C.

3. Kaolin ($2SiO_2,Al_2O_3,2H_2O$). Shows retardation towards 770° C., and a slight acceleration towards 1000° C.

4. Pyrophyllite ($4SiO_2,Al_2O_3,H_2O$). The first distinct retardation occurs at 700° C., and a second, but less-evident one, at 850° C.

5. Montmorillonite ($4SiO_2,Al_2O_3,H_2O+Aq$). First retardation at about 200° C., a second at 770° C., and a third less-marked one at 950° C.

Other Minerals

Quartz.—This mineral whose formula is SiO_2 is found in at least small quantities in nearly every clay, whether residual or sedimentary, but the grains are rarely large enough to be seen with the naked eye. They are translucent or transparent, usually of angular form in residual clays and rounded in sedimentary ones, on account of the rolling they have received while being washed along the river channel to the sea, or dashed about by the waves on the beach previous to their deposition in deeper, quiet water. The quartz grains may be colorless, but are more often colored superficially red or yellow by iron oxide. Nodular masses of amorphous silica, termed chert or flint, are found in some clays. These are not uncommon in many residual clays of the Southeastern States, and quartz pebbles are by no means rare in many sedimentary clays of Mesozoic or Pleistocene age; indeed, most of the sand-grains found in the coarse, gritty surface clays of sedimentary character are quartz. This mineral also forms most of the hard pebbles found in the so-called "feldspar" beds of the Woodbridge district of New Jersey.[1]

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[1] Ries and Kümmel, N. J. Geol. Surv., Fin. Rept., VI, p. 468, 1904.

Both quartz and flint are highly refractory, being fusible only at cone 35 of the Seger series (see Fusibility, Chap. III), but the presence of other minerals in the clay may exert a fluxing action and cause the quartz to soften at a much lower temperature.

The amount of quartz in clays varies from under one per cent in some kaolins or fire-clays to over 50 or 60 per cent in some very sandy brick-clays.

Feldspar.—This mineral is nearly as abundant in some clays as quartz, but, owing to the ease with which it decomposes, the grains are rarely as large.

When fresh and undecomposed the grains have a bright luster, and split off with flat surfaces or cleavages. Feldspar is slightly softer than quartz, and while the latter, as already mentioned, scratches glass, the former will not.

There are several species of feldspar, which vary somewhat in their chemical composition, and are known by different names, as shown below.

COMPOSITION OF FELDSPARS

Feldspar Species.	Chemical Composition.				
	SiO_2.	Al_2O_3.	K_2O.	Na_2O.	CaO.
Orthoclase	64.70	18.40	16.90	..	..
Albite	68	20	.....	12	12
Oligoclase	62	24	.....	9	5
Labradorite	53	30	.....	4	13
Anorthite	43	37	.....	..	20

The fusing-point of feldspar is about cone 9 (see Seger Cones, under Fusibility), but the different species vary somewhat in their melting-points. The feldspar grains may, however, begin to flux with other ingredients of the clay at a much lower temperature. (See under Alkalies.)

Mica.—This is one of the few minerals in clay that can be easily detected with the naked eye, for it occurs commonly in the form of thin, scaly particles whose bright, shining surface renders them very conspicuous, even when small. Very few clays are entirely free from mica, even in their washed condition, for, on account of the light scaly character of the mineral, it floats off with the clay particles. Some clays are highly micaceous, but such are rarely of much commercial value.

There are several species of mica, all of rather complex composition, but all silicates of alumina, with other bases. Two of the commonest species are the white mica or muscovite, $H_3KAl_3(SiO_4)_3 = (SiO_2$ 45.2, Al_2O_3 38.5, K_2O 11.8, H_2O 4.5), and the black mica or biotite $(H_1K)_2(Mg,Fe)_2(Al,Fe)_2(SiO_4)_3$. Of these two, the muscovite is the most abundant in clay, because it is not readily attacked by the weathering agents. The biotite, on the other hand, decomposes much more rapidly on account of the iron oxide which it contains. Other species of the mica group are no doubt present in some clays. The effect of mica in burning is mentioned under Alkalies.

Lepidolite occurs in some clays, as evidenced by the small amounts of lithia which have been occasionally noted.[1]

Iron Ores.—This title includes a series of iron compounds which are sometimes grouped under the above heading, because they are the same ones that serve as ores of iron when found in sufficiently concentrated form. The mineral species included under this head are: Limonite ($2Fe_2O_3,3H_2O = Fe_2O_3$ 85.5%, H_2O 14.5%), hematite (Fe_2O_3), magnetite (Fe_3O_4), siderite ($FeCO_3 = FeO$ 62.1%, CO_2 37.9%).

Limonite.—This mineral occurs in clays in a variety of forms, and is often widely distributed in them, its presence when in a finely divided condition being shown by the yellow or brown color of the material. When the clay is uniformly colored the limonite is evenly distributed through it, sometimes forming a mere film on the surface of the grains; at other times it is collected into small rusty grains, or again forms concretionary masses of spherical or irregular shape; in still other clays it is found in the form of stringers and crusts, extending through the clay in many directions. The concretions are often especially abundant in some weathered clays. At times they take the shape of thick-walled cylindrical bodies which have apparently formed around plant-roots. The beds of sandstone found in many of the sand and gravel deposits associated with some clays are caused by limonite cementing the sand-grains together.

Limonite concretions can often be removed by hand-picking. If left in the clay, they cause fused blotches which are unsightly and sometimes even cause splitting of the ware.

Limonite is most abundant in surface clays, especially those which are of sandy character or sufficiently porous to admit the oxidizing waters from the surface. It is also found quite frequently in the weathered outcrops of many shales.

Hematite, the oxide of iron, is of a red color and may be found in clays, but it changes readily to limonite on exposure to the air and in the presence of moisture.

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[1] N. W. Lord, Amer. Inst. Min. Eng., Trans., XII, 505.

Magnetite, the magnetic oxide of iron, forms black magnetic grains, and, while not common, is sometimes found when the material is examined microscopically. Like the hematite, it changes to limonite.

Siderite, the carbonate of iron, may occur in clay in the following forms: 1. As concretionary masses known as clay-ironstones, ranging in size from a fraction of an inch to several feet in diameter. They are very abundant in some Carboniferous shales, and are often strung out in lines parallel with the stratification of the clay. If near the surface, the siderite concretions often change to limonite. 2. In the form of crystalline grains, scattered through the clay and rarely visible to the naked eye. 3. As a film coating other minerals in the clay. This mineral will also change to limonite if exposed to the weather.

When iron carbonate is in a finely divided condition and evenly distributed through the clay it may give it a blue or slate-gray color.

Siderite may be present in some surface clays, but it is probably of greatest importance in shales, notably those associated with coal-seams, and may occur in either finely divided (disseminated) or concretionary form.

Pyrite[1] (FeS_2 = Fe 46.6%, S 53.4%).—This mineral, which is not uncommon in some clays, can be often seen by the naked eye, and is known to the clay-miners in some districts as *sulphur*. It has a yellow color, metallic luster, and occurs in large lumps, small grains or cubes, or again in flat rosette-like forms. Not infrequently it is formed on or around lumps of lignite, showing quite clearly that the carbonaceous matter has reduced some iron sulphate present to sulphide. It is a familiar object to all clay-miners of the Raritan district of New Jersey, and abundant also in many Carboniferous clays.

When exposed to the weather pyrite alters rather easily, first to the sulphate of iron and then to limonite. Clays containing pyrite are not, as a rule, desired by the clay-worker, and in mining the pyritic material is rejected.

Pyrite may be found in almost any clay or shale, but owing to the ease with which it is converted into limonite its formation or permanence in surface clays is rare.

Calcite ($CaCO_3$ = CaO 56.00%, CO_2 44.00 %).—This mineral, when abundant, is found chiefly in clays of recent geological age, but some shales also contain considerable quantities of it. It can be easily detected, for it dissolves rapidly in weak acids, and effervesces violently upon the application of a drop of muriatic acid or even vinegar. It is

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[1] In some clays this may be marcasite, the orthorhombic form of FeS_2.

rarely present in grains large enough to be seen with the naked eye, but has been detected with the microscope.[1]

In some clays calcite, as well as some other minerals, may form concretions. Many of the lacustrine and glacial clays found in Wisconsin and Michigan contain large quantities of lime carbonate, and some of those found in other states are highly calcareous. The flood-plain clays mentioned under Texas often carry a high percentage of carbonate of lime.

Gypsum ($CaSO_4,2H_2O = CaO$ 32.6%, SO_3 46.5%, H_2O 20.9%).—It is doubtful whether this mineral is widely distributed in clays, but it is true that some deposits contain large quantities of it. It may occur in a finely divided condition, or in the form of crystals, plates, or fibrous masses of selenite.

The Salina shales of New York frequently contain large plates of nearly clear selenite, while some clays of the southern Atlantic coastal plain exhibit fine crystals of it. Its softness, pearly luster, and transparency render its identification easy when the pieces are of macroscopic size. When heated to a temperature of 250° F. (121° C.) the gypsum loses its water of combination, and when burned to a still higher temperature the sulphuric acid passes off.

Rutile ($TiO_2 = Ti$ 60%, O 40%) is presumed to be of wide-spread occurrence in clays, because titanium is usually found on chemical analysis when proper tests are made. Rutile grains can be seen under the microscope in many fire-clays, and the analyses frequently show the presence of titanium oxide to the extent of two per cent or more. The presence of this mineral, however, is unfortunately too commonly ignored in the analysis of clay, and yet, as will be shown later, its effect on the fusibility of clay is such that it should not be neglected in the higher grades at least. It occurs mostly in the form of bristle-like crystals. No systematic study of their occurrence in clay has ever been taken up. The writer has observed them in some of the Staten Island, N. Y., clays, and reference has been made to them from time to time by other writers.[2]

Ilmenite ($TiFe_2O_3$) probably occurs in clays, but as far as the writer is aware its presence has not been definitely mentioned. If present, it would probably be in part altered to leucoxene. Ilmenite is most likely to occur in those clays which have been derived from soda-rich and basic eruptive rocks.

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[1] Wheeler, Mo. Geol. Surv., XI; Buckley, Wis. Geol. and Nat. Hist. Survey, Bull. VII, Pt. I.

[2] See J. J. H. Teall, Min. Mag., III, 201; G. E. Ladd, Amer. Geol., XXIII, 240, 1899.

Glauconite, a hydrous silicate of potash and iron, is a common ingredient of some clays. Its composition is often somewhat variable, and it may contain other ingredients as impurities. Thus a sample from New Jersey analyzed:[1] Silica 50.70%, alumina 8.03%, iron oxide 22.50%, magnesia 2.16%, lime 1.11%, potash 5.80%, soda 0.75%, water 8.95%. It is an easily fusible mineral, and hence a high percentage of it is not desired in a clay. It is found in the Clay Marl formations of the New Jersey Cretaceous,[2] and in the Eocene formations of Maryland [3] and other coastal-plain states.

Dolomite and Magnesite.—Dolomite ($CaMgCO_3 = CaO$ 30.4%, MgO 21.7%, CO_2 47.8%) and magnesite ($MgCO_3 = MgO$ 47.6%, CO_2 52.4%) may both occur in clay. They are soft minerals resembling calcite, and either alone is highly refractory, but when mixed with other minerals they exert a fluxing action, although not at so low a temperature as lime.

In some residual clays derived from dolomitic limestone the grains of the dolomite are clearly visible in those portions of the mass in which disintegration has not proceeded very far.

Hornblende and Garnet.—These are both silicate minerals of complex composition, which are probably abundant in many impure clays, but their grains are rarely larger than microscopic size. Both are easily fusible, and weather readily on account of the iron oxide in them, and therefore impart a deep-red color to clays formed from rocks in which they are a prominent constituent.

Garnet in fair-sized grains has been noted by the writer in some of the North Carolina kaolins.

Vanadiates, though not common in clays, may cause discoloration. In Germany they have been found in clays associated with the lignites, and also in some fire-clays,[4] but in this country, so far as the writer is aware, they have never been investigated. Clays containing soluble vanadiates, if not burned at a sufficiently high temperature, will show on the surface of the ware a green discoloration which, though it can be washed off with water, will continue to return as long as any of the salt is left in the brick. Vanadiates may be rendered insoluble by burning the clay to a point of vitrification.[5]

Tourmaline.—Since this mineral is not an uncommon constituent of many pegmatite veins, it is sometimes found in kaolins derived from pegmatites. Large crystals of tourmaline are frequently found in the kaolin of Henry County, Virginia.

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[1] N. J. Geol. Surv., Fin. Rept., VI, p. 46, 1904.
[2] Ibid., p. 151.
[3] Md. Geol. Surv., Eocene, p. 52, 1901.
[4] Seger, Ges. Schrift, p. 301; also Tonindus.-Zeit., 1877, No. 46, p. 53.
[5] Ibid.

Wavellite.—This mineral, which has the formula $Al_6(OH)_6(PO_4)_4 + 9H_2O$, has been found in the white clay associated with manganese and iron ores on the northern slope of South Mountain, near Mt. Holly Springs, Pa.[1] The wavellite which occurs in aggregates of white nodules, appears to be limited to a streak of the residual clay 40 to 50 feet wide.

Its occurrence has also been mentioned by Hopkins from North Valley Hill in Chester County, Pa.[2]

Nontronite.—$H_4Fe_2Si_2O_9$, the ferric equivalent of kaolinite[3], described by Weinschenk, may occur in clays, but is rarely referred to or identified. It is less stable than kaolinite, being easily decomposed, either by acid or alkaline solutions, yielding limonite as a final product of aqueous action.

Manganese oxides.—These occur in many clays in small amounts, and when determined are found to rarely exceed one per cent. In some residual clays the manganese has been sufficiently concentrated to be worth collecting.

Vivianite ($Fe_2P_2O_8 + 8H_2O = FeO$ 43%, P_2O_5 28.3%, H_2O 28.7%) has not been described as a common constituent of clay. It has been noted in certain Pleistocene clays of Maryland,[4] in which it occurs as small blue spots. It is not known what effect large quantities of it might have on the clay.

Rare elements.—Even such rare elements as cerium, yttrium, and beryllium oxides have been determined in some clays.[5] Another writer mentions molybdenum, copper and cobalt.[6]

THE CHEMICAL ANALYSIS OF CLAYS

There are two methods of quantitatively analyzing clays. One of these is termed the ultimate analysis, the other is known as the rational analysis.

The ultimate analysis.—In this method of analysis, which is the one usually employed, the various ingredients of a clay are considered to exist as oxides, although they may really be present in much more com-

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[1] G. W. Stose, U. S. Geol. Surv., Bull. 315, p. 474, 1907.

[2] Ann. Rept. Pa. State Coll., 1889-1900, Appen. 3, p. 13.

[3] Zeitschr. Kryst. u. Min., XXVIII, p. 150, 1897.

[4] Md. Geol. Surv., IV, 228, 1902.

[5] J. R. Strohecker, Jour. prakt. Chem. (2), XXXIII, p. 132; Abs. Jour. Chem. Soc., L, p. 314, 1886.

[6] Deutsch. Töpf. u. Zieg. Zeit., 1880, p. 367, and 1881, p. 387.

plex forms. Thus, for example, calcium carbonate ($CaCO_3$), if it were present, is not expressed as such, but instead it is considered as broken up into carbon dioxide (CO_2) and lime (CaO), with the percentage of each given separately. The sum of these two percentages would, however, be equal to the amount of lime carbonate present. While the ultimate analysis, therefore, fails to indicate definitely what compounds are present in the clay, still there are many facts to be gained from it.

The ultimate analysis of a clay might be expressed as follows:

		Silica	(SiO_2)
		Alumina	(Al_2O_3)
Fluxing impurities		Ferric oxide	(Fe_2O_3)
		Ferrous oxide	(FeO)
		Lime	(CaO)
		Magnesia	(MgO)
	Alkalies	Potash	(K_2O)
		Soda	(Na_2O)
		Titanic oxide	(TiO_2)
		Sulphur trioxide	(SO_3)
		Carbon dioxide	(CO_2)
Organic Matter:			
		Water	(H_2O)

In most analyses the first eight of these, excepting the fourth, and the last one are usually determined. The percentage of carbon dioxide is small, except in very calcareous clays, and therefore commonly remains undetermined. Titanic oxide is rarely looked for, except in fire-clays, and even here its presence is frequently neglected. Since the sulphur trioxide, carbon dioxide, and water are volatile at a red heat, they are often determined collectively and expressed as "*loss on ignition*." If carbonaceous matter, such as lignite, is present, this also will burn off at redness. To separate these four, special methods are necessary, but they are rarely applied, and in fact are not very necessary except in calcareous clays or highly carbonaceous ones. The loss on ignition in the majority of *dry*[1] clays is chiefly chemically combined water. The ferric oxide, lime, magnesia, potash, and soda are termed the fluxing impurities, and their effects are discussed under the head of Iron, Lime, Magnesia, etc., and also under Fusibility in Chapter III.

All clays contain a small but variable amount of moisture in their pores, which can be driven off at 100° C. (212° F.). In order, therefore,

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[1] This means dried at 100° C. until their weight is constant. See under Moisture.

to obtain results that can be easily compared, it is desirable to make the analysis on a moisture-free sample which has been previously dried in a hot-air bath. This is unfortunately not universally done.

Interpretation of ultimate analysis.—Much has been said for and against the usefulness of the ultimate analysis of a clay to be used for the manufacture of burned clay wares,[1] but whatever the predominating opinion, ultimate analyses are still made. There are some ceramists who profess to have little or no use for the chemical analysis, while other persons, not all ceramists, attempt to make all sorts of interpretations from it. Neither class is probably right. It seems to the author that an ultimate analysis is sometimes, or even often, of value, but that there are many physical characters, regarding which the analysis affords no data. It might also be reasonably argued that even in the case of those physical properties which are shown by the analysis, their determination is often more easily accomplished by other and simpler tests. The ultimate analysis often lacks also some of the value which it might possess, through neglect to determine separately such substances as titanium oxide, sulphur trioxide, carbon and ferrous iron.

Attempting to regard the matter from a fair and conservative standpoint, it would seem that the following data are obtainable from the ultimate composition, remembering, however, that there may be exceptions to every case, which do not necessarily render the conclusions worthless.

1. The purity of the clay, showing the proportions of silica, alumina, combined water and fluxing impurities present. High grade clays often show a percentage of silica, alumina and chemically combined water approaching quite closely to kaolinite.[2] (See analyses I and II below.)

2. The approximate refractoriness of a clay; for other things being equal, a clay with high total fluxes, is commonly less refractory than one with low total fluxes. In this connection it is to be remembered that texture, irregularity of distribution of the constituents, and condition of kiln atmosphere are among conditions affecting the result.

3. The color to which the clay burns. This must be judged with caution. Assuming the constituents to be evenly distributed, then a clay with 1% or less of ferric oxide is likely to burn pure white, but at high temperatures titanium if present produces discoloration. One

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[1] Clay for Portland cement is not considered, of course, in this discussion, as every one admits the necessity of chemically analyzing such material.

[2] Exceptions would be those containing other hydrous silicates, such as halloysite or pholerite.

with 2–3 per cent of ferric oxide is likely to burn buff; one with several per cent or more of ferric oxide will usually burn red if there is no excess of lime or alumina.[1] It should be remembered that condition of the kiln atmosphere, texture of the clay, and sulphur in the fire gas may all affect the results.

4. The quantity of chemically combined water. Clays with a large amount sometimes show a high shrinkage, but there are many exceptions to this.

5. Excess of silica. A high percentage of silica (80–90%) may indicate a sandy clay, and possibly one of low shrinkage, but does not necessarily point to a very lean one. High silica in a fire-clay usually shows moderate refractoriness provided it is evenly distributed.

6. Organic matter. This should be determined, as it causes trouble in burning if present to the extent of several per cent,[2] requiring thorough oxidation in firing before the clay is allowed to pass to the vitrification stage.

7. Sulphur trioxide. Since this may be the cause of swelling in improperly burned wares, and also indicate the presence of soluble sulphates, it should always be determined.[3]

8. The presence of several per cent of lime and carbon dioxide shows the clay to be of calcareous character, and not only often of buff-burning character, but with a narrow margin between vitrification and viscosity.

9. Titanium dioxide should be determined, especially in fire-clays, for, as has been shown by the author,[4] a small quantity may reduce the fusion point of fire-clay several cones.

It might seem from the above, that the ultimate analysis yields us much, and yet it leaves us practically in the dark as to the plasticity, air and fire shrinkage, density and hardness of burning, tensile strength, etc.

Two clays which show marked resemblance in their chemical composition may show a wide divergence in their physical properties.

As an illustration of this we have the two following clays from Harrisburg, Tex., which form different beds in the same bank. Their characters are given in parallel columns.

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[1] See Iron, Lime, Alumina.

[2] See Carbon, Iron Oxide, Changes in Burning.

[3] See Sulphur; Sulphates.

[4] See Titanium.

Silica (SiO_2)	80.39	80.84
Alumina (Al_2O_3)	9.82	8.09
Ferric oxide (Fe_2O_3)	2.88	2.25
Lime (CaO)	.42	1.44
Magnesia (MgO)	.45	.26
Soda (Na_2O)	.19	.10
Potash (K_2O)	tr	tr
Titanic oxide (TiO_2)	.35	.78
Water (H_2O)	3.11	6.00
	97.61	99.76
Water required for mixing	18.7%	19.8%
Aver. tens. strength, lbs. per sq. in.	188	275
Air shrinkage	4.8	8.6
Plasticity	Fair	High
Drying	No cracking	Cracks
Absorp. cone 5	15.64	8.19
Steelhard	Cone 9	Cone 5

A more interesting contrast could hardly be desired, and it forms no exceptions.

Variation in chemical composition of clays.—The variation in the ultimate composition of clays is well brought out by the following analyses:

ANALYSES SHOWING VARIATION IN COMPOSITION OF CLAYS

	I.	II.	III.	IV	V	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	46.3	45.70	57.62	59.92	68.62	82.45	54.64	38.07	90.00	47.92
Alumina (Al_2O_3)	39.8	40.61	24.00	27.56	14.98	10.92	14.62	9.46	4.60	14 40
Ferric oxide (Fe_2O_3)	....	1.39	1.9	1.03	4.16	1.08	5.69	2.70	1.44	3.60
Ferrous oxide (FeO)	....	....	1.2	....	....	....	....	....	....	....
Lime (CaO)	....	.45	.7	tr.	1.48	.22	5.16	15.84	.10	12.30
Magnesia (MgO)	....	.09	.3	tr.	1.09	.96	2.90	8.50	.10	1.08
Potash (K_2O)	....	2.82	.5	.64	3.36	..	5.89	2.76	tr.	1.20
Soda (Na_2O)	....	....	.2			..			tr.	1 50
Titanic oxide (TiO_2)	....	....	....	....	....	1.00	....	....	.70	1 22
Water (H_2O)	13.9	8.98	10 5	9.70	3.55	2.4	3.74	2.49	3.04	4.85
Moisture	....	.35	2.7	1.12	2.78	....	.85		...	....
Carbon dioxide (CO_2)	....	....	....	....	....	....	4.80	20.46	....	9.50
Sulphur trioxide (SO_3)	....	....	.35	....	....	....	....	....	....	1.44
Organic matter	....	....	....	....	....	....	....	....	....	1.34
Manganous oxide (MnO)	....	....	....	....	.64	....	.76	....	....	....
Total	100.00	100.39	99.97	99.97	100.66	99.03	99.05	100.28	99.98	100.35

I. Kaolinite.
II. Kaolin, Webster, N. Ca.
III. Plastic fire-clay, St. Louis, Mo.
IV. Flint fire-clay, Salinesville, O.
V. Loess-clay, Guthrie Centre, Ia.
VI. Rusk, Cherokee County, Tex.
VII. Brick shale, Mason City, Ia.
VIII. Calcareous clay, Milwaukee, Wis.
IX. Sandy brick-clay, Colmesneil, Tex.
X. Blue shale-clay, Ferris, Tex.

Variations in the same deposit.—Similar differences may not infrequently be shown by the different layers of any one bank, as the following analyses indicate:

ANALYSES SHOWING VARIATIONS IN THE SAME DEPOSIT

	I.	II.	III.
Silica (SiO_2)	59.10	51.5	56.2
Alumina (Al_2O_3)	28.84	17.6	23.7
Ferric oxide (Fe_2O_3)	1.00	16.6	1.5
Lime (CaO)	.70	1.00	.6
Magnesia (MgO)	none	1.1	1.5
Potash (K_2O)	trace	1.5	1.4
Soda (Na_2O)	trace	tr.	2.2
Titanium oxide (TiO_2)	.87	1.6	1.6
Water (H_2O)	9.30	7.7	11.1
	99.81	98.6	99.8

Rational analysis.[1]—This method has for its object the determination of the percentage of the different mineral compounds present, such as quartz, feldspar, kaolinite, etc., and gives us a much better conception of the true character of the material. Most kaolins and other high-grade clays consist chiefly of kaolinite (or some similar hydrous aluminum silicate), quartz, and feldspar, the first forming most of the finest particles of the mass, while the balance is quartz, feldspar, and perhaps some mica. The finest particles are known as the clay substance, which may be looked upon as having the properties of kaolinite. Now, as each of these three compounds of the kaolin—clay substance, quartz, and feldspar—have characteristic properties, the kaolin will vary in its behavior according as one or the other of these constituents predominates or tends to increase.

As to the characters of the three, quartz is of high refractoriness and practically non-plastic, has very little shrinkage, and is of low tensile strength; feldspar is easily fusible, and alone has little plasticity; kaolinite is plastic and quite refractory, but shrinks considerably in burning. The mica, if extremely fine, may serve as a flux, and even alone is not refractory. It is less plastic than the kaolinite, and, when the percentage of it does not exceed 1 or 2 per cent, it can be neglected. To illustrate the value of a rational analysis we can take the following example: Porcelain is made from a mixture of clay, quartz, and feldspar. Suppose that a manufacturer of porcelain is using a clay of the following rational composition:

Clay substance	67.82%
Quartz	30.93
Feldspar	1.25

If now to 100 parts of this there are added 50 parts of feldspar, it would give a mixture whose composition is:

Clay substance	45.21%
Quartz	20.62
Feldspar	34.17

If, however, it became necessary to substitute for the one in use a new clay which had a composition of:

Clay substance	66.33%
Quartz	15.61
Feldspar	18.91

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[1] The method is described in the Manual of Ceramic Calculations, issued by the American Ceramic Society. See also Langenbeck, Chemistry of Pottery, 1895, p. 8.

and added the same quantity of it as we did of the old clay, it would change the rational analysis of the body to the following proportions:

Clay substance	44.22%
Quartz	10.41
Feldspar	45.98

Such an increase of feldspar, as shown by this formula, would greatly increase the fusibility and shrinkage of the mixture; but, knowing the rational composition of the new clay, it would be easy, by making a simple calculation, to ascertain how much quartz and feldspar should be added to bring the mixture back to its normal composition.

The rational composition of a clay can be determined from an ultimate analysis, but the process of analysis and calculation becomes much more complex. The rational analysis is, furthermore, useful only in connection with mixtures of the better grades of clay, in which the variation of the ingredients can only be within comparatively narrow limits. For ordinary purposes the ultimate analysis is of greater value.

Comparison of ultimate and rational analyses.[1]—If we compare the ultimate and rational analyses of a series of clays we find that two clays which agree closely in their ultimate composition may differ markedly in their rational composition and vice versa, as shown in the table on page 63.

In this table Nos. I and II represent two clays which agree very closely in their ultimate composition, but their rational analyses differ by 6 per cent in their clay substance, 12 per cent in quartz, and nearly 19 per cent in feldspar. Nos. III and V, and X and XII also illustrate this point.

In Nos. VI and VII, one a German and the other a North Carolina kaolin, the ultimate analyses are very closely alike, and the rational analyses also agree very well. This is frequently the case when the clay substance is very high, between 96 and 100 per cent, as in Nos. IX and XI.

A third case would be presented if the rationals agreed but the ultimates did not, but such instances seem to be much less common.

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[1] Ries, Amer. Inst. Min. Eng., Trans., XXVIII, p. 160, 1899.

ULTIMATE AND RATIONAL ANALYSES OF CLAYS

	I.	II.	III.	IV.	V.	VI	VII.	VIII.	IX.	X.	XI.	XII.
ULTIMATE ANALYSIS.												
Silica (SiO_2)	62.40	62.52	63.17	64.87	63.07	54.51	53.10	47.60	46.61	58.39	46.82	57.08
Alumina (Al_2O_3)	26.51	25.57	25.09	23.83	24.67	31.41	33.06	34.00	36.47	27.52	38.49	29.94
Ferric oxide (Fe_2O_3)	1.14	.92	.64	.83	.59	.68	1.18	1.30	2.81	.36	1.09	.65
Lime (CaO)	.57	.65	.35	.....	.....	.04	.38	tr.	.14	1.52	.....	.....
Magnesia (MgO)	.01	.10	.26	.50	.40	.43	.08	.50	.....	.41	tr.	.49
Alkalies (K_2O,Na_2O)	.98	1.04	.80	1.39	4.25	.55	.83	3.00	1.44	4.29	1.40	2.26
Loss by ignition	8.80	9.27	9.70	8.36	7.00	12.37	11.32	13.60	12.80	7.19	12.86	9.87
	100.41	100.07	100.01	99.78	99.98	99.99	99.95	100.00	100.27	99.68	100.66	100.29
RATIONAL ANALYSIS.												
Clay substance	66.33	72.05	67.82	63.77	54.92	83.04	83.39	88.34	96.08	55.88	96.55	74.09
Quartz	15.61	27.78	30.93	35.50	23.52	16.28	14.99	8.95	1.93	5.95	2.30	17.21
Feldspar	18.91	.10	1.25	.73	21.56	.68	1.57	2.73	1.99	38.17	1.15	8.70
	100.85	99.93	100.00	100.00	100.00	100.00	99.95	100.02	100.00	100.00	100.00	100.00

I. Crude kaolin, Springer mine, Webster, N. C. N. C. Geol. Surv., Bull. 13.
II. Slip-clay from Rühle's mine, Löthain, Saxony. Thon.-Ind.-Zeit., 1892, p. 1031.
III. Slip-clay from Kaschkau, Germany. Ibid.
IV. Kaolin from Sennewitz, Saxony. Notizblatt, 1876.
V. Porcelain-clay mixture. Ibid.
VI. White earthenware-clay, Löthain, Saxony. Seger's Ges. Schr., p. 887.
VII. Kaolin (unwashed), West Mills, N. C. N. C. Geol. Surv., Bull. 13.
VIII. White earthenware-clay, Wiesau, Germany. Thon.-Ind.-Zeit., 1894, p. 358.
IX. Fire-clay, Bautzen, Germany. Ibid., 1894, p. 842.
X. Kaolin, Limoges, France. Seger's Ges. Schr., p. 552.
XI. Kaolin, Zettlitz, Bohemia. Ibid., p. 50.
XII. Kaolin, Lettin, Saxony. Ibid., p. 50.

Although, as pointed out above, the rational analysis may be an invaluable aid to the investigator of high grade clays, still the methods thus far devised are far from satisfactory for several reasons.

One of these is that the treatment with concentrated sulphuric acid, which is supposed to decompose only the clay substance, may also attack the feldspar. This fact was noted by Langenbeck, in his Chemistry of Pottery,[1] although Seger [2] has stated that quartz and orthoclase are hardly attacked at all by boiling dilute sulphuric acid.

At a later date Jackson and Rich[3], in a paper on the Proximate Analysis of Clays, found that the feldspar was slightly decomposed by the acid treatment, and, curiously enough, to the same extent noted by Seger, viz., 2.24%.[4] They also found that the strength of the alkali must not be neglected. Thus, in "*warming*" for one hour with a 5% caustic soda solution, 2.4% silica and 1% alumina were extracted from the feldspar, and on a second treatment 1.4% and .4% respectively. It therefore appeared that 5% caustic soda not only dissolves the silica separated by the sulphuric acid but also attacks the feldspar.

They moreover found that the finer grained the feldspar the more it was attacked.

Again other attackable sandy minerals, which should not be grouped with the hydrous aluminum silicate (the pure clay substance) may be present. In the rational analysis, it is perhaps doubtful just how much mica is attacked by the acid treatment, and moreover the different species of mica are not all equally affected. Muscovite is said to be but slightly decomposed, but for that matter the same has been said or assumed for feldspar. So whether it is decomposed or not, it is incorrect to place it with either clay substance or sand. But there are other micas which might be present, such as lepidolite, biotite, phlogopite or even paragonite. Dana states that the first of these is not completely decomposed, the second and third are, and gives no data regarding the fourth.[5]

Some data on this point have, however, been furnished by Zschokke,[6] who tested two samples of finely ground mica with the following results:

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[1] p. 3–12.

[2] Collected Writings, I, p. 543.

[3] Jour. Soc. Chem. Indus., Dec. 31, 1900, p. 1087.

[4] Collected Writings, I, p. 53.

[5] System of Mineralogy, 610.

[6] Baumaterialienkunde, VII, 165, 1902.

MUSCOVITE (FAIRLY FERRUGINOUS)

	I.	II.	Average.
Soluble in HCl	18.64	17.80	18.22
Insoluble in H_2SO_4	42.61	40.40	41.10
Sol. in hot conc. H_2SO_4 (by diff.)	38.75	41.80	40.68
	100.00	100.00	100.00

BIOTITE (STRONGLY FERRUGINOUS)

	I.	II.	Average.
Soluble in HCl	77.73	73.34	75.54
Insoluble in H_2SO_4	20.23	18.78	19.50
Soluble in H_2SO_4	2.04	7.88	4.96
	100.00	100.00	100.00

Since mica is quite different from kaolinite in its physical properties, it is important to keep the two separated in the rational analysis.

Again, if the clay is calcareous further trouble may arise. Lime carbonate might be present as coarse sandy grains acting as a non-plastic element, but by the usual method of rationally analyzing clays, it would go in with the clay substance; gone astray, all will admit.

These very apparent defects in the rational analysis led Buckley[1] among others to adopt the following method for the Wisconsin clays, which are usually impure and often of a highly feldspathic character. "The feldspar and kaolinite were calculated from the ultimate analysis, using the following percentage compositions of feldspar: K_2O, 16.9; Al_2O_3, 18.4; $6SiO_2$, 64.7; and Na_2O, 11.8; Al_2O_3, 19.5; $6SiO_2$, 68.7; and kaolinite as Al_2O_3, 39.5; $2SiO_2$, 46.5; $2H_2O$, 14; as given by Dana.[2]

"All the potash and soda were figured to feldspar. The alumina required for the feldspar was deducted from the total alumina, and the difference was taken as the starting-point from which to figure the kaolinite substance. The difference between the total silica (SiO_2) and that required by both feldspar and kaolin gives the quartz and the silica in silicates other than those mentioned."

Binns,[3] while approving of Buckley's suggestion, has pointed out that in some clays the calculation method clearly does not apply, because there is not enough silica present to supply both the required amount for the feldspar (figured from the amount of potash present) and the clay substance demanded by the balance of the alumina. He

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[1] Wis. Geol. and Nat. Hist. Surv., Bull. 7, Pt. I, p. 267, 1901

[2] Text-book of Mineralogy, pp. 371, 377, and 481.

[3] Trans. Amer. Ceram. Soc., VIII, p. 198.

shows that all of the alkali present is not necessarily an ingredient of feldspar, but may be free alkali held in the clay by adsorption, and removable by dilute hydrochloric acid. Experiments made by him showed that the less free alkali a clay contains the more it will absorb when allowed to do so. The amount of free alkali found in a series of clays examined ranged from .079% to .22%, while the quantity of potassium carbonate absorbed varied from .087% to .409% (Fig. 17*b*).

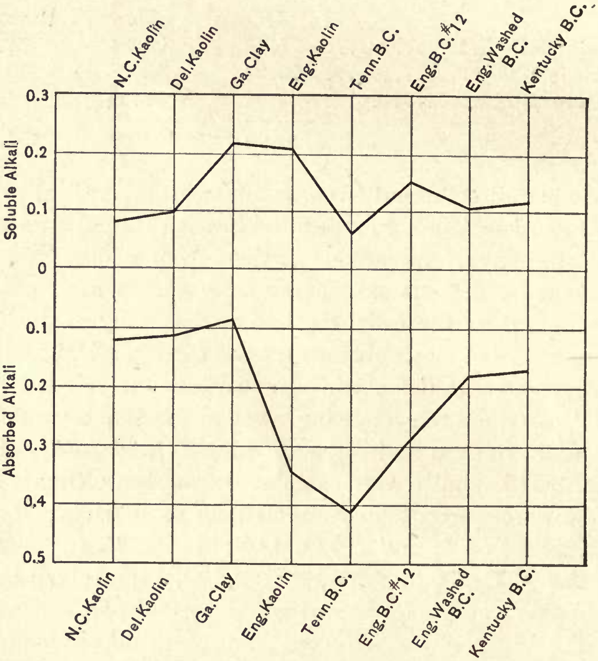

FIG. 17*b*.—Diagram showing percentage of soluble and absorbed salts in clays. (After Binns, Trans. Amer. Ceram. Soc., VIII.)

There still remains to be investigated the degree of solubility of the several hydrous aluminum silicates, such as kaolinite, pholerite, halloysite, etc., which may be present in the clay.

A somewhat elaborate method of rational analysis was devised and used by Zschokke[1] in his work on the Swiss clays. It is a combination of the mechanical and rational analysis, and was carried out somewhat as follows:

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[1] Baumaterialienkunde, VII, p. 165, 1902.

A 50 gm. sample of clay was dried at 110° C., and then boiled for one half hour in water, replacing any of the latter lost by heating. This was then allowed to stand for 24 hours, after which it was washed onto a sieve of 4900 meshes per square centimeter, and washed until the water ran through clear. Any lumps were broken up by careful rubbing. The residue on the sieve consists of sandy particles of quartz and feldspar, carbonates, gypsum, pyrite, etc. This was dried and weighed and = A.

A is examined petrographically and then treated with 1:10 HCl on water bath until the washings from it show no more lime reaction. Filter, dry and weigh = B.

A – B = coarse calcite, some gypsum and some iron.

The fine material which passed through the sieve carries all the clay substance, and some very fine sand, calcite grains and iron oxide. This is dried and weighed and = C.

Two to three grams of this is heated with HCl (1:10) until the filtrate shows no lime reaction, then wash, dry and weigh = D.

C – D = fine grained calcite, gypsum and iron oxide.

The residue is then treated in accordance with the method of rational analysis. It is put in a porcelain dish with 25 c.cm. H_2O and 25 c.cm. conc. H_2SO_4, covered with a watch glass, and heated over a Bunsen burner until the white fumes begin to pass off. After cooling, dilute with water, wash by decantation, and then boil first with NaOH (1:20) and then with HCl (1:10), repeating this treatment with these. The residue is transferred to a filter, washed with diluted HCl, ignited, and weighed = E.

The combined results are tabulated as follows, the figures given being those of a brick clay.

(*a*) Ordinary mechanical analysis:

Non-plastic constituents	51.42
Clay substance (by diff.)	48.58
	100.00

(*b*) Rational analysis:

Quartz, feldspar, etc. (Insol. in H_2SO_4)		58.05	67.91 non-plastic constituents
$CaCO_3$	Determined from ultimate analysis	.20	
Fe_2O_3		4.74	
$CaSO_4$		1.48	
CaO		.27	
MgO		3.17	
Clay substance (by diff.)			32.09
			100.00

(*c*) Combined chemical-mechanical analysis:

Coarse sand (B)	38.62	62.26	76.29 non-plastic
Fine sand (E)	23.64		
Coarse $CaCO_3$, Fe_2O_3, $CaSO_4$ (A—B)	1.44	14.03	
Fine ditto (C—D)	12.59		
Clay substance			23.71
			100.00

He rightly observes that one may get a different per cent of clay substance by all three methods, but submits the combination method as the most satisfactory one.

Method of Making Ultimate Analysis

The methods which work successfully in the ultimate analysis are outlined below. For additional ones, or for all the details of manipulation, it is better to consult some standard work on analysis, as space forbids a complete description of them all here.[1]

Moisture.—Two grams are heated in a platinum crucible at 100° C. until they show a constant weight. The loss is reported as moisture.

Loss on Ignition.—The crucible and clay are heated to redness over a blast lamp until they show no further loss in weight. This loss represents chemically combined water, and if present also carbon dioxide, sulphur trioxide and organic matter.

Silica.—One gram of clay is mixed with 5 grams sodium carbonate and one quarter gram potassium nitrate, and brought to calm fusion over a blast lamp. The melt is removed from the crucible, heated with an excess of hydrochloric acid and evaporated twice to approximate dryness in a casserole or platinum dish. Dilute hydrochloric acid is then added, the solution brought to boiling and filtered. The silica is washed thoroughly with boiling water and then ignited in a platinum crucible, weighed, and moistened with concentrated sulphuric acid. Hydrofluoric acid is cautiously added until all the silica has disappeared. The solution is evaporated to dryness upon a sand-bath, ignited, and weighed. The difference in weight is silica. The residue may contain iron, alumina and titanium.

Alumina.—The filtrate from the silica is acidified with hydrochloric acid, brought to a boil, and ammonium hydrate added until the odor

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[1] See Hillebrand, Some Principles and Methods of Rock Analysis, U. S. Geol. Surv., Bull. 176, 1900; Washington, Manual of the Chemical Analysis of Rocks, N. Y., John Wiley & Sons, 1904.

of it is perceptible. Boil, settle and filter. A solution of the precipitate[1] and reprecipitation is desirable. Wash the precipitate until free from chlorides, ignite and weigh as Al_2O_3, Fe_2O_3,[2] and TiO_2. The last two are later determined separately and deducted from above total weight.

Ferric Oxide.—To the ignited precipitates of alumina and ferric oxides add 5 to 10 grams coarsely powdered acid potassium sulphate. Heat gently until the salt is fused, and keep it so for about an hour at a gentle heat, and another hour at a higher heat, until all the precipitate has dissolved. Cool. Dissolve in about 150 cc. hot water to which about 10 cc. of concentrated sulphuric acid has been added.

Filter to remove any silica that may be present. The filtrate contains the iron in the ferric state. It is reduced with zinc, or better, hydrogen sulphide, and titrated with potassium permanganate.

Titanic Oxide.—The solution for the iron titration is evaporated to about 150 c.c. Hydrogen dioxide is added to an aliquot part, and the tint compared with that obtained from a standard solution of titanium sulphate.

Calcium Oxide.—The filtrate from the precipitate of iron and aluminium hydroxides is concentrated to about two hundred cubic centimeters, and the calcium precipitated in a hot solution by adding one gram of ammonium oxalate. The precipitate is allowed to settle during twelve hours, filtered, and washed with hot water, ignited, and weighed as calcium oxide. When the calcium is present in notable amounts, the oxide is converted into the sulphate and weighed as such.

Magnesium Oxide.—The filtrate from the calcium oxalate precipitate is concentrated to about one hundred cubic centimeters, cooled, and the magnesium precipitated by means of hydrogen disodium phosphate in a strongly alkaline hydroxide solution. The magnesium ammonium phosphate, after standing overnight, is caught upon an ashless filter, washed with water containing at least five per cent ammonium hydroxide, burned, and weighed as magnesium pyrophosphate.

Sulphur (total present).—The sulphur is determined by fusing one-half gram of clay with a mixture of sodium carbonate, five parts, and potassium nitrate, one part. The melt is brought into solution with hydrochloric acid. The silica is separated by evaporation, heating, re-solution, and subsequent filtration. Hydrochloric acid is added to the filtrate to at least five per cent, and the sulphuric acid is precipitated

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[1] Use conc. HNO_3.

[2] These can be weighed in same crucible containing residue from hydrofluoric treatment of silica.

by adding barium chloride in sufficient excess, all solutions being boiling hot. The barium sulphate is filtered off and washed with hot water, burned, and weighed as such.

Ferrous Oxide is determined by fusing one-half gram with five grams sodium carbonate, the clay being well covered with the carbonate, the top being upon the crucible. The melt is dissolved in a mixture of dilute hydrochloric and sulphuric acids in an atmosphere of carbon dioxide. The ferrous iron is determined at once by titration with a standard potassium permanganate solution.

Alkalies.—About .5 grams of finely ground clay are mixed with about 4 grams calcium carbonate and about .5 grams ammonium chloride. The mixture is thoroughly ground together and then transferred to a platinum crucible, with cover. Heat over a low frame for about ten minutes or so until no more vapors of ammonia or ammonium chloride are given off. Then continue the heating over nearly the full flame of a Bunsen burner, keeping the lower third of the crucible heated to redness. After heating three-quarters hour, cool, and soak the cooled crucible in water sufficient to slake the quicklime. Transfer contents of crucible to a platinum dish, break up with agate pestle, and boil gently for a few minutes. Wash by decantation, boiling each time, and run wash water as well as solid matter from dish onto a filter. Wash with hot water.

To the filtrate add some ammonia water and boil. Then add 50 c.c. water containing 1.5 to 2 grams ammonium carbonate, and boil. Allow precipitate to settle, filter, and wash with hot water until there is no more reaction for chlorine. The volume of the filtrate should be 400 to 500 c.c. Evaporate down to 50 c.c. on water bath, transfer to a platinum dish and evaporate to dryness. Cover with watch glass and heat gently on sand bath, avoiding decrepitation. When ammonium chloride vapors begin to appear, raise the heat a little and continue until the watch glass and sides of basin are covered with ammonium chloride. Remove the cover, and drive off the ammonium chloride by heating sides of dish, after which heat the bottom. Add water to dissolve the chlorides, and if any sulphides are present, add a drop of barium chloride to precipitate the sulphur. Then add a few drops of ammonium carbonate to precipitate the excess of barium and lime. Evaporate to dryness. Add 2 to 3 c.c. of water and filter into a weighed platinum crucible. Add a drop of hydrochloric acid to the crucible and evaporate to dryness on water-bath. When dry, heat the covered crucible over a small flame until ammonium chloride is driven off. Then uncover and heat. Cool, weigh and get combined weights of NaCl and KCl.

Add 5 or 10 c.c. water to dissolve the chlorides, and if there is no insoluble matter requiring filtering, add potassium platinic chloride, and evaporate to a syrupy consistency on the water bath. Add 80% alcohol, and filter through a Gooch crucible. The precipitate is thoroughly washed with 80% alcohol, dried at 100° C. and weighed.

The potassium platinic chloride, multiplied by .1939, gives K_2O, or by .307 to get KCl. The weight of the latter can then be deducted from the mixed chlorides to give NaCl, which, multiplied by .5308, gives Na_2O.

Method of making Rational Analysis

This may be made in several ways, two of which are given.

1. The first consists in separating the "insoluble residue" in the clay, as follows: Two grams of the material are digested with twenty cubic centimeters of dilute sulphuric acid for six or eight hours on a sand-bath, the excess of acid being finally driven off.

One cubic centimeter of concentrated hydrochloric acid is now added and boiling water. The insoluble portion is filtered off, and after being thoroughly washed with boiling water is digested in fifteen cubic centimeters of boiling sodium hydroxide of ten per cent strength. Twenty-five cubic centimeters of hot water are added and the solution filtered through the same filter-paper, the residue being washed five or six times with boiling water. The residue is now treated with hydrochloric acid in the same manner and washed upon the filter-paper, until free from hydrochloric acid, is burned and weighed as insoluble residue.

The alumina found in the portion insoluble in sulphuric acid and sodium hydroxide is multiplied by 3.51. This factor has been found to represent the average ratio between alumina and silica in orthoclase feldspar; therefore the product just obtained represents the amount of silica that would be present in undecomposed feldspar. The sum of this silica with the alumina, ferric oxide, and alkalies equals the "feldspathic detritus." The difference between silica as calculated for feldspar and the total silica in the insoluble portion represents the "quartz" or "free sand." The difference between that portion of the sample insoluble in sulphuric acid and sodium hydroxide and the total represents the "clay substance."

2. A second method, and one used in Germany,[1] is conducted as follows:

After five grams of clay are weighed and placed in a 200 c.c. Erlen-

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[1] Ladenburg, Handwörterbuch der Chemie, 12, p. 15.

meyer flask, 100–150 c.c. of water and 2 c.c. of sodium hydrate are added, and the contents boiled. covering the flask with a small glass funnel. The contents of the flask are allowed to cool, and 25 c.c. of sulphuric acid is added. Continue the boiling until the fumes of the acid begin to be driven off the flask.

As a result of the reactions which have taken place the calcium carbonate has been changed to calcium sulphate, the aluminum silicate has been converted into aluminum sulphate and silicic acid, while the quartz and feldspar remain. Water is added to the flask and most of the sulphuric acid and aluminum sulphate washed out of the residue by decantation.

In washing by decantation the water which is decanted should be placed upon a filter-paper, for the reason that, should any of the residue be removed from the flask, it can be returned by making a hole in the filter and washing back into the flask.

After washing by decantation the contents of the flask are treated with hydrochloric acid (100 c.c.) and boiled. Decant off the liquid and add sodium hydroxide (100 c.c.), boil and decant. Repeat the above process with hydrochloric acid and sodium hydrate. The residue is then transferred to a filter and washed with dilute hydrochloric acid (1 to 20). The filter with contents is transferred to a platinum crucible and weight determined.

The contents of the crucible are treated with a few drops of sulphuric acid and small quantities of hydrofluoric acid, evaporated to dryness in the water-bath, ignited, weighed, and from the loss calculate and determine aluminum, iron, etc. From the aluminum found in the residue the feldspar is calculated, 1 part of alumina (aluminum oxide) = 5.41 of feldspar.

MINERAL COMPOUNDS IN CLAY AND THEIR CHEMICAL EFFECTS

All the constituents of clay influence its behavior in one way or another, their effect being often noticeable when only small amounts are present. Their influence can perhaps be best discussed individually.

Silica [1]

This is present in clay in two different forms, namely, uncombined as silica or quartz and in silicates, of which there are several. Of these one of the most important is the mineral kaolinite, which probably

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[1] See also description of the minerals quartz, feldspar, kaolinite, and mica above.

occurs in all clays, and is termed the clay base or clay substance. The other silicates include feldspar, mica, glauconite, hornblende, garnet, etc. These two modes of occurrence of silica, however, are not always distinguished in the ultimate analysis of a clay, but when this is done they are commonly designated as "free" and "combined" silica, the former referring to all silica except that contained in the kaolinite, which is indicated by the latter term. This is an unfortunate custom, for the silica in silicates is, properly speaking, combined silica, just as much as that contained in kaolinite. A better practice is to use the term sand to include quartz and silicate minerals other than kaolinite, which are supposedly not decomposable by sulphuric acid. In most analyses, however, the silica from both groups of minerals is expressed collectively as "total" silica.

The percentage of both quartz and total silica found in clays varies between wide limits, as can be seen from the following examples. Wheeler gives a minimum [1] of 5 per cent in the flint-clays, and the sand percentage as 20 to 43 per cent in the St. Louis clays, and 20 to 50 per cent in the loess-clays. Twenty-seven samples of Alabama clays analyzed by the writer contained from 5 to 50 per cent of insoluble residue, mostly quartz.[2] In seventy North Carolina clays [3] the insoluble sand ranged from 15.15 to 70.43 per cent.

The following table [4] gives the variation of total silica in several classes of clays, the results being obtained from several hundred analyses:

AMOUNT OF SILICA IN CLAYS

Kind of clay.	Per cent of total silica.		
	Min.	Max.	Aver.
Brick-clays	34.35	90.877	59.27
Pottery-clays	45.06	86.98	45.83
Fire-clays	34.40	96.79	54.304
Kaolins	32.44	81.18	55.44

The free silica or quartz is one of the commonest constituents of clay, and ranges in size from particles sufficiently large to be visible to the eye down to the smallest grains of silt.

With the exception of kaolinite, all of the silica-bearing minerals

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[1] Mo. Geol. Surv., Vol. XI, p. 54.

[2] Ala. Geol. Surv., Bull. 6, 1900.

[3] N. C. Geol. Surv., Bull. 13, p. 24, 1898.

[4] Bull. N. Y. State Museum, No. 35, p. 525.

mentioned above are of rather sandy or silty character, and, therefore, their effect on the plasticity and shrinkage will be similar to that of quartz. In burning the clay, however, the general tendency of all is to affect the shrinkage and also the fusibility of the clay, but their behavior is in the latter respect more individual.

Sand (quartz and silicates) is an important antishrinkage agent, which greatly diminishes the air-shrinkage, plasticity, and tensile strength of clay, its effect in this respect increasing with the coarseness of the material; clays containing a high percentage of very finely divided sand (silt) may absorb considerable water in mixing, but show a low air-shrinkage. The brickmaker recognizes the value of the effects mentioned above and adds sand or loam to his clay, and the potter brings about similar results in his mixture by the use of ground-flint.

It is thought by some that because of the refractoriness of quartz its addition to any clay will raise its fusion-point, but this is true only of those clays containing a high percentage of common fluxes and silica and which are burned at low temperatures. Its effect on highly aluminous low-flux clays reduces their refractoriness.

In considering the effects of sand in the burning of clays, it must be first stated that the quartz and silicates fuse at different temperatures. A very sandy clay will, therefore, have a low fire-shrinkage as long as none of the sand-grains fuse, but when fusion begins a shrinkage of the mass occurs. We should, therefore, expect a low fire-shrinkage to continue to a higher temperature in a clay whose sand-grains are refractory.

Of the different minerals to be included under sand the glauconite is the most easily fusible, followed by hornblende and garnet, mica (if very fine grained), feldspar, and quartz. The glauconite would, therefore, other things being equal, act as an antishrinkage agent only at low temperatures. Variation in the size of the grain may affect these results, but this point is discussed under Fusibility (Chapter III).

The following tests give interesting data on the effect of quartz on clay.

F. Krage,[1] after experimenting with a series of mixtures made up of a blue clay (fusion point = cone 34), and a red clay (fusion point = cone 6), each mixed with quartz sand grains of different degrees of fineness and burned to cones 08, 6, and 14, drew the following conclusions:

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[1] Der Einfluss des Quarzes von verschiedener Korngrösse auf einen feuerfesten und einen nicht feuerfesten Ton, Tonindus.-Zeit., XXXII, No. 67, p. 934, 1908.

1. The finer the texture of the quartz sand.
    - *a.* The more water required for tempering.
    - *b.* The slower the clay must be dried.
    - *c.* The higher the air and fire shrinkage.
    - *d.* The lower the porosity of the mass.
    - *e.* The lower the permeability of the mixture.
    - *f.* The higher the tensile and crushing strength.
    - *g.* The higher the refractoriness.
    - *h.* The lighter the color of the burned ware.
    - *i.* The less the ware is able to withstand rapid changes of temperature.
    - *j.* The more complete the fluxing between clay and quartz.
2. The greater the percentage of quartz sand added.
    - *a.* The smaller the amount of water required for mixing.
    - *b.* The more rapidly the clay can be dried.
    - *c.* The lower the air and fire shrinkage.
    - *d.* The lower the porosity in soft burned pieces, and the higher the porosity in harder burned ones.
    - *e.* The greater the permeability of the mass.
    - *f.* The lower the tensile and crushing strength.
    - *g.* The higher the refractoriness.
    - *h.* The lighter the color after burning.
    - *i.* The better the ability to withstand rapid temperature changes.

It is unfortunate that the investigator did not carry his tests to higher cones, as the refractoriness would have shown a falling off.

Hydrous silica.[1]—From the observations of W. H. Zimmer[2] it would appear that some kaolins carry hydrated silicic acid. In a kaolin of the composition:

Silica (SiO_2)	57.00
Alumina (Al_2O_3)	24.85
Ferric oxide (Fe_2O_3)	.25
Lime (CaO)	.05
Water (H_2O)	17.81

he found that the rational analysis showed only 0.05 per cent not decomposed by sulphuric acid, which would lead one to suppose that the clay was a pure kaolin. The analysis, however, disproved this, and led to the conclusion that there must be free hydrated silicic acid. His

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[1] In this connection see also chapter on fullers earth.

[2] Trans. Amer. Ceram. Soc., III, p. 25, 1901.

experiments with this clay, and with artificial mixtures containing silicic acid, showed that the presence of any important quantity of free hydrated silicic acid in a clay tends:

1. To produce an increase of translucency over that obtained where the silica used is all quartzitic at equal temperatures; 2, to bring about an improvement in color; 3, to increase the shrinkage both in air and in fire; 4, to produce a lowering of the temperature at which vitrification occurs; 5, a tendency to warp in drying; 6, a tendency to form a hard coating on the surface of the clay or ware, due to the deposition of H_2SiO_3 from water used in making wares plastic.

Iron Oxide

Sources of iron oxide in clays.—Iron oxide is one of the commonest ingredients of clay, and a number of different mineral species may serve as sources of it, the most important of which are grouped below:

Hydrous oxide, limonite; oxides, hematite, magnetite; silicates, biotite, glauconite (greensand), hornblende, garnet, etc.; sulphides, pyrite; carbonates, siderite; sulphate, melanterite.

In some, such as the oxides, the iron is combined only with oxygen, and is better prepared to enter into chemical combination with other elements in the clay when fusion begins. In the case of the sulphides and carbonates, on the contrary, the volatile elements, namely, the sulphuric-acid gas of the pyrite and the carbonic-acid gas of the siderite, have to be driven off before the iron contained in them is ready to enter into similar union. In the silicates the iron is chemically combined with silica and several bases, forming mixtures of rather complex composition and all of them of low fusibility, particularly the glauconite. Several of these silicates are easily decomposed by the action of the weather, and the iron oxide which they contain combines with water to form limonite. This is usually in a finely divided condition, so that its coloring action is quite effective.

The range of ferric oxide, as determined from a number of published clay analyses, is as follows:[1]

AMOUNT OF FERRIC OXIDE IN CLAYS[2]

Kind of clay.	Min.	Max.	Aver.
Brick-clays	0.126	32.12	5.311
Fire-clays	0.01	7.24	1.506

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[1] Bull. N. Y. State Museum, No. 35, p. 520.

[2] The percentage of FeO is rarely determined in the ultimate analysis of clay, but it always should be.

Effects of iron compounds.—Iron is the great coloring agent of both burned and unburned clays. It may also serve as a flux and even affect the absorption and shrinkage of the material.

Coloring action of iron in unburned clay.—Many clays show a yellow or brown coloration due to the presence of limonite, and a red coloration due to hematite; magnetite is rarely present in sufficient quantity to color the clay; siderite or pyrite may color it gray, and it is probable that the green color of many clays is caused by the presence of silicate of iron, this being specially true of glauconitic ones. The intensity of color is not always an indication of the amount of iron present, since the same quantity of iron may, for example, color a sandy clay more intensely than a fine-grained one, provided both are nearly free from carbonaceous matter; the latter, if present in sufficient quantity, may even mask the iron coloration completely. The coloring action will, moreover, be effective only when the iron is evenly distributed through a clay in an extremely fine form. It is probable that the limonite coloring clays is present in an amorphous or non-crystalline form, and forms a coating on the surface of the grains.

Coloring action of iron oxide on burned clay.[1]—All of the iron ores will in burning change to the red or ferric oxide, provided a sufficient supply of oxygen is able to enter the pores of the clay before it is vitrified; if vitrification occurs the iron oxide enters into the formation of silicates of complex composition. The color and depth of shade produced by the iron will, however, depend on first, the amount of iron in the clay; second, the temperature of burning; third, condition of the iron oxide, and fourth, the condition of the kiln atmosphere.

Clay free from iron oxide burns white. If a small quantity, say 1 per cent, is present a slightly yellowish tinge may be imparted to the burned material, but an increase in the iron contents to 2 or 3 per cent often produces a buff product, while 4 or 5 per cent of iron oxide in many cases makes the clay burn red. There seem, however, to be not a few exceptions to the above statements. Thus we find that the white-burning clays carry from a few hundredths per cent to over 1 per cent of iron oxide,[2] the more ferruginous containing more iron than the purer grades of buff-burning clays. Again, among the buff-burning clays we find some with an iron-oxide content of 4 or 5 per cent, an amount equal to that contained in some red-burning ones.

The facts would therefore seem to indicate that the color of the burned clay is not influenced solely by the quantity of iron present.

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[1] See also color of burned clay, p. 161.

[2] Seger's Collected Writings, Translation, I, p. 109; also Orton, Trans. Amer. Ceram. Soc., V, p. 380.

Seger has divided the buff-burning clays into two groups, namely, (1) those of such high iron contents as to burn red normally, but which are sufficiently calcareous to enable the lime to destroy the red iron color and form a yellow compound of iron and lime, and (2) those low in iron and high in alumina, which would normally burn pale red, but develop a yellow color due to the formation of an alumina-iron compound. He thus believes that the red coloration of the iron is destroyed by similar causes, but on account of the lime being a stronger or more active base than the alumina it is able to take care of a greater quantity of iron.

Orton[1] has argued against the effect of alumina, claiming that if this were true synthetic mixtures should easily give the buff color which, in his experience, it is not possible to produce. As he states, there is a great uniformity in the color of buff-burning clays, while their iron-alumina ratios fluctuate greatly; some fire-clays containing 40 per cent of alumina and 0.5 per cent iron, and yielding a good buff product, while others with 15 to 20 per cent alumina and 2.5 per cent iron burn to almost exactly the same tint. On the other hand, some clays with about the same alumina and iron content burn red. If Orton is correct it would seem, therefore, as if the cause of this buff-burning quality must be sought for in some other direction.

The evenness of color is apparently closely connected with the physical condition of the iron oxide, that in colloidal form giving a uniformity of shade not obtainable by the admixture of very finely ground material.

If a clay is heated at successively higher temperatures, it is found that, other things being equal, the color usually deepens as the temperature rises. Thus, if a clay containing 4 per cent of iron oxide is burned at a low temperature it will be pale red, and harder firing will be necessary to develop a good brick red, which will pass into a deep red and then reddish purple.

Seger explained the successive shades of red by assuming that the iron oxide increased in density with rising temperature.

The brilliancy of the color appears to be influenced by the texture, as the more sandy clays can be heated to a higher temperature, without destruction of the red color, than the more aluminous ones. Alkalies also appear to diminish the brightness of the iron coloration.[2]

Among the oxides of iron two kinds are recognized, known respectively as the ferrous oxide (FeO) and ferric oxide (Fe_2O_3). In the former

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[1] Trans. Amer. Ceram. Soc., V, p. 389, 1903.

[2] Ries, N. Y. State Mus., Bull. 35, 515, 1900; Orton, Trans. Amer. Ceram. Soc., V, p. 414, 1903.

we see one part of iron united with one of oxygen, while in the latter one part of iron is combined with one and one-half parts of oxygen. The ferric oxide, therefore, contains more oxygen per unit of iron than the ferrous salt, and represents a higher stage of oxidation. In the limonite and hematite the iron is in the ferric form, representing a higher stage of oxidation. In magnetite both ferrous and ferric iron are present, but in siderite the ferrous iron alone occurs. In the ultimate analysis the iron is usually determined as ferric oxide, no effort being made to find out the quantity present in the ferrous form, although if there is any reason to suspect that much of the latter exists it should be determined. Iron passes rather readily from the ferric to the ferrous form. It also oxidizes easily unless carbon and sulphur are present, in which case its oxidation is not possible until these two substances have been oxidized. Indeed they are sometimes supplied with oxygen at the expense of the iron, which may be left in a ferrous, magnetic, or even spongy, metallic condition (Orton)[1]; so if there is a deficit ofoxygen in the inside of the kiln the iron does not get enough oxygen and the ferrous compound results, but the latter changes rapidly to the ferric condition if sufficient air carrying oxygen is admitted. If, however, the oxidation of the iron does not begin until the clay has become so dense as to prevent free circulation of the air through it, then it may form ferrous silicates, which impart black or dark colors to the clay.[2]

There is consequently a necessity for recognizing these two forms of iron oxide because they affect the color of the clay differently. Ferrous oxide alone is said to produce a green color when burned, while ferric oxide alone may give purple or red, and mixtures of the two produce yellow, cherry red, violet, blue, and black.[3]

Seger[4] found that combinations of ferric oxide with silica produced a yellow or red color in the burned clay. We may thus get a variation in the color produced in burning clay, depending on the character of oxidation of the iron or by mixtures of the two oxides.[5]

Moreover, in the burning of ferruginous clays it is usually desirable to get the iron thoroughly oxidized to prevent trouble in the later stages of burning. To accomplish this the iron must be freed of any sulphur or carbon dioxide which may be combined with it, and other volatile

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[1] Third Report Committee on Technical Investigation Indianapolis, 1908.

[2] See also Tonindus, Zeit., No. 90, p. 1432, 1903; Trans. Eng. Ceram Soc., II, p. 100 (Quoted by Orton, l. c.)

[3] Keramic, p. 256.

[4] Notizblatt, p. 16, 1874.

[5] See "Flashing of Brick," under Burning.

or combustible elements in the clay must be driven off, so as to allow the oxidizing gases to enter the clay and unite with any ferrous iron that may be present.

Sulphide of iron (pyrite) loses half its sulphur at a red heat, and the balance will, under oxidizing conditions, pass off probably by 900° C., while siderite or ferrous carbonate loses its carbon dioxide between 400° and 500° C.; magnesium carbonate and calcium carbonate lose their CO_2 at about 500° C.[1] and 800° to 900° C. respectively. Carbonaceous matter or sulphur if present, must also be carefully burned off. If the clay contains much volatile or combustible matter the burning must proceed slowly below 1000° C., in order to remove it and allow the iron to get oxidized while the clay is still porous.

After oxidation the clays will show a more brilliant iron color than they do at the end of the dehydration period. They are also harder and show a slight decrease in volume.

If the clay has been improperly oxidized it shows later when vitrification is reached, by the dark ferrous silicate cores in the center of the brick. This may form, however, without the development of any swelling.[2] When swelling does accompany the formation of this blackcore, it is to be traced to sulphur.

Fine-grained clays are more difficult to oxidize than coarse-grained ones, because of the small size of their pores, and grog is, therefore, added at times to open the grain of the material.

G. C. Matson[3] came to the conclusion that if ferruginous clays are burned to viscosity in an oxidizing atmosphere, that the ferric oxide does not tend to reduce to a ferrous form, as some have believed.

Since the stage of oxidation of the iron is dependent on the quantity of air it receives during burning, the condition of the kiln atmosphere is of great importance. If there is a deficiency of oxygen in the kiln, so that the iron oxide, if present, is reduced to the ferrous condition, the fire is said to be *reducing*. If, on the contrary, there is an excess of oxygen, so that ferric oxides are formed, the fire is said to be *oxidizing*. These various conditions are often used by the manufacturer to produce certain shades or color-effects in his ware. Thus, for example, the manufacturer of flashed brick produces the beautiful shading on the surface of his product by having a *reducing* atmosphere in his kiln fol-

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[1] Brill's work cited under magnesia show that some of the CO_2 may pass off earlier.

[2] Orton and Staley, Third Report of Committee on Technical Investigation, Indianapolis, 1908.

[3] Clay Worker, July, 1904.

lowed by an *oxidizing* one. The potter aims to reduce the yellow tint in his white ware by cooling the kiln as quickly as possible to prevent the iron from oxidizing.

Fluxing action of iron oxide.—Iron oxide is a fluxing impurity, lowering the fusing-point of a clay, and this effect will be more pronounced if the iron is in a ferrous condition or if silica is present.

Wheeler, in his work on the Missouri clays, formed the opinion that ferrous iron produces fluxing action about 150°–200° F. lower than ferric iron, whereas Orton and Staley, in their work referred to above, failed to find that any such great difference existed, althogh some was noticeable.[1]

Purdy and DeWolf, on the other hand, mention the case of a clay which fused to a globule at cone 16 under reducing conditions, but in an oxidizing fire did not fuse to a bead until cone 26.[2]

In burning a clay at low temperatures the hydrous ferric oxide (limonite) loses its water of hydration. Heating the clay to vitrification in a reducing atmosphere is believed to produce a ferrous silicate, which is seen on the brown, black, or greenish glassy portion of the surface of paving-brick and unglazed sewer-pipe.[3] When well-vitrified bricks show a red color it is thought by some that the iron oxide is merely dissolved in the vitrified mass and has not entered into combination.

A low iron content is, therefore, desirable in refractory clays, and the average of a number of analyses of these shows it to be 1.3 per cent. Brick-clays, which are usually easily fusible, contain from 3 to 7 per cent of iron oxide.[4]

Effect of iron oxide on absorptive power and shrinkage of clay.—So far as the writer is aware no experiments have been made to discover the increased absorptive power of a clay containing limonite, although the clay soils show that the quantity of water absorbed is greater with limonite present. Senfft believes that it influences the power of clay for absorbing both gases and solutions.[5] This greater absorptive power may be accompanied by an increased shrinkage. The fire-shrinkage might also be great, because of the increased loss of combined water due to the presence of limonite.[6]

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[1] They quote Wheeler figures as 200° C., instead of 200° F., which is about 111° C.

[2] Ill. Geol. Surv., Bull. 4, p. 158, 1907.

[3] Ia. Geol. Surv., XIV, 59, 1904.

[4] Many fire-brick of good refractoriness show as much as 2 or 3 per cent Fe_2O_3.

[5] Thonsubstanzen, Berlin, 1879, p. 21.

[6] See tests under Fire-shrinkage, Chap. III.

Lime

Lime is found in many clays, and in the low-grade ones may be present in large quantities. Quite a large number of minerals may serve as sources of lime in clays, but all fall into one of the three following groups:

1. Carbonates. Calcite, dolomite.
2. Silicates containing lime, such as feldspar and garnet.
3. Sulphates. Gypsum.

Whenever the ultimate analysis of clay shows several per cent of lime (CaO) it is usually there as an ingredient of lime carbonate ($CaCO_3$), and in such cases its presence can be easily detected by putting a drop of muriatic acid or vinegar on the clay.[1] When present in this form it is apt to be finely divided, although it may occur as concretions or limestone pebbles, or as cylindrical bodies along rootlets.

The feldspars are the commonest source of lime among the silicates, oligoclase and anorthite being the usual lime-bearing varieties, but the amount of lime present in silicates is usually very low.

When lime is present as an ingredient of silicate minerals, such as those mentioned above, its presence cannot be detected with muriatic acid. Gypsum, which is found in a few clays, is often of secondary character, having been formed by the action of sulphuric acid on lime-bearing minerals in the clay. Since these three groups of minerals behave somewhat differently their effects will be discussed separately.

Effect of lime carbonate on clay.—Lime is probably most effective in the form of the carbonate, and if finely divided is an active flux. When clays containing it are burned, they not only lose their chemically combined water but also their carbon dioxide; but while the water of hydration passes off between 450° C. (842° F.) and 600° C. (1112° F.) the carbon dioxide (CO_2) does not seem to go off until between 600° C. (1112° F.) and 725° C. (1562° F.). In fact, it more probably passes off between 850° C. (1562° F.)[2] and 900° C. (1652° F.). The result of driving off this gas, in addition to the chemically combined water, is to leave calcareous clays more porous than other clays up to the beginning of fusion.[3]

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[1] See Minerals in Clay, Calcite.

[2] Bourry, Treatise on Ceramic Industries, p. 103; also Kennedy, Trans. Amer. Ceram. Soc., IV, p. 146.

[3] Some bricks made from calcareous clays and burned at cones 1 to 3 show over 30 per cent absorption.

If the burning is carried only far enough to drive off the carbonic-acid gas, the result will be that the quicklime thus formed will absorb moisture from the air and slake. No injury may result from this if the lime is in a finely divided condition and uniformly distributed through the brick, but if, on the contrary, it is present in the form of lumps, the slaking and accompanying swelling of these may split the brick.

If, however, the temperature is raised higher than is required simply to drive off the carbon dioxide, and if some of the mineral particles soften, a chemical reaction begins between the lime, iron, and some of the silica and alumina of the clay, the result being the formation within the clay of a new silicate of very complex composition. The effects of this combination are several: In the first place, the lime tends to destroy the red coloring of the iron and imparts instead a buff color to the burned clay. Seger found that this bleaching action, if we may call it such, is most marked when the percentage of lime is three times that of the iron. It should be remembered, however, that all buff-burning clays are not calcareous, and that a clay containing a low percentage of iron oxide may also give a buff body. Another effect of lime, if present in sufficient quantity, is to cause the clay to soften rapidly, thereby sometimes drawing the points of incipient fusion and viscosity within 41.6° C. (75° F.) of each other. This rapid softening of calcareous clays is one of the main objections to their use, and on this account also it is not usually safe to attempt the manufacture of vitrified products from them, but, as mentioned under Magnesia, the presence of several per cent of the latter substance will counteract this. It has also been found possible to increase the interval between the points of incipient fusion and viscosity by the addition of quartz and feldspar.[1]

One of the most extensive series of tests, are those made by R. Rieke,[2] who sought to determine in detail the effect of lime carbonate on kaolin. In his tests he mixed up different quantities of finely ground

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[1] The Collected Writings of H. Seger, Vol. I, p. 336.

[2] Ueber die Einwirkung von Marmor auf Zettlitzer kaolin, Sprechsaal, XXXIX, No. 38, 1906.

marble with Zettlitz kaolin, determining their shrinkage and porosity at different cones as indicated below.

SHRINKAGE OF MIXTURES OF ZETTLITZ KAOLIN AND LIME CARBONATE

Per cent marble.	1	3	5	10	20	30	40	50	60	70	80
Cone 05	2.1	2	2.1	3.1	3.3	3.2	2.9	2.6	2.6	1.7	1.2
“ 2	3.5	4.1	4.2	4.4	3.4	3.1	2.6	2.4	3.0	1.7	1.0
“ 5	8.8	8.0	7.8	5.6	3.2	3.0	3.9	4.7	2.8	1.5	3.7
“ 8	9.8	9.2	8.8	7.1	3.0	4.3	9.6	15.0	4.2	4.6	5.9
“ 10	10.3	9.8	9.8	8.3	3.2	6.4	A	A	5.7	22.8	8.2
“ 12	11.9	11.2	11.1	9.4	3.8	6.6	A	A	6.0	A	9.5
“ 14	12.7	12.5	11.0	10.8	7.4	10.0	A	A	17.0	A	10.2

A. Test-piece began to fuse and could not be measured.

PER CENT POROSITY OF MIXTURES OF ZETTLITZ KAOLIN AND LIME CARBONATE

Per cent marble.	1	3	5	10	20	30	40	50	60	70
Cone 05	29.3	28.4	27.0	24.5	22.2	24	26.3	28.3	29.4	30.3
“ 2	25.7	23.4	21.3	19.8	21.1	22.8	25.3	27.3	30.8	42.5
“ 5	12.0	12.2	12.7	15.3	23.1	29.5	27.7	26.8	32.0	45.9
“ 8	8.7	9.7	9.9	11.9	24.6	29.2	14.4	.....	33.2	42.0
“ 10	6.5	5.6	4.4	8.5	21.6	23.0	.....	.....	23.8	10.2
“ 12	4.4	2.4	1.5	3.4	21.0	17.7	.....	.....	22.6	.....
“ 14	2.0	0.3	0.3	0.2	9.1	7.7	.....	.....	4.1	.....

In order to determine the fusibility of the mixtures which did not fuse, the following special tests were made:

Per cent marble	0	1	3	5	10	20	30	40	50	60	70	80
Cone of fusion	35*	35	34*	33	30†	15	15†	8*	7–8	16	12	23–24

* Above. † Nearly.

Rieke concludes from his experiments that:

1. Marble acts the reverse of magnesite in decreasing the shrinkage. That while a mixture of kaolin with 20% magnesite shows the maximum shrinkage, a similar mixture of kaolin and marble shows a very low and almost uniform shrinkage throughout a great range of temperature.

2. The porosity of the burnt samples increases with an increase in the percentage of carbonate of lime, excepting at the lowest temperatures at which the carbon dioxide had not been entirely expelled. Only the mixtures carrying from 1 to 10 per cent of lime carbonate burn to a dense body at a temperature much below their fusing point. A higher percentage of lime causes the points of vitrification and viscosity to draw close together.

3. The most easily fusible mixture is one having the formula Al_2O_3, $2SiO_2$, $2CaO$,[1] which fuses at cone 7–8.

Mixtures of the formula Al_2O_3, $2SiO_2$, $4CaO$; or Al_2O_3, $2SiO_2$, CaO; and $2(Al_2O_3 \cdot 2SiO_2)$ CaO melt at about cone 16. If we have more than two molecules Al_2O_3, SiO_2, to one of CaO, very refractory mixtures result. With $6CaO$, Al_2O_3, $2SiO_2$, an easily fusible mixture is obtained, but an increase in the lime content raises it again.

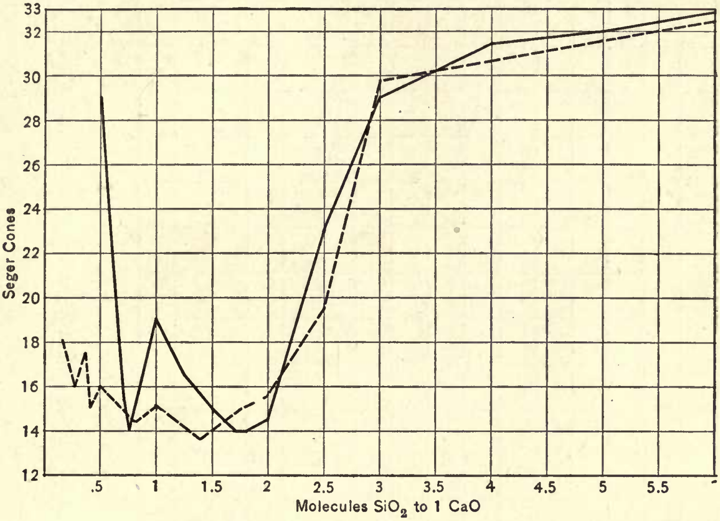

FIG. 17*c*.—Diagram showing fusion-points of lime-silica mixtures. (After Rieke, Sprechsaal, XL, p. 595.) Dotted lines represents curve obtained by Boudouard.

The same writer has carried his experiments further, in determining the fusibility of lime-alumina-silica mixtures.[2] He points out that lime differs from magnesia in its fluxing action, in that its fusion curve shows not one, but three minima and two maxima, the last two corresponding to the formula CaO, Al_2O_3, $2SiO_2$ and $4CaO$, Al_2O_3, $2SiO_2$.

In the series of lime silica mixtures (Fig. 17*c*), the fusion curve showed one maximum point corresponding to CaO, SiO_2, but that found by Day and Shepherd of $2CaO$, SiO_2 was not observed. Two minima were found, one at about 1410° or between CaO, $0.7\ SiO_2$ and CaO,

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[1] This contained 46.3% CaO.

[2] R. Rieke, Ueber die Schmelzbarkeit von Kalk-Tonerde-Kieselsäuremischungen, Sprechsaal, XL, No. 44, p. 594, 1907.

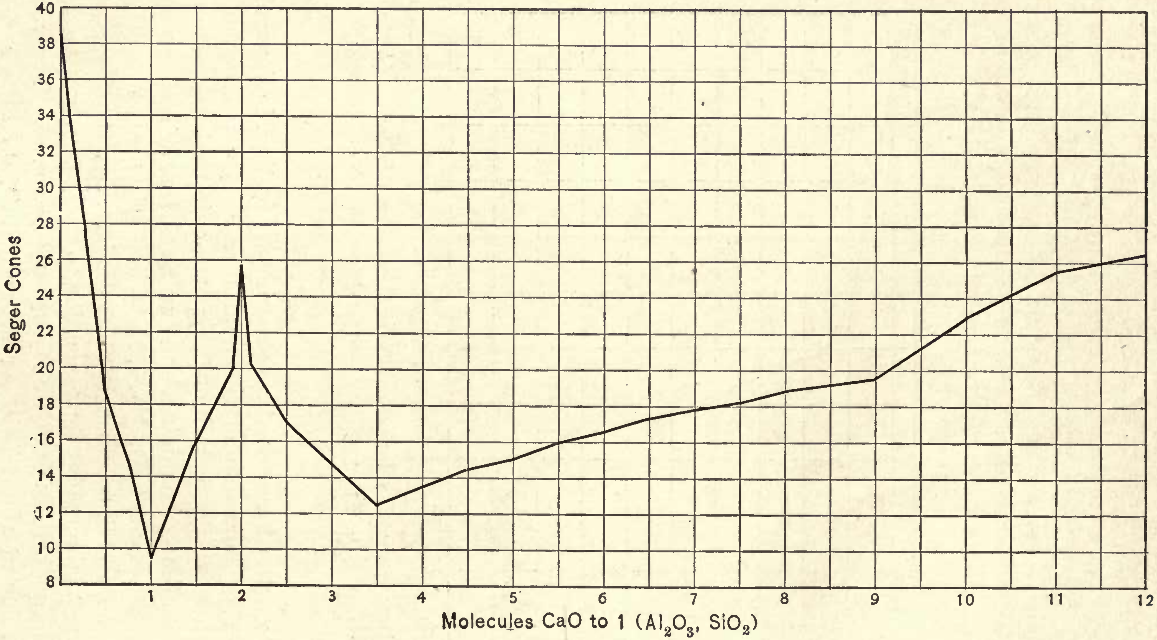

FIG. 17*d*.—Diagram showing fusing-point of lime-alumina-silica mixtures. (After Rieke, Sprechsaal, XL, p. 610.)

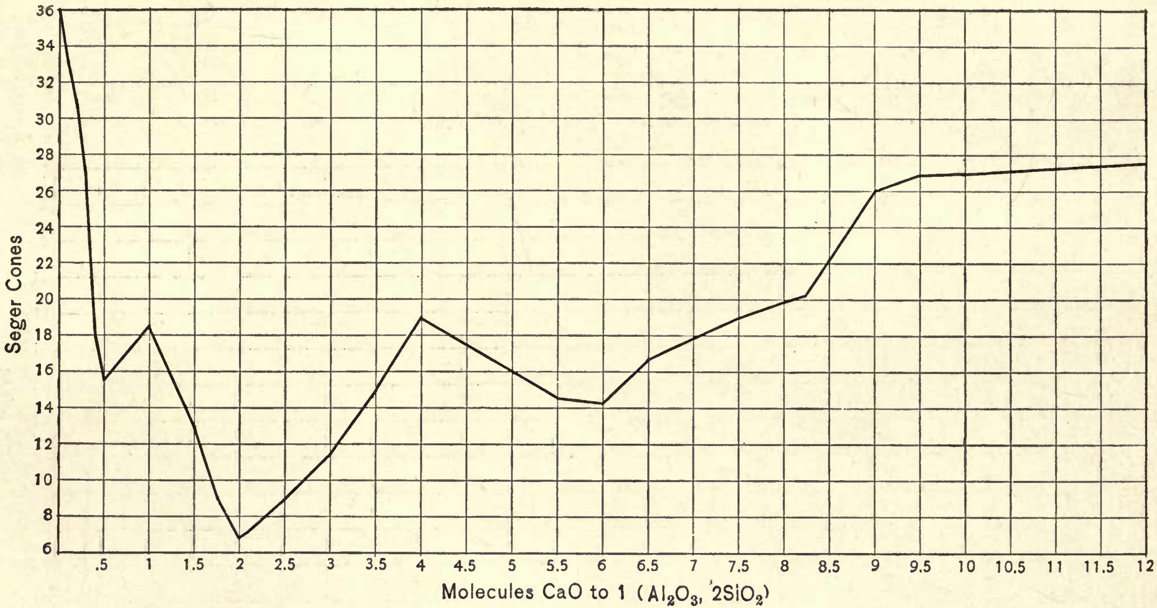

FIG. 17*e*.—Diagram showing fusion-point of mixtures of CaO.1(Al_2O_3 $2SiO_2$). (After Rieke, Sprechsaal, XL, p. 612.)

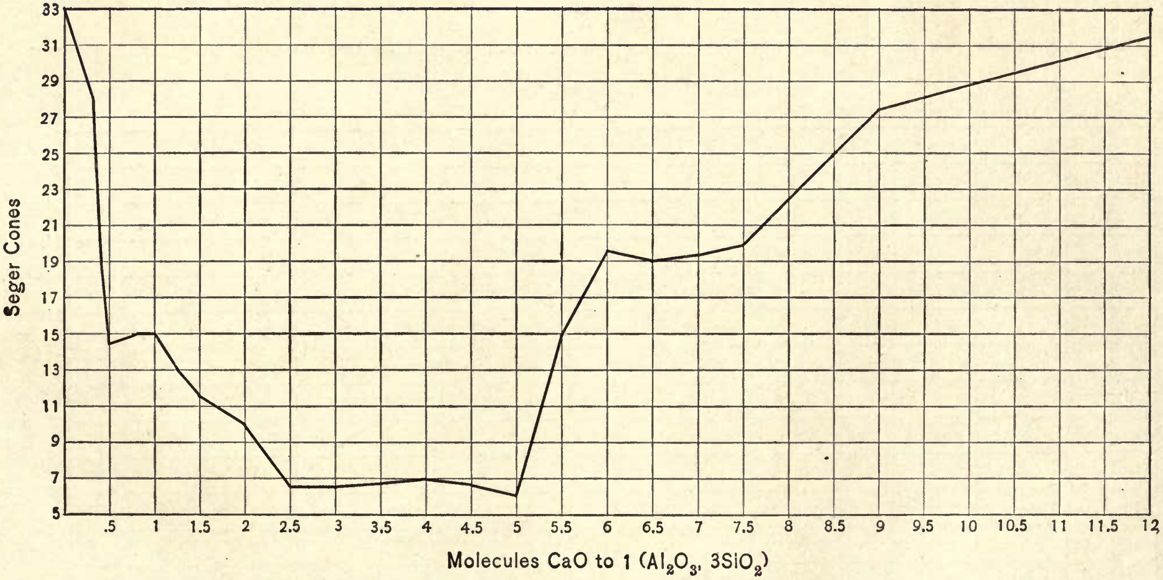

FIG. 17*f*.—Diagram showing fusion-points of mixtures of CaO and 1($Al_2O_3.3SiO_2$). (After Rieke, Sprechsaal, XL, p. 625.)

0.8 SiO_2, and the other at 1420° C. Both these agree with Day and Shepherd's observations, but their third minimum point was not found. In the lime-alumina-silica mixtures the ratios of alumina and silica employed were Al_2O_3, SiO_2; Al_2O_3, $2SiO_2$; Al_2O_3, $3SiO_2$; and Al_2O_3, $4SiO_2$. To each of these the lime was added in increasing amounts.

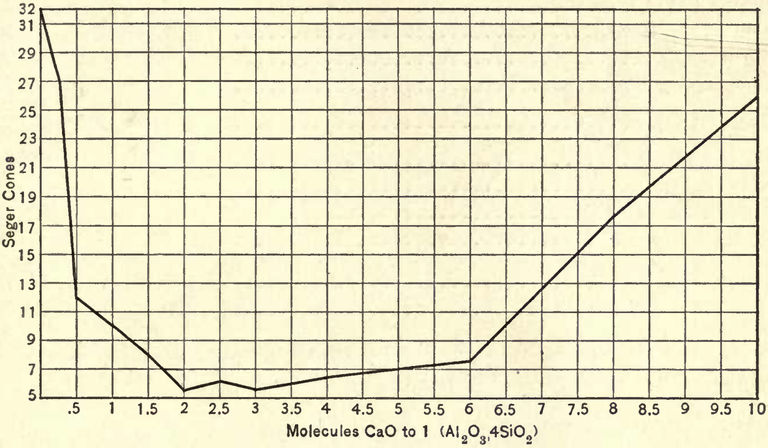

FIG. 17*g*.—Diagram showing fusion-points of mixtures of CaO and $(Al_2O_3.4SiO_2)$. (After Rieke, Sprechsaal, XL, p. 626.)

The results of his tests are more clearly brought out by his diagrams, which are reproduced in Figs. 17*d*–*g*.

Many erroneous statements are found in books regarding the allowable limit of lime in clays, some writers putting it as low as 3 per cent; still a good building-brick can be made from a clay containing as much as 20 or 25 per cent of lime carbonate, provided it is in a finely divided condition,[1] and a vitrified ware is not attempted. If, however, that quantity of lime is contained in the clay in the form of pebbles, then much damage may result from bursting of the bricks, when the lumps of burned lime slake by absorbing moisture from the air.

Clays containing a high percentage of lime carbonate are used in the United States, especially in Michigan, Wisconsin, and Illinois, for making common bricks, common earthenware, roofing-tile, and some terra-cotta, and the highly calcareous character of some brick-clays is

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[1] For analyses and uses of calcareous clays, see H. Ries, Clays and Shales of Michigan, Mich. Geol. Surv., VIII, Pt. I; and E. R. Buckley, Clays and Clay Industries of Wis., Wisconsin Geol. Surv., Bull. 2, Economic Series.

shown by the following analyses. Of these No. II is the most calcareous that the writer has ever examined.

ANALYSES OF CALCAREOUS CLAYS

	I.	II.
Silica (SiO_2)	44.15	18.62
Alumina (Al_2O_3)	10.00	3.23
Ferric oxide (Fe_2O_3)	4.08	1.26
Lime (CaO)	13.30	41.30
Magnesia (MgO)	1.50	.42
Potash (K_2O)	1.55	None None
Soda (Na_2O)	By diff.	2.42
Water (H_2O)	12.13	
Carbon dioxide (CO_2)	11.34	32.50
Organic matter	1.95	
Total	100.00	99.75
Total fluxes	20.43	42.98

I. Ionia, Mich. A. N. Clark, Anal. Mich. Geol. Surv., VIII, Pt. I, p. 53.
II. Seguin, Tex. O. H. Palm, Analyst.

Effect of lime-bearing silicates.—The effect of these is much less pronounced than that of lime carbonate. They contain no volatile elements, and hence do not affect the shrinkage to the extent that lime carbonate does. They serve as fluxes,[1] but do not cause a rapid softening of the clay.

Effect of gypsum.—Gypsum in clay has probably often been formed by sulphuric acid, liberated by the decomposition of iron pyrite, acting on lime carbonate. Lime, if present in the form of gypsum, seems to behave differently from lime in the form of carbonate, although few clays contain large percentages of it.

Gypsum, as already shown,[2] is a hydrous sulphate of lime. In calcining gypsum for making plaster of Paris, the chemically combined water is driven off at 250° F., but only a portion of the sulphuric acid is driven off at a low red heat, the balance passing off at a much higher temperature. To illustrate this a mixture[3] consisting of 75 per cent of a white-burning clay and 25 per cent of nearly pure white gypsum was made up. This mixture contained 15.11 per cent of combined water

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[1] See also under Alkalies.

[2] Chapter III, Minerals in Clay.

[3] N. J. Geol. Surv., VI, p. 63, 1904

and 11.65 per cent of sulphur trioxide (SO_3), and was burned at a number of different temperatures with the following results:

TABLE SHOWING LOSS IN WEIGHT BY BURNING

Temperature.	Loss in weight, per cent.	
	Sample No. 1.	Sample No. 2.
860° C. (1580° F.)	11.60%	11.50%
1000° C. (1832° F.)	13.18%	12.59%
1100° C. (2012° F.)	19.93%	19.58%
1200° C. (2192° F.)	23.15%	23.05%
1300° C. (2372° F.)	23.21%	23.11%

These figures show that at 860° C. the loss had not exceeded the amount of combined water contained in the mass; at 1000° C. the loss was not equal to the sum of the water contained in the clay and gypsum; a large loss occurred between 1100° and 1200° C., while between the latter temperature and 1300° C. the loss was exceedingly small. Therefore, even at 1300° C., or slightly above the theoretic melting-point of cone 8, there was still over 3 per cent of what would be considered volatile material remaining in the mixture. It is presumed that this represents sulphur trioxide which has not been driven off.

The presence of silica is said to facilitate the decomposition of the calcium sulphate, and the evolution of the SO_3 is thought to cause some of the swelling or blistering seen in some wares after burning.

The range of lime, as determined from a series of clay analyses, is as follows:[1]

AMOUNT OF LIME IN CLAYS

Kind of clay.	Min.	Max.	Aver.
Brick-clays	0.024	15.38	1.513
Pottery-clays	0.011	9.90	1.098
Fire-clays	0.03	15.27	0.655
Kaolins	tr.	2.58	0.47

Magnesia

Magnesia (MgO) rarely occurs in clay in larger quantities than 1 per cent. When present, its source may be any one of several classes of compounds, that is, silicates, carbonates, and sulphates.

The range of magnesia in several classes of clays, as figured from a number of analyses is as follows:[1]

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[1] Bull. N. Y. State Museum, No. 35, p. 523. Owing to an error in the analysis of one of the brick clays, the averages in this table has been recalculated.

AMOUNT OF MAGNESIA IN CLAYS

Quality.	Min.	Max.	Aver.
Brick clays	0.02	7.29	1.052
Pottery-clays	0.05	4.80	0.85
Fire-clays	0.02	6.25	0.513
Kaolins	tr.	2.42	0.223

In the majority of clays the silicates, no doubt, form the most important source, and minerals of this type carrying magnesia are the black mica or biotite, hornblende, chlorite, and pyroxene. These are scaly or bladed minerals, of more or less complex composition, and containing from 15 per cent to 25 per cent of magnesia. The biotite mica decomposes readily, and, its chemical combination being thus destroyed, the magnesia is set free, probably in the form of a soluble compound, which may be retained in the pores of the clay. Hornblende is probably not an uncommon constituent of some clays, especially in those which are highly stained by iron, and have been derived from dark-colored igneous rocks. Like biotite, it alters rather rapidly on exposure to the weather. Dolomite, the double carbonate of lime and magnesia, is no doubt present in some clays, and would then serve as a source of magnesia. Magnesium sulphate, or Epsom salts, probably occurs sparingly in clays, and might form a white coating either on the surface of clay spread out to weather, or else on the ware in drying. It is most likely to occur in those clays which contain pyrite, the sulphide of iron (FeS_2), for the decomposition of the latter would yield sulphuric acid, which, by attacking any magnesium carbonate in the clay, might form magnesium sulphate. This substance has a characteristic bitter taste. On heating, both magnesium carbonate and dolomite have been supposed to lose their CO_2 between 400° C. and 600° C.[1]

Magnesia was for many years regarded as similar to lime in its fluxing action. The experiments of Mäckler[2] have indicated, however, that its effect was quite different.

In order to prove this point he selected a clay which was free from lime or magnesia, and in its raw and burned condition had the composition shown at top of page ~~81~~. 97

To one hundred parts by weight of this clay, either lime or magnesium carbonate was added in the proportions given in the second table on page 81, the percentages given in parenthesis representing the quantity

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[1] Brill's work (Zeitschr. Anorg. Chem., XLV, p. 277, 1905) shows that MgCO, begins to lose some CO_2 at 255° C., and additional quantities at 295°, 325°, 340°$_3$ 380°, 405°, and 510° C. These points are believed to show the successive formations and breaking up of various basic carbonates.

[2] Tonindustrie-Zeitung, Vol. XXVI, p. 705, 1902.

ANALYSIS OF CLAY USED BY MÄCKLER

	Raw.	Burned.
Loss on ignition	7.07	.....
Silica (SiO_2)	63.25	68.06
Alumina (Al_2O_3)	22.97	24.72
Ferric oxide (Fe_2O_3)	4.98	5.36
Lime (CaO)	.....	.....
Magnesia (MgO)	.....	.....
Alkalies (Na_2O, K_2O)	2.07	2.22
	100.34	100.36

of lime or magnesia contained in the amount of carbonate added. The physical tests of these mixtures are also given.

It will be seen here that the effect of magnesia was quite different from that exerted by the lime. The mixtures containing magnesia did not vitrify suddenly, as did the limy clays; nor did the magnesia exert as strong a bleaching action on the iron, and the points of incipient fusion and viscosity were also separated.

PHYSICAL TESTS ON MÄCKLER'S MIXTURES

	Water required.	Air-shrinkage.	Loss of weight in firing.	Fire-shrinkage cone numbers.				
				010	05	1	3	5
A. Clay alone	28.8	6.4	9.8	0.1%	3.5	7.2	7.9	6.7
B. Clay + 25 $CaCO_3$ (14CaO)	31.1	8.4	14.3	1.4	1.8	*		
C. Clay + 12.5 $CaCO_3$ (7 CaO)	33.6	8.3	10.4	1.0	1.7	†	—	—
D. Clay + 21 $MgCO_3$ (10MgO)	34.0	8.2	16.3	0.6	3.0	11.7	11.9	*
E. Clay + 10.5 $MgCO_3$ (5MgO)	32.4	7.5	11.1	1.7	3.7	11.1	11.3	†

* Melted. † Warped.

With a mixture of kaolin and magnesia similar results were obtained. The mixture of kaolin and magnesia showed a higher shrinkage at the beginning of the burning than the kaolin alone, and then increased but little until a high temperature was reached, when the shrinkage suddenly began again. A hard body was obtained at cone 1 with the kaolin-magnesia mixture.

The effect of magnesia therefore, if present in sufficient quantity, is to act as a flux and make the clay soften slowly, instead of suddenly as in the case of calcareous clays. The results mentioned above have been corroborated in this country by Hottinger. An important characteristic of magnesian clays is, that they can be made into wares of extreme length and very thin walls, which may be nearly vitrified without warping.[1]

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[1] Hottinger, Trans. Amer. Ceram. Soc, V, p 130, 1903.

Barringer[1] has pointed out that the action of magnesia depends largely on the composition of the clay; in bodies containing a number of active fluxes, and which vitrify at a low temperature, it has a marked influence on the fusing point and temperature of the vitrifying stage, but, "as the number and character of the bases change in going towards high fire-products, the influence of magnesia lessens considerably."

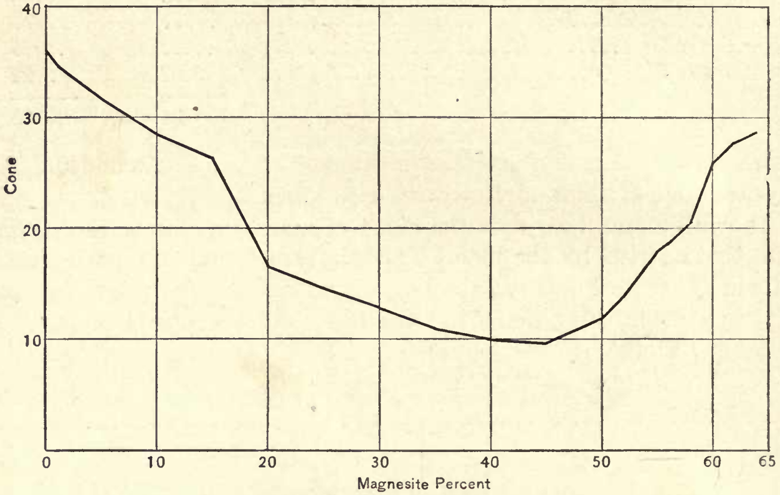

Fig. 17*h*.—Diagram showing fusibility of kaolin-magnesite mixtures. (After Rieke, Sprechsaal, Nos. 46–48, 1905.)

To the data supplied us by Mäckler and Barringer, there must be added a more extensive series, embodying the results of R. Rieke's

Per Cent Linear Shrinkage of Zettlitz Kaolin and Magnesite

Per cent magensite.	0	1	3	5	10	20	30	40	50	60	70	80	90
Cone 09	2.0	2.2	2.4	2.5	2.7	2.8	3.1	3.1	3.7	3.8	3.3	3.0	2.7
" 05	2.7	3.0	2.8	3.1	3.2	3.6	3.4	4.1	5.4	5.5	5.1	5.5	5.7
" 1	2.8	3.1	3.1	3.1	3.1	3.0	3.8	4.8	5.7	5.5	5.0	5.6	6.2
" 3	6.8	7.5	8.2	8.8	10.6	12.2	11.2	9.2	7.5	5.6	5.0	5.9	7.3
" 5	8.4	9.1	10.7	11.3	12.3	12.5	11.7	9.3	8.5	7.8	7.0	7.9	10.4
" 7	10.5	10.5	11.2	12.6	13.5	13.4	13.0	9.8	9.5	8.0	7.6	8.9	11.0
" 10	12.5	12.6	13.4	13.6	13.4	13.5	11.9	....	24.0	18.9	7.7	10.5	25.0
" 12	12.8	12.6	13.4	13.1	13.4	13.6	9.2 bls'd	....	....	23.0	10.0	16.2	25.3
" 15	12.5	12.3	12.5	12.8	14.1	12.5 bls'd	....	....	....	25.3	13.8	21 1	28.2

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[1] Trans. Amer. Cer. Soc., VI, p. 86, 1904.

[2] Sprechsaal, Nos. 46–48, 1905.

PERCENTAGE POROSITY OF ZETTLITZ KAOLIN AND MAGNESITE

Per cent, magnesite.	0	1	3	5	10	20	30	40	50	60	70	80	90
Cone 09	30.1	29.9	30.8	30.5	31.6	34.6	41.7	42.4	49.5	53.6	Undetermined mostly over 50%		
" 05	30.5	29.2	28.8	29.2	30.0	31.1	35.9	37.5	37.9	40.2			
" 1	30.6	28.2	29.6	29.2	30.8	31.6	36.2	37.7	38.0	41.7			
" 3	19.4	17.0	14.3	12.6	11.1	11.2	15.5	23.8	34.8	44.4			
" 5	16.1	12.7	8.0	6.4	4.2	2.8	11.7	21.8	25.5	43.3			
" 7	9.7	10.0	6.3	0.4	0.3	0.1	8.3	17.6	18.0	18.7			
" 10	2.1	1.8	0.4	0.1	0.1	0.1	3.1	....	0.5	8.5	43.2	39.6	11.7
" 12	2.4	2.0	0.5	0.0	0.0	0.0	....	....	....	2.0	38.0	30.2	8.2
" 15	1.1	0.7	0.2	0.0	0.0	....	....	....	....	0.0	28.1	17.3	3.4

work on kaolin-magnesite mixtures, of which he determined the linear shrinkage, porosity and fusibility. The results of the first two series of tests are given in the accompanying tables, while the fusion points are given in Fig. 17*h*. It will be noticed there that the fusion point gradually falls until a content of 45 per cent magnesite is reached, after which it again rises.

Of equal interest are a later series of experiments, in which quartz was added to the original mixture, the results being shown in tabulated form on pages 100 and 101.

Alkalies

The alkalies commonly present in clays include potash (K_2O), soda (Na_2O), and ammonia (NH_3). There are other alkalies, but they are probably of rare occurrence.

Ammonia is no doubt present in some raw clays, judging from their odor, and it may possibly exert some effect on the physical structure of the clay, it being found that the bunches of grains in a clay tend to separate more easily, when the clay is agitated with water, if a few drops of ammonia are added. As ammonia is easily volatile, it leaves the clay as soon as the latter is warmed, and therefore plays no part in the burning of the clay. The two other common alkaline substances, potash and soda, are more stable in their character, and are therefore sometimes termed *fixed alkalies*. These have to be reckoned with in burning, for they are present in nearly every clay.

The amount of total fixed alkalies contained in a clay varies from a mere trace in some to 9 per cent in others. The range of alkalies in several classes of clays was determined to be as follows:[1]

AMOUNT OF TOTAL ALKALIES IN CLAYS

	Min.	Max.	Aver.
Kaolins	0.1	6.21	1.01
Fire-clay	0.048	5.27	1.46
Pottery-clays	0.52	7.11	2.06
Brick-clays	0.17	15.32	2.768

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[1] Bull. 35, N. Y. State Museum, p. 515.

RIEKE'S TESTS ON KAOLIN, QUARTZ-MAGNESITE MIXTURES

No. of mixture.	Per cent of			Cone 09.		Cone 2.		Cone 5.		Cone 6–7.		Cone 8–9.		Cone 11.		Cone 13–14.		Cone 15.		Cone of fusion.
	Kaolin.	Qtz.	Mag.	S.[1]	P.[2]	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	
1	90	10	..	2.0	28.9	4.4	23.0	7.3	16.0	8.8	13.2	9.2	11.0	10.4	7.1	11.5	3.7	12.7	0.5	+34
2	90	5	5	2.2	30.6	6.3	21.0	10.3	9.6	10.7	5.5	11.8	0.9	12.8	0	12.4	0	13.2	0	30
3	80	20	....	1.8	28.9	4.2	23.9	6.5	19.1	7.6	16.3	8.5	14.7	9.7	9.4	12.6	5.3	13.1	0.9	33
4	80	15	5	2.1	30.1	5.3	22.2	9.0	15.4	10.6	9.8	12.5	2.0	13.6	0	13.2	0	13.5	0	−29
5	80	10	10	2.1	31.8	7.1	19.0	10.1	11.1	11.9	3.4	12.7	0	12.3	0	12.2	0	12.5	0	20
6	80	5	15	2.4	33.3	9.1	14.3	11.0	10.4	12.9	0.3	12.5	0	12.6	0	12.8	0	12.8	0	−19
7	70	30	....	1.5	29.5	3.9	24.3	5.2	20.9	6.2	19.0	7.3	16.8	9.2	11.4	10.7	7.2	12.0	3.4	31–32
8	70	25	5	1.4	29.8	5.4	22.8	7.5	17.0	8.9	11.0	12.4	3.0	12.8	0.3	13.9	0	13.9	0	27–28
9	70	20	10	1.7	31.5	5.7	20.2	9.3	15.5	11.9	4.8	12.4	0.0	12.5	0	12.5	0	12.7	0	+19
10	70	15	15	2.1	33.4	7.2	20.9	9.6	15.3	11.6	4.5	11.7	0.1	11.7	0	11.9	0	11.7	0	15–16
11	70	10	20	2.0	34.3	7.3	21.8	10.5	13.5	11.3	4.2	11.4	0.1	11.3	0	11.3	0	.....	.....	14–15
12	70	5	25	2.2	34.5	8.5	19.5	10.6	14.3	11.0	1.8	11.1	0.2	10.5	0	10.6	0	.....	.....	14
13	60	40	....	1.4	27.4	3.2	23.9	4.0	23.2	5.4	20.3	5.4	19.9	8.1	13.8	9.8	10.9	12.4	4.4	31
14	60	35	5	1.4	30.0	4.7	24.4	5.2	22.4	8.2	16.8	9.7	14.7	12.0	4.2	13.0	0.2	13.2	0	20–26
15	60	30	10	1.7	30.5	5.4	23.7	6.1	22.4	9.4	13.9	11.0	5.5	12.6	0.8	12.7	0	13.3	0	−19
16	60	25	15	1.9	33.7	5.6	24.0	6.3	23.1	9.2	12.7	10.5	9.6	12.8	0.7	13.0	0	.....	.....	−15
17	60	20	20	2.0	34.0	6.4	24.3	7.0	24.0	9.3	10.7	10.3	10.8	12.3	0.6	15.0	0	.....	.....	−14
18	60	15	25	2.3	34.6	6.7	25.3	7.2	24.1	9.8	14.8	10.1	11.8	10.9	4.9	11.0	1.1[3]	.....	.....	−(13–14)
19	60	10	30	2.5	36.7	6.8	26.7	7.5	25.5	10.7	13.5	11.1	12.2	13.0	7.8	.....	.....	.....	.....	+12
20	60	5	35	2.6	38.4	6.7	28.7	7.1	28.2	11.7	13.4	12.6	8.0	.....	0	.....	.....	.....	.....	+11
21	50	50	....	0.8	27.3	2.3	24.8	2.7	25.0	3.8	23.0	4.5	21.0	6.5	16.8	8.2	13.9	11.3	10.4	29–30
22	50	45	5	1.0	28.9	3.6	24.5	4.8	22.4	6.5	17.8	7.9	12.6	9.4	5.8	10.2	4.8	12.3	.6	−20
23	50	40	10	1.3	29.7	4.1	24.6	5.4	22.9	7.9	17.0	8.5	12.6	9.0	6.6	10.6	0.8	11.9	0	+(15–16)
24	50	30	20	1.7	32.5	5.7	24.8	5.8	24.5	6.7	21.1	8.9	14.6	10.4	9.2	.....	.....	.....	.....	+13
25	50	20	30	2.2	35.8	5.2	30.0	5.7	28.9	7.2	21.4	10.8	14.7	11.6	12.9	.....	.....	.....	.....	11–12
26	50	10	40	3.0	40.1	7.1	31.2	7.2	31.0	7.5	29.2	10.0	19.4	.....	.....	.....	.....	.....	.....	11

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[1] S. = linear shrinkage, per cent.

[2] P. = porosity, per cent.

[3] Blistered.

RIEKE'S TESTS ON KAOLIN, QUARTZ-MAGNESITE MIXTURES

No. of mixture.	Per cent of			Cone 09.		Cone 2.		Cone 5.		Cone 6–7.		Cone 8–9.		Cone 11.		Cone 13–14.		Cone 15.		Cone of fusion.
	Kaolin.	Qtz.	Mag.	S.[1]	P.[2]	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	S.	P.	
27	50	5	45	3.2	42.2	6.7	35.8	7.7	31.5	9.1	29.4	9.5	19.9	.....	.....	.....	.....	.....	.....	−11
28	40	60	....	0.4	28.4	2.0	25.3	1.9	25.5	2.8	24.3	3.9	22.1	4.7	18.8	6.2	15.7	7.8	12.8	−29
29	40	55	5	0.4	28.6	3.7	22.4	5.2	20.3	5.8	18.7	5.8	18.0	6.1	14.6	8.1	10.8	12.3	7.2	+17
30	40	50	10	1.0	30.1	5.0	22.0	6.0	20.0	6.8	17.5	6.1	17.2	7.3	11.0	8.4	5.2	.....	.....	+(13–14)
31	40	40	20	1.4	33.2	4.9	33.1	6.8	22.3	7.5	19.7	7.1	18.8	9.8	9.7	.....	.....	.....	.....	−12
32	40	30	30	1.9	35.3	6.1	29.5	6.7	25.3	10.3	15.5	9.7	16.5	.....	.....	.....	.....	.....	.....	10
33	40	20	40	2.7	39.8	5.9	32.9	7.6	28.4	10.1	22.9	8.3	24.1	.....	.....	.....	.....	.....	.....	−11
34	40	10	50	3.4	43.9	6.0	37.9	8.9	31.8	11.7	26.1	21.5	3.5	22.8	0.1	.....	.....	.....	.....	12
35	40	5	55	3.8	45.7	5.8	41.5	8.2	35.9	10.5	30.9	23.4	0.9	26.0	0	26.5	0	27.6	0	17
36	30	70	....	0.4	27.6	1.2	24.6	1.2	24.0	1.8	23.7	2.7	22.3	3.4	19.7	4.8	18.0	6.2	14.7	27–28
37	30	65	5	0.6	27.7	2.7	21.8	3.5	21.6	3.7	20.6	3.5	20.0	4.2	17.2	4.7	16.6	10.9	11.8	+16
38	30	60	10	0.6	29.1	3.0	23.6	4.8	20.7	5.3	20.7	3.4	20.3	5.0	16.3	5.1	17.9	12.7	0.4	−16
39	30	50	20	0.8	32.5	3.5	26.2	5.8	21.9	6.9	18.2	5.3	20.7	8.8	12.2	(11.5)	0	.....	.....	13–14
40	30	40	30	1.1	34.3	3.9	29.6	6.3	25.2	8.0	19.5	7.3	21.2	.....	.....	.....	.....	.....	.....	−10
41	30	30	40	1.9	38.4	4.7	33.2	6.7	29.1	10.7	21.2	9.7	19.1	.....	.....	.....	.....	.....	.....	−(10–11)
42	30	20	50	2.7	43.7	4.8	38.6	7.2	35.0	8.4	31.3	23.2	0.2	22.3	0	.....	.....	.....	.....	11
43	30	10	60	3.4	47.9	7.2	39.8	7.5	38.9	10.7	32.5	21.5	8.3	25.1	1.1	25.9	0	27.5	0	+19
44	30	5	65	3.7	49.8	6.5	46.0	7.6	41.7	7.7	40.0	8.8	37.9	9.0	33.5	12.0	29.8	24.7	14.3	−31

[1] S. = linear shrinkage, per cent

[2] P. = porosity, per cent.

[3] Blistered.

Several common minerals may serve as sources of the alkalies. Feldspar may supply either potash or soda. Muscovite, the white mica, contains potash. Greensand, or glauconite, contains potash. Other minerals, such as hornblende or garnet, might serve as sources of the alkalies, but are unimportant, as they are rarely present in clays in large quantities.

Orthoclase, the potash feldspar, contains 17 per cent of potash (K_2O), while the lime-soda feldspars contain from 4 to 12 per cent of soda (Na_2O), according to the species. The lime-soda feldspars fuse at a lower temperature than the potash ones, but are also less common.[1]

Muscovite mica contains nearly 12 per cent of potash, and may contain a little soda. Muscovite flakes, if heated alone, seem to fuse at cone 12, but, when mixed in a clay, they appear to act as a flux at different temperatures, according to the size of the grains. If very finely ground, the mica appears to vitrify the body at as low a temperature as cone 4,[2] but if the scales are larger they will retain their individuality up to cone 8, or even 10. The latter is true, for example, of micaceous talc-like clays found in the Miocene formation around Woodstown, N. J., a large amount of which are composed of white mica.[3]

We therefore see that the minerals supplying alkalies are all silicates of complex composition. Each has its fixed melting-point, and the temperature at which the alkalies flux with the clay will depend on the containing mineral, and also on the size of the grains. If the alkali-bearing mineral grains decompose, the potash or soda are set free and form soluble compounds.[4]

Alkalies are considered to be the most powerful fluxing material that the clay contains, and, if present in the form of silicates, are a desirable constituent, except in clays of a refractory character. On account of their fluxing properties they serve, in burning, to bind the particles together in a dense, hard body, and permit a white ware, made of porous-burning clays, to be burned at a lower temperature. In the manufacture of porcelain, white earthenware, encaustic tiles, and other wares made from white-burning clays and possessing an impervious or nearly impervious body, feldspar is an important flux.

According to the experiments of Berdel[5] on kaolin, quartz, feldspar bodies, the action of feldspar on the vitrification of bodies is noticeable

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[1] Seger, Ges. Schrift, p. 413.

[2] Trans. American Ceramic Society, IV, p. 255.

[3] Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 68, 1904.

[4] See Origin of Clay, Chapter I.

[5] Sprechsaal, Nos. 2–11, 1904.

at cone 1, but its effect on high-heat bodies starts with the melting-point of feldspar at cone 9. The vitrifying action of feldspar becomes greater the finer the grain is, and to such an extent that very fine feldspar may vitrify Zettlitz kaolin at cone 2.

Alkalies alone seem to exert little or no coloring influence on the burned clay, although in some instances potash appears to deepen the color of a ferruginous clay in burning.

Titanium

Titanum is an element which is found in several minerals, some of which are more common in clays than is usually imagined, although they appear rare because they are seldom found in large quantities. The two commonest of these, *rutile* and *ilmenite*, have already been referred to. So far as known, neither of these is ever found in clays in sufficiently large grains to be visible to the naked eye, so that a microscopic examination would be necessary to identify them. Although titanium is such a common constituent of clay, it is rarely shown in an analysis, because its determination by chemical methods is attended with more or less difficulty and is rarely carried out. In the ordinary process of chemical analysis it is usually included with the alumina.

As early as 1862 Riley [1] referred to the universal occurrence of titanic oxide in clay, and, in a series of English ones, found from .42 to 1.05 per cent. Since that time a number of additional occurrences have been noted, as follows:

Twenty-one New Jersey clays, 1.06 to 1.93 per cent.[2]

A series of Pennsylvania clays, .85 to 4.30 per cent.[3]

Eleven Ohio coal-measure clays, 0.16 to 1.68 per cent.[4]

Fire-clays from St. Louis, 1 to 1.91 per cent.[5]

Thirty-five clays and sands from Virginia Coastal Plain, .0 to 1.88 per cent.[6]

One hundred Texas clays, .0 to 2.12 per cent.[7]

Among the foreign observers, Vogt [8] has noted percentages as high

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[1] Quart. Jour. Chem. Soc., XV, 311, 1862.

[2] Cook and Smock, Report on the Clays of New Jersey, 1878, p. 276.

[3] Second Pa. Geol. Surv., MM, p. 261 et seq.

[4] Orton, Ohio Geol. Surv., VII, Pt. I.

[5] Wheeler, Mo. Geol. Surv., XI, p. 56.

[6] Ries, Va. Geol. Surv., Bull. II.

[7] Unpublished manuscript.

[8] Tonindustrie-Zeitung, XXVII, 1247, 1903.

as 2.08, and Kovar[1] the unusually high percentage of 10.06, while Odernheimer found up to 4.6 per cent in certain Basaltic residual clays from the Duchy of Nassau. The fact that most of it was soluble in a 20 per cent hydrochloric-acid solution would suggest its being ilmenite.

Effect of titanium.—Messrs. Seger and Cramer, of Berlin,[2] endeavored to determine the effect of titanium on clay by burning artificial mixtures of this material and kaolin. Two samples of Zettlitz kaolin (containing 98.5 per cent clay substance) were mixed with 6.5 per cent and 13.3 per cent titanium oxide respectively; both were then heated to a temperature above the fusing-point of iron, with the result that, while the first softened considerably on heating and showed a blue fracture, the second fused to a deep-blue enamel.

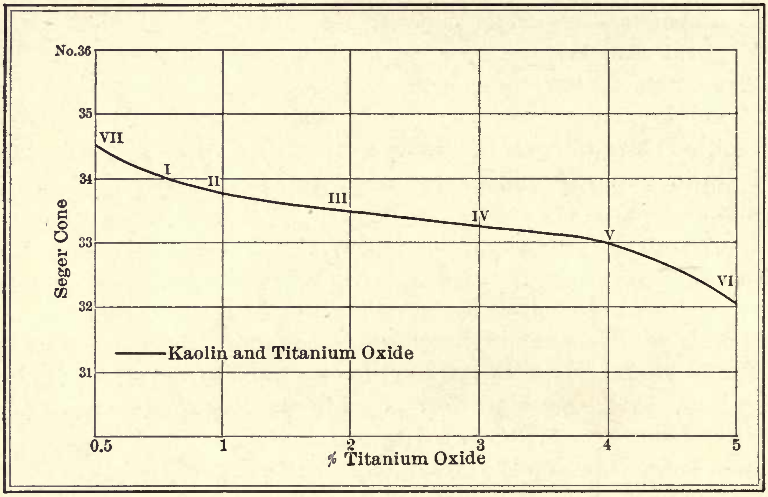

FIG. 18.—Curve showing effect of titanium oxide on fusibility of clay. (After Ries, N. J. Geol. Surv., VI, p. 71, 1904.)

A second series of mixtures, consisting each of one hundred parts of kaolin, with 5 per cent and 10 per cent of silica respectively, showed no signs of fusion, and burned simply to a hard white body, thus indicating that the titanium acts as a flux at a lower temperature than quartz.

More recently the author[3] has shown that even small amounts of titanium lower the refractoriness of a clay. In these experiments a white-

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[1] Sprechsaal, 1891, p. 106.

[2] Seger's Collected Writings, I, p. 519.

[3] N. J. Geol. Surv., Fin. Rept., VI, p. 71, 1904.

burning sedimentary clay fusing at cone 34 was mixed with amounts of ½, 1, 2, 3, 4, and 5 per cents of very finely ground rutile.

These mixtures were then formed into small cones and tested in the Deville furnace, the results of these tests being shown graphically by the curve in Fig. 18. In this figure the vertical line at the left represents the cone number of the Seger series,[1] and the horizontal line at the bottom the per cent of titanium oxide. No. VII, at the extreme left, represents the fusion-point of the clay alone, while I, II, etc., indicate respectively the fusion-points of the clay and titanium mixtures. From this it will be seen that even one-half per cent of titanium oxide lowered the fusing-point of the clay half a cone, while 5 per cent lowered it two cones. All the mixtures, when heated to cone 27, were apparently vitrified, and showed a deep-blue fracture. This coloration was, however, destroyed by the presence of a few per cent of silica. At lower temperatures (cone 8) a mixture containing 5 per cent of titanium oxide burned yellow.

A recent series of experiments by Rieke[2] form an interesting continuation of those by the author (described above). He made up a series of mixtures of chemically pure TiO_2 and Zettlitz kaolin, determining their fusing points with the following results:

FUSION POINTS OF KAOLIN-TITANIUM OXIDE MIXTURES

Kaolin per cent.	TiO_2, per cent.	Cone of fusion.	Kaolin per cent.	TiO_2, per cent.	Cone of fusion.
100	..	35	40	60	20
90	10	30	30	70	+20
80	20	−26	20	80	−26
70	30	20	10	90	26
60	40	−20	..	100	−27
50	50	19−20			

The heat was raised at the rate of one cone in 4–5 minutes. With very much slower heating the fusion points lay slightly higher for mixtures with 40% or more of TiO_2.

A similar series of mixtures in which the kaolin was replaced by alumina or silica showed that the titanium was less effective. The results of these other series were as below.

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[1] See Fusibility, Chapter III.

[2] Sprechsaal, XLI, p. 406, 1908.

FUSION POINTS OF ALUMINA-TITANIUM OXIDE MIXTURES

Alumina, per cent.	TiO^2, per cent.	Cone of fusion.	Alumina, per cent.	TiO^2, per cent.	Cone of fusion.
100	..	42	40	60	33 – 34
80	20	37	30	70	31
70	30	– 35	20	80	– 29
60	40	33	10	90	– 28
50	50	+ 33	..	100	– 27

FUSION POINTS OF SILICA-TITANIUM OXIDE MIXTURES

Silica, per cent.	TiO_2 per cent.	Cone of fusion.	Silica, per cent.	TiO_2 per cent.	Cone of fusion.
100	..	36	40	60	+ 30
90	10	33 – 34	30	70	29
80	20	29 – 30	20	80	29 – 30
70	30	26	10	90	– 29
60	40	20	..	100	– 27
50	50	27			

Water in Clay

Under this head are included two kinds of water: 1. Mechanically combined water or moisture. 2. Chemically combined water.

Mechanically combined water.—The mechanically combined water is that which is held in the pores of the clay by capillary action, and fills all the spaces between the clay-grains. When these are all small, the clay may absorb and retain a large quantity, because each interspace acts like a capillary tube. If the spaces exceed a certain size, they will no longer hold the moisture by capillary action, and the water, if poured on the clay, would fast drain away. The fine-grained clays, for these reasons, show high powers of absorption and retention, while coarse, sandy clays or sands represent a condition of minimum absorption. This same phenomenon shows itself in the amount of water required for tempering a clay. Thus, a very coarse sandy clay mixture from one deposit required only 15.9 per cent of water, while a very fat one from another deposit took 45 per cent of water. It is not the highly aluminous ones, however, that always absorb the most water. The total quantity found in different clays varies exceedingly. In some air-dried clays it may be as low as 0.5 per cent, while in those freshly taken from the bank it may reach 30 to 40 per cent without the clay being very soft.

Clay is very hygroscopic, and when thoroughly dry greedily absorbs moisture from the atmosphere, indeed it may absorb as much as 10 per cent of its weight.[1]

Water held mechanically in a clay will pass off partly by evaporation in air, but can all be driven off by heating the clay to 100° C. (212° F.). The evaporation of the mechanical water is accompanied by a shrinkage of the mass, which ceases, however, when the particles have all come in contact and before all the moisture is driven off, because some remains in the pores of the clay. This last portion is driven off during the early stages of burning. The shrinkage that takes place when the mechanical water is driven off varies—ranges from 1 per cent or less in very sandy clays up to 10 or 12 per cent in very plastic ones.

Since most clays having a high absorption shrink a large amount in drying, there is often danger of their cracking, especially if rapidly dried, owing to the rapid escape of the water-vapor. Mechanical water may hurt the clay in other ways. Thus, if the material contains any mineral compounds which are soluble in water, the latter, when added to the clay, will dissolve a portion of them at least. During the drying of the brick the water rises to the surface to evaporate and brings out the compounds in solution, leaving them behind when it vaporizes. It may also help the fire-gases to act on certain elements of the clay, a point explained under Burning

Chemically combined water.—Chemically combined water, as its name indicates, is that which exists in the clay in chemical combination with other elements, and which, in most cases, can be driven out only at a temperature ranging from 400° C. (752° F.) to 600° C. (1112° F.).[2] This combined water may be driven from several minerals, such as kaolinite, which contains nearly 14 per cent, white mica or muscovite with 4 to 5½ per cent, and limonite with 14.5 per cent. Unless a clay contains considerable limonite or hydrous silica, the percentage of combined water is commonly about one third the percentage of alum-

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[1] Seger's Collected Writings, I, p. 214. In this connection see also Patten and Gallagher, Absorption of Vapors and Gases by Soils, Bureau of Soils, Bull. 51, 1908, and Cameron and Gallagher, Moisture Content and Physical Condition of Soils, ibid., Bull. 50, 1908.

[2] See Bourry, Treatise on Ceramic Industries, p. 103; also W. M. Kennedy, Trans. Amer. Ceram. Soc., IV, p. 146; and further experiments under Fire-shrinkage (Chapter III). E. Plenske (Sprechsaal, No. 21, p. 290, 1908) noted a loss of H_2O at 380° C., while at 745° C. he found 1.37 per cent, and further heating to 920° C. in a muffel furnace still showed 0.60 per cent H_2O; Laubman (Tonindus.-Zeit., V, p. 400, 1881) noted dehydrations at 360° C.; Mühlhäuser (Ibid., p. 149) at 376° C.; Rohland (Sprechsaal, 1905, p. 1745) claims the last passes off between 900° and 1000° C.

ina found in the clay. In pure, or nearly pure kaolin, there is nearly 14 per cent, and other clays contain varying amounts, ranging from this down to 3 or 4 per cent, the latter being the quantity found in some very sandy clays. The loss of its combined water is accompanied by a slight but variable shrinkage in the clay, which reaches its maximum some time after all the volatile matters have been driven off.

In many clay analyses the chemically combined water is determined as loss on ignition, which is incorrect if the clay contains carbon dioxide sulphur trioxide, or organic matter, all of which are driven off, in part at least, at a dull red.

Carbonaceous Matter

Under this head is included all matter of carbonaceous character, most of which is of vegetable origin. Few sedimentary clays are entirely free from it, the material having become incorporated with the clay during its deposition. Although when first mixed with the clay it may have been more or less fresh, it has since then often undergone changes due to burial within the clay out of direct contact with the air, which have imparted to it an asphaltic or a coaly character.

Carbonaceous material may occur in clay in three different forms, namely:

1. Vegetable tissue, such as wood, leaves, stems, etc., in which form it is but slightly altered, and when of this character is commonly found in surface clays of recent origin. Organic matter of this character rarely affects the color of the raw clay and burns out easily, so that it causes but little trouble; then, too, it is usually present in but small amounts, rarely exceeding 1 per cent.

2. Carbonaceous matter of asphaltic or bituminous character. This burns readily at a low red heat, because of the highly combustible gases given off from it. It is found in some clays and in many shales, especially those associated with coal-seams, and in the shales which are worked may range anywhere from 0 to 10 per cent. If it increases above this the shales are not workable. Even 5 to 6 per cent causes much trouble in burning.

3. Hard, or coaly carbon, resembling anthracite. This burns slowly, and gives off few combustible gases.

Effects of carbon in clay.—Only the second and third of the groups mentioned need to be considered. The first alone causes trouble when it occurs in the form of sticks or thick roots and has to be screened out. It is, therefore, not included in what follows.

Carbonaceous matter often serves as a strong coloring agent of raw clays. If present in small amounts it tinges them gray or bluish gray, while larger quantities cause a black coloration. Indeed, so strong may this be that it masks the effect of other coloring agents such as iron. In fact, two clays colored black might burn red and white respectively, because one had much iron and the other none, and yet, owing to their black color, this could not be foretold with definiteness.

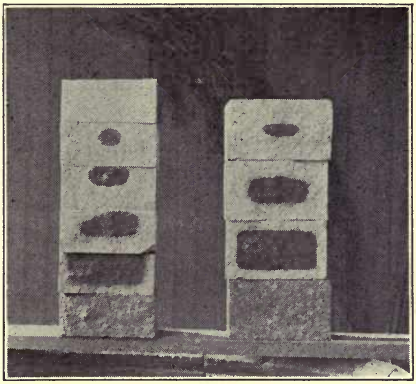

Fig. 19.—Changes in burning a black clay to a buff-colored brick. The lightest one was not removed from kiln until all the carbon was burned off. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 140, 1904.)

Asphaltic carbon, aside from its coloring action, often causes much trouble in burning, causing black cores, or even swelling and fusing of the brick. More than this, it may keep the iron in a ferrous condition and prevent the development of the best color-effects in the ware.

The reason for this is due to several causes:

Carbon has a strong affinity for oxygen, much stronger than that of iron, therefore as long as it remains in the clay it will monopolize the supply of oxygen and keep the iron in a ferrous condition, the form in which much of it is, in gray or black clays and shales. Now, in burning a clay, one of the aims of the clay-worker is to get the iron into a ferric condition, so as to fully develop its coloring properties and prevent other troubles. As long as any carbonaceous matter remains the oxidation of the iron is prevented or retarded, and consequently the carbon must be burned out.

The experiments of Orton and Griffin[1] have shown that between 800° and 900° C. is the best temperature interval for burning off the carbon, as below this the oxidation of it does not proceed as rapidly, and above this there is danger of vitrification beginning and the oxidation being stopped.

The method of procedure would therefore be to drive all moisture out of the clay first, then raise the heat as rapidly as possible to a temperature between 800° and 900° C., and hold it there until the ware no longer shows a black core denoting ferrous iron.

In order to burn off the carbon and oxidize the iron, air supplying oxygen must be drawn into the kiln during burning, for the gases of combustion from the fuel will supply none. Oxidation may be accelerated by increasing the amount of air entering the kiln and by reducing the density of the clay as much as possible.

In case this is not done, and the pores of the clay close up before all the carbon is burned off, it interferes with the expulsion of sulphur present which may result in a swelling of the clay. This may be even followed by complete fusion of the interior of the mass, caused by the formation of an easily fusible ferrous silicate. When the carbon is all burned off then the iron has a chance to oxidize.

If the clay contains much asphaltic carbon, then the oxidation must be carried on with as little air as possible, otherwise the heat generated by the burning hydrocarbons may be so intense as to vitrify the ware before the oxidation is completed.

Since dense clays are more difficult to oxidize than porous ones, the process of manufacture may also influence the results, and in this connection it has been found that bricks made by the soft-mud process are most rapidly oxidized, followed by either the stiff-mud or dry-press (there being no difference between the two), and lastly by the semi-dry-press.

Effect of water on black coring.—It is often stated by brickmakers that black cores are caused by the brick being set too wet. This is not strictly true, and the relation is but a very indirect one. While carbon burns off most rapidly between the temperatures of 800° and 900° C., still it also passes off somewhat at much lower temperatures. If now the brick is set wet it requires so much more heat in the early stages of firing to drive out or evaporate the water that other changes, such as the oxidation of the carbon, will be retarded, and brick begins to vitrify before the process is completed.

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[1] Second Report of Committee on Technical Investigation, Indianapolis, 1905.

Sulphur.—Many clays contain at least a trace of sulphur, and some show appreciable quantities, but determinations of it are rarely made, unless the clay is to be employed for Portland cement manufacture. As can be seen from the experiments of Seger, and more especially Orton and Staley, it may cause serious trouble, and should always be determined in the analysis of a clay.

Sulphur might be present in a clay, as

1. Sulphate, such as gypsum ($CaSO_4$, $2H_2O$), epsomite ($MgSO_4$, $7H_2O$) or melanterite ($FeSO_4$, $7H_2O$).
2. Sulphide, as pyrite (FeS_2) or marcasite (FeS_2).

Few investigators have, however, given much attention to the matter.

From experiments on a Columbus black shale, running high in carbon, ferrous iron and sulphur, Orton and Staley[1] adopted the series of conclusions given below.

The shale contained an average of 2.997% of total sulphur, expressed as the element, of which .76% was contained in soluble sulphates and 2.235 in sulphides.

They conclude:

1. Both sulphates and sulphides experience rapid diminution by dissociation, in that portion of the burn up to 800° C., in those portions of the ware which get air freely. This loss of sulphur may amount to two-thirds or three-fourths of the amount originally present.
2. Both sulphates and sulphides experience a further slow diminution by dissociation or oxidation, beginning at 800° C., and continuing as long as the clay structure remains porous and permeable to air. The loss of sulphur may amount to 90% or more of the initial sulphur content at the end of the period, but it proceeds increasingly slowly, and would probably never become complete.
3. In the interior portions of the clay, to which air cannot readily penetrate, the loss of sulphur may be less, and if there are any bases, such as FeO, CaO or MgO present, with which the sulphur may combine, the sulphur is not likely to be expelled.
4. Carbon, even in small quantities, interferes strongly with the expulsion of sulphur, which does not pass off to any extent until after the carbon goes. The clay may therefore have become too dense by that time for the oxidation of the sulphur to proceed, so that the carbon has virtually prevented its escape.

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[1] Third Report of Committee on Technical Investigation, Nat. Brick Makers' Assoc., Indianapolis, 1908.

5. Sulphur retained in the clay in any form and from any cause is not likely to cause physical disturbances in the clay until a fairly complete degree of vitrification is reached.

6. When a clay reaches a dense vitrified condition it proceeds normally, after a longer or shorter interval, to become less dense, by reason of the development of multitudes of minute vesicles in the viscous body; this process is progressive and in the end the body becomes spongy and worthless.

7. The length of this period of dense vitrification is much shortened, and in some cases practically abolished, by the presence of sulphur compounds, which break down and evolve gases copiously, producing a prematurely spongy body.

8. The cause of this gas evolution is chiefly the dissociation of sulphides and sulphates by silicic acid, which becomes increasingly active as the temperature rises, and appropriates the bases formerly combined with the sulphur.

9. In clays of low sulphur content, and of favorable structure for oxidation, the amount of sulphur left in the clay at vitrification is very small. Hence the period of good structure is long, the vesicular structure develops slowly, and the clay is said to stand over firing well.

10. In clays of high sulphur content, or of dense structure unfavorable for oxidation, or of high content of iron and carbon, the escape of the sulphur is prevented, the clay has a very narrow period of usefulness, or none at all, and the vesicular structure becomes enormously exaggerated.

11. While this premature and exaggerated swelling from sulphur may in bad cases occur in well oxidized clays, it is practically certain to occur where clays containing a partly oxidized core are allowed to reach the vitrification period.

12. This breaking down of sulphur compounds by silicic acid is the chief or common cause of the premature swelling of black colored clays, and the occasional cause of sudden and severe swelling of properly oxidized clay wares.

13. The proper way to avoid the effects of sulphur in vitrifying clay bodies is to apply a deliberate and complete oxidation treatment while the clay remains porous. This will rid the clay of the greater part of the sulphur, and will prevent sudden or premature slagging of the clay by ferrous oxide, if it is true that ferrous oxide has such a tendency, and will thus avoid, so far as possible, the conditions which favor swelling. Clays which still give trouble from swelling after this treatment must be regarded as bad clays.

Reactions involved in expulsion of sulphur

These may be expressed briefly as follows, the simpler and most probable ones only being given:

Pyrite heated to 400° C. gives

$$FeS_2 + \text{heat} = FeS + S$$

The S in the air catches fire and burns to SO_2 or SO_3, but if liberated in a clay soft and spongy by heat it may attack FeO, CaO or MgO. However, most of it probably escapes.

FeS exposed to oxidizing conditions might oxidize to ferrous sulphate, but further heating to 550–650° C. breaks it up, leaving FeO, the latter in an oxidizing atmosphere changing to Fe_2O_3.

Calcium sulphate also breaks down, but at higher temperatures than ferrous sulphate and less completely.[1] The action of carbon in restraining the liberation of sulphur is explained as follows:[2]

$$FeCO_3 + 425^\circ \text{ C.} = FeO + CO_2.$$

If now free sulphur is liberated in the immediate vicinity

$$FeO + C + S = FeS + CO.$$

This ferrous sulphide cannot be broken up by heat alone, but only by roasting in air or interaction with silicic acid, for as pointed out by Seger,[3] silicic acid at high temperatures has the power of displacing all other common acids, and combining with their bases to form silicates. It thus has the power to replace sulphuric acid, and the sulphur of sulphides. He found that a bisilicate glass mixture, saturated with sulphates, showed 4% sulphuric acid, while the same glass with one more molecule of silica added and melted at the same temperature and under same conditions contained but 2% sulphuric acid. Now, in raising the temperature of burning, the fusing matrix of a clay becomes more siliceous, resulting in the expulsion of sulphur.

The diagram, Fig. 19*a*, shows the rate of expulsion from the Columbus shale tested by Orton and Staley.[4]

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[1] See also Ries, N. J. Geol. Surv., p. 63, 1904, and Gypsum, this book.

[2] Orton, Trans. Amer. Ceram. Soc., V, p. 400.

[3] Collected Writings (Translation), II, p. 646, 1902.

[4] l. c.

Phosphoric acid.—This substance is rarely determined in clays, though it is not unlikely to have a wide distribution. It might be present as an ingredient of either amorphous or crystalline phosphate of lime, or of vivianite, the phosphate of iron, or perhaps even other phosphates.

In West Virginia it was found in all the clays examined in the laboratory of the Geological Survey.[1] About one quarter of the clays showed only a trace, but in the others it varied from .04 to 1.09 per cent, with an average of .316 per cent.

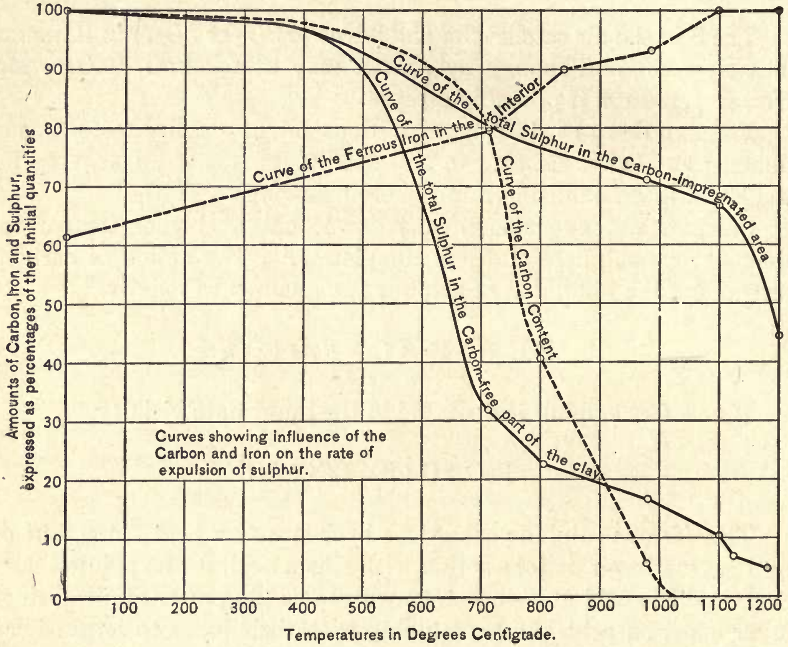

Fig. 19*a*.—Curves showing influence of the carbon and iron on the rate of expulsion sulphur. (After Orton and Staley.)

Whether such small amounts exert any recognizable effect in burning is not known, but C. W. Parmelee[2] states that the presence of phosphoric acid in sufficient amount gives translucency to the ware, improves the color, and acts as a flux and vitrifying agent.

With a slight increase in silica, the fusibility is increased, and the

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[1] W. Va. Geol. Surv., III. p. 21, 1906.

[2] Action of Phosphoric Acid in Body Mixtures, Trans. Amer. Ceram. Soc., VIII, p. 238, 1906.

addition of lime or feldspar in small quantities also made the mixture more fusible.

Thus a mixture of the formula Al_2O_3, $.56\,SiO_2$, $.7\,P_2O_5$ showed marked translucency, but stood at cone 13. One with Al_2O_3, $2.8\,SiO$ $.7\,P_2O_5$ was half over, while a third with $.3K_2O$, Al_2O_3, $2.8\,SiO_2$, $.7\,P_2O_5$ was melted at the same cone.

Soluble Salts

Origin.—It has been pointed out in Chapter I (Origin of Clay) that in the decomposition of mineral grains in clay soluble compounds are often formed. During the drying of the clay the moisture brings these to the surface and leaves them there when it evaporates, thus forming a scum on the air-dried ware, and sometimes a white coating on the clay after it is burned. Those found in the clay are commonly sulphates [1] of lime, iron, or alkalies, and their formation is generally due to the decomposition of the iron pyrite frequently contained in the clay. A much greater quantity of soluble sulphates will be formed if the pyrite is in a finely divided condition and evenly distributed through the clay, but soluble compounds may also be formed without the aid of pyrite, as when carbonates are set free by the decomposition of silicates, such as feldspar. When the soluble compounds have formed in the green clay their presence can often be detected by spreading the dug clay out to weather, which will result in their forming a crust on the surface of the mass.

Their formation does not cease, however, when they are removed from the ground, for in some cases fresh pyrite grains remain in the clay after mixing, and if the clay is stored in a moist place these may decompose, yielding an additional amount of soluble material. One means of preventing this would seem to be the use of the clay as soon as possible after mixing.

In some cases soluble sulphates may be even introduced into the clay by the water used for tempering, for distilled water is the only kind that is free from soluble salts. All well and spring waters contain some at least, and if these flow or drain from clays or rocks containing any pyrite they are almost sure to contain soluble salts. Those flowing from lime rocks are usually "hard," on account of the lime carbonate which they contain. Still another source of soluble salts in raw clay lies in some of the artificial coloring materials which are sometimes used.

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[1] Grimsley and Grout (W. Va. Geol. Surv., III) in their work on the W. Va. clays found that some of the soluble salts were unexpectedly high in Al_2O_3 and SiO_2, and showed no sulphates.

Soluble salts brought out in the drying of the clay are termed *dryer-white,* but do not differ in composition from those formed during burning and known as *kiln-white.*

Soluble sulphates are sometimes formed in burning, through the use of sulphurous fuel, that is, coal containing more or less iron pyrite. When the coal is burned part of the sulphur in the pyrite is expelled, and, uniting with the oxygen, forms sulphuric-acid gas (SO_3). This passes through the kiln, and, if it comes in contact with carbonates in the clay, converts them into sulphates, because some substances, such as lime (CaO), have a stronger affinity for sulphur trioxide (SO_3) than for carbon dioxide (CO_2).

It frequently happens that clay products come from the kiln apparently free from any superficial discoloration or coating, but develop one later on if subjected to moisture. This type of coating is known as *wall-white.* It may be derived from salts formed within the body of the ware during burning, and subsequently brought to the surface by the evaporation of moisture absorbed during rainy weather, or it may come from the mortar, either by the direct introduction of soluble salts from it, or by reaction between carbonates of magnesium, potassium and sodium of the mortar, with calcium sulphate in the brick. This gives calcium carbonate.

Mäckler[1] found that, in a series of fifty bricks examined, the sum of the sulphates of lime, magnesium, and alkalies varied from .0134 per cent to .7668 per cent.

The coatings thus far mentioned are all white in color. In some instances, however, the product becomes covered with a yellow or green stain, which is caused either by the growth of vegetable matter on the surface of the bricks, or by soluble compounds of the rare element vanadium.

Quantity of soluble salts in a clay.—The amount of soluble salts present in a clay is never very great, but less than 0.1 per cent is often sufficient to produce a white incrustation.

Prevention of soluble salts.—The methods of prevention that have been suggested for dryer-white and kiln-white are:

1. Use of the clay in its unweathered condition, or before the soluble salts have time to form.

2. Use of the clay in a thoroughly weathered condition, thus permitting removal of soluble salts by leaching.

3. Change the soluble salts to a harmless form by precipitation with barium compounds.

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[1] Tonindustrie-Zietung, No. 43, 1904.

4. Prevention of concentration of salts on surface of brick by rapid firing.

5. Removal of whitewash in the kiln by using a reducing flame.

6. Coating of the brick with some combustible substance, as wheat flour or coal-tar, which burns away with a strong reducing action and removes the whitewash.

Referring in more detail to 3, it may be explained that the substance commonly added is either barium chloride or barium carbonate. When barium salts come in contact with soluble sulphates, barium sulphate is formed, a combination which is insoluble in water. This is expressed by the first of the following chemical reactions if barium carbonate is used, and by the second if barium chloride is employed:

1. $CaSO_4 + BaCO_3 = CaCO_3 + BaSO_4$.
2. $CaSO_4 + BaCl_2 = CaCl_2 + BaSO_4$.

We thus see that in both cases we get compounds which are insoluble, or nearly so. If soluble sodium compounds are present, the addition of barium carbonate, or barium chloride, will form either sodium carbonate or sodium chloride (common salt), but since both of these are easily soluble in water they can be washed off without much trouble.

Method of use.—As carbonate of barium is insoluble in water, in order to make it thoroughly and uniformly effective it should be used in a finely powdered condition and distributed through the clay as thoroughly as possible, because it will only act where it comes into immediate contact with the soluble sulphates. While only a small quantity of barium is necessary, still it is desirable to use somewhat more than is actually required.

According to Gerlach,[1] a clay containing 0.1 per cent sulphate of lime, which is the same as 0.4 grams per pound, would need 0.6 of a gram of barium carbonate per pound of clay. For safety, however, 6 or 7 grams should be added to every pound of clay. This would be about 100 pounds for every thousand bricks, based on the supposition that a green brick weighs 7 pounds. As a pound of barium carbonate costs about two and one-half cents, the amount of it required for 1000 bricks would be $2.50. It is cheaper to use barium chloride, for the reason that the salt is soluble in water, and hence can be distributed more evenly with the use of a smaller quantity; the chemical reaction also takes place much more rapidly when it is used. There is this objection to it, however, that as near the theoretic amount as possible must be used; for if any remains in the clay unchanged, that is, without hav-

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[1] The Brickbuilder, 1898, p. 59 et seq.

ing reacted with the soluble salts, it may of itself form an incrustation.

In the case of a clay containing 0.1 per cent calcium sulphate it would require 26 pounds of barium chloride per thousand bricks, and this, at two and one-half cents a pound, would mean an outlay of $0.65. With the barium-chloride treatment, chloride of lime is formed, but this is decomposed in burning.

Since, in drying molded-clay objects, the evaporation is greatest from the edges and corners of the ware, the incrustations may be heaviest at these points, but the more rapidly the water is evaporated the less will be the quantity of soluble salts deposited on the surface. Incrustations which appear during drying are found more commonly on bricks made from very plastic clays, which, owing to their density, do not allow the water to evaporate quickly.

Remedy for wall-white.—This is more difficult, but consists primarily in preventing entrance of moisture to the walls. It is suggested to make the walls as impervious as possible by the use of well-burned brick, and proper drainage and waterproofing of the foundations. If the efflorescence appears, the walls may be painted so as to cover the efflorescence, but it may then peel off in damp spots. A coat of paraffine or linseed oil will conceal the white coating somewhat, but also darken the brick. They should also be made waterproof if possible.

References on soluble salts.—Those desiring to look up further details are referred to the articles listed below:

Segers' Collected Writings (translation), I.
    Efflorescence on terra cotta, p. 376.
    Influence of sulphur in fuel, p. 369.
    Yellow and green efflorescence on bricks, p. 381.
    Use of barium compounds, p. 396.
    Action of "water" in burning clay wares, p. 213.
Guenther, Baumaterialienkunde, I, p. 386, 1896.
Mäckler, Tonindustrie-Zeitung, No. 43, 1904.
Gerlach, Brickbuilder, 1898, p. 59.
Jones, Trans. Amer. Ceram. Soc., VIII, p. 369, 1906.
Lovejoy, Ibid, VIII, p. 255, 1906.

CHAPTER III

PHYSICAL PROPERTIES OF CLAY

Introductory.—Under Physical Properties there are included plasticity, texture, tensile strength, shrinkage, porosity, specific gravity, fusibility, color, slaking, absorption.

Plasticity

Definition.—Plasticity is probably by far the most important property of clay, lacking which it would be of comparatively little value for the manufacture of clay products. Seger[1] has defined it as the property which solid bodies show of absorbing and holding a liquid in their pores, and forming a mass which can be pressed or kneaded into any desired shape, which it retains when the pressure ceases, and, on the withdraawl of the water,[2] changes to a hard mass. The term hard of course refers to its hardness as compared with its wet condition, for some air-dried clays are rather soft.

This is a somewhat narrow interpretation of the property of plasticity, and one which would practically exclude anything except very plastic clays.

A broader conception, and probably a more satisfactory one to the physicist, would be to define plasticity as the property which many bodies possess of changing form under pressure, without rupturing, which form they retain when the pressure ceases, it being understood that the amount of pressure required, and the degree of deformation possible, will vary with the material.

Plasticity is not a property of clays alone, for, as pointed out by B. Zschokke[3] in connection with his study of the methods of testing it,

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[1] Beziehungen zwischen Feuerfestigkeit und Plasticität der Tone.—Tonindustrie-Zeitung, 1890, p. 201.

[2] By evaporation.

[3] Tonindustrie-Zeitung, No. 120, p. 1658, 1905; and Baumaterialienkunde, 1902, No. 24, 25–26; 1903, Nos. 1–2, 3–4, and 5–6.

other bodies, such as lead and wax, are plastic in their natural condition at ordinary temperatures, while copper, steel, and glass are plastic at higher temperatures.

Others, like clay and some mineral aggregates, are plastic only when wet, but even then vary greatly in their plasticity.

Some writers on clay, in attempting to give examples of plastic and non-plastic bodies, have sought to compare clay and sand, stating that the latter, even when fine-grained and wet, shows no plasticity; and, while it is true that a very fine-grained wet sand, or a finely ground mass of quartz, does not under pressure show the same amount of deformability without rupture as clay, still it shows some,[1] and the question may be asked whether both are not classifiable as plastic bodies, the one but slightly plastic and the other highly so. It is indeed possible to get a series of samples showing a complete gradation from a highly plastic clay to a but slightly plastic ground quartz. The latter will moreover hold its shape when dry, even though it will stand practically no handling without breaking.

Instead, therefore, of intimating that plasticity when wet is a property peculiar to clay, it would perhaps seem more correct to state that this property is highly developed in clays as compared with other earthy and sandy materials of very fine grain.

The amount of water required to develop the maximum plasticity in any clay varies with the material, this being shown by Wheeler[2] for a number of Missouri clays and shales, as follows:

Kind.	Per cent.[3]
Loess, or brick-clay	16–19
Fire- and potters' clay	15–33
Flint-clay	15–24
Kaolins	18–35
Shales	14–25

An important character, closely dependent on the degree of plasticity exhibited by finely textured mineral aggregates, is the assumption of a more or less hard condition when dry, the degree of hardness increasing usually with the plasticity.

Hardening on exposure to heat is not necessarily a function of plasticity, but is due to the particles softening by fusion and becoming welded together. In those highly plastic mineral aggregates (our most

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[1] See G. P. Merrill, Non-metallic Minerals, p. 221.

[2] Mo. Geol. Surv., XI, p. 98, 1896.

[3] It may be noted here that liquids like absolute alcohol, ether, petroleum ether, benzole, etc., do not bring out the plasticity in a clay.

plastic clays) this hardening takes place at a comparatively low temperature, because the particles are very fine-grained and come into the closest contact, thereby facilitating heat reactions; while, in the coarser-grained ones, the particles are not only more or less separated by interspaces, but there are more quartzose grains, which of themselves are refractory, and therefore heat reactions occur at higher temperatures, or else, if any fusion occurs at a lower heat, it is insufficient to bind the mass together into an impervious body.

Cause of plasticity in clay.—Scientists have for a long time sought to discover the cause of this most interesting physical property, and, while many theories have been advanced, none are wholly satisfactory. The more important ones are referred to below.

Water-of-hydration theory.—It has been held by many that the plasticity of a clay stood in close relation to the hydrated silicate of alumina,[1] kaolinite, and that, when the water of combination of this mineral was driven off, the plastic quality of the clay disappeared with it. Indeed, so firm a hold has this theory obtained that even to the present day it is still quoted in many instances.

While it is true that heating the clay to a sufficiently high temperature to drive off the chemically combined water causes a loss of its plastic qualities, still these, so far as known, stand in no relation whatever to the amount of kaolinite present, and it is more probable that a temperature necessary to drive off the water of combination may also break up other structures closely related to the plasticity. Then, too, some of the most highly plastic clays contain but a very small percentage of the hydrated silicate of alumina.

As bearing against the hydration theory, we find that two clays of practically identical composition may differ widely in their plastic qualities. Thus, for example, a white residual clay from Webster, N. C., was found to be decidedly less plastic than a white sedimentary clay from Edgar, Fla., although the two agreed closely in their chemical composition and contained over 98 per cent of clay substance.[2]

Texture theory.—Among the theories advanced to explain the cause of plasticity is that of fineness of grain. Mr. Whitney, for example, in studying soils, has designated as clay all those portions which were under .005 mm. in diameter.[3]

While it is true that the clayey particles of clays consist of grains of all sizes below the limits mentioned above, still plasticity cannot be

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[1] Among others Vogt, Bull. d. l. Soc. d'encour. l'ind. nat., 1897, p. 633.

[2] Ries, Md. Geol. Surv., IV, p. 248, 1902. Seaman (Chem. Centralbl., 1890, I) describes a highly plastic clay which contains practically no Al_2O_3, but shows, Ign., 7.95; ZnO, 54.06; SiO_2, 35.29; CaO, 1.80; Al_2O_3, 1.64.

[3] Mechanical Analysis of Soils, Dept. of Agric., Bur. of Soils, Bull. 4, p. 15, 1896.

explained on this ground alone. Very finely ground quartz, feldspar or mica are slightly plastic, but not nearly as much so as most clays. Moreover, the finest-grained clays are not always the most plastic ones. Wheeler[1] has noted that samples of quartz and limestone ground sufficiently fine to pass a 200-mesh sieve felt plastic when wet, but fell to pieces when dry, and the same results were obtained by Orton[2] with glass ground to exceeding fineness. When we recollect, however, that clay particles are smaller than .0001 mm., 0.02 in. (0.508 mm.) is not sufficiently fine grinding for testing the accuracy of the theory. That fineness no doubt exerts some influence on plasticity is evidenced by the fact that fairly plastic clays can often be rendered more plastic by fine grinding, and the addition of sand is said by Beyer and Williams to injure plasticity directly as the diameter of the grains increases.[3]

On the other hand Wheeler found that finely ground gypsum and brucite had considerable binding power and plasticity, but in this case the plasticity was not ascribed to fineness alone.

In this connection we may point to the researches of Daubrée, who claimed that feldspar, ground wet, gradually became plastic if allowed to stand, but that dry-ground feldspar lacked plasticity, and from this Olchewsky has reasoned that it is prolonged contact of the mineral grains with water during their sedimentation that develops plastic qualities in the mass.

A somewhat unique modification of this theory has been proposed by E. Linder,[4] who considers that the particles are of extreme fineness, and that weathering produces very long or round particles, the former giving greater contact surface, and thereby increasing the surface tension and the plasticity. He also believes that if clays have rounded particles they will burn dense only at high temperatures, while in those clays whose particles are elongated the reverse occurs.

Plate theory.—Johnson and Blake[5] advanced the theory that most plastic clays seem to be composed largely of small transparent plates, which were bunched together. They state:

"We have examined microscopically twenty specimens of kaolins, pipe- and fire-clays. . . . In them all is found a greater or less proportion of transparent plates, and in most of them the plates are abundant, evidently constituting the bulk of the substance.

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[1] Mo. Geol. Surv., XI, p. 102, 1896.

[2] Brick, Vol. XIV, p. 216.

[3] Ia. Geol. Surv., XIV, p. 86, 1904.

[4] Tonindustrie-Zeitung, XXXVI, p. 382.

[5] Amer. Jour. Sci. (2), p. 351, 1876.

"The plasticity of a clay is a physical character, and appears to have close connection with the fineness of the particles. The kaolinite of Summit Hill, consisting of crystal plates averaging .003 of an inch in diameter, is destitute of this quality. The nearly pure kaolinite from Richmond, Va., occurring mostly in bundles of much smaller dimensions, the largest being but .001 of an inch in diameter, is scarcely plastic. . . . The more finely divided fire-clay from Long Island is more 'fat,' while the Bodenmais porcelain earth, and other clays in which the bundles are absent and the plates are extremely small, are highly plastic."

Other investigators appear to have attributed the cause of the plasticity to these plates, for this same view was advanced in 1878 by Biedermann and Herzfeld,[1] and in this country a similar view was held by Cook,[2] who considered the plasticity to be due to the plates of kaolinite. He noted the bunched character of these in some clays, and pointed out that attrition broke up these bunches and increased the plasticity.

Haworth,[3] in examining the Missouri clays, found the most plastic clays to be composed of minute scales, and Wheeler[4] sought to prove this point experimentally by finely grinding minerals possessing a plate-like structure. Calcite and gypsum when finely ground were found to develop good plasticity when mixed with water, and to have tensile strengths when air-dried of 100 and 350 lbs. per sq. in. respectively. Talc and pyrophyllite were likewise plastic when finely ground and mixed with water, but developed little strength when dry.

Interlocking-grain theory.—Olchewsky[5] was probably the first to suggest that the plasticity and cohesion of a clay were dependent on the interlocking of the clay particles and kaolinite plates, and in this connection used the briquette method of testing the plasticity, or rather obtaining a numerical expression for it, by determining the tensile strength of the air-dried clay.

More recently two Russian investigators, U. Aleksiejew and P. A. Cremiatschenski, in studying the Russian clays[6] have come to the conclusion that plasticity is due not only to the interlocking of the clay particles, but varies also with the fineness of the grain, the extreme coarse and fine ones both having less plasticity.

If the tensile strength of a clay depends on the degree of interlocking

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[1] Bischof, Die Feuerfesten Thone, p. 23; also Hussak, Sprechsaal, 1889, p. 135.

[2] N. J. Geol. Surv., Report on Clays, 1878, p. 287.

[3] Mo. Geol. Surv., Vol. XI, p. 104, 1896.

[4] Ibid., p. 106, 1896.

[5] Töpf. u. Zieg. Zeit., No. 29, 1882.

[6] Zap. imp. russk. techn. obschtsch., 1896, XXX, pt. 6–7.

of the clay particles, then the tensile strength should afford us a means of expressing numerically the plasticity of the clay. It appears, however, that there is no such constant relation between these two properties.

Ball theory.—Aaron suggested that the plasticity of clay was due to the presence of globular particles, but Zschokke has with reason disputed this, on the ground that if the grains were of this form they would, when in closest contact (as when air-dried), touch at the fewest number of points,—a condition, therefore, not favorable to the great cohesion which exists between the grains of highly plastic clays.[1]

Colloid theory.—In the last thirty years not a few observers have called attention to the fact that many clays appear to contain grains of non-crystalline material, which is apparently of colloidal character. It is believed that these colloids, or glue-like particles, which are mixed with the mineral grains, form one cause of plasticity, in fact the main one.

As this theory, or a modification of it, seems to have appealed to many investigators, it may be well to discuss it in some detail.

The presence of colloids in clay was suggested at a comparatively early date, for Way[2] in 1850, while endeavoring to explain the high absorptive powers of clay for water, found that this property was destroyed by exposure to high heat, and considered that it was due to some peculiar form or modification of aluminum silicate which formed the clayey or impalpable portion of the soil. In searching for evidence he was able to prepare an artificial hydrated sodium aluminum silicate which possessed high absorptive properties.

At a somewhat later date (1893), Van Bemmelen[3] announced, as the result of his investigations on the inorganic colloids or hydrogels, that "nearly all metallic oxides and many salts have the power of entering into that peculiar hydrated, non-crystalline condition which Graham[4] in 1861 denominated colloid or glue-like. The special hydrogel which Van Bemmelen studied most minutely was that of silicic acid, although his researches included the oxides of copper, tin, iron, aluminum, etc., etc. As a result of these extensive investigations the author cited adopts the suggestion of Nageli of the micellian structure of colloids, that is to say, that these curious substances consist of heterogeneous molecular

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[1] See also Wolf, Tonindus.-Zeit., XXX, p 41, 1906, and Rohland, Sprechsaal, XXXIX, p. 758, 1906.

[2] Royal Agric. Soc. Jour., XI, 1850. Quoted by Cushman, Trans. Amer. Ceram. Soc., VI, p. 7, 1904.

[3] Zeitschr. anorg. Chem., V. p. 466; XIII, p. 233; XVIII, p. 14; XX, p. 185; XXII, p. 313. Quoted by Cushman, Jour. Amer. Chem. Soc., XXV, No. 5, May, 1903.

[4] Phil. Trans. (1861), p. 183. Quoted by Cushman, l.c.

complexes which possess a submicroscopical, web-like, porous formation, one of the distinguishing characteristics of which is the peculiar relation to and dependency on water which they exhibit. The water-content of these hydrogels varies continually with the temperature and the vapor pressure of the atmosphere in which they find themselves. Dried at high temperatures up to a certain critical point, they will lose nearly all their water, only to take it back again eagerly when allowed to cool in free air or in moist atmospheres. This dehydration and rehydration can be repeated indefinitely, unless the temperature of drying is carried too high, when the faculty is gradually lost and finally destroyed.

"The water thus absorbed is denominated 'micellian' water, and differs from hygroscopic water in the ordinary sense of the word. It is absorbed into the particles of a powder of an inorganic hydrogel without changing the physical appearance when under the microscope, while hygroscopic water is usually absorbed on the particles producing a distinct appearance of wetness."

Among the ingredients of clay which might assume a colloidal form are aluminum hydroxide, iron oxide, hydrated silicic acid, and organic matter. Some clays undoubtedly contain large amounts of colloids, but in others, as in many common clays, it is claimed that there is but a small proportion of ingredients which are capable of assuming the colloid state by the action of the water alone.[1]

Schlossing[2] states that in all kaolins there are finely crystalline substances and colloidal ones, which latter he separated by treatment with ammoniacal water, and found them to be singly refracting, globular aggregates, but Kasai,[3] on the other hand, disputed the existence of colloidal matter, for he finds that the apparently colloidal bodies of Zettlitz kaolin are doubly refracting.

Still later P. Rohland[4] suggested the colloidal nature of plasticity, while Van der Bellen[5] a little later expressed a similar view.

Lucas[6] in commenting on Rohland's observation calls attention to the fact that Zettlitz kaolin must have some colloidal matter because it flows freely through a die, and regards as significant the fact that a non-plastic crystalline powder will, under pressure, allow the water to be squeezed out, and will only form a plastic mass when tragacanth is mixed with it.

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[1] Ia. Geol. Surv., XIV, p. 90, 1904.

[2] Comp. rend. 1874, LXXIX, pp. 376 and 473.

[3] Die Wasserhaltigen Aluminum Silikate. Diss. München, 1896.

[4] Zeitschrift für anorganische Chemie, Vol. XXXI, Pt. I, p. 158, 1902.

[5] Chem. Zeit., XXXVI, 1903.

[6] Geol. Centralbl. f. Min., Geol. u. Pal., No. 2, p. 33, 1906.

The theory of Olchewsky that plasticity was due to the spongy porous nature of the smallest particles, which by reason of pressure arrange themselves into a sort of felt, may be regarded as admitting the presence of colloidal matter, but of more definite character are the statements of Arons[1] and Bischof, who suggest that plasticity was no doubt due to some special form of hydrated aluminum silicate, while Seger[2] remarks further that there is probably some effective molecular arrangement, which was already fixed in the structure of the parent rock.

In this country the colloid theory seems to have received little attention. In studying the clays of Maryland the author[3] noted the presence of what he assumed were colloidal bodies in the highly plastic clays, and the subject has been followed up in greater detail by Cushman,[4] who believes that plasticity is due to a "colloid condition of the fine particles, or of some proportion of the particles which go to make up the clay mass. These amorphous inorganic particles possess a submicroscopic structure. They absorb water eagerly, and gradually assume the coherent condition which causes in the wet mass the quality we call plasticity."

In order to prove the existence of colloids in clays, Cushman[5] prepared some silicic acid. This jelly dries rapidly to a powder, which is hydrated and loses or gains water with changes in the moisture content of the atmosphere in which it stands, but if heated above 1000° C. it loses its absorptive power. Hydrated colloid alumina was also prepared artificially.

On mixing the former with clay[6] it was found that the silicic acid increased the binding power and shrinkage but not the plasticity; while the alumina increased the plasticity but not the shrinkage or binding power.

A mixture of the two, prepared by adding sodium silicate (water glass) to the solution of alum,[7] showed that its addition to a clay increased both its binding power and plasticity.

Ries[8] found that the addition of one per cent gallotannic acid to a

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[1] Dammer, Chem. Tech., I; Notizbl, IX, p. 167.

[2] Tonindustrie-Zeitung, p. 37, 1877.

[3] Md. Geol. Surv., Vol. IV, p. 251.

[4] Jour. Amer. Chem. Soc., XXX, p. 5.

[5] Trans. Amer. Cer. Soc., VI, p. 7, 1904.

[6] The percentage added is not given.

[7] The suggested formula of this mixture is $XAl_2O_3,YSiO_2,ZH_2O$.

[8] Trans. Amer. Cer. Soc., VI, p. 44, 1904.

clay appeared not only to increase its plasticity but also its binding power.

Grout[1] by using a dilute solution of agar-agar for tempering two clays found that 0.08 per cent increased their plasticity approximately 60 and 36 per cent respectively.

He dried the same mass, mixed it with water, filtered off the latter, and tested the clear filtrate for soluble salts, but got no jelly, which was probably due to the fact, overlooked by him, that the clay adsorbs the colloidal material. (See Adsorption.)

Alumina cream was then tried instead of agar-agar, and it was found that it took 3 per cent of the former to raise the plasticity as much as 0.08 per cent of the latter; furthermore, after air-drying, powdering, and remixing, the plasticity of the mass dropped to its original figure. Grout consequently argues that since plastic clays are not injured by air-drying, it is evident that "such colloids as alumina cream do not explain plasticity, and that some colloid is required which will soften in water after air-drying, a type which is extremely rare in the inorganic kingdom." He says further: "The suggestion of Cushman, that a hydrated silicate of alumina could be precipitated so as to give the desired properties, has been carefully tried, but all resulted exactly as alumina cream."

Grout, moreover, questions the value of detecting colloids by staining with methylene blue, since he finds that most clays contain from 1 to 5 per cent of grains which will take a stain from methylene blue, gentian violet, eosine, or fuchsine. Both fresh and dried silicic-acid jelly he states take the stain, but the latter acts like quartz in decreasing the plasticity. Weathering, he further claims, does not increase the number of grains capable of taking the stain.

It would appear from what has been said that most clays contain (1) both non-plastic bodies or grains, of either crystalline or amorphous character, and (2) colloids, which appear to at least influence the plasticity.

If the colloids are the main cause of plasticity, this fact is not proven definitely either by showing their presence in the clay or by demonstrating that their addition to an already plastic clay increases its plasticity.

On the contrary, it would seem necessary to add them to some fine-grained mineral aggregate of exceedingly low plastic qualities, and by this addition be able to change it into a thoroughly plastic mass. A mass of colloidal material by itself does not show the solidity and cohesiveness which a strongly plastic clay does. It is as if it lacked

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[1] W. Va., Geol. Surv., III, 1906.

some strengthening internal structure, such as a mass of mineral grains might supply.

Molecular-attraction theories.—Several writers, to be referred to below, have inclined to the theory that the plasticity of clay was due to molecular attraction between the clay particles themselves or between the clay grains and water surrounding them.

Ladd,[1] as a result of his work on the Georgia clays, advocates the theory that the mutual attraction between water and clay particles, and surface tension of the water-films, may exert an important influence in determining plasticity.

The affinity of the clay particles for water will, however, vary with their chemical nature;[2] and particles of the same material have a varying affinity, under different conditions not now well understood. Moreover, salts and organic matter, in solution, modify the value of the surface tension of the liquid, the former generally increasing, the latter decreasing. This latter seems an important point for all clays containing a variable quantity of soluble matter.

The importance of molecular attraction between the clay substance and water was looked on by Zschokke [3] as an important cause of plasticity, he having pointed out that since clay particles are plastic bodies, they have greater attraction for water than non-plastic grains such as sand, and that therefore the grains will be surrounded by a thicker film of water than sand-grains would be. The addition of an excess of water separates the clay-grains so far that they are no longer able to attract each other, and the mass loses much of its cohesiveness. Moreover it is thought that the absorption of the water into the pores of the clay is accompanied by a superficial alteration of the clay particles, giving them a gelatinous coating, which permits them to change their form and at the same time keep in close contact; a point which is rather corroborated by the experiments of Cushman [4] and Mellor.[5] He finally suggests that plasticity must be dependent on (1) the size of the smallest particles; (2) the form and character of the surface; and (3) other peculiar properties possibly of a molecular character.

Grout,[6] reasoning along somewhat similar lines, believes that the chief cause of plasticity is the molecular attraction depending on the

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[1] Ga. Geol. Surv., Bull. 6*a*, p. 29, 1898.

[2] Whitney, U. S. Dept. of Agric., Bull. No. 4, 1892; Briggs, ibid., Bull. 10, 1897.

[3] l. c.

[4] Bull. U. S. Dept. Agric., 92, 1905.

[5] Trans. Eng. Ceram. Soc., V, Pt. I, p. 72, 1905–6.

[6] W. Va. Geol. Surv., III, p. 54, 1906.

chemical constitution of molecules, but that it may be improved by the addition to the clay of colloids such as tannin, etc., or such solutions as ammonia, alum, etc.

While several of these theories—plate structure, colloids, and molecular-attraction theory—have much to commend, still there seem to be serious objections in many cases against their being the *sole cause* of plasticity.

It is urged that many clays show little or no plate structure, and yet the evidence of Vogt (p. 47), Cook (p. 98), and Wheeler (p. 98) certainly indicate that it must at least be a factor governing the plastic qualities of many clays.

Although the colloid theory may be discarded by some, still the experiments of Cushman (p. 101), Ries (p. 101), and Grout (p. 102) point to its importance.

The examination of any extensive series of clays hardly seems to bear out the theory that any one of the causes suggested is the sole one, but rather that plasticity is dependent on a combination of them.

Effect of bacteria.—Aging a clay mixture, that is, allowing it to lie in cellars for six months or a year, appears to improve its plasticity, and it has been suggested that this is due to bacterial action. Bacteria are not uncommon in clay, and the prevalent one, according to Stover,[1] is believed to be bacillus sulphureus, whose development is facilitated by a temperature of 37° to 38° C.

Seger, although not referring to bacteria, stated that in the aging of a clay an acid was gradually developed by organic decomposition, which destroyed the alkalinity of the mass and was supposed to be responsible for the improvement in plasticity.

Since bacteria are known to exist in clays, they may add organic colloids (protoplasm) to it, and thereby increase its plasticity.[2]

Weathering clay.—It is a well-known fact that weathering a clay often increases its plasticity, but this might be due to several causes, such as mechanical disintegration of the mass by frost, water soaking, the oxidation of organic matter, or to the production of colloids by hydrolysis or bacterial action.

Grinding may sometimes improve the plasticity as much as weathering.

Rohland states that it may be increased: (1) By contact with spring or river water; (2) decrease in temperature; and (3) addition of colloids.[3]

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[1] Trans Amer. Ceram. Soc., IV, p. 185, 1902.

[2] W. Va. Geol. Surv., III, p. 47, 1906.

[3] Sprechsaal, XLII, p. 1371.

The Measurement of Plasticity

Clays vary widely in their plasticity, ranging from those which are very lean or low in plasticity to those which are very fat or of high plasticity.

Clay technologists have for a long time been searching for a satisfactory means of measuring the plasticity of clays, but this seems to be as difficult to find as the true cause of this peculiar property.

The methods which have been developed fall into two classes, namely, tests of the wet clay and tests of the dry clay, the former being probably the more logical.

Tests of the wet clay.—The commonest and most practical of these consists in feeling the clay between the fingers. It is not entirely satisfactory, but about the only one that can be used in the field, and, on the whole, gives us an important clue to the workability of the clay.

Bischof[1] suggested forcing the wet clay through a cylindrical die, and measuring the length of the pencil extruded before it broke of its own weight, and a similar method has been advised by E. C. Stover,[2] but there are serious objections to this, because the clay should be worked up into its most plastic condition before testing, and there is no means of determining accurately when the condition of maximum plasticity has been reached.

The use of the Vicat needle has also been suggested, the operation consisting in forcing a needle into the plastic clay by the pressure of a known weight. Langenbeck[3] states that the proper consistency is reached when the needle under a weight of 300 grams penetrates to a depth of four centimeters in five minutes. The same principle is involved in Ladd's test, which consists in suspending a plumb-bob from one arm of a balance and allowing it to settle into the moist clay for a given period.[4] Both these methods suppose that the more water a clay requires for mixing the higher its plasticity, an assumption not altogether correct.

Another method suggested by Ladd[5] consists in having two small sheet-iron troughs with perforated bottoms, in the center of which are set test-tube brushes, so placed that the ends of the brushes touch

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[1] Die feuerfesten Thone, p. 84.

[2] Trans. Amer. Cer. Soc. VII, p. 397, 1905.

[3] Chemistry of Pottery, p. 19.

[4] Ga. Geol. Surv., Bull. 6*a*, p. 51, 1898.

[5] Ibid., p. 52, 1898.

when the ends of the troughs are in contact. The dry clay is sifted into the brushes and water absorbed from below until the point of saturation is reached. The pull required to tear the column of clay between the brushes is measured by placing weights on a scale-pan attached to one of the troughs until the two separate.

The criticism urged against this method is that it gives little information regarding the plasticity, but measures the strength of the clay through different degrees of saturation.[1]

A somewhat detailed investigation is that of Zschokke.[2] According to him, it is necessary, in testing the plasticity of a clay, to consider (1) its property of deformability; (2) its degree of cohesion; (3) its stickiness or adhesiveness.

The degree of deformability was first tested by molding the thoroughly worked clay into cylinders 60 mm. high and 30 mm. in diameter, and subjecting these to pressure applied at the ends until cracks appeared, but this was found to be unsatisfactory, as some lean sandy clays were deformed more than highly plastic ones.

A more satisfactory method consisted in placing these freshly molded cylinders in a specially designed machine and pulling them in two. The amount of expansion showed the degree of deformability, while the force required to pull the cylinder in two showed the tensile strength. The product of the two Zschokke terms the plasticity coefficient. It was found that higher figures were obtained by stretching the bar rapidly, or by a succession of short rapid strokes. The following figures illustrate these points.

RUPTURE EXPERIMENTS

No. of sample.	Slow pull.			Jerky pull.			Per cent H_2O reg.
	Tensile strength β kgm. per sq. cm.	Deformability λ in per cent.	Plasticity coefficient $\beta\lambda$.	Tensile strength β kgm. per sq. cm.	Deformability λ in per cent.	Plasticity coefficient $\beta\lambda$.	
269	.63	70	44.1	1.73	127	220	29.8
250	.48	28.6	13.7	1.52	97	147	22.9
631	.42	18.4	7.7	.96	91	87	26.0
901	.36	17.4	6.3	.93	82	76	21.8
705	.27	33.4	9.	.86	94	81	20.8
507	.25	20.	5.	.96	90	86	20.8
702	.20	8.6	1.7	.76	73	55	23.9
636	.08	5.	.4	.20	5	1	21.8

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[1] Ia. Geol. Surv., Vol. XIV, p. 100, 1904.

[2] l. c.

Commenting on the results of his tests, Zschokke states that in very plastic clays there appears to be a slight amount of elasticity, so that it is necessary to distinguish between elastic and permanent changes of form.

The reason for the change of shape, without rupture under pressure, is considered to be as follows:

Given two moist sand-grains in contact. Since these are not plastic bodies, they have but little absorptive power for water, and are therefore covered by but a thin film of the latter. If these two grains are slowly drawn apart, the water film binding them together is soon ruptured. On the other hand two moist-clay particles will be surrounded by a thicker layer of water because of their greater attraction for it, and these two can be separated much farther without rupturing the mass.

Now the cylinder of moist clay can be considered as being composed of a great number of clay particles surrounded by water, and the smaller the size, and greater the number of particles of clay substance in the mass, the more intimate will be the attraction between clay and water. With an increase in coarseness of texture, and corresponding decrease in water-content and cohesion, there will be a depression of the tensile strength. While an excess of water may depress the tensile strength of the soft clay, still very plastic clays, although showing higher cohesiveness than lean ones, have a higher strength, which Zschokke believes indicates that there is an intimate relation, of either chemical or physical character, between the clay substance and admixed water.

Grout,[1] in his work on the West Virginia clays, arrived at conclusions somewhat similar to those of Zschokke.[2] He considers that plasticity may be considered as involving two variable factors, viz., (1) amount of possible flow before rupture, and (2) resistance to flow or deformation. Plasticity, he says, "increases in direct proportion to each of these factors, and is therefore equal to the product."

He measured the plasticity by carefully mixing and tempering the clay, and then forced it into a thin-walled metal cylinder three fourths inch in diameter. A plunger forced the clay through this die, and the bar of clay was cut into two-inch lengths.

These small cylinders were placed vertically under a movable plate and pressure applied, the amount necessary to compress it one half centimeter being taken as the measure of resistance to flow or deformation.

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[1] W. Va. Geol. Surv., III, p. 40, 1906.

[2] l. c.

The cylinder was then further compressed until the appearance of cracks at about 45 degrees to the vertical line, and this was considered the point of fracture. Vertical cracks, due to tension as the cylinder "expanded, were disregarded, and an irregular swelling of the cylinder under pressure was an indication that the mass was not uniform." The amount of flow was measured by the increase in area of the head of the cylinder.

The resistance to flow was found to be more satisfactorily measured by use of a Vicat needle; a needle of seven square mm. (1/8 in.) was used, and weight determined which was necessary to cause the needle to sink three centimeters in 1/2 min.

Tests of dry clay.—Of the dry methods, the tensile-strength test is the best known. It is made by molding the wet clay into briquettes, and testing the tensile strength of these when dry, this strength being expressed in lbs. per sq. in. The objection to this method is the assumption that the plasticity of a clay stands in direct relation to its tensile strength, which is incorrect.

Bischof [1] suggested using a set of mixtures of a standard clay with varying amounts of sand. Each of these is rubbed with the fingers, and the amount of dust that can be rubbed off is noted. The clay to be tested is similarly rubbed, and rated with the one of the standard series which has lost a similar amount by rubbing. The method is crude and inaccurate.

Texture

Definition.—By the texture of a clay is meant its size of grain or fineness, and since this exerts an important influence on the physical properties, such as plasticity, shrinkage, porosity, fusibility, etc., it should receive more than passing consideration. Many clays contain sand-grains of sufficient size to be visible to the naked eye, but the majority of clay particles are too small to be seen without the aid of a microscope, and are therefore so small that it becomes impossible to separate them with sieves. In testing the texture of a clay, it is perhaps of sufficient importance for practical purposes to determine the per cent of any sample that will pass through a sieve of 100 or 150 meshes to the inch, since, in the preparation of clays for the market by the washing process, they are not required to pass through a screen any finer than the one above mentioned.

Mechanical analysis.—If it is desired to measure the size of all the grains found in the clay, some more delicate method of separation becomes

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[1] Die feuerfesten Thone, p. 88.

necessary, and in order to do this it is essential that the mass of clay should be first thoroughly disintegrated and the grains separated from each other. This is best done by shaking the clay for a long time in water.[1] For this purpose the bottles used in sterilizing milk for infants are very convenient. Twenty grams of clay are weighed out and washed into such a bottle and the latter about half filled with distilled water. The bottle is closed with a rubber stopper and put into a shaking-machine. A convenient form consists of a box with compartments for holding four tiers of bottles lying on their sides, allowing four bottles in each compartment. This box is supported by chains, attached to the corners, hanging from brackets above. It is fastened by rubber bands to the table below, to steady it, and a guide-rod is fastened to the bottom, which works between two uprights to give a true lateral motion to the box. The box is then moved rapidly back and forth by a crank, with a throw of about 5 inches, at a rate of about 170 revolutions per minute. This gives a very good motion to the liquids in the bottles and keeps the clay constantly agitated. Motion may be imparted to the shaker by a water-motor or other suitable power. The shaking is continued for from one to two days, according to the nature of the sample, the heavier clays requiring the longer time.

When shaking is stopped, the contents of the bottles are washed into beakers, and the sediment, which quickly subsides, is examined with the microscope. If the disintegration is not complete, a small amount of pestling with the rubber-tipped pestle will finish it. Usually sandy clays are very thoroughly disintegrated after being shaken a day, while clay soils frequently require pestling after having been shaken for two days.

When clean, the grains should show sharp outlines under the microscope, being as a rule quite transparent. Adhering particles make them appear rounded and more or less deeply colored and the outlines indistinct. When pestling alone is resorted to for the disintegration of the material, it may require from fifteen minutes to an hour or more, depending upon the nature of the sample.

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[1] U. S. Dept. of Agric., Bur. of Soils, Bull. 4, p. 9, 1896.

Methods of Separation

Beaker method.—This method suggested by Whitney is simple, but somewhat inconvenient on account of the large amount of water required. Its operation is as follows:[1]

"The thoroughly disintegrated clay is transferred to a 3-inch beaker, which we may call *S*. This is filled with water and thoroughly stirred. It is then allowed to settle until all solid particles larger than 0.05 mm. have subsided. This is determined by taking a sample of the turbid liquid from near the bottom of the beaker by lowering a small tube, with the top closed by the finger, to a point just above the sediment, then removing the finger for an instant and letting the liquid enter the tube, closing the tube with the finger again and withdrawing the sample. A drop of this is placed upon a microscope slide, a cover-glass placed over it, and the particles examined by a good microscope containing an eyepiece micrometer. It is convenient to use a 1-inch eyepiece and a three-fourths and one-fifth inch objective.

"When the particles larger than 0.05 have subsided, the turbid liquid is carefully decanted into a larger beaker, *M*. This turbid liquid contains silt, fine silt, and clay, but no sand if the separation has been properly timed. The sediment in *S* consists of sand, containing still some silt, fine silt, and clay. This is stirred up with water and again allowed to settle until all the grains of sand have subsided, when the turbid liquid is again decanted into *M*. This operation is continued until an examination of the sediment in *B* shows that all particles smaller than 0.05 mm. have been removed. The contents of this beaker *B* are then washed into a small porcelain dish and evaporated to dryness on the water-bath. When dry this sand may be gently ignited to burn off the organic matter, and when cool it is sifted through a series of sieves which will be described further on.

"It is often convenient in separating the silt, fine silt, and clay from the sand to decant before the last portions of sand have settled. This hastens the operation of separating the fine and the coarse material, especially where there is a large mass of sand and but little fine material to be removed. In this case, the turbid liquid which is decanted is put into a separate beaker, and the sand which has been poured off is recovered by a further decantation, and when free from all fine material it is added to the sand in the porcelain dish while the latter is evaporating to dryness. The turbid liquid in the breaker *M* is thoroughly stirred

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[1] U. S. Dept. Agric., Bur. of Soils, Bull. 4, p. 10, 1896.

and allowed to settle until a drop taken from near the bottom of the the beaker contains no solid particles larger than 0.01 mm., equal to two spaces of the eyepiece micrometer using the $\frac{1}{5}$-inch objective. The turbid liquid, containing only fine silt and clay in suspension, is then carefully decanted into another beaker, *P*. The sediment remaining in *M* is again stirred up with water and allowed to settle, and decanted as before. This operation is continued until all particles smaller than 0.01 mm. have been washed out of the sediment in the beaker. Care must be taken in pouring off the turbid liquid that none of the silt goes over, or if it does it must be recovered and added to that in beaker *M* at some later stage of the operation. The sediment remaining in beaker *M* should contain nothing larger than 0.05 nor smaller than 0.01, if the separation has been carefully and completely made. This is washed into a platinum dish, evaporated to dryness on the water-bath, ignited at a low red heat, cooled in a desiccator, and finally weighed.

"The sediment in beaker *P* containing fine silt and clay is stirred up with water and allowed to settle until everything larger than 0.005 mm. has subsided, as determined by a microscopic examination as before. The turbid liquid, containing only 'clay' or material finer than 0.005 mm. equal to one space of the micrometer, is then decanted into a larger beaker, *C*, of 1 or 2 liters capacity, and the sediment in *P* repeatedly washed until all of the clay has been removed. When this has been accomplished, the sediment is washed into a platinum dish, evaporated to dryness, ignited, and weighed.

"The clay water usually amounts to a number of liters, and to prevent it accumulating to any great extent it is the practice in this Division to measure it in a liter flask and take 100 cc. from each liter to evaporate to dryness. The remainder of the clay solution is thrown away. When the liter flask is full to the mark with the clay solution, care must be taken to thoroughly mix it before taking out the tenth part to be evaporated to dryness. The successive 100 cc. of clay water are poured into a beaker and evaporated in a platinum dish as rapidly as possible. When this clay water has been evaporated to dryness, the sediment is ignited and weighed and the weight multiplied by ten to give the total amount of fine material in the original sample.

"In the course of the analysis, several of these grades may be separated at once, to facilitate the operation, by the use of additional beakers. It is best to transfer material into smaller beakers as the quantity becomes less in being freed from the finer particles, as this materially hastens the time required for the material to subside.

"The sand which was separated in the beginning of the operation and dried and ignited in the porcelain dish is sifted through a series of sieves of the following dimensions: Three round brass sieves 4 inches in diameter are used, which fit into each other and into a cup at the bottom. The top sieve has circular holes 2 mm. in diameter, the second has similar holes 1 mm. in diameter, and the third has holes 0.5 mm. in diameter. These grades are sifted in a very short time.

"The material which passes through the lower sieve is then sifted through two grades of bolting-cloth—Nos. 5 and 13—having square holes approximately 0.25 and 0.1 mm. in linear dimensions. This sifting requires quite a long time, on account of the fineness of the spaces through which the particles have to pass. It can conveniently be done upon the shaker which is used for the disintegration of the original sample. The two pieces of bolting-cloth can be fitted into conveniently arranged brass rings, and the samples should be shaken for an hour or two on this shaker.

"Each of these grades of sand are weighed without previous drying, as the amount of hygroscopic moisture is usually inappreciable.

"The operation of mechanical analysis is frequently made tedious and sometimes impossible by flocculation. If any tendency to this is discovered, vigorous stirring should be resorted to, and this can best be done with one of the improved forms of egg-beaters found in the market. A small trace of ammonia also assists in overcoming this tendency to flocculation, but it should be added very cautiously, as an excess of ammonia will cause many soils to flocculate. If the sediments are left standing for a length of time, flocculation is liable to occur, and it is very important that the work should be pushed along as rapidly as possible. The operator will find by experience that while waiting for one sediment to subside he may be decanting into extra beakers, which in time may be added to the proper beaker.

"The water used in the mechanical analysis should be distilled, if possible, but clear river, well, or hydrant water may be used. In case distilled water is not available, the solid matter in suspension or in solution in the water used should be determined by evaporating 500 cc. of the water to dryness, and igniting and weighing the residue. Allowance should then be made for this residue in the clay determination.

"Eight or ten samples can be started at once and can be pushed through about as readily as a single sample. It is not advisable, however, to attempt to carry on more than this number, because the proper attention cannot be given to the beakers. A fresh set of samples may be started on the shaker, however, a day or two before the last set is finished.

It requires from six to ten days to complete the analyses of a set of samples, if close attention is given to the decantations."

Schoene method.—A second method consists in separating the pebbles and coarse-sand particles out of the disintegrated clay by means of sieves, and then placing the finer portion in a tube where it is exposed to an upward current of water. Since the carrying power of the current will increase with its velocity, a current of water rising very slowly in the tube will carry off only the finest particles, while the heavier ones remain behind. If the velocity of the current be kept at this speed, it will finally become clear when all the finest particles are carried off.

A form of apparatus used for this purpose is the Schoene elutriator shown in Fig. 20.

The apparatus consists of the separating funnel A, which at the bottom ends is a bent tube, and is connected at the top with a narrow tube 1 meter long. This latter is Z-shaped and has an opening at *L*, 1.5 mm. in diameter. The grains of the clay to be separated are first disintegrated by boiling and then placed in the funnel *A*. Water is then run in from the reservoir *D* and the supply regulated by the stopcock *E*, so that there is always a definite velocity in the funnel *A*. The rapidity of flow depends on the amount of water entering the funnel per second. Knowing the amount of water and the cross-section of *A*, the velocity is equal to the quantity divided by the cross-section. The quantity is measured by allowing it to run into a measuring-vessel for a definite length of time, care being taken that the level of the water in *k* remains constant. In this way the flow per second can be calculated.

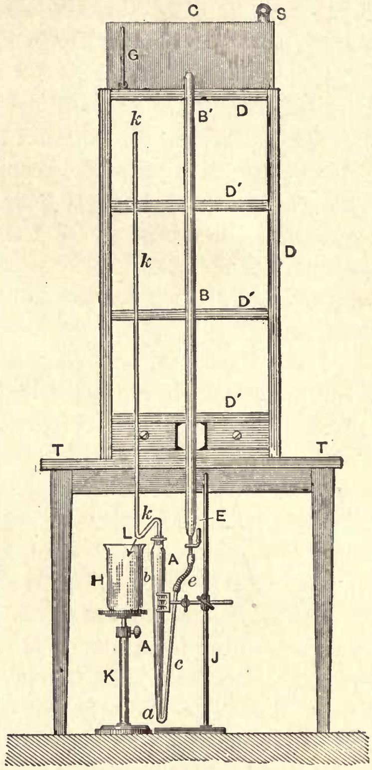

Fig. 20.—Schoene's apparatus for mechanical analysis of clay.

The velocity of the flow can be told by the height to which the water backs up in the tube *k*. This has to be determined in calibrating the instrument.

To every velocity there corresponds a size of grain determined by calculations, and five sizes are made, as follows:

1. Clay substance, including particles removed by a flow of 0.18 mm. per second. Maximum diameter 0.01 mm.
2. Silt, including grains removed by a flow of 0.70 mm. per second. Maximum diameter 0.025.
3. Dust-sand, including particles removed by a flow of 1.5 mm. per second. Maximum size 0.04 mm.
4. Residue remaining in funnel, called fine sand. Diameter 0.04 to 0.2 mm.
5. Coarse sand, everything larger than 0.2 mm.

This form of apparatus is much used in Germany, and but little in the United States. An objection which has been urged against it is that, on account of the funnel-shaped character of the vessel *A*, counter-currents are set up, which interfere with accurate results.

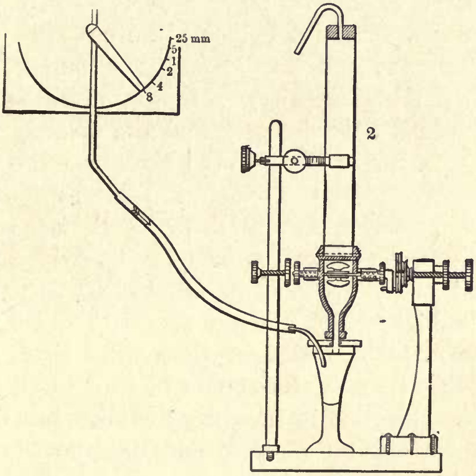

FIG. 21.—Hilgard's apparatus for making mechanical analyses.

Hilgard's elutriator.—E. W. Hilgard devised the form of apparatus shown in Fig. 21 for overcoming the defects of Schoene's separator. It is known as Hilgard's Churn Elutriator. It consists of an upright glass cylinder, 300 mm. in height and 45 mm. in diameter; this cylinder is united at its lower end to a brass cup-shaped funnel, crossed by a horizontal axis furnished with four wings; this churn is separated from the cylinder by a wire screen with meshes 0.8 mm. in diameter. The churn is worked by any convenient motor-power; about 500 revolutions per minute is the speed required when separating the two finest groups of particles, but for the other separations a smaller velocity will suffice.

The lower end of the brass funnel is fixed into a conical test-glass, which is in connection with the water-supply. The water is supplied from a reservoir maintained at a constant level. The lever opening the water-tap moves over a graduated arc, on which are marked the positions of the lever which yield supplies of water, giving the required velocities in the glass cylinder.

The apparatus being half filled with water and the churn in motion, the sediment is introduced, and the water-current adjusted to the lowest velocity, 0.25 mm. per second; this current is continued till the water ceases to remove any more matter. The operation requires many hours for its completion. The object of the churn is to break up the aggregations of fine particles which are very apt to form. Should any be seen on the sides of the cylinder, the apparatus must be stopped, and the flocks detached with a feather. The water leaving the cylinder is conducted by a tube nearly to the bottom of a tall, wide vessel, from the top of which the water runs to waste. The receiving vessel being much wider than the separating cylinder, the upward current of water in it is too slow for any of the solid matter carried into it to escape.

When no more particles are removed by the current moving 0.25 mm. per second, the regulator is changed, and the velocity of the current increased to 0.5 mm. per second. When the second group of particles has been in this way removed, the velocity of the current is again doubled, and this mode of proceeding is continued till the last separation, with a velocity of 64 mm. per second, is completed. With velocities above 4 mm. per second, the churn may be dispensed with. The work gets more rapid as the higher velocities are reached. When the apparatus is in action day and night, the separations will be completed in three or four days. Soft, filtered water should be used in all the operations.

A most serious objection to the three methods just described is the time required for making an analysis, and the quantity of water consumed.

Centrifugal separator.—The most satisfactory method is that known as the centrifugal method. The apparatus (Fig. 22) used consists of a fan-motor [1] placed with the armature shaft in a vertical position. This carries a framework with eight test-tube holders, trunnioned so that they can swing outward and upwards as the frame revolves.

The disintegrated sample in suspension in water is placed in these tubes, and twirled at a high speed for several minutes. As a result of this, all particles except the finest clay grains are thrown to the bot-

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[1] For complete description, see Bulletin No. 64, Bureau of Soils, Dept. of Agriculture, Washington, 1900.

tom of the tube by centrifugal force. These are decanted off, the tubes refilled with water, and the sediment again stirred up. A second twirling of the tubes, either at a lower speed or for a shorter period, precipitates everything except the fine silt, which is then also decanted off. The subsequent sizes are then separated from each other partly by settling and partly by sieves.

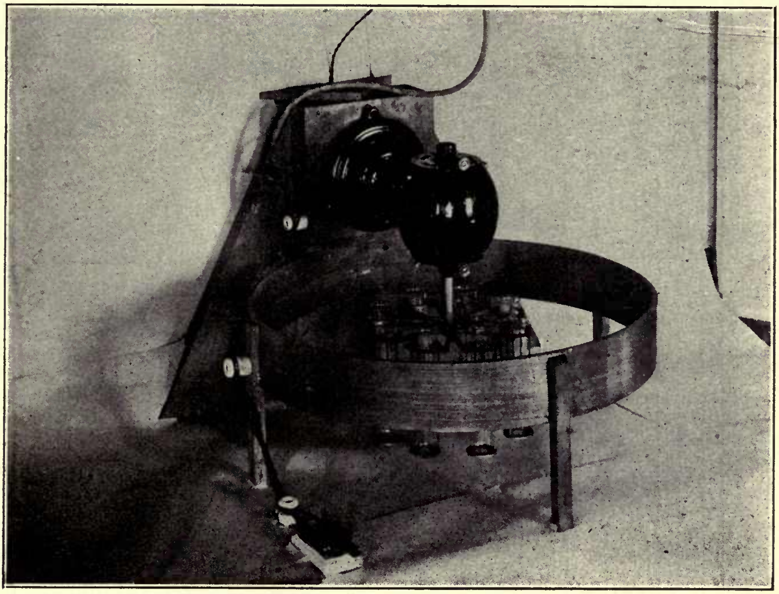

FIG. 22.—Centrifugal separator for mechanical analysis. (Photo loaned by Bureau of Soils.)

The different sizes which can be so separated and their dimensions are shown in the table below:

TABLE SHOWING SIZE OF GRAINS OF SAND, SILT, AND CLAY

Conventional name.	Size of diameters. Inches.	Millimeters.
1. Gravel	1/12 –1/25	2–1
2. Coarse sand	1/25 –1/50	1–0.5
3. Medium sand	1/50 –1/100	0.5–0.25
4. Fine sand	1/100–1/250	0.25–0.1
5. Very fine sand	1/250–1/500	0.1–0.05
6. Silt	1/500–1/2500	0.05–0.01
7. Fine silt	1/2500–1/5000	0.10–0.005
8. Clay	1/5000–1/25000	0.005–0.001

Krehbiel elutriator.—A type of separator which is a modification of Schultz's, but seemingly possessing several advantages, and being at any rate cheaper to construct, is that suggested and successfully used by Krehbiel.[1] It consists essentially of three cylinders with cone-shaped bottoms placed at different heights (Fig. 22*a*), so that the overflow from the first flows through the thistle tube to the bottom of the second, and so from the second to the third. The water supply is constant, coming from a tank with an overflow and fed from a faucet. The height of the tank depends on the opening in the end of the delivery tube, and is adjusted by trial. The cylinders have different diameters to produce a separation of the particles according to the sizes outlined by Seger, namely, in the first or smallest can: particles .12 mm. to .04 mm. in width (.33 mm. to .04 mm., Seger); in the second can: those .04 mm. to .025 mm. in width, and in the third .025 mm. in width, and in the third .025 to .01 mm. The overflow consisted of particles from .01 mm. to 0.

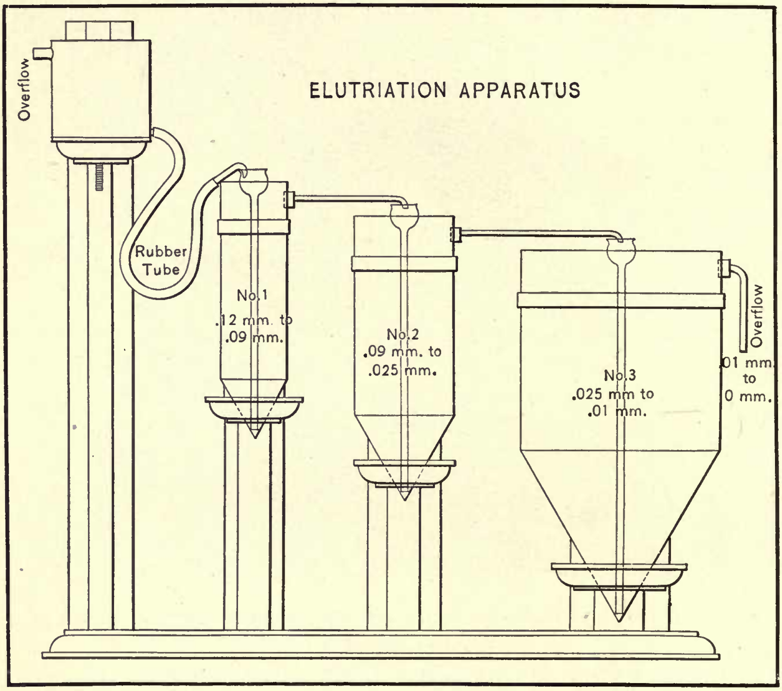

Fig. 22*a*.—Krehbiel's elutriator for mechanical analysis of clay. (After Krehbiel, Trans. Amer. Ceram. Soc., VI, 1904.)

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[1] Trans. Amer. Ceram. Soc., VI, p. 173, 1904.

Air elutriator.[1]—This form of apparatus was devised in order to overcome the defects of any wet method of separation. "The apparatus (Fig. 22*b*) consists of five percolating jars set in a wooden frame and connected by tubes of glass passing through close-fitting caps tightly clamped to the jar tops. The first jar is of 3 gallons capacity, the second 2 gallons, and the remaining ones of 1 gallon each. In the bottom of No. 1 is placed a flat spiral tube closed at one end, but with a number of very small openings through small jets soldered into the upper surface of the spiral at an angle of about 30°. The open end of the spiral passes through a tightly fitting rubber stopper inserted in the neck of the jar and is connected to the source of air supply. An inverted funnel tube whose stem passes through another rubber stopper fitted in the cap at the top of the jar is connected to a glass tube which passes in a similar manner nearly to the bottom of No. 2. An inverted thistle tube connects No. 2 with No. 3 in like manner, and so on through Nos. 4 and 5, the exit tube of No. 5 being connected to a vacuum. The exit of No. 5 was covered with fine linen lawn. Rubber stoppers close the necks of the jars and are removed only when it is desired to draw off the charges of powder which have accumulated during a run. A charge of oven-dried powder not exceeding 1 kilogram is placed in jar No. 1. Blast and vacuum are then turned on and adjusted so that a steady stream of air passes through the powder with sufficient force to

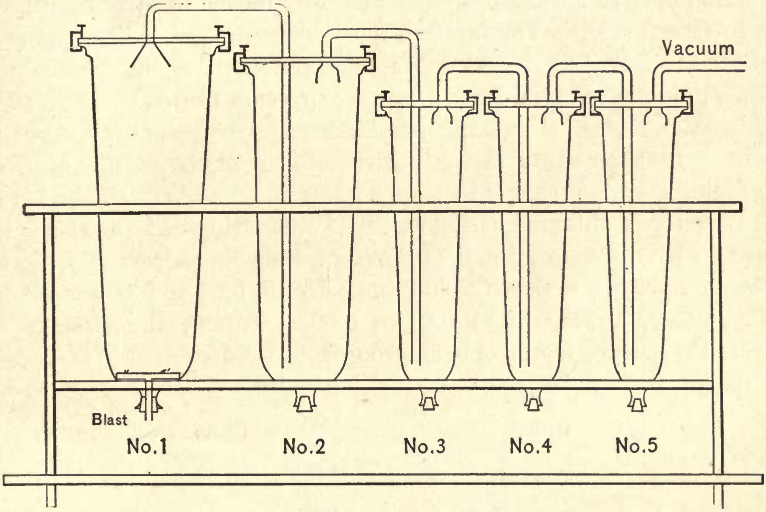

FIG. 22*b*.—Cushman's air elutriator. (After Cushman and Hubbard, Jour. Amer. Chem. Soc., XXIX, No. 4.)

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[1] A. S. Cushman and P. Hubbard, Air Elutriation of Fine Powders, Jour. Amer. Chem. Soc., XXIX, No. 4, Apr., 1907.

raise a dense white cloud, which assumes a vortex motion as it ascends, owing to the arrangement of the air jets. The heavier particles continually fall in a ring near the walls of the vessel, where they build up until caved in by the air jets, while the lighter particles are carried into No. 2 through the funnel tube, and so on, the very finest being caught in the last jar."

The method is not intended to be quantitative, but simply to serve the purpose of separating the different sizes for examination. With care, however, it might be made to yield quantitative results.

Fineness factor.—The fineness of ground materials used in the ceramic industry is frequently expressed by means of a term known as the surface factor.[1] The factor often used is that of Jackson as modified by Purdy. It is based on the assumption that the surface areas of two powders, derived from a unit volume are in inverse ratio to the average diameter of their grains, and hence the reciprocal of the average diameter is taken as the factor. Although the assumption is in error,[2] the factor affords a convenient approximation, and is often used. The Purdy factor is obtained as follows: The elutriation of a powder is supposed to have separated it into the four following sizes: No. 1, diameters ranging from 0.12 to 0.04 mm.; No. 2, 0.04 to 0.025 mm.; No. 3, 0.025 to 0.01 mm.; No. 4, 0.01 to 0.00. Taking the average diameters the surface factor of each group is as follows:

Group	Average Diameter	Surface Factor	Per Cent. Present
1	0.080	$\frac{100}{8} = 12.50$	10
2	0.0325	$\frac{10000}{325} = 30.77$	20
3	0.0175	$\frac{10000}{175} = 57.14$	20
4	0.0050	$\frac{10000}{50} = 200.00$	50

The total surface factor is obtained by multiplying the surface factor of each size by the percentage weight of each group, and finding the sum of the products thus obtained. Thus

$$\begin{array}{rr} 12.50\times & .10 \\ 30.77\times & .20 \\ 57.14\times & .20 \\ 200.00\times & .50 \\ \hline & 118.83 \end{array}$$

If a raw clay is examined under the microscope, it is usually seen to be composed of a number of different-sized grains. These may show

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[1] See Jackson, Trans. Eng. Ceram. Soc., III, p. 16; Krehbiel, Trans. Amer. Ceram. Soc., VI, p. 173, 1904; Binns, Trans. Amer. Ceram. Soc., VIII, p. 244, 1906; Purdy, Trans. Amer. Ceram. Soc., VII, Pt. III, p. 441, 1905; Cushman and Hubbard, Jour. Amer. Chem. Soc., XXIX, No. 4, 1907.

[2] Cushman and Hubbard, l. c.

a wide range of sizes as given in Fig. 23, which represents a gritty clay from the Cape May formation of New Jersey. In other clays, such as those of the Alloway formation in the same State, there is often less variation in the size of the grains (Fig. 24), the grains in the latter being bunched together more than in the former. Fig. 25 represents several grains of sand from a sample of Clay Marl I, which have been separated by the mechanical analysis and enlarged 115 diameters; they consist of quartz (*Q*), mica (*M*), feldspar (*F*), and lignite (*L*), the cloudiness of the feldspar being due to partial kaolinization.

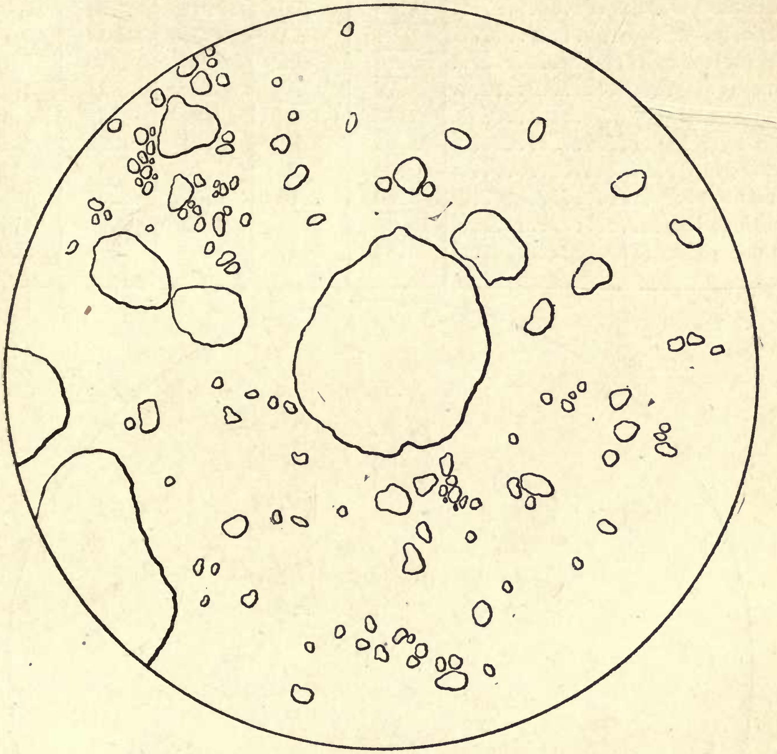

Fig. 23.—Drawing showing particles of a Cape May clay, enlarged 362 diameters. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 109, 1904.)

Relation between composition and texture.—Few analyses have been published showing the chemical composition of the different-sized grains in a clay.

Recently Grimsley and Grout have analyzed the mechanical separations of 16 samples of clay with the following results:[1]

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[1] W. Va. Geol., III, p. 61, 1906.

Sizes in mm.	00 to 0.001	0.001 to 0.005	0.005 to 0.02	0.02 to 0.15	0.15 up
Silica (SiO_2)	44.08	54.54	70.30	81.16	73.63
Alumina (Al_2O_3)	28.16	23.00	16.04	9.76	13.01
Ferric oxide (Fe_2O_3)	7.94	5.91	3.21	2.13	4.71
Ferrous oxide (FeO)	.99	.99	.63	.40	.18
Lime (CaO)	.76	.82	.72	.31	.47
Magnesia (MgO)	1.36	1.02	.80	.39	.48
Potash (K_2O)	3.05	3.31	2.14	1.78	.93
Soda (Na_2O)	.00	.29	.45	.56	.00
Moisture	2.80	1.10	.56	.35	.87
Ignition, loss	10.86	7.79	4.33	2.59	4.40
Titanic oxide (TiO_2)	.84	1.12	1.08	.78	.60

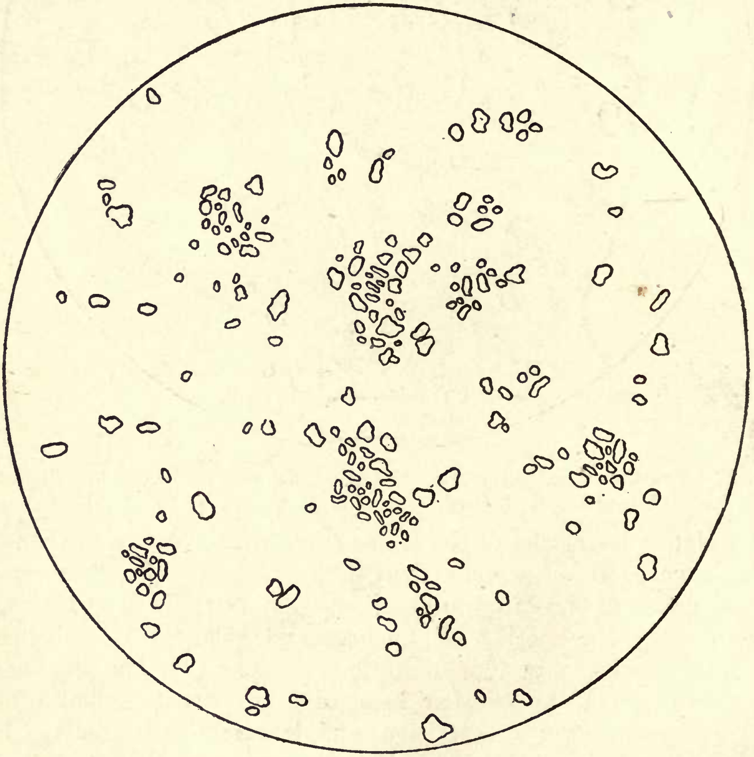

FIG. 24.—Drawing of the Alloway, N. J., clay, enlarged 362 diameters. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 110, 1904.)

As might be expected, these analyses show a higher percentage of silica in the coarser grains, still the increase is not a steady one, but none of the other ingredients show either an increase or decrease from

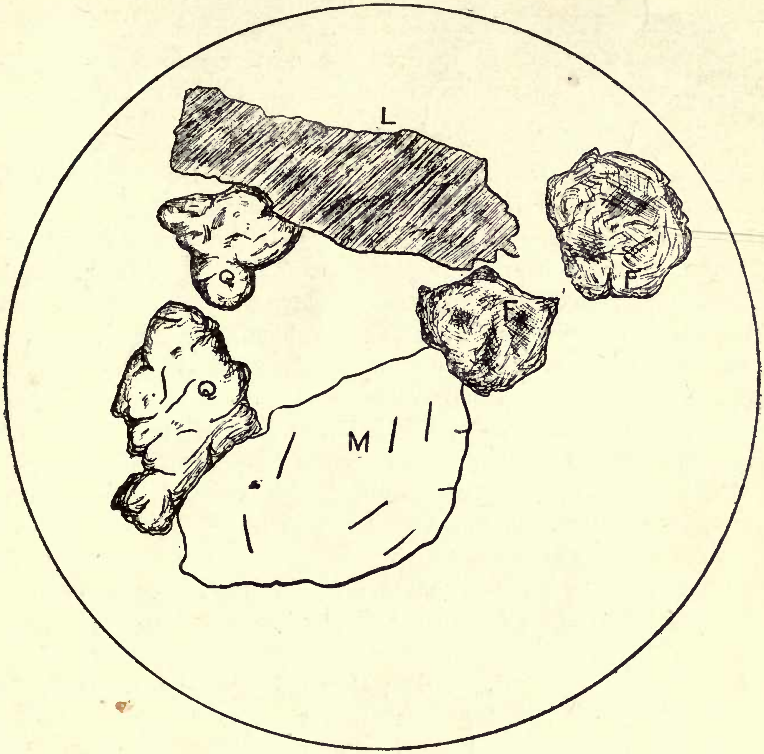

Fig. 25.—Drawing of sand-grains in a New Jersey clay marl, enlarged 115 diameters. *M*, mica; *Q*, quartz; *F*, feldspar; *L*, lignite. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 111, 1904.)

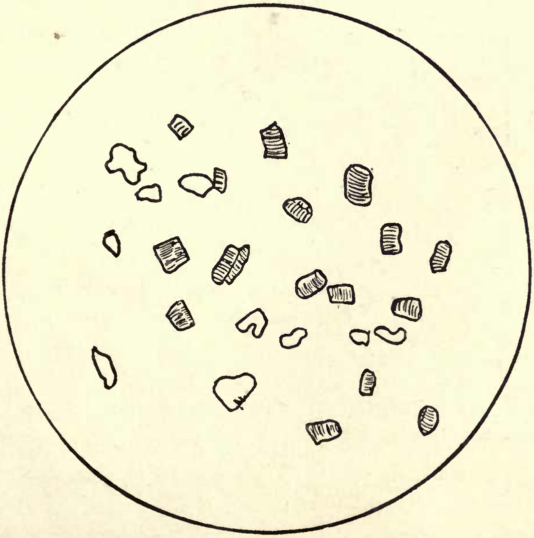

Fig. 26.—Drawing showing bunches of kaolinite (?) plates in a ball-clay from Edgar, Fla., enlarged 362 diameters. (After Ries, Md. Geol. Surv., IV.)

coarse to fine. The maxima are in each case underscored. The appreciable titanium percentage in even the coarser grains is of interest, although it is not known in what form the titanium occurs therein.

Tensile Strength

Definition.—The tensile strength of a clay is the resistance which it offers to rupture or being pulled apart when air-dried.

Practical bearing.—The tensile strength is an important property, and has a practical bearing on problems connected with the handling molding, and drying of the ware, since a high strength enables the clay to withstand the shocks and strains of handling. Through it, also, the clay is able to carry a large quantity of non-plastic material, such as flint or feldspar, ground bricks, etc.

Relation to plasticity.—Although it was formerly believed by many that tensile strength and plasticity were closely related, this view is no longer generally accepted. High tensile strength and high plasticity often go together, but a clay low in tensile strength may have high plasticity and vice versa.

Measurement of tensile strength.—The tensile strength is measured by molding the thoroughly kneaded clay into briquettes, of the form and dimensions shown in Fig. 27, and, when thoroughly air-dried, pulling them apart in a suitable testing-machine. The cross-section of the briquettes when molded is 1 square inch, and, after being formed, they are allowed to dry first in the air and then in a hot-air bath at a temperature of 100° C. (212° F.). When thus thoroughly dried the briquette is placed in a machine, in which its two ends are held in a pair of brass clips, and is subjected to an increasing tension until it breaks into two. The type of machine used is of either type shown in Figs. 28 and 29. Theoretically the briquette should break at its smallest cross-section with a smooth, straight fracture, and when this does not occur it is due either to a flaw in the briquette or because the clips tend to cut into the clay. In such event the briquette breaks across one end, and to prevent this it is necessary to put some soft material,

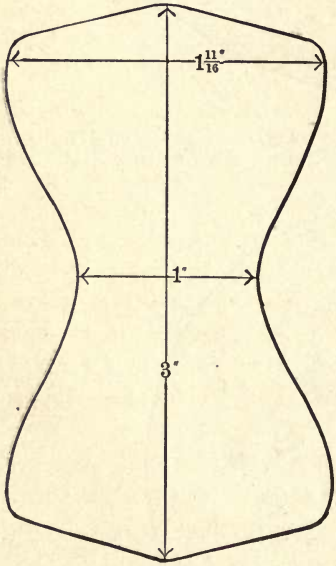

FIG. 27.—Outline and dimensions of a briquette for testing the tensile strength of a clay.

such as asbestos, pasteboard, or rubber between the inner surface of the clip jaws and the sides of the briquette. If the briquettes are molded and dried with care, the variation in the breaking strength of the individual briquettes should not vary more than 15 or 20 per cent, but with some very plastic clays it is extremely difficult to keep the variation within these limits.

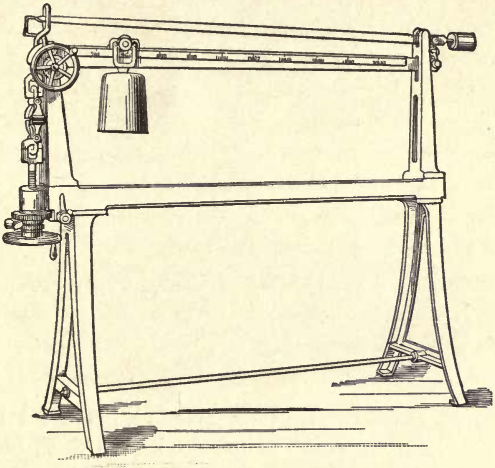

FIG. 28.—Riehlé tensile-strength machine.

Great care has to be exercised in filling the briquette molds, in order to prevent flaws in the piece, and the best method consists in cutting a lump of the tempered clay of approximately the shape and size of the mold, and then pounding it in from both sides with the hands.

Wheeler[1] advocates filling the mold by pressing in separate small pieces of wet clay with the fingers, the object of this being to avoid air-bubbles and prevent laminations in the briquette; but some have obected to this, on the ground that it is difficult to make the separate pieces of clay amalgamate.

Since the briquettes of any one clay will always show more or less variation, at least 10 or 12 should be tested in order to get a fair average. The author's experience has shown that the greatest variation usually appears in clays of high tensile strength, in which the fracture nearly always occurred in the head, indicating that the briquettes broke before the limit of their strength was reached. The tensile strength of clay briquettes is expressed in pounds per square inch; but, since

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[1] Mo. Geol. Surv., Vol. XI, p. 111.

the briquette shrinks in drying, the strength actually obtained in testing will be less than that for a square inch, and the result must be increased in proportion to the amount the brick has shrunk.

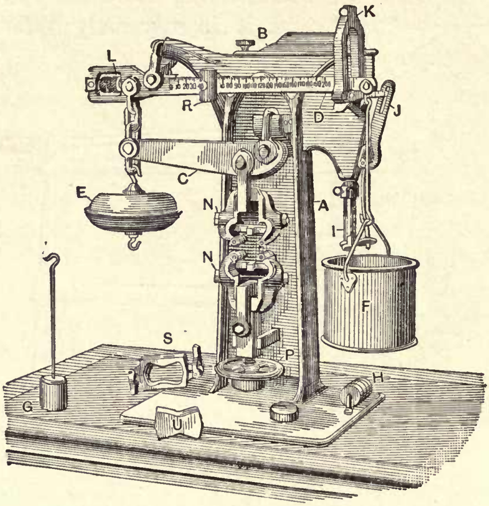

Fig. 29.—Fairbanks tensile-strength machine. *N*, clips for holding briquettes; *P*, screw for applying strain to balance-lever *C*; *F*, bucket to hold shot fed in through *I* from the hopper *K*; *J*, automatic cut-off.

Clays vary widely in their tensile strength, ranging from but a few pounds up to over 400, and even in clays of the same class a wide variation is not uncommon, as the following approximate figures will show:

	Minimum.	Maximum.
Kaolins	20	60
Fire-clays	0 (Flint-clays)	150
Brick-clays	50	300
Pottery-clays	50	250

Wheeler[1] in testing 135 Missouri clays found that their tensile strength ranged from an average of 8 to 380 lbs. per square inch, distributed among the several kinds as follows:

Kind.	Range.	Average.
Flint-clays	8 to 50	20
Kaolins	12 to 20	20
Fire-clays and pottery-clays	50 to 284	150
Shales	87 to 192	120
Gumbo	275 to 410	340
Loess	97 to 354	150

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[1] Mo. Geol. Surv., XI, p. 111.

Beyer and Williams[1] give a range of from 46 to 319 lbs. per square inch for the Iowa clays.

The range in strength determined by the writer for the Texas clays was as follows:

Fire clays	46 to 277
Stoneware clays	66 to 320
Calcareous clays	119 to 366
Sandy brick clays	77 to 455
Semi-refractory brick clays	161 to 329
Red- or brown-burning brick clays	74 to 487

while in the New Jersey clays[2] the extremes were 20 and 453 lbs. per square inch.

When any series of clays is tested, it is found that both the very sandy ones and very fine-grained ones often have a low tensile strength, although there are marked exceptions to both these cases.

Cause of tensile strength.—In order to get satisfactory and reliable results, great care is necessary in molding and drying the briquettes, it being claimed by some that fine-grained clays will show an abnormally low strength unless dried very slowly.

Experiments by Orton[3] seem to bear out this fact. Five series of the same clay were tested by him as follows:

Series.	Rate of drying.	Average tensile strength, lbs. per sq. in.
1	Quickest, severest drying	182.49
2	Somewhat slower	178.17
3	Still slower	176.13
4	Very slow indeed	204.80
5	Artificial conditions	205.53

The fifth series was placed in a tightly closed jar with calcium chloride.

With such a variation existing in the tensile strength of clays, it becomes a matter of importance to know the cause of this variation. It is a well-known fact that all clays shrink in drying, and that this shrinkage is accompanied by a drawing together of the particles. Indeed, some clays shrink to such a hard mass as to suggest a close interlocking of the grains, which, it seems to the writer, may be the explanation of the tensile strength shown; that is to say, those clays in which the inter-

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[1] Ia. Geol. Surv., XIV, p. 83, 1904.

[2] N. J. Geol. Surv., Final Report, Vol. VI, p. 85, 1904.

[3] Trans. Amer. Cer. Soc., Vol. III, p. 202, 1901.

locking of the particles is the tightest will show the highest tensile strength and vice versa. If this is true it becomes necessary to determine, if possible, what arrangement or size of particles produces the tightest and strongest structure.

E. Orton, Jr.,[1] attempted to determine the effect of the fineness of grain on the tensile strength of clays by taking a very fine-grained clay and mixing different sizes of sands with it, the sand being obtained by grinding and screening vitrified bricks. His conclusions were "(1) that the tensile strength of mixtures of a plastic ball-clay with equal quantities of non-plastic sands will vary inversely with the diameter of the grains of the sand from grains of 0.04 inch down to the finest sizes obtainable. (2) That the non-plastic ingredients of clay influence its tensile strength inversely as the diameter of their grains, and fine-grained clays will, other things being equal, possess the greatest tensile strength." In other words, the coarser the grains of sand the less the tensile strength of the mixture containing them.

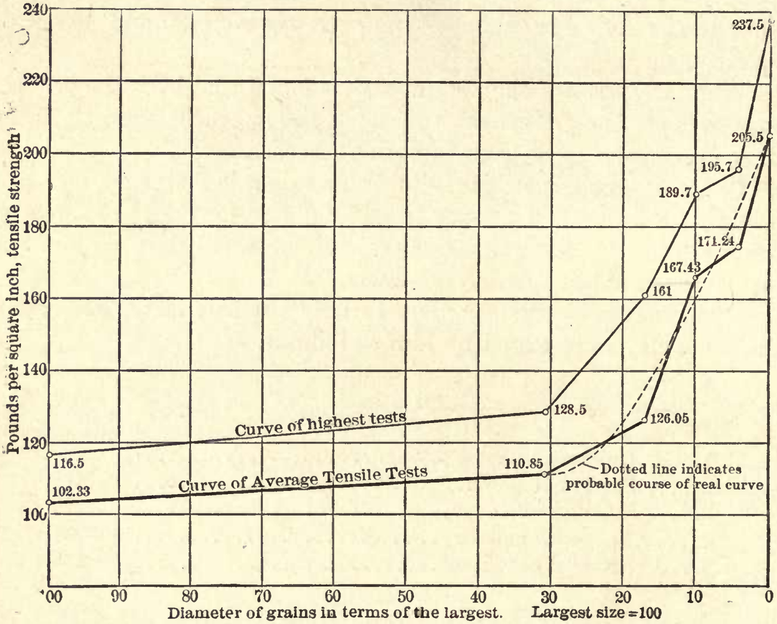

FIG. 30.—Curve showing relation between fineness of grain of non-plastic material and tensile strength of clay mixtures. (After Orton, Trans. Amer. Cer. Soc., III.)

The results of these tests are shown graphically in Fig. 30.

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[1] Transactions American Ceramic Society, Vol. II, p. 100, and Vol. III, p. 198.

A series of tests on natural mixtures of varying texture were undertaken by the writer in connection with a study of the New Jersey clays.[1] Five samples were selected at random as follows:

1. A very plastic, slightly gritty, dense, red-burning clay from the Alloway formation, with an average tensile strength of 453 pounds per square inch.

2. A Pleistocene clay of gritty, plastic character, but not as dense as the previous one. Its average tensile strength was 297 pounds per square inch.

3. A gritty, plastic clay from the Cape May formation, with an average tensile strength of 289 pounds per square inch.

4. A Raritan clay of black color and sandy, micaceous character, with an average tensile strength of 105 pounds per square inch.

5. A soft, powdery, washed ball clay from the Raritan. It was plastic to the feel, with very little grit, and a tensile strength of under 20 pounds per square inch.

The percentage of the sizes in each of the 5 samples is shown in the following table:

MECHANICAL ANALYSES OF SOME NEW JERSEY CLAYS

Conventional names.	I. Lab. No. 680.	II. Lab. No. 659.	III. Lab. No. 645.	IV. Lab. No. 615.	V. Lab. No. 723.
Clay substance	59.00%	44.00%	22.00%	30.645%	87.96%
Fine silt	11.00	7.11	5.66	14.21	6.95
Silt and fine sand	14.70	24.35	26.55	5.585	3.00
Medium sand	3.50	7.80	11.45	6.400	1.00
Sand	11.40	16.35	33.44	42.950	.....
	99.60	99.61	99.10	99.790	98.91

These figures seem to throw some light on the relation of the texture to the tensile strength, but, while highly suggestive, are not to be taken as final. The results of these tests are also shown graphically in the table (Fig. 31), in which the horizontal lines represent percentages. Of the 6 columns, the first 5 represent the grain sizes and the sixth the tensile strength.

Taking No. 5 of the above table of analyses we find that it contains 87.96 per cent of clay substance. This point is plotted in the first column. The point representing the percentage of fine silt is then plotted in the next column, and so on with the other sizes. These points are then

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[1] N. J. Geol. Surv., Final Report, Vol. VI, p. 87, 1904.

connected with a curved line. In the same way the percentages of the different sizes of grains of the other samples were plotted and connected by curved lines. The lines are drawn in different ways, so that those representing the different clays can be more readily distinguished at a glance. From a study of this table it is seen that the clay having the

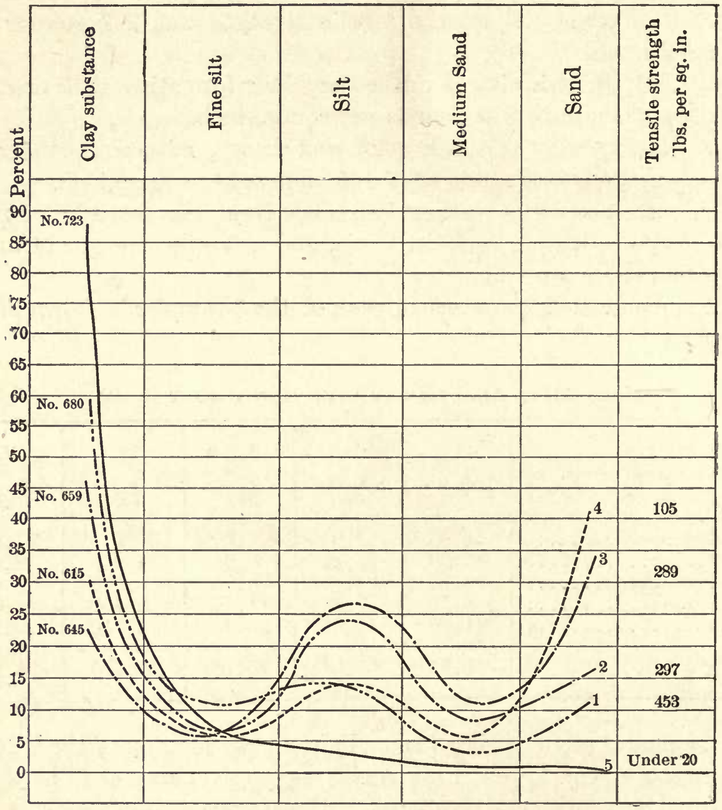

Fig. 31.—Curves showing relation of texture to tensile strength. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 89, 1904.)

lowest tensile strength (No. 5) contains a very high percentage of the finest clay particles, furthermore, the clay having the second lowest tensile strength (No. 4) contains the largest percentage of sand (42.9 per cent). From this it appears that an excess of either coarse or fine grains lowers the tensile strength. On the other hand, in those clays having the highest tensile strength the percentages of fine, medium, and coarse particles are more nearly equal. This is perhaps what might be expected, for if the tensile strength is due to the interlocking of the grains, a mixture of different sizes would fit together more closely than if particles of one size predominated, as in Nos. 4 and 5 of the table. It is rather difficult, however, to compare these results with Orton's, as in his artificial mixtures the non-plastic particles were of uniform size, while in the natural mixtures a variety of sizes existed.

Beyer and Williams[1] reached somewhat similar conclusions at about the same time, their work on the mechanical analyses of the loess-clays indicating that the clays showing the highest tensile strength were the ones in which there was the most evenly proportioned amounts of the sizes of the grains represented, therefore those possessing a large proportion of excessively fine particles or those running high in some intermediate size of grain are weaker. The following mechanical analyses made by them indicate this:

MECHANICAL ANALYSES OF IOWA LOESS CLAYS

Clay.	Loss at 230°.	Size of clay particles.					Total per cent.	Average tensile strength, lbs.
		Above .1 mm.	.1 to .05 mm. incl.	.05 to .01 mm. incl.	.01 to .003 mm. incl.	Below .003 mm.		
Besley, Council Bluffs, top clay..........	1.55	3.44	22.10	49.11	13.44	10.35	99.99	149
Gethman, Gladbrook .	2.59	5.19	22.46	32.04	14.15	23.55	99.98	279
Besley, Council Bluffs, bottom clay	2.04	1.62	25.26	29.72	17.85	23.74	100.23	244

If the theory of interlockment is true, then it should be possible to make a mixture of two clays whose tensile strength is higher than that of either of the clays alone or vice versa.

The writer[2] has noted a case of two clays from near Asbury Park, N. J. One of these was a slightly gritty, black clay, with an average tensile strength of 182 lbs. per square inch. The other was a plastic loam, whose average tensile strength was 137 lbs. per sq. in. A mixture of the two in equal proportions, however, had an average tensile strength of 258 lbs. per sq. in.

Another clay from a different formation had an average tensile strength of 108 lbs. per sq. in., while a mixture of equal parts of this clay and a

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[1] Ia. Geol. Surv., Vol. XIV, p. 102, 1904.

[2] N. J. Geol. Surv., Final Report, Vol. VI, p. 90, 1904.

somewhat coarse sand had a tensile strength of but 65 lbs. per sq. in., the decrease being evidently due to the excess of sand.

Grimsley and Grout claimed that a constant relation exists between the tensile strength of a clay and the percentage of soluble salts which it contains.[1] While it is true that each series, when plotted by itself, shows a parallel rise between salts and tensile strength, yet no such regularly ascending curve would be obtained if all the data were combined into one. For example, the amount of soluble salts (.40) in the W. Va. clays of 150 lbs. tensile strength, is hardly any greater than those of the New York series (.37) ranging from 0–50 lbs. in tensile strength.

Shrinkage

All clays shrink in drying and burning, the former loss being termed the air-shrinkage and the latter the fire-shrinkage.

Air-shrinkage.—In a clay which is perfectly dry all the grains are in contact, but between them there will be a variable amount of pore-space depending on the texture of the clay. The volume of this pore-space is indicated somewhat by the quantity of water that will be absorbed without the clay changing its volume, this water filling in the space between the grains. It may be termed pore water.

The presence of more water than is required to fill the spaces between the grains produces a swelling of the mass, and in this condition each grain is regarded as being surrounded by a film of water; but while the grains still mutually attract each other the attraction is less than in the dry clay, and the mass yields readily to pressure. An excess, however, separates the clay particles to such an extent that the clay softens and runs. A clay will therefore continue to swell as water is added to it, until the amount becomes too great to permit it to retain its shape.

Some clays absorb very little water, while others take up a large quantity, and G. P. Merrill[2] mentions one from Wyoming which when placed in a measuring-flask absorbed and retained sufficient water to increase its bulk eightfold.

When a clay has been mixed with water and set aside to dry evaporation of the moisture commences and the particles of clay draw closer together, causing a shrinkage of the mass. This will continue until all the particles come in contact, but since they do not fit together perfectly there will still be some pore-spaces left between the grains, and these will hold moisture which cannot be driven off except by

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[1] W. Va. Geol. Surv., III, p. 58, 1906.

[2] The Non-metallic Minerals, p. 233.

heating at 100° C. The air-shrinkage may therefore cease before all the water has passed off.

The amount of air-shrinkage is usually low in sandy clays, at times being under 1 per cent in coarsely sandy ones, while it is high in very plastic clays or in some very fine-grained ones, reaching at times as much as 12 or 15 per cent. Five or six per cent is about the average seen in the manufacture of clay products.

All clays requiring a high percentage of water in mixing do not show a high air-shrinkage. The air-shrinkage of a clay will not only vary with the amount of water added, but also with the texture of the materials.

Sand or materials of a sandy nature counteract the shrinkage, and are frequently added for this purpose, but, since they also render the mixture more porous, they facilitate the drying as well, permitting the water to escape more readily, and reducing the danger from cracking. If the sand added to dilute the shrinkage is refractory it also aids the clay in retaining its shape during burning.

The effect of sand on a clay is well seen from the following experiment with a clay from Herbertsville, N. J.[1]

	Per cent water required.	Per cent air-shrinkage.	Tensile strength. lbs. per sq. in.
Clay	32.6	5.3	108
Clay + 50% sand	15.6	3.3	65

From the above it is seen that the addition of 50 per cent of sharp sand reduced the amount of water required a little over one half. The air-shrinkage was reduced 37.73 per cent, but it was accompanied by a loss in the tensile strength of nearly 40 per cent.

Fire-shrinkage.—All clays shrink during some stage of the burning operation, even though they may expand slightly at certain temperatures. The fire-shrinkage, like the air-shrinkage, varies within wide limits, the amount depending partly on the quantity of volatile elements, such as combined water, organic matter, and carbon dioxide, and partly on the texture and fusibility.

Fire-shrinkage may begin at a dull-red heat, or about the point at which chemically-combined water begins to pass off and reaches its maximum when the clay vitrifies, but does not increase uniformly up to that point. The clay worker, however, always tries to get a low fire-shrinkage, using a mixture of clays if necessary in order to prevent cracking and warping. After the expulsion of the volatile elements the clay is left in a porous condition, until the fire-shrinkage recommences. In the table[2] on the next page there are given the results of a series of tests made on eight different clays, which were burned at temperatures 100° C. apart from 500° C (932° F.) up to 1100° C. (2012° F.) inclusive.[2]

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[1] N. J. Geol. Surv., Final Report, Vol. VI, p. 92, 1904.

[2] Ibid., p. 94, 1904.

Table showing Progressive Shrinkage and Loss of Weight at Different Temperatures

Lab. No.	Per cent of air-shrinkage.	Per cent weight lost in air-bath.	500° C. 932° F.	600° C. 1112° F.		700° C. 1292° F.		800° C. 1472° F.		900° C. 1652° F.		1000° C. 1832° F.		1100° C. 2012° F.	
			Per cent weight lost.	Per cent weight lost.	Per cent fire-shrinkage.	Per cent weight lost.	Per cent fire-shrinkage.	Per cent weight lost.	Per cent fire-shrinkage.	Per cent weight lost.	Per cent fire-shrinkage.	Per cent weight lost.	Per cent fire-shrinkage.	Per cent weight lost.	Per cent fire-shrinkage.
648	9.0	2.69	6.38	1.72	0.3	0.70	.0	0.88	0	0.56	0	0.19	0.7	0.38	4.0
655	4.6	1.36	6.10	1.38	0.0	0.55	.0	0.33	0	0.33	0	0.12	0.7	0.21	2.4
663	5.3	1.50	4.24	1.37	0.7	0.35	.3	0.05	0	0.27	0	+0.06	0.0	0.19	1.3
665	7.0	1.43	8.65	1.07	0.3	0.48	.0	0.39	0	0.12	0	0.10	2.7	0.00	12.6
696	5.6	3.48	9.42	2.61	0.4	1.61	.0	0.46	0	0.33	0	0.14	1.3	0.22	4.7
703	1.0	0.63	2.52	1.05	0.0	0.26	.0	0.10	0	0.02	0	0.09	1.4	0.03	0.0
717	8.0	3.29	5.32	1.70	0.3	0.83	.0	0.41	0	0.49	0	0.34	1.3	0.24	4.0
728	2.0	0.70	3.23	1.03	0.6	0.61	.0	0.22	0	0.15	0	0.10	1.3	0.12	2.7

Explanation of table.—The clays tested were the following:

648. Fat, black, micaceous clay, of Clay Marl I from Maple Shade, N. J.

655. A clay marl. Exact locality unknown.

663. A Pleistocene clay from Vineland, N. J.

665. A yellow, finely gritty, Cohansey clay, heavily stained with limonite from Toms River, N. J.

696. Black, Asbury clay from west of Asbury Park, N. J.

703. Sandy, Raritan clay from near Fish House, N. J.

717. A very plastic clay from Clay Marl III, south of Woodbury, N. J.

728. Hudson River shale from Port Murray, N. J.

The bricklets had been standing in a warm room for several weeks, and, although they appeared perfectly dry, they were placed in a hot-air bath and kept at a temperature of 110° C. for a day, being weighed both before and after. This drove off the moisture remaining in the pores, and the resulting loss in weight indicated in the third column of the above table shows the quantity of moisture that may remain in a brick after the air-shrinkage has ceased. It is least in the sandy, lean clays and highest in the black one, which is colored by organic matter. The second column indicates the per cent of air-shrinkage, calculated upon the length of a freshly molded bricklet. The fourth column, headed 500° C. (932° F.), gives the loss in weight from the thoroughly dried condition up to 500° C., calculated on the weight of the air-dried sample. The following columns give the additional loss in weight for each 100° C. (180° F.), as well as the fire-shrinkage taking place in this temperature interval. From an inspection of the table it is seen that most of the volatile substances, such as the chemically combined water contained in the hydrous aluminum silicate, mica, or limonite, and organic matter, pass off before 500° C. (932° F.), and that an additional appreciable amount is expelled between 500° C. and 600° C. Between 600° C. (1112° F.) and 1100° C. (2012° F.) there was a small but steady loss, while in one case (No. 663) there was even a gain in weight at 1000° C. (1832° F.). Two samples, Nos. 696 and 665, showed a high loss at 500° C. and 600° C., as compared with the others, but this was due to the former containing considerable organic matter, and the latter having a very high percentage of limonite, which would supply an additional quantity of chemically combined water.

The amount of fire-shrinkage shown by these samples is equally interesting, for it is seen that, although the loss in weight between 500° C. (932° F.) and 900° C. (1652° F.) is considerable, still there is little or even no shrinkage, so that, after the volatile elements have been driven off, the clay must be very porous, and remains so until the fire-shrinkage begins again. From the table it will be seen that, with one exception, no shrinkage occurred between 600° C. (1112° F.) and 900° C. (1652° F.); but between 900° C. (1652° F.) and 1000° C. (1832° F.), all except No. 663 decreased in size, and there was an additional but greater shrinkage between 1000° C. (1832° F.) and 1100° C. (2012° F.). None of the bricklets became steel-hard, that is, sufficiently hard to resist scratching with a knife, until 1000° C. (1832° F.), or even 1100° C. (2012° F.). In the case of those burning red, a good red coloration began to appear at 1000° C. (1832° F.). From this it can be seen, and this is a fact already known, that, up to 600° C. (1112° F.), a clay should be heated slowly; but from that point up to 1000° C. the temperature can be raised quite rapidly, unless much carbonaceous matter is present. The gradual burning-off of this carbon is well shown in Fig. 19, which represents a series of bricks taken from a kiln at regular intervals as the burning proceeded. Further heating should be done slowly, as the shrinkage recommences at the last-mentioned temperature.

Wheeler [1] claims that the most potent factor in fire-shrinkage is the size of grain: the finer it is, the greater the fire-shrinkage.

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[1] Mo. Geol. Surv., Vol. XI, p. 121, 1897.

Since many clays, when used alone, shrink to such an extent as to cause much loss from warping and cracking, it is necessary to add materials which of themselves have no fire-shrinkage, and so decrease the shrinkage of the mixture in burning. Sand or sandy clays are the materials most commonly used for this purpose, but ground bricks (grog), and even coke or graphite, may be employed. These materials serve not only to decrease the shrinkage in drying and burning, but also tend to prevent blistering in an easily fusible ferruginous clay when hard-fired. They furthermore add to the porosity of the ware, and thus facilitate the escape of the moisture in drying and in the early stages of burning, as well as enabling the product to withstand sudden changes of temperature. If sand is added for this purpose, it may act as a flux at high temperatures, and this action will be the more intense the finer its grain.

Large particles of grog are undesirable, especially if they are angular in form, because, in burning, the clay shrinks around them, and the sharp edges, serving as a wedge, open cracks in the clay, which may expand to an injurious degree. Large pebbles will do the same, and at many common brickyards it is not uncommon to see bricks split open during the burning, because of some large quartz-pebble left in the clay, as the result of improper screening of the tempering sand. For common brick, the type of sand used does not make much difference, as long as it is clean; but if sand is to be added to fire-brick mixtures, it should be coarse, clean, quartz-sand. Burned clay-grog is more desirable than sand for high-grade wares, since it does not affect the fusibility of the clay, or swell with an increase of temperature as sand does, but precaution should be taken to burn the clay to its limit of shrinkage before using it.

Measurement of shrinkage.—A knowledge of the air- and fire-shrinkage of a clay is of vital importance to the manufacturer of clay-products, since, in order to produce a burned ware of the required dimensions, he must know the air- and fire-shrinkage of his raw clays.

The shrinkage of a clay may be expressed linearly or cubically. The former is given in percentage terms of the original length of the ware, and is easily determined by direct measurement. To determine the cubical shrinkage in drying, it is necessary to carefully determine the volume of clay when moist and again when dry, while the difference in volume between the latter and that of the burned clay gives the cubic fire-shrinkage.

Determination of volume.—The change in volume, to be determined for getting the cubic shrinkage, is measured by means of a Seger volumeter (Fig. 32). This consists of a four-litre, wide-mouthed, glass-stoppered jar. A circular opening in the center of the stopper is fitted with the ground-end of a short glass tube *m*, which expands above into a bulb *b*, and is again contracted above it. The jar has a glass stopcock *e* near its base, which is connected above with a burette *a* of 125 c.c. capacity, and graduated to tenths. The upper end of the burette also widens to a bulb *f*, from the top of which there extends a bent tube for the attachment of a rubber, this tube being used to draw the liquid into the burette.

When the stopcock in the lower part of the burette is open, and the liquid filled in jar up to the mark on the small glass tube *m*, the liquid stands at the zero-point in the burette.

The method of using the apparatus, together with the results obtained on a number of Iowa clays, was as follows:[1]

"To use the volumeter for determining the volume of clay, it is filled with oil, ordinary kerosene with a specific gravity of 0.8 (which must be accurately known) having been found to give satisfactory results.

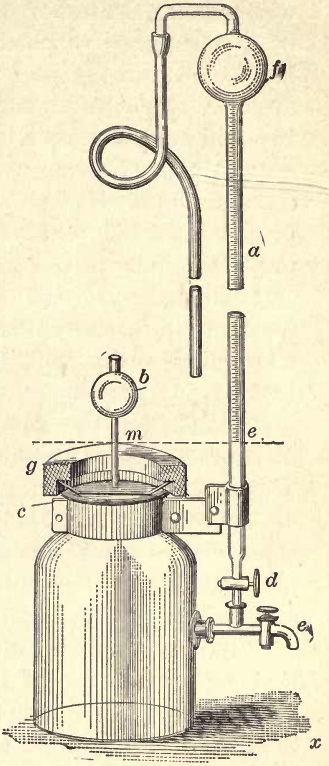

Fig. 32.—Seger's volumeter, for determining porosity and specific gravity.

"After filling the jar the burette is drawn full of the liquid by suction through the rubber tube, and held full by turning the burette-valve or by means of a pinch-cock on the rubber. The stopper is now removed and the test-piece of the clay, which is still plastic and permeated with water, is carefully wiped dry of the coating film and put in. The test-pieces, which were approximately 3 inches long, were allowed to dry till, on picking up a piece endwise between the thumb and finger, the middle portion did not sag. This point was noted carefully and all samples were treated in this regard exactly the same. Care is taken not to spatter any of the liquid in placing the block of clay

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[1] Ia. Geol. Survey, Vol. XIV, p. 107, 1904.

in the jar. In order to prevent this, and to avoid breaking or otherwise marring the test-piece by dropping it into the vessel, a small wooden float or support by which the clay may be carefully let down into the liquid is advantageous. This float is conveniently made with a small eye or hook near each end so that it may be handled by reaching in with two stiff bent-wire rods. Some such arrangement as this is found quite necessary in handling raw clays, but can be dispensed with when the clays are burned. The stopper is now replaced, and by releasing the pinch-cock *d* oil from the burette is allowed to flow back into the jar until it stands at the mark on the short tube.

"The volume of the clay is then indicated by the height of the liquid in the burette above the zero mark. The piece of clay is taken out and placed to dry while the volumeter is again filled to the zero points to be ready for the next test.

"When dry the clay is heated to 230° F. to expel all hygroscopic moisture and after weighing it is placed in a vessel of oil until saturated. This is found to require from three to six hours for small test-pieces of approximately $3\times1\frac{1}{2}\times1\frac{1}{2}$ inches. When saturated the piece is again weighed and its volume measured as before. Having now the wet and dry volumes, the percentages of cubical shrinkage in drying are easily calculated.

"In measuring fire-shrinkage the same test-pieces were employed that were made use of in determining drying shrinkage. They were placed in a small muffle-furnace and burned to a temperature of 700° to 800° C. By burning at this heat dehydration and oxidation of the clay were completed. It is about the temperature at which common, porous red-building brick is burned. For the large number of clays vitrification has not yet begun at this heat, and they are left in the most porous condition attained during any part of the burning process."

The results of a number of determinations made on Iowa clays, giving the cubic air- and fire-shrinkage, as well as the porosity of the dried and burned clay, are tabulated on page 163.

It will be seen from the above table that in two cases there was a slight expansion of the mass, as indicated by the minus fire-shrinkage.

Porosity

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

Porosity and Cubic Shrinkage of Iowa Clays

Clay.	Porosity of unburned clay.	Porosity of burned clay.	Cubic air-shrinkage.	Cubic fire-shrinkage.
Flint Brick Co., bottom of bank	30.04	26.94	9.44	1.99
Flint Brick Co., middle of bank	23.00	24.74	23.34	1.82
Flint Brick Co., top of bank	17.31	22.31	26.23	4.24
Corey Pressed Brick Co., red-burning	30.10	33.24	16.94	2.37
Corey Pressed Brick Co., buff-burning	28.10	29.59	27.00	2.91
Colesburg Potters' Clay	28.36	25.51	18.25	5.92
Granite Brick Co., top stratum	23.00	25.57	4.86	−2.88
American Brick & Tile Co., plastic shale	26.71	30.46	21.52	0.00
L. C. Besley, top of bank	29.77	32.66	6.83	−2.47

clay made up entirely of spherical grains of the same size, but such clays are practically unknown. On the contrary, all clays, so far as known, are made up of a mixture of sizes, which greatly reduces the porosity. In general we may say, however, that increasing fineness means increasing pore-space.

The rapidity with which a clay absorbs water is not to be regarded as a criterion of its porosity, for two clays of the same porosity may differ in grain, on which account the coarse-grained one will absorb water more rapidly than the fine-grained one.

The porosity of a clay is of importance, because it influences the behavior of it towards water, heat, etc. These effects may be summarized as follows:

Porosity influences the amount of water which a clay will absorb, or the amount required to make them plastic, and this will in turn influence the air-shrinkage.

The possible rate of safe drying depends on the amount of water absorbed and the facility with which it can escape; large pores permitting the water to escape rapidly. Small pores, on the other hand, retard both the absorption and evaporation of the water.

In the burned clay, too, the porosity has to be considered, for all clays after burning are more or less porous unless burned to vitrification. In most clay products a low porosity is desirable in order to increase its resistance to the weather. If a product is very porous, it will absorb considerable water, which on freezing expands. If the pores are large, the pressure exerted by the expanding water on freezing will be relieved by the exudation of small ice crystals from the pores, and no harm results. If, on the other hand, the pores are small, this cannot occur, and a sufficient pressure may be exerted from the contained ice to disintegrate the mass. With close-textured clays the porosity may be so small that not enough water can enter to cause any harm.

The porosity of the clay in either its raw or burned condition is determined by means of a Seger volumeter described under Shrinkage. The porosity percentage is determined by the formula

$$P=\frac{\frac{g}{s}}{V}\times 100,$$

in which V = volume of dry test-piece;

g = difference in weight between dry and saturated test-piece or the weight in grams of oil absorbed;

s = specific gravity of oil.

In testing the porosity of burned wares distilled water can be used. The specific gravity of this at ordinary temperatures can be taken as unity, and s therefore disappears from the formula, g becomes cubic centimeters, and the expression reduces to

$$P=\frac{g}{V}\times 100.$$

Specific Gravity

The specific gravity of a clay is not a factor of great economic importance, although it has to be known in order to determine the porosity by the formula mentioned under that head. Since also it is related to the density of the mass, which no doubt exerts some influence on the fusibility of the material, it is required for the determination of the fusibility factor by certain methods (see under Fusibility).

This is assuming that the more compact a clay the lower its fusion point, and it has been pointed out [1] that according to this a clay might have one specific gravity as it came from the bank, and this would change with each manipulation. A knowledge of the specific gravity of clay based on this conception is of little value, however, since it is not the true specific gravity which depends on the mineralogical composition and not the porosity. As such, the specific gravity of the clay will remain constant, whatever its condition.

There is comparatively little variation in the specific gravity of the minerals most abundant in clay, as can be seen from the following:

Kaolinite.........	2.6	Quartz......	2.65
Calcite...........	2.71	Feldspars....	2.55–2.75
Biotite...........	2.7–3.1	Muscovite...	2.76–3

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[1] Ia. Geol. Surv. XIV. p. 114, 1904.

Iron oxides would be heavier; still they form but a small percentage of the entire mass.

Some of the recorded specific gravities of clay fall considerably below the average specific gravity of that of the common minerals found in clay, which may be due to the method of determination used.

In a series of New Jersey clays tested by the writer the gravity ranged from 2.34 to 2.84.[1]

Beyer and Williams give the range of Iowa clays tested as from 2.32 to 2.64.[2]

The Missouri clays tested by Wheeler[3] ranged from 1.66 to 2.64, while the determinations of Smock[4] on the New Jersey clays ranged from 1.80 to 2.60.

The lower values obtained by Wheeler and Smock are no doubt due to the method used by them, which consisted in coating a lump of clay in paraffin so that it could not slack in water, and then determining the weight in water of this lump. This should perhaps be called the apparent specific gravity.

The differences obtained by the two methods have been well brought out by a series of tests on West Virginia clays given below:[5]

Clay	Apparent specific gravity.	Porosity.	Real specific gravity.	
			Calculated.	Pycnometer.
Point Pleasant River clay	1.75	30.2	2.51	....
Barboursville clay	1.68	29.1	2.37	....
Clarksburg clay	1.92	23.8	2.52	....
Morgantown shale	1.86	25.5	2.49	....
Morgantown shale	1.88	26.1	2.53	....
Bridgeport pottery clay	1.76	25.1	2.35	....
Thornton plastic clay	1.84	23.6	2.41	....
Thornton flint clay	1.94	25.8	2.61	....
Hammond flint clay	1.71	26.5	2.34	2.57
Charlestown River clay	1.88	29.4	2.66	2.61

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[1] N. J. Geol Surv., Final Report, Vol. VI, p. 114, 1904.

[2] Ia. Geol. Surv., Vol. XIV, p. 116, 1904.

[3] Mo. Geol. Surv., Vol. XI, p. 562 et seq., 1896.

[4] N. J. Geol. Surv., Report on Clays, 1878.

[5] W. Va. Geol. Surv., III, p. 65, 1906.

Determination of specific gravity.—The simplest method of determining the true specific gravity of a clay is by means of a pycnometer of the ordinary type, or it can also be made with a Seger volumeter, using the formula

$$\text{Sp. gr.} = \frac{G}{V(100 \text{ per cent}) - P},$$

in which

G = actual weight or mass of test-piece when dry;
V = apparent volume, or clay plus pore-space;
P = percentage of porosity.

Fusibility

All clays fuse at one temperature or another, the temperature of fusion depending on (1) the amount of fluxes; (2) the size of grain of the refractory and non-refractory particles; (3) the homogeneity of the mass; (4) the condition of the fire, whether oxidizing or reducing; and (5) the form of chemical combination of the elements contained in the clay.

The changes occurring in the early stages of burning have been referred to under Fire-shrinkage and Chemical Properties, and in the table given on page 158 it was seen that the clay had become steel-hard, due to a partial fusion of some of the particles.

In considering the changes which occur in the fusion of clays it is necessary to remember that clay is not a substance of definite chemical composition, but consists of a mixture of minerals each having its own melting-point.

When clays undergo a fusion process they do not soften at once, but melt with comparative slowness. This is not surprising when we consider their heterogeneous composition, and may account for their slow softening as one kind of a mineral after another fuses. As soon as a softening of one or more of the mineral grains occurs interreactions between the different ones begin, the number involved increasing until all constituents of the mass are involved. In most cases no reaction occurs between any of the grains until one melts, but it is not necessary to reach the fusion-point of each before it can react with the others.

Thus carbonate of lime and carbonate of magnesia lose their carbon dioxide at a comparatively low temperature, and the remaining oxides of these elements are highly refractory if heated alone. If, however, they are mixed with other minerals, they appear to react with them long before their fusion-points are reached.

On account of the gradual softening of clays when heated to their fusion-point Wheeler has suggested the recognition of the following stages:

Incipient vitrification.—In this stage the clay has softened sufficiently to make the grains stick together, and enough to prevent the recognition of any, except the larger ones. The particles have not, however, softened sufficiently to close up all pores of the mass.

Complete vitrification.—A further heating of the clay, through a variable temperature interval ranging from about 27.7° C. (50° F.) to 111.1° C. (200° F.), or sometimes even more, produces an additional softening of the grains sufficient to close up all the pores and render the mass impervious. Clays burned to this condition of complete vitrification show a smooth fracture with a slight luster. The attainment of this condition also represents the point of maximum shrinkage.

Viscosity.—A still further but variable rise in the temperature is accompanied by both swelling and softening of the clay, until it flows or gets viscous.

It is sometimes difficult to recognize precisely the exact attainment of these three conditions, for the clay may soften so slowly that the change from one to the other is gradual.

According to Wheeler[1] the hardness of a clay when it has reached the first of these three stages is from 6 to 6.5 according to Mohs' scale; or in other words it cannot be scratched with a knife. The temperature of steel-hardness varies with the character of the material, impure, easily fusible clays becoming so at a low temperature, such as cone 05, while others, such as kaolins and some fire-clays, fail to reach this condition before cone 5 to 8;[2] but with other things equal, a highly plastic clay will burn steel-hard at a much lower temperature than one of low plasticity.

The difference in temperature between the points of incipient fusion and viscosity varies with the composition of the clay. In many calcareous clays these points are within 27.7° C. (50° F.) of each other, while in refractory clays they may be 277° C. (500° F.) apart. The glass-pot clays which are refractory, but still burn dense at a comparatively low temperature, approach the last-mentioned condition quite closely.

Wheeler gives the following figures of variation based on the tests of 135 clays.[3]

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[1] Mo. Geol. Survey, Vol. XI, p. 130, 1896.

[2] For explanation of these see p. 180.

[3] Mo. Geol. Survey, Vol. XI, p. 131, 1896.

Number of clays.	Range.	Character.
2	75° F.	Very calcareous.
33	300° F.	Very impure clays and shales.
11	350° F.	Less impure clays and shales.
63	400° F.	Fire-clays, potters' clays, kaolins.
26	500° F.	Some china-clays, pure fire-clays.

It is of considerable practical importance to have the points of incipient vitrification and viscosity well separated, because in the manufacture of many kinds of clay-products the ware must be vitrified or rendered impervious. If, therefore, the temperature interval between the points of incipient vitrification and viscosity is great, it will be safer to bring the ware up to a condition of complete vitrification without the risk of reaching the temperature of viscosity and melting all the wares in the kiln, because it is impossible to control the kiln temperature within a range of a few degrees. In many clays the point of complete vitrification seems to be midway between that of incipient vitrification and viscosity, but in others it is not.

Effect of chemical composition on fusibility.—Other things being equal, the temperature of fusion of a clay will fall with an increase in the percentage of total fluxes. If we compare the analyses of a brick-clay and a fire-clay, we shall find that the analysis of the former shows perhaps 12 or 15 per cent of fluxing or fusible ingredients, while that of the latter may show only 2 or 3 per cent, and that their fusion-points are perhaps 1093° C. (2000° F.) and 1644° C. (3000° F.) respectively. But while in general the fusion-point falls as the percentage of fluxes rises, it is found that the different fluxes exert a different fluxing influence; that is to say, it requires more of one than another to bring about the same degree of fusibility. Moreover there is a variation in the temperature at which the different ones become active.

One of the first investigators to throw some light on this subject was a German by the name of Richter, whose researches have become classic. He formulated three laws, as follows:

1. The refractory quality of a clay of any given proportion of silica and alumina is most influenced by the fluxes in the following order: MgO, CaO, FeO, Na_2O, K_2O.

2. Chemically equivalent quantities of these oxides exert equal influences on the refractoriness of a given clay; that is, 40 parts of magnesia, 56 parts of lime, 72 parts of ferrous oxide, 62 of soda, and 92 parts of potash will each produce an equal degree of fusion in the same quantity of the same clay.

3. If a number of fluxes are present in a clay, the fusibility produced will be proportional to the sum of their chemical equivalents. For example, a clay with the formula

$$\left.\begin{matrix} 0.15\ K_2O \\ 0.15\ CaO \end{matrix}\right\}, Al_2O_3, 2SiO_2$$

should fuse at the same temperature as one of the composition

$$\left.\begin{matrix} 0.1\ K_2O \\ 0.1\ CaO \\ 0.1\ FeO \end{matrix}\right\}, Al_2O_3, 2SiO_2.$$

In working out these laws, Richter used a series of alumina-silica mixtures, to which known proportions of the fluxes were then added.

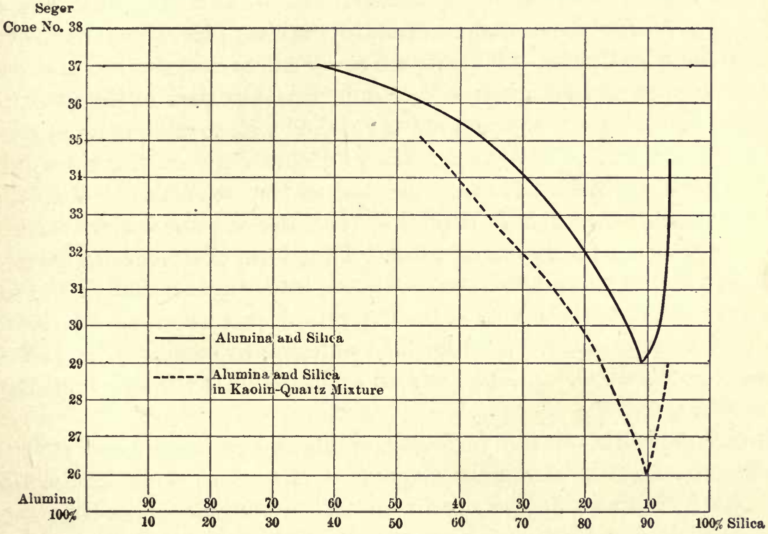

Fig. 33.—Diagram showing effect of silica on the fusion-point when mixed with alumina and with kaolin. (From Seger's experiments.)

In his first series he employed silica and alumina mixed in the same proportions as in kaolinite, while in a second but similar series he used a higher silica percentage than is present in kaolinite.

Considering the case of silica and alumina in the proportions that they exist in kaolinite, it is found that they have a fusion-point of about 1830° C. (3326° F.), or cone 36 of the Seger scale. The continued addition of silica to this lowers its fusion-point until the ratio of Al_2O_3,

$17SiO_2$ (or 1:10 by weight), is reached, the fusion-point of this being about 1650° C. (3002° F.), or cone 29, but a continued increase of silica raised it.

Silica, therefore, is to be regarded as a flux to alumina, at high temperature, and should not, therefore, be present in excess in refractory clays.

Moreover, the presence of silica in a clay seems to intensify the effect of other fluxes.

Cramer[1] at a later date attempted to verify Richter's experiments, but found that the fluxing power of oxides is only true in so far as it concerns kaolinite, while in the presence of free silica he found the fluxing power as follows: FeO, MgO, CaO, Na_2O, K_2O. In other words, if free silica is present the oxides do not act according to their chemical equivalency, 72 parts of ferrous oxide, for example, being more effective than 40 parts of magnesia, etc.

Important as the results of Richter and Cramer are, the laws do not hold true for the changes ordinarily taking place in a kiln, even though they be burned to vitrification. That is to say, the law only holds true when all the elements of the clay can take part in the fusion of the mass; in other words, when it has reached a state of complete fusion.

In the melting of a clay, a reaction occurs between the silica, alumina, and the various fluxes, giving rise to the formation probably of complex silicates, and it is supposed that the various elements enter into combination in the same form. Thus iron, whatever its state of oxidation in the clay, is believed to enter into combination in the ferrous form, and therefore its fluxing power is regarded as due to the action of ferrous oxide. So, too, lime enters into combination as CaO, magnesium as MgO, and sodium and potassium as Na_2O and K_2O, respectively.

Richter's work on the fusibility of clays has been more recently discussed by Ludwig[2] from the view-point of modern chemical theories:

"The fusion of silicates results in the production of igneous solutions holding dissolved various silicates. Thus Seger Cone No. 1, consisting of a mixture of feldspar, kaolin, quartz, and ferric oxide, is, when fused, a mutual solution of feldspar, quartz, augite or hornblende. If we could cool this mass slowly, these silicates would crystallize out one after the other. This has actually been done by Prof.

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[1] Tonindustrie-Zeitung, 1895, Nos. 40 and 41.

[2] Tonindustrie-Zeitung, XXVIII, p. 773, 1904. The abstract of the paper here given is that of Bleininger, Trans. Amer. Ceram. Soc., VII, p. 275, 1905.

Vogt of Christiania, who has shown that the temperature of fusion is always highest when only one definite silicate crystallizes out, and lowest when it represents a mixture of several silicates. This coincides perfectly with the general phenomenon observed in all solutions, namely, that, on dissolving any substance, a decrease of the melting-point takes place. It is immaterial whether the melting-point lies at 0° or at 1200° C. The compositions of the slags and glazes are practical illustrations, inasmuch as the most fusible combinations of either kind of silicate are always the most complex ones. When two silicates are combined, they invariably result in a mixture having a lower melting-point than either, owing to the formation of the so-called eutectic mixture. Thus, mono-calcium silicate fuses at cone 15; on adding one molecule of silica to two molecules of this silicate, the melting-point falls to cone 7, but on adding more quartz the fusion-point again rises, Again, in a clay containing besides silica and alumina the various fluxes. the melting-point is governed by the fusing-point of the eutectic mixture of these constituents, which represents the most fusible combination possible. This explains also why feldspar begins its fusing effect in a body much below its melting-point. The eutectic mixture is invariably high in fluxes at the lower temperatures, but takes up more and more silica as the temperature is raised. Silicates proper are more fusible than high alumina mixtures, and hence more silica is brought into solution than alumina, which is dissolved only at high temperatures. This explains the fact that aluminous clays show the greatest refractoriness. As the solution increases in amount the clay softens, and finally, when there remains but little undissolved matter, fusion takes place. This manner of melting is characteristic of solutions while substances homogeneously crystalline melt suddenly without softening. Thus the final melting-point depends upon the ratio of the alumina to the silica and the amount and kind of flux.

"The foundation of these fusion phenomena is the following general law applying to dilute solutions:

"Equi-molecular quantities of different substances dissolved in equal amounts of the same solvent lower the melting-point in the same degree.

"The law applies to substances in general, indifferent as to whether they are bases or acids, the only requirement being that they are soluble. With reference to clay we must therefore consider lime, magnesia, potash, soda, and titanic acid as the dissolved substances.

"If now we are to compare refractory clays as to their melting-points we must calculate the molecular formula of each clay, making the alumina equivalent equal to unity and adding the equivalents of various fluxes, obtaining thus a formula like

$$Al_2O_3 + 2.125SiO_2 + 0.0755RO.$$

"Since in this expression there are but two variables, Ludwig plotted the silica equivalent as the abscissa of a curve and ten times the equivalent of the RO as the ordinate, and in this manner he located various German fire-clays in a chart, verifying the clays by their melting-points in Seger cones.

"Richter's law, strictly speaking, applies only to dilute solutions, and hence if the amount of fluxes is considerable the law loses much of its force. If does not apply, therefore, completely to glazes or glasses. Differences from this general law are not due to chemical reasons, since it does not matter in what chemical combination a flux enters into a clay, whether as feldspar or as potash, but must be sought for in the different mechanical conditions.

"Ludwig summarizes his work in the following conclusions:

"1st. Richter's law is a special case of the general law of dilute solutions.

"2d. This law is restricted by the following conditions:

"(*a*) It applies only to very dilute solutions, that is clays with a small amount of fluxes and not to brick-clays or glazes.

"(*b*) It assumes intimate mixture.

"(*c*) Iron shows a different effect, due to its two stages of oxidation, since one molecule of ferric oxide corresponds to two molecules of ferrous oxide. A given percentage of iron contains fewer molecules of ferric oxide than of ferrous oxide, since the former has a higher molecular weight. On changing to the ferrous oxide the number of molecules is doubled, and hence the fluxing effect is doubled.

"3d. The analysis of a fire-clay is of great importance in estimating the refractoriness.

"4th. The estimation of the refractoriness by means of the percentages of alumina and fluxes leads to erroneous results."

Kaolin, Quartz, Feldspar Mixtures.—It was found by M. Simonis,[1] that of a series of mixtures of these three substances, the mixtures of feldspar and kaolin fused at higher temperatures than feldspar-quartz mixtures, although the melting-point of the quartz was higher than that of the kaolin. With a content of 70 per cent of feldspar

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[1] Sprechsaal, No. 29, p. 390, and No. 30, 402, 1907. Abstracted by Bleininger, Amer. Chem. Soc. Abstracts.

the two curves were found to intersect. With 85 per cent feldspar the kaolin mixture fused lower than the corresponding quartz mixture. The fusion curve of kaolin and quartz showed the minimum fusing-point to be 1 molecule Al_2O_3 to 17 molecules of SiO_2. The minimum fusing-point of 25 per cent kaolin and 75 per cent quartz was found to lie between cone $26\frac{1}{2}$ and $26\frac{3}{4}$. The following table shows the melting-points of a number of feldspar-quartz-kaolin mixtures.

Zettlitz kaolin. per cent.	Quartz, per cent.	Feldspar, per cent.	Melting-point in Seger cones.	Zettlitz kaolin, per cent.	Quartz, per cent.	Feldspar, per cent.	Melting-point in Seger cones.
..	15	85	9–10	30	55	15	26
..	30	70	14	30	70	..	27
..	45	55	15–16	45	..	55	26
..	55	45	17	45	15	40	26–27
..	70	30	26–27	45	30	25	27–28
..	85	15	30–31	45	45	10	29
15	..	85	9	45	55	..	29–30
15	15	70	10–11	55	..	45	28
15	30	55	13–14	55	15	30	29–30
15	45	40	15	55	30	15	30+
15	55	30	17–18	55	45	..	30–31
15	70	15	–26	70	..	30	31+
15	85	..	28–29	70	15	15	32
30	..	70	14	70	30	..	32+
30	15	55	16–17	85	..	15	33–34
30	30	40	17–18	85	15	..	33–34
30	45	25	–26				

The writer plotted the compositions on a triaxial diagram and connected the points by isothermals. In this way the two refractory areas, one high in clay the other high in quartz, are clearly located as well as the areas of soft porcelain, whiteware, and hard porcelain. The feldspar invariably acts as a neutral and constant flux. Hence, in order to determine the melting-point of a porcelain or whiteware mixture, it is necessary only to divide the clay and quartz into the ratio of 1:3 and to consider the balance as raising and the feldspar content as lowering the fusibility. This consideration applied only to bodies containing not more than 60 per cent feldspar, and the mode of calculation is simply a practical one which has worked out very well in practice. If the percentages of kaolin, quartz, and feldspar are z, qu, and f, for bodies high in clay in which $z>\frac{qu}{3}$, the refractory index $=z-\frac{qu}{3}-f+60$. For bodies high in quartz, where

$\frac{qu}{3} > z$, the index$= \frac{qu}{3/2} - z - f + 60$. For the purpose of obtaining the value of the refractory index in terms of the Seger cones, the following table is given:

Ref. index	17.5	22.6	28	33.7	39.2	44.6	50	57.6
Seger cone	14	15	16	17	18	19	20	26
Ref. index	65	72	80	89	102	114	127	141
Seger cone	27	28	29	30	31	32	33	34

The melting-point of these mixtures were determined in electric carbon resistance furnaces.

Homogeneity.—Unless the particles of each element or compound are uniformly distributed through the mass they will not produce their maximum effect. Few clays as they occur in nature are perfectly uniform in composition.

It is sometimes argued from this that in testing clays for their fusibility it is necessary to render them as homogeneous as possible, but in order to obtain results of practical value the clay should not be mixed and ground up any more than it would be for the particular class of clay products to which it is adapted.

Influence of texture.—The size of the mineral grains exerts an important effect on the fusibility of the clay. Other things being equal, a fine-grained clay will fuse at a lower temperature than a coarse-grained one, partly because finely divided particles can come into more intimate contact, and the air-spaces being diminished the heat will be transmitted better. Then, too, when the particles begin to fuse or flux with each other, this action begins on the surface of the grains and works inward towards the center. If, therefore, the easily fusible grains are of small size they fuse more rapidly, and are more effective in their fluxing action than if the grains were large. Since some of the mineral grains in the clay are more refractory than others, the clay in the earlier stages of fusion can be regarded as a mixture of fused particles with a skeleton of unfused ones. If the proportion of the former to the latter is very small there will be a strong hardening of the clay with little shrinkage, and the burned clay will still be porous. With an increase of temperature and the fusion of more particles, the pores fill up more and more, and the shrinkage goes on until, at the point of vitrification, the spaces are completely filled. Above this point there is no longer a sufficiently strong skeleton to hold the mass together, and the clay begins to flow. The conditions which influence the difference in temperature between vitrification and viscosity still remain to be satisfactorily explained, but it probably depends on the relative amounts of fluxes and non-fluxes and the size of grain of the latter. The effect of grain size is shown by the following experiments:[1]

A white clay from Georgia, having a fusion-point equal to cone 35 of the Seger series, was made up into a series of mixtures with other minerals. One set of mixtures consisted of:

A. Equal parts of clay and hornblende, the latter being ground to pass a 150-mesh sieve.

B. The same as A, the hornblende passing through a 100-mesh sieve and stopping on a 150-mesh.

C. The same as A, but the hornblende ground to pass an 80-mesh, but retained on a 100-mesh.

When burned to cone 5 the three were little affected, except that the one with the finest grains was colored uniformly red, while that with the coarsest grains presented a speckled appearance. When burned to cone 8 the bar of mixture A was considerably bent at both ends, while that of B was nearly straight, and C was perfectly straight. At cone 10, B was thoroughly fused and C slightly bent.

This seemed to show well the effect of grain size in the case of hornblende. The object of taking such a large amount of fluxing material was simply to get results at moderate temperatures. A second similar set of mixtures, containing calcite in place of hornblende, gave similar results.

Condition of oxidation.—Finally it is found that the same clay will fuse at a lower temperature, if in burning it is deprived of oxygen, than it will if burned in an atmosphere containing plenty of the latter.[2]

Specific gravity changes.—Purdy and Moore[3] found in burning a series of clays that as the heat was raised the specific gravity decreased,[4] although in a few there appeared to be a slight increase at first. The decrease in porosity appeared to be approximately parallel with the specific gravity decrease, which points to the fact that the rate of decrease in specific gravity is proportional to the rate of vitrification. It is their belief that these data determined for any clay will afford them a safe means of judging its value.

Figs. 33*a* and 33*b* show the decrease in specific gravity and porosity with rising temperature of a fire-clay and a paving-brick shale.

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[1] Ries, Trans. Amer. Inst. Min. Engrs., Vol. XXXIV, p. 205, 1904.

[2] See also under Iron Oxide.

[3] Trans. Amer. Ceram. Soc., IX, p. 203, 1907.

[4] This same phenomenon appears to have been noted by Laurent (Brogniart, I, p. 282) and Rose (Pogg. Ann., LXVI, p. 97, 1845).

Expression of fusibility.—Several investigators have aimed to express the fusibility of a clay by means of a formula based on the relation of fluxes to refractory elements, fineness of grain, or density.

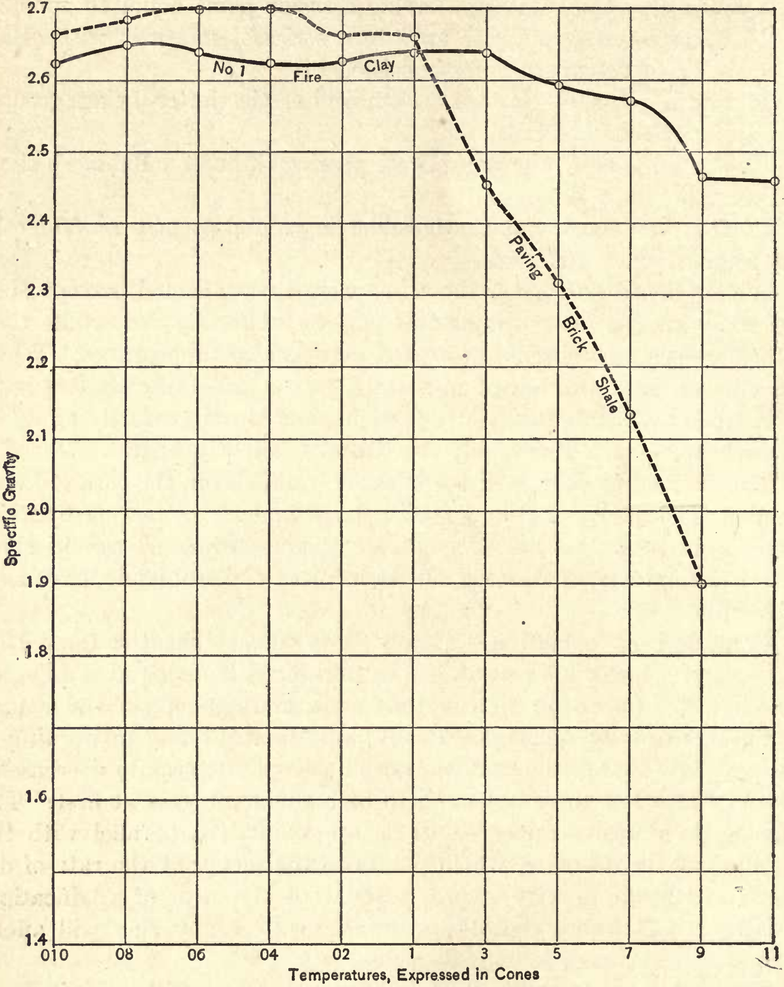

FIG. 33*a*.—Diagram showing relation between specific gravity and temperature of burning. (After Purdy and Moore.)

Bischof's formula.—One of the earliest developed was that of Bischof[1] whose expression termed the *Feuerfestigkeits-Quotient* is as follows:

$$\text{F.Q.} = \frac{(\text{Oxygen in } Al_2O_3)^2}{(\text{Oxygen in RO})(\text{Oxygen in } SiO_2)},$$

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[1] Die feuerfesten Thone, p. 116.

in which RO represents the sum of the fluxes, each considered as the protoxid. The F.Q. may range from a small decimal to 25.

According to this formula the fusibility of a clay will vary directly as the square of the oxygen in the alumina, and inversely as the oxygen in the fluxes and silica, and Bischof concluded that the amount of alumina in a clay practically influenced its fusibility.

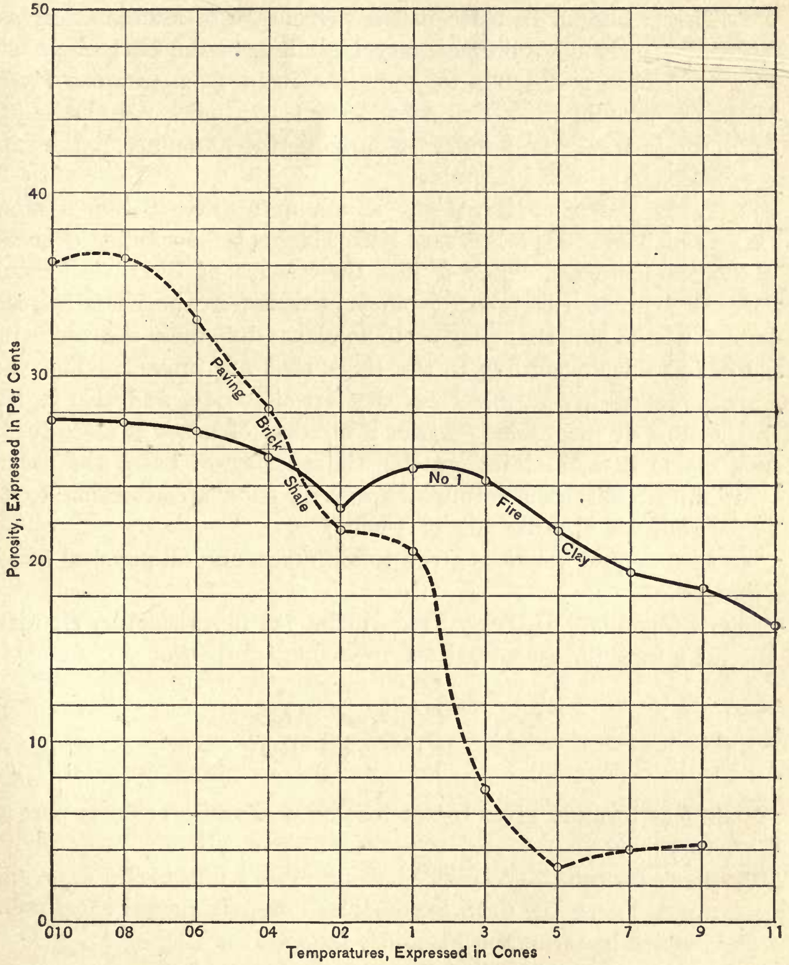

FIG. 33b.—Diagram showing relation between porosity and temperature of burning. (After Purdy and Moore.)

Bischof, on the basis of this formula, classified fire-clays into seven types or groups, in which the most refractory has a value for F.Q.

of 14, and the least refractory that is used for fire-brick has a value of 1.6. He selected seven type clays, which he considered representative of each of these groups.

Objections to Bischof's formula have been stated by Wheeler[1] as follows:

"1. That while an increase in the percentage of alumina decreases the fusibility, when it becomes very high it acts the part of an acid instead of a base and tends to lower the fusing-point, or the reverse of Bischof's formula when this point is reached; neither does the fusibility decrease when the alumina is in moderate amounts, at the rapid rate of the square of the alumina.

"2. When the silica is present in amounts greater than a monosilicate (which is always the case with clays), the fusibility decreases as the silica increases, which is just the reverse of Bischof's formula.

"3. As a broad rule, the fusibility increases as the bases increase, at least to the extent that they occur in clays; but there is a very great range of fusibility according to the bases that are present. The alkalies are more readily fusible than the ferrous oxide, and this in turn than the lime or magnesia. Again a mixture of bases is more fusible than a single base, and the greater the number of bases the greater the fusibility. Bischof's formula, however, pays no attention to the bases present, or the number of them.

"4. Again equal weight is given to all fluxes, and all physical factors are ignored.

Seger's formula.—H. Seger,[2] recognizing the unsatisfactory character of Bischof's formula, suggested the following substitute:

$$\text{F.Q.} = \frac{(Al_2O_3)_2}{RO \times SiO_2} + \frac{Al_2O_3}{RO}.$$

While this formula gives better results, it likewise neglects porosity and texture.

Wheeler's formula.—Wheeler[3] has suggested a formula for expressing the relation between the detrimentals and non-detrimental constituents of a clay, which he terms the *Fusibility factor* It is

$$\text{F.F.} = \frac{N}{D + D'},$$

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[1] Mo. Geol. Surv., Vol. XI, p. 146, 1896.

[2] For discussions on development of this formula, see Collected Writings of Seger, Translation, I, p. 486, 1902.

[3] Mo. Geol. Surv., Vol. XI, p. 149, 1896.

in which N = sum of total silica, alumina, titanic acid, water, and carbonic acid;

D = total fluxes, namely, alkalies, iron oxide, lime, magnesia;

D′ = sum of alkalies.

This formula makes no distinction between free and combined silica and assumes that silica in a free state does not act as a flux. The alkalies are added twice, because of their supposed greater fluxing power. This formula is applicable however only to clays which are physically alike.

For those of differing physical properties Wheeler suggests the fusibility factor

$$F.F. = \frac{N}{D + D' + C},$$

C having these values: C = 1 when clay is coarse grained and specific gravity exceeds 2.25;

C = 2 when clay is coarse grained and specific gravity ranges from 2 to 2.25;

C = 3 when clay is coarse grained and specific gravity ranges from 1.75 to 2.00;

C = 2 when clay is fine grained and specific gravity is over 2.25;

C = 3 when clay is fine grained and specific gravity is from 2 to 2.25;

C = 4 when clay is fine grained and specific gravity is from 1.75 to 2.25.

While this formula is a step in the right direction, it is not altogether satisfactory, as, for example, the values are not specific because there is no accurate method of expressing the fineness. Moreover, the specific gravity is not the true specific gravity.

There is, after all, some question in the author's mind whether a formula involving the necessity of at least a chemical analysis and specific-gravity determination is any more valuable than a statement of the actual temperature or cone of fusion.

Methods of Measuring Fusibility

The methods used for measuring the fusibility of clays may be divided into two classes, namely, the direct and indirect.

Direct methods.—The temperature at which a clay fuses is determined either by means of test-pieces of known composition or by some form of apparatus or mechanical pyrometer, the principle of which depends on the expansion of gases or solids, thermoelectricity, spectrophotometry, etc.

While there are many different forms of these on the market a few only, especially those which have been most commonly used, need be described.

Seger cones.—These test-pieces consist of a series of mixtures of clays with fluxes, so graded that they represent a series of fusion-points, each being but a few degrees higher than the one next to it. They are so called because originally introduced by H. Seger, a German ceramist. The materials which he used in making them were such as would have a constant composition, and consisted of washed Zettlitz kaolin, Rörstrand feldspar, Norwegian quartz, Carrara marble, and pure ferric oxide. Cone 1 melts at the same temperature as an alloy composed of one part of platinum and nine parts of gold, or at 1150° C. (2102° F.). Cone 20 melts at the highest temperature obtained in a porcelain furnace, or at 1530° C. (2786° F.). The difference between any two successive numbers is 20° C. (36° F.), and the upper member of the series is cone 39. Cone 36 is composed of a very refractory clay slate, while cone 35 is composed of kaolin from Zettlitz, Bohemia. A lower series of numbers was produced by Cramer, of Berlin, who mixed boracic acid with the materials already mentioned. Hecht obtained still more fusible mixtures by adding both boracic acid and lead in proper proportions to the cones.[1] The result is that there is now a series of 61 numbers, the fusion-point of the lowest being 590° C. (1094° F.) and that of the highest 1940° C.

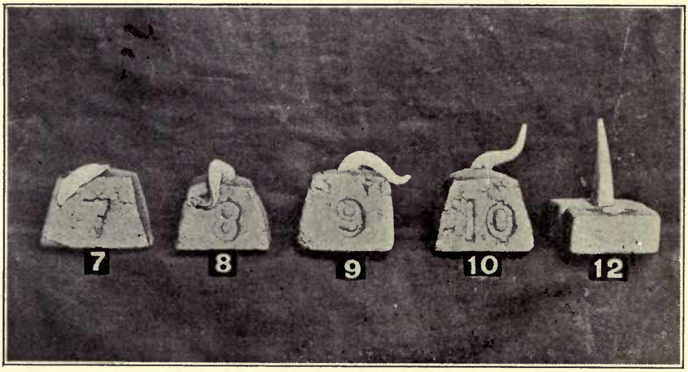

FIG. 34.—Seger cones used for determining heat effects in kilns. Nos. 7 and 8 were completely melted; No. 10 was slightly softened; No. 12 was unaffected; No. 9 was bent completely over, but not melted. The fusing-point of cone 9 was reached.

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[1] The Tonindustrie Laboratorium of Berlin, Ger., has more recently added numbers 37, 38, and 39 to the series, but their circular does not give the composition of them.

(3470° F.). As the temperature rises the cone begins to soften, and when its fusion-point is reached it begins to bend over until its tip touches the base (Fig. 34). For practical purposes these cones are very successful, though their use has been somewhat unreasonably discouraged by some. They have been much used by foreign manufacturers of clay products and their use in the United States is increasing.

The composition and fusing-points of the different members of the series are given below:

COMPOSITION AND FUSING-POINTS OF SEGER CONES

No. of Cone.	Composition.			Fusing-point. ° F.	° C.
.022	0.5 Na_2O 0.5 PbO			2.0 SiO_2 1.0 B_2O_3	1,094	590
.021	0.5 Na_2O 0.5 PbO	0.1	Al_2O_3	2.2 SiO_2 1.0 B_2O_3	1,148	620
.020	0.5 Na_2O 0.5 PbO	0.2	Al_2O_3	2.4 SiO_3 1.0 B_2O_3	1,202	650
.019	0.5 Na_2O 0.5 PbO	0.3	Al_2O_3	2.6 SiO_2 1.0 B_2O_3	1,256	680
.018	0.5 Na_2O 0.5 PbO	0.4	Al_2O_3	2.8 SiO_2 1.0 B_2O_3	1,310	710
.017	0.5 Na_2O 0.5 PbO	0.5	Al_2O_3	3.0 SiO_2 1.0 B_2O_3	1,364	740
.016	0.5 Na_2O 0.5 PbO	0.55	Al_2O_3	3.1 SiO_2 1.0 B_2O_3	1,418	770
.015	0.5 Na_2O 0.5 PbO	0.6	Al_2O_3	3.2 SiO_2 1.0 B_2O_3	1,472	800
.014	0.5 Na_2O 0.5 PbO	0.65	Al_2O_3	3.3 SiO_2 1.0 B_2O_3	1,526	830
.013	0.5 Na_2O 0.5 PbO	0.7	Al_2O_3	3.4 SiO_2 1.0 B_2O_3	1,580	860
.012	0.5 Na_2O 0.5 PbO	0.75	Al_2O_3	3.5 SiO_2 1.0 B_2O_3	1,634	890
.011	0.5 Na_2O 0.5 PbO	0.8	Al_2O_3	3.6 SiO_2 1.0 B_2O_3	1,688	920
.010	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.50 SiO_2 0.50 B_2O_3	1,742	950
.09	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.55 SiO_2 0.45 B_2O_3	1,778	970
.08	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.60 SiO_2 0.40 B_2O_3	1,814	990
.07	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.65 SiO_2 0.35 B_2O_3	1,850	1,010
.06	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.70 SiO_2 0.30 B_2O_3	1,886	1,030
.05	0.3 K_2O 0.7 CaO	0.2 0.3	Fe_2O_3 Al_2O_3	3.75 SiO_2 0.25 B_2O_3	1,922	1,050

Composition and Fusing-points of Seger Cones—(*Continued*)

No. of Cone.	Composition.	Fusing-point. °F.	Fusing-point. °C.
.04	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \begin{matrix}0.2\ Fe_2O_3\\0.3\ Al_2O_3\end{matrix}\ \left\{\begin{matrix}3.80\ SiO_2\\0.20\ B_2O_3\end{matrix}\right\}$	1,958	1,070
.03	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \begin{matrix}0.2\ Fe_2O_3\\0.3\ Al_2O_3\end{matrix}\ \left\{\begin{matrix}3.85\ SiO_2\\0.15\ B_2O_3\end{matrix}\right\}$	1,994	1,090
.02	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \begin{matrix}0.2\ Fe_2O_3\\0.3\ Al_2O_3\end{matrix}\ \left\{\begin{matrix}3.90\ SiO_2\\0.10\ B_2O_3\end{matrix}\right\}$	2,030	1,110
.01	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \begin{matrix}0.2\ Fe_2O_3\\0.3\ Al_2O_3\end{matrix}\ \left\{\begin{matrix}3.95\ SiO_2\\0.05\ B_2O_3\end{matrix}\right\}$	2,066	1,130
1	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \left.\begin{matrix}0.2\ Fe_2O_3\\0.3\ Al_2O_3\end{matrix}\right\}4\ SiO_2$	2,102	1,150
2	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \left.\begin{matrix}0.1\ Fe_2O_3\\0.4\ Al_2O_3\end{matrix}\right\}4\ SiO_2$	2,138	1,170
3	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ \left.\begin{matrix}0.05\ Fe_2O_3\\0.45\ Al_2O_3\end{matrix}\right\}4\ SiO_2$	2,174	1,190
4	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.5\ Al_2O_34SiO_2$	2,210	1,210
5	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.5\ Al_2O_35SiO_2$	2,246	1,230
6	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.6\ Al_2O_36SiO_2$	2,282	1,250
7	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.7\ Al_2O_37SiO_2$	2,318	1,270
8	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.8\ Al_2O_38SiO_2$	2,354	1,290
9	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 0.9\ Al_2O_39SiO_2$	2,390	1,310
10	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 1.0\ Al_2O_310SiO_2$	2,426	1,330
11	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 1.2\ Al_2O_312SiO_2$	2,462	1,350
12	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 1.4\ Al_2O_314SiO_2$	2,498	1,370
13	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 1.6\ Al_2O_316SiO_2$	2,534	1,390
14	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 1.8\ Al_2O_318SiO_2$	2,570	1,410
15	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 2.1\ Al_2O_321SiO_2$	2,606	1,430
16	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 2.4\ Al_2O_324SiO_2$	2,642	1,450
17	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 2.7\ Al_2O_327SiO_2$	2,678	1,470
18	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 3.1\ Al_2O_331SiO_2$	2,714	1,490
19	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}\ 3.5\ Al_2O_335SiO_2$	2,750	1,510

Composition and Fusing-points of Seger Cones—(*Continued*)

No. of Cone.	Composition.	Fusing-point. °F	Fusing-point. °C.
20	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $3.9\ Al_2O_3 39SiO_2$	2,786	1,530
21	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $4.4\ Al_2O_3 44SiO_2$	2,822	1,550
22	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $4.9\ Al_2O_3 49SiO_2$	2,858	1,570
23	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $5.4\ Al_2O_3 54SiO_2$	2,894	1,590
24	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $6.0\ Al_2O_3 60SiO_2$	2,930	1,610
25	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $6.6\ Al_2O_3 66SiO_2$	2,966	1,630
26	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $7.2\ Al_2O_3 72SiO_2$	3,002	1,650
27	$\left\{\begin{matrix}0.3\ K_2O\\0.7\ CaO\end{matrix}\right\}$ $20\ Al_2O_3 200SiO_2$	3,038	1,670
28	$Al_2O_3\ 10\ SiO_2$	3,074	1,690
29	$Al_2O_3\ 8\ SiO_2$	3,110	1,710
30	$Al_2O_3\ 6\ SiO_2$	3,146	1,730
31	$Al_2O_3\ 5\ SiO_2$	3,182	1,750
32	$Al_2O_3\ 4\ SiO_2$	3,218	1,770
33	$Al_2O_3\ 3\ SiO_2$	3,254	1,790
34	$Al_2O_3\ 2.5\ SiO_2$	3,290	1,810
35	$Al_2O_3\ 2\ SiO_2$	3,326	1,830
36	$Al_2O_3\ 1.5\ SiO_2$	3,362	1,850
37	——	3,398	1,880
38	——	3,434	1,910
39	——	3,470	1,940

In actual use they are placed in the kiln at a point where they can be watched through a peep-hole (Fig. 35), but at the same time will not receive the direct touch of the flame from the fuel. It is always well to put two or more cones of different numbers in the kiln, so that warning can be had, not only of the end point of firing but also of the rapidity with which the temperature is rising.

In determining the proper cone to use in burning any kind of ware, several cones are put in the kiln, as, for example, numbers .08, 1 and 5. If .08 and 1 are bent over in burning and 5 is not affected the temperature of the kiln is between 1 and 5. The next time numbers 2, 3, and 4 are put in, and 2 and 3 may be fused, but 4 remains unaffected, indicating that the temperature reached the fusing-point of 3.

While the temperature of fusion of each cone is given in the preceding table, it must not be understood that these cones are for measuring temperature, but rather for measuring pyrochemical effects. Thus if certain changes are produced in a clay at the fusing-point of cone 5, the same changes can be reproduced at the fusion-point of this cone, although the actual temperature of fusion may vary somewhat, due to variation in the condition of the kiln atmosphere. As a matter of fact, however, repeated tests with a thermoelectric pyrometer demonstrate that the cones commonly fuse close to the theoretic temperatures.

Manufacturers occasionally claim that the cones are unreliable and not satisfactory, forgetting that their misuse may often be the true reason for irregularities in their behavior. It is unnecessary, perhaps, to state that certain reasonable precautions should be taken in using these test-pieces. The cones are commonly fastened to a brick with a piece of wet clay, and should be set in a vertical position. After being placed in a position where they can be easily seen through a peephole, the latter should not be opened widely during the burning, lest a cold draft strike the cones, and a skin form on its surface and interfere with its bending. If the heat is raised too rapidly, the cones which contain much iron swell and blister and do not bend over, so that the best results are obtained by the slow softening of the cone under a gradually rising temperature. Aside from this, however, trouble has been experienced with cones Nos. 010 to 3, which may act irregularly

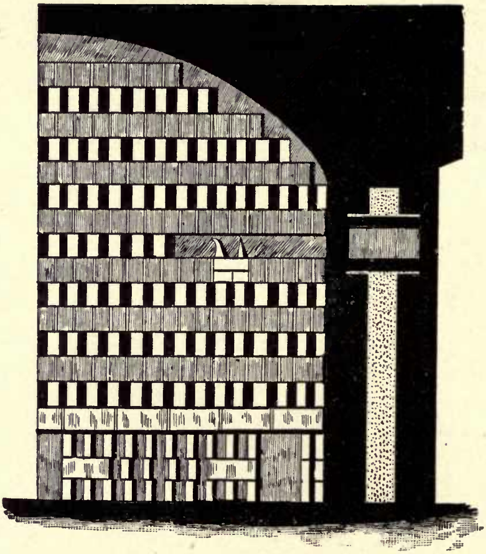

Fig. 35.—Section of kiln showing method of placing Seger cones.

if exposed for any length of time to sulphurous fumes from the fuel, as in burning in some muffle-kilns, where there is not a free circulation of air in the muffle. The sulphuric acid appears to cause a volatilization of the boracic acid, and unite with the lime in the exterior of the cone, forming a hard skin of less fusible character than the interior, which melts while the outside is still hard. It has been suggested that the composition of these members of the cone series be changed.[1] One set of cones cannot be used to regulate an entire kiln, but several sets should be placed in different portions of the same. One advantage possessed by cones over trial-pieces is that the cones can be watched through a small peep-hole, while a larger opening must be made to draw out the trial-pieces. If the cones are heated too rapidly, those containing a large percentage of iron are apt to blister.

Zimmer[2] has pointed out that with slow firing in a large biscuit-kiln the cones 1–9 reached a melting-point of 25° to 30° C. lower than those placed in a small trial-kiln, whose temperature increased faster, but since it is heat effects and not degrees of temperature that we are measuring, this makes no difference.

While the different members of any one make of cones are usually consistent with each other, the same numbers of different makes do not always agree. This fact was well brought by H. E. Ashley,[3] who tested the different makes together, plotting the results of his tests in the table shown in Fig. 35*a*. In this the Columbus cones are spaced equidistant for convenience. The temperature at which the cones are supposed to melt, as given by the Tonindustrie-Zeitung, are placed to the left of the Orton (Columbus) cones in the figure, while the temperature at which Geijsbeek[4] found them to melt are given in a corresponding column on the right of them. The column on the extreme right gives the melting points of Holdcroft & Co.'s patent thermoscopes. These are straight, dry-pressed bars, placed horizontally with a support at either end. Under the influence of heat they sag in the middle.

After many years of experience with these cones, not a few ceramists believe that some of the cone numbers are too close together, and could be properly left out.

Experience has also shown that while the cones are not designed to measure degrees of temperature, nevertheless they often, if not usually, fuse quite close to their theoretic melting-point. Such at least has been

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[1] Trans. Amer. Ceram. Soc., Vol. II, p. 60, and III, p. 180.

[2] Ibid., Vol. I, p. 23.

[3] Trans. Amer. Ceram. Soc., VIII, p. 159, 1906.

[4] Trans. Amer. Ceram. Soc., Vol. VI, p. 94, 1904.

the author's experience when the heat was not raised too rapidly, but Geijsbeek's figures given in Fig. 35*a* show a somewhat strong divergence.

Rothe[1] determined the softening points of cones 4-20 in an iridium furnace, in an atmosphere of nitrogen, each test lasting 90 minutes. Both a Le Chatelier iridium, iridium-ruthenium couple and an optica pyrometer were used.

The cones, which were smaller than the commercial articles, were fastened to a Marquand porcelain tile, and it was found that the rate

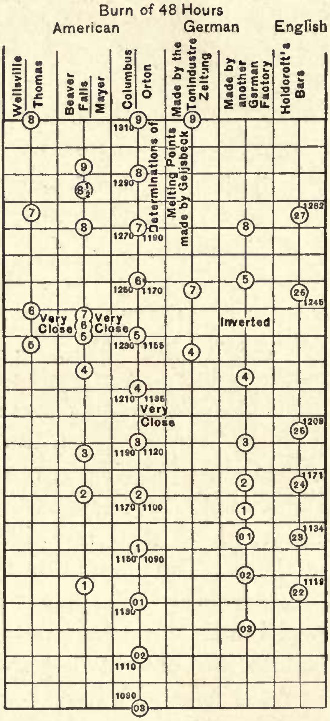

FIG. 35*a*.—Diagram showing relative fusibility of different makes of cones. (Trans. Amer. Ceram. Soc., VIII, 1906).

of heating for at least 20 minutes before the softening point should not exceed 5° C. per minute.

His result are given in the table on the next page.

Another observer, M. Simonis[2] made up a series of mixtures corres-

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[1] Tonind.-Zeit., XXXI, No. 101, p. 1366, 1907.

[2] Sprechsaal, No. 6, p. 71, 1907.

Cone No.	Theoretic fus. point.	Observed fus. point.	Cone No.	Theoretic fus. point.	Observed fus. point.	Cone No.	Theoretic fus. point.	Observed fus. point.
4	1210	1225	10	1330	1345	16	1450	1460
5	1230	1225	11	1350	1360	17	1470	1480
6	1250	1260	12	1370	1375	18	1490	1510
7	1270	1285	13	1390	1395	19	1510	1525
8	1290	1305	14	1410	1410	20	1530	1530
9	1310	1335	15	1430	1435	..	....	....

ponding to the composition of Seger cones 19 to 25. These were prepared from Zettlitz kaolin, sand, marble and feldspar, ground in a porcelain ball mill, and made into tetrahedra of the usual size. They were melted down at both slow and rapid rates in an electric carbon resistance furnace, having tubes 6.5 and 13 cm. in diameter. The temperatures, as determined by the Le Chatelier pyrometer were as follows:

Cone.	Observed. fusion point.	Cone.	Observed. fusion point.
19	1530° C.	23	1555° C.
20	1548	24	1560
21	1548	25	1566
22	1550	26	1566

The melting-points are so close together that the use of cones 21–25 seems unnecessary, they are moreover not numbers which are much used in the industries.[1]

The cone numbers used in the different branches of the clay-working industry in the United States are approximately as follows:

Common brick	012–01
Hard-burned, common brick	1– 2
Buff front brick	5– 9
Hollow blocks and fireproofing	03– 1
Terra cotta	02– 7
Conduits	7– 8
White earthenware	8– 9
Fire bricks	5–14
Porcelain	11–13
Red earthenware	010–05
Stoneware	6– 8
Electric porcelain	10–12

Thermoelectric pyrometer.—This pyrometer is one of the best instruments for measuring temperatures. It is based on the principle of generating an electric current by the heating of a thermopile or thermoelectric couple consisting of two wires, one of platinum and the other of an alloy of 90 per cent platinum and 10 per cent rhodium. These two are fastened together at one end, while the two free ends are carried to a galvanometer which measures the intensity of the current. That portion of the wires which is inserted into the furnace or

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[1] For discussion of Simonis results, see also Sprechsaal, No. 9, p. 118, and No. 17, p. 157, 1907.

kiln is placed within two porcelain tubes, one of the latter being smaller and sliding within the other in order to insulate the wires from each other. The larger tube has a closed end to protect the wires from the action of the fire-gases. The shortest tubes put on the market are about 15 inches long, while the longest are 54 inches.

To measure the temperature of a furnace or kiln the tube containing the wires is placed in it either before starting the fire, or else during the burning. If the latter method is adopted, the tube must be introduced very slowly, to prevent its being cracked by sudden heating. The degrees of temperature are measured by the amount of deflection of the needle of the galvanometer.

Thermoelectric pyrometers are useful for measuring the rate at which the temperature of a kiln is rising, or for detecting fluctuations in the same. It is not necessary to place the galvanometer near the kiln, for it can be kept in the office some rods away. This pyrometer is not to be used as a substitute for Seger cones; but to supplement them The more modern forms have an automatic recording-device. As at present put on the market the thermoelectric pyrometer costs about $130, and the price, delicacy of the instrument, and lack of realization of its importance have all tended to restrict its use. However, many of the larger clay-working plants are adopting it, as it is better than other forms of pyrometer for general use and probably more accurate. It can be used up to 1600° C. (2912° F.).

Wedgewood pyrometer.—This pyrometer, which has been used from time to time in ceramic establishments, depends on the shrinkage of clay cylinders, whose contraction is supposed to be proportionate to the temperature to which they are exposed. Their behavior is unreliable.

Lunette optical pyrometer.—This consists of a small telescope containing a quartz plate between two Nicol prisms. When looking at a heated body through it one of the prisms is revolved until the red color changes to yellow, then green, and lastly blue. The angle of rotation necessary to extinguish the red is measured, and the temperature determined by this means. It is only approximate in its recording action and rather unsatisfactory in its work.

Classification of clays based on fusibility.[1]—The fact that different clays fuse at different temperatures makes it possible to divide them into several different groups, the divisions being based on the degree of refractoriness of the material. Such a grouping, however, is more or less arbitrary, since no sharp natural lines can be drawn between the different groups, and it is to be expected that no grouping pro-

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[1] N. J. Geol. Surv., Fin. Rept., VI, p. 100.

posed will meet with universal approval. The following classification was adopted by the author in studying the New Jersey fire-clays:

1. Highly refractory clays, those whose fusing-point is above cone 33. Only the best of the so-called No. 1 fire-clays belong to this class.

2. Refractory clays, those whose fusion-point ranges from cone 31–33 inclusive. This group includes some of the New Jersey No. 1, as well as some No. 2 fire-clays.

3. Semi-refractory clays, those whose fusion-point lies between cones 27 and 30 inclusive.

4. Clays of low refractoriness, those whose fusion-point lies between cones 20 and 26 inclusive.

5. Non-refractory clays, fusing below cone 20.

Indirect methods.—There are several indirect methods of determining temperatures, but that of Bischof [1] is perhaps the best known. This consists in increasing the refractoriness of weighed samples by adding to them increasing quantities of an intimate mixture of equal parts of chemically pure silica and alumina, and heating them with a prism of Saarau fire-clay (whose fusing-point is Seger cone 36) to above the melting-point of wrought iron. The amount of the mixture required to tone the clay up to the same refractoriness as the standard indi. cates its quality. It was used by Bischof chiefly for refractory clays-

Hofman and Demond [2] tried the method of mixing various samples of fire-clays with varying proportions of calcium carbonate, and calcium carbonate and silica, to render them fusible at temperatures below the melting-point of platinum, while common brick-clays were mixed with alumina and silica to decrease their fusibility, the object being to arrive at a standard temperature at which both refractory and fusible clays could be tested. The results obtained at first were very satisfactory, but subsequent ones did not result as was desirep and the method had to be abandoned.

More recently, however, this method has been tried by J. L. Newell and G. A. Rockwell with much better results.[3] In these last experiments the Seger cone 26 was used as a standard, as it was regarded as forming the line between refractory and non-refractory clays, the non-refractory ones being toned up until they showed the same behavior in the fire as cone 26. The amount of toner added then gave an idea how far the clay stood below the lower limit of refractoriness.

The silica used in the experiments was quartz, ground to pass a

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[1] Dingler's Polyt. Jour., Vol. CXCVI, pp. 438, 525, and CXCVIII, p. 396.

[2] Trans. Amer. Inst. Min. Engrs., XXV, p. 3, 1896.

[3] Ibid., XXVIII, p. 435, 1899.

100-mesh sieve and purified by boiling in nitrohydrochloric acid. It had 99.88 per cent silica. The alumina contained 98.48 Al_2O_3.

The method followed was to weigh out samples of 1 gram of the clay to be tested and mix them severally with 0.1, 0.2, 0.3, etc., grams of the silica-alumina mixture. The samples were then tested in the Deville furnace.

The following table gives the results of the experiments just described, the clays being arranged in the order of their refractoriness, and in each case the amount of flux being given that was required to raise the fusing-point to that of cone 26 of Seger.

Analyses of Clays and Results of Tests

Sample No.	26[1]	25[1]	3[1]	22[1]	24[1]	23[1]	1982[2]
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
SiO_2	64.10	55.60	57.10	57.45	57.15	49.30	43.94
Al_2O_3	21.79	24.34	21.29	21.06	20.26	24.00	11.17
H_2O comb.	6.05	6.75	6.00	5.90	5.50	9.40	3.90
Total	91.94	86.69	84.39	84.41	82.91	82.70	59.01
Fe_2O_3	2.51	6.11	7.31	7.54	7.54	8.40	3.81
CaO	0.10	0.43	0.29	0.29	0.90	0.56	11.64
MgO	0.58	0.77	1.53	1.22	1.62	1.60	4.17
K_2O	2.62	3.00	3.44	3.27	3.05	3.91	2.90
Na_2O	0.03	0.09	0.61	0.39	0.58	0.17	0.71
Total	5.84	10.40	13.18	12.71	13.69	14.64	23.23
Moisture	1.10	2.65	1.30	1.90	2.70	1.20	15.66[3]
Grand total	98.88	99.74	98.87	99.02	99.30	98.54	98.00[4]
Stiffening ingredient, %	20	40	60	80	80	100	180

[1] N. W. Lord anal. [2] E. Orton, Jr., anal. [3] Includes CO_2. [4] Includes P_2O_5 0.10%.

Changes Taking Place in Burning

The changes which occur in burning are of two kinds, chemical and physical, the two being more or less closely related; in fact the physical effects are often the results of chemical changes.

While the chemical changes are much the same for all clays, still they vary greatly in degree. The temperature at which many of these occur is also fairly constant, but may be influenced somewhat by the composition of the clay and the fire-gases.

The changes which occur in burning may be roughly divided into three stages, termed the periods of dehydration, oxidation, and vitrification, each of which are characterized by certain reactions, but there is no sharp dividing-line between the different ones, the changes of one stage beginning before those of the preceding stage are completed.

Dehydration period.—In the beginning of burning the last traces of moisture are driven off. This vapor, which is termed water-smoke or steam by the brick-maker, is simply the moisture which has been retained in the pores of the clay. Its expulsion results in a slight loss of weight. The driving out of the moisture is facilitated by raising the heat slowly, and by allowing sufficient draft to pass through the kiln in which the clay is being burned. Raising the temperature too fast expels the steam too quickly and causes a popping of the brick.

On the other hand, a stopping or retardation of the draft results in a saturation of the kiln atmosphere with moisture, and its deposition on the surface of the ware, producing the effect known as "scumming" or "whitewashing." This is caused in this way: All bituminous coals contain some sulphur, which on burning is given off in the form of sulphurous gas, and is then absorbed by the condensed moisture on the surface of the ware. The acid solution thus formed attacks certain salts (especially lime) in the clay, forming soluble sulphates, which are left as a white scum on the surface of the ware when the moisture evaporates. Sulphur in a dry atmosphere would cause but little harm. It is therefore desirable to use a fuel for dehydration which contains as little water and sulphur as possible. This is often a difficult matter, for most soft coal has much of both, and wood contains water. Coke and charcoal are good, but their use is not always economically practicable.

From the point at which the water evaporates, up to 450° C. (842° F.), there is practically no change, unless gypsum and magnesite are present, and these might lose their carbon dioxide at a lower temperature (pages 94, 96). The amount of loss in this manner is usually so small as to be negligible, but at this point the expulsion of the chemically combined water begins and is practically complete by 700° C. (1292° F.), that is, it begins at a very dull red and is completed at a bright-red heat.

Before the dehydration of the water is completed, however, other gases begin to pass off, including CO_2 from lime and iron carbonates, sulphur from pyrite,[1] and gases produced by the combustion of carbonaceous matter in the clay, but all of these may not have passed off after the dehydration of the clay is ended. Moreover the expulsion

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[1] Pyrite loses only a portion of its sulphur at this temperature, the balance passing off later.

of some of them requires the presence of oxygen, so that the periods of dehydration and oxidation overlap.

Oxidation period.—In the oxidation process, which may begin at a comparatively low temperature, as low as 500° C. (932° F.), and is probably completed by 900° C. (1652° F.), the following changes may take place:

1. The oxidation or burning off of the combustible matter.
2. The expulsion of the remaining sulphur from pyrite.
3. The driving off of carbon dioxide.
4. The oxidation of any ferrous iron to the ferric condition.

Two things should be borne in mind in this connection:

1. Oxidation may be accomplished without the aid of heat, the process going on slowly when the clay is exposed to the weather. In this case both FeS_2 and $FeCO_3$ may be changed to the oxide, and even organic matter may be partly eliminated.

2. The porosity of the clay materially affects the process, a loose, open-textured clay allowing these changes to take place more readily than a close-textured, fine-grained one, which retards the entrance of the oxidizing gases into the mass. Grog is sometimes added to open the grain.

From this we can see that the presence of much air mixed with the fuel-gases facilitates the removal of combustible elements in the clay, especially organic matter. Since air carrying oxygen is necessary to help in removing them, it follows that the clay must be sufficiently porous to allow the air to penetrate it. Now if the expulsion of the water in the clay is retarded, thereby keeping the pores of the clay more or less closed up, it may retard the expulsion of other gases, some of which may be retained in the clay, until the rising temperature has sealed up the pores by vitrification. Thus imprisoned, and subjected to a rising temperature, they may by expansion bloat the ware. As pointed out by Beyer and Williams,[1] it is not definitely known what gases become thus imprisoned, but they may be CO_2, or SO_2, and some have suggested that oxygen liberated by the reduction of iron to the ferrous condition may also aid in bloating or blistering the ware.

In burning bricks, for example, if the ware is raised to a vitrifying heat before oxidation is complete, the iron in the central part of the mass remains in a ferrous condition, and forms a black core. This may be followed by a swelling as explained under sulphur.

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[1] Ia. Geol. Surv., XIV, p. 278, 1904.

During the temperature interval in which dehydration and oxidation occur there are few or no reactions going on between the clay particles, but as the temperature of vitrification is approached chemical union occurs between the different minerals in the clay, and as it goes on involves an increasing number of elements in the reactions, which become exceedingly complex.

The clay, if red-burning, will show a much brighter color at the end of the oxidation period.

Vitrification period.—In this stage texture plays an important rôle (see under Fusibility), for in finer-grained clays chemical reactions are more wide-spread and take place more easily than in coarse-grained ones. Increasing density of the clay and increasing homogeneity of the mass produce similar effects.

These chemical reactions result in the formation of silicates of exceedingly complex character.

The temperature of vitrification is exceedingly variable, being as low as 900° C. (1652° F.) or 1000° C. (1832° F.) in some clays, while in others it may be 1200° C. (2192° F.) or even higher.

After the clay is completely vitrified a further rise of temperature causes it to swell, soften still more, and finally run.

The effect of ferrous iron, carbon and sulphur have been referred to under their respective captions, which see, but still it will do no harm to refer to them collectively in this place, for the three acting jointly reach the culmination of their efforts at vitrifying heats.

It was seen that the carbon was the primary cause of the black-coring reaction, by preventing the oxidation of sulphur and iron at the proper time, but that iron is the main cause of the black coloration, but only to a small degree of the swelling which sometimes accompanies it, in that it helps to hold the sulphur in the clay, and possibly causes the clay to fuse at a lower temperature. The sulphur (p. 111) is the real cause of the swelling, by the substitution of silicic acid for sulphur.

If all three substances—ferrous iron, carbon and sulphur—are present at the same time, they act jointly, sulphur being the worst. Clays high in carbon and iron, but free from sulphur, would probably blacken by improper burning, but it is not likely to swell. Clay free from iron, but high in carbon and sulphur, would probably swell without blackening. Clay high in sulphur, but free from both carbon and iron, is likely to swell from over-firing, but this will occur on the exterior before the interior.

We may therefore summarize the effects of heating as follows:

1. Loss of volatile substances present, such as water, carbon dioxide, and sulphur trioxide, the volatilization of these leaving the clay more or less porous.

2. Oxidation of ferrous to ferric compounds, if oxygen is present.

3. A shrinkage of the mass, by further heating.

4. Hardening of the clay due to fusion of some, at least, of the particles.

5. Increasing density with rising temperature, the maximum being reached at the vitrifying point of the clay.

6. Complete softening of the mass.

Effects due to variation in the clay.—Burned clays may be of many different colors. Although the majority of clays contain sufficient iron oxide to burn red, nevertheless it is not safe to predict, from the color of the raw clay, the shade that it will burn, since some bright red or yellow clays may yield a buff brick. If considerable iron oxide is present, 4 to 5 per cent, the brick usually burns red, unless much lime or alumina is also present. If only 2 to 3 per cent or under, the clay may burn white or buff. An excess of lime in the clay will, however, counteract the effect of the iron oxide and yield a buff brick, but a brick owing its buff color to this cause will not stand as much fire as one which owes its buff color simply to a low percentage of iron oxide.

Where a clay is mottled, as red and white for instance, the colors of the different spots will retain their individuality most plainly after burning, unless the clay is thoroughly mixed. Many clays contain lumps of whitish clay, much tougher than the rest of the mass. These resist disintegration in the tempering-machines, so that after burning they can be plainly seen, as white spots in the red ground of the brick.

The normal iron coloration may often be destroyed by the effects of the fire-gases. When these are reducing in their action (i.e., taking a part of the oxygen from the ferric compounds and reducing them to ferrous compounds) the red color may be converted to gray, or even bluish black, if the reduction is sufficient, so that in some districts the bricks, on account of lack of air in the kilns and carbonaceous matter in the clay, do not burn a very bright red. Moreover, other things being equal, the higher the temperature at which a clay is burned, the deeper will be its color.

The surface coloration of a burned brick may often be different from the interior. This is due to several causes. (1) Soluble salts may accumulate on the surface, sometimes causing a white coating

ANALYSES SHOWING DIFFERENCE BETWEEN RAW AND BURNED CLAY[1]

	I.	II.	III.	IV.	V.	VI.	VII.
Silica (SiO_2)..........	74.03	78.5	74.04	73.94	49.45	56.6	56.5
Alumina (Al_2O_3)......	17.10	21.3	15.15	20.47	17.11	20.4	20.2
Ferric oxide (Fe_2O_3)...	.57	tr.	.50	1.80	3.45	6.2	6.1
Lime (CaO)...........	.10	....	.50	1.08	12.67	11.7	11.6
Magnesia (MgO).......	.22	....	.27	1.16	1.77	1.4	1.8
Potash (K_2O).........	.30	.5	.42	.61	.13	1.5	1.5
Soda (Na_2O)..........	.60	.3	1.12	.64	.21	1.4	1.3
Titanium oxide (TiO_2).	1.36	with Al_2O_3	1.31	.83	.70	with Al_2O_3	with Al_2O_3
Water (H_2O)..........	6.15	none	6.00	....	4.84	.5	none
Carbon dioxide (CO_2)...	....	....	....	....	7.10	none	none
Sulphur trioxide (SO_3)..	....	....	....	....	2.00	none	none
Ferrous oxide.........	....	....	....	....	....	none	none
Total..............	100.43	100.6	99.31	100.53	99.43	99.7	99.1
Total fluxes.........	1.79		2.81	5.27	18.23		

I. Fire-clay from six miles southeast of Sulphur Springs, Tex. O. H. Palm, analyst.
II. Brick from same. S. H. Worrell, analyst.
III. Fire-clay, Athens, Tex. O. H. Palm, analyst.
IV. Fire-brick, Athens, Tex. O. H. Palm, analyst.
V. Brick shale, Ferris, Tex. O. H. Palm, analyst.
VI. Brick from same. O. H. Palm, analyst.
VII. Hard-burned brick. O. H. Palm, analyst.

because they have been drawn out by the evaporation of the water during the drying on the brick.[2] (2) The deposition of foreign substances by the fire-gases may cause a colored glaze. This is especially seen on the ends of arch-brick, and on the bag walls of a down-draft kiln, where the particles of ash carried up from the fires stick to the surface of the hot brick and cause a fluxing action. (3) If the clay contains much lime carbonate, and there is much sulphur in the coal, the latter may unite with the lime, forming sulphate of lime, and thereby prevent the combination of the lime and iron. In this case the center of the brick, not being thus affected by the gases, may show a buff color, whereas the outside has another tint.

Loss of volatile products in burning.—The analyses (see table above) giving the composition of several clays, and the bricks made from them, are interesting in showing the loss of the volatile products in burning.

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[1] These analyses would have been of greater value had it been possible to make each of a pair on the same sample. The main point they bring out is the loss of volatile elements.

[2] See "Soluble Salts in Clays," pp. 115 et seq.

Development of silicates in burning.—In many cases a mass of clay which has been heated up to a condition of thorough vitrification or higher, will, even though cooled moderately fast, show the development of at least crystallites, but in some instances of crystalline grains sufficiently well developed to permit their identification. In the study of these more attention has perhaps been given to porcelain than other types of ware, andalusite being the mineral most often identified or suspected. Those desiring to follow this subject up in greater detail are referred to the articles listed below.[1]

Color

Color of unburned clay.—An unburned clay owes its color commonly to some iron compound or carbonaceous matter, more rarely manganese. A clay free from any of these is white.

Carbonaceous matter will color a clay blue, gray, black, or even purplish, depending on the quantity present, 3 per cent being probably sufficient to produce a deep black; clays in actual use having sometimes as much as 10 per cent.

Iron oxide colors a clay yellow, brown, or red, depending on the form of oxide present. The greenish color may be due to the silicate of iron, and in some clay marls of the Cretaceous it is caused by the mineral glauconite. The iron coloration is, however, often concealed by the black coloration due to carbonaceous matter, and it is sometimes more or less difficult to make even an approximate estimate of the iron content in a clay from its color. Thus, for example, two clays have been noted by the writer[2] which were nearly of the same color and had respectively 3.12 and 12.40 per cent of ferric oxide.

There is often a marked difference in color between the wet and the dry clay, in fact such a difference at times as to make one doubt that they are the same material. The dry clay is usually of a lighter tint.

Color of burned clay.—The color of a raw or unburned clay is not always an indication of the color it will be when burned. Red clays

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[1] E. Plenske, Ueber Mikrostructur und Bildung der Porcellane, Sprechsaal, XLI, Nos. 19, 20, 21, 22, 23, 1908, contains an excellent *résumé* of literature on the subject; W. Vernadsky, Bull. Soc. min., France, XIII, p. 256, 1890; J. W. Mellor, Jour. Soc. Chem. Ind., XXVI, p. 375, 1907; C. H. Wegemann, Trans. Amer. Ceram. Soc., IX, p. 231, 1907; Anon. Sprechsaal, XXXIX, p. 1387, 1906.

[2] N. J. Geol. Surv., Final Report, Vol. VI, p. 112, 1904.

usually burn red; deep-yellow clays may burn buff or red; chocolate ones commonly burn red or reddish brown; white clays burn white or yellowish white; and gray or black ones may burn red, buff, or white. Green ones usually change to red on firing. Calcareous clays are often either red, yellow, or gray, and may burn red at first, but turn cream, yellow, or buff as vitrification is approached, and show a greenish yellow at viscosity.

An excess of alumina seems to exert a bleaching effect similar to that of lime.

The vitrification of ferruginous clays yields browns, greens, and blacks, due to the formation of ferrous silicates.[1]

Seger states that the colors which a burned clay may show depend on:

1. The quantity of iron oxide contained in the clay.
2. The other constituents of the clay accompanying the iron (see Alumina and Lime).
3. The composition of the fire-gases during the burning.
4. The degree of vitrification.
5. The temperature at which the clay is burned.

The same author has attempted to classify clays according to their color-burning qualities as follows:[2]

Group.	Character of clay.	Color after burning.
1	High in alumina and low in iron	White, or nearly so
2	High in alumina and moderate iron contents	Pale yellow to pale buff
3	Low in alumina and high in iron	Red
4	Low in alumina and high in iron and lime	Cream or yellow

Slaking

When a lump of raw clay or shale is immersed under water it falls to pieces or slakes, the process ceasing only when the clay has broken down to a fine powdery mass. The time required for this varies from a few minutes in the case of soft porous clays to several weeks for tough shales, and some may be incompletely disintegrated even after that.

The slaking property is one of some practical importance, as easily slaking clays temper more readily, or if the material is to be washed, it disintegrates more rapidly in the log-washer.

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[1] Ia. Geol. Surv., Vol. XIV, p. 59, 1904.

[2] Seger's Collected Writings, Vol. I, p. 109.

Permeability

An interesting series of experiments has been made by W. Spring,[1] who finds that clay when under pressure and confined so that it cannot expand on wetting is nearly impervious to water; under such conditions it will only soak up enough water to fill the pores. The percentage of water thus absorbed may range from as low as 3.37 per cent in glass-pot clays to 24.56 per cent in some loams. Wet clay under pressure will part with its water even though the mass be entirely surrounded by that liquid.

Adsorption

By this term is meant the power which a clay has of removing solid substances from solutions with which it is in contact.

More than fifty years ago T. Way [2] noticed that clays, and soils with a clay base, possessed extraordinary powers for absorbing water, but that in addition the clay substance exhibited greater facility for absorbing the bases contained in certain salts which were dissolved in water. This action was also selective, certain bases and substances being held so that they could not be washed out again.

Bourry [3] states that kaolins do not absorb more than 2 per cent of calcium carbonate from a solution, while plastic clays can absorb from 10 to 20 per cent of it. More recently Dr. Hirsch [4] has made a number of experiments to test the amount of dissolved salts which a clay can absorb when stirred up in a solution. He found that clays and kaolins absorb some of the dissolved salt, because after settling the supernatant liquid had a lower concentration than it did before; but sand and burned clay do not show this power, while feldspar and marble possess it to some extent. The amount of salt thus absorbed was independent of the time, and the removal of the salt ceased with the settling of the clay. It is, however, dependent on the kind of clay and kind of salt and the degree of concentration. Thus barium, lead, and aluminum compounds were removed in considerable quantities, while strontium, magnesium, and calcium salts were absorbed to a less degree. The

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[1] Ann. de la Soc. géol. de Belg., XXVIII, 1901.

[2] Royal Ag. Soc. Jour., XI, 1880. Quoted by Cushman, Trans. Amer. Cer. Soc., VI, p. 7, 1904.

[3] Treatise on Ceramic Industries, p. 54, 1901.

[4] Tonindustrie-Zeitung, No. 26, 1904.

acid of the salt seems to influence the result appreciably. Chlorides, nitrates, and acetates are absorbed more than sulphates, but alkali salts, except the carbonates, are not. The higher the concentration of the solution the greater the quantity of salt absorbed, although in a weak solution all of the salt may be carried down. The conditions are more complicated in the presence of several salts; thus the absorption of barium chloride is decreased by the presence of alkali salts, acids and bases, and entirely prevented by aluminum chloride. Sulphates are absorbed in the presence of caustic alkalies and acids, while the alkali chlorides seem to be lacking in effect.

Experiments by the author[1] have also shown that some tannins, as gallo-tannic acid, are absorbed by clay, a clear filtrate from a mixture of gallo-tannic acid and clay giving no reaction with ferric chloride.

In this connection it is of interest to refer to the observations of Kohler,[2] who finds that clays, among other substances, have the power of abstracting metallic oxides from solutions which are filtered through them.

E. C. Sullivan,[3] in experimenting along these lines, found that when a solution containing 100 cc. of water with 252 grains of copper as the sulphate was shaken up with powdered orthoclase, albite, shale, or microcline, it was found that there was a remarkable interchange of bases instead of absorption. The copper entered the silicates, and an exact molecular equivalent of the K_2O, Na_2O, CaO, MgO, or MnO went into solution. The feldspar proved much more efficient than kaolin, and removed from 60 to 100 per cent of the copper from the liquid.

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[1] Trans. Amer. Ceram. Soc., VI, p. 44, 1906.

[2] Adsorptionsprozesse als Faktoren der Lagerstättenbildung und Lithogenesis Zeitschr. für prakt. Geologie, Feb. 1903, p. 49.

[3] The Chemistry of Ore Deposition, Jour. Amer. Chem. Soc., XXVII, p. 976 and Economic Geology, I, p. 67, 1905.

CHAPTER IV

KINDS OF CLAYS

In this chapter it is proposed to give briefly the characters of the clays employed for different purposes, beginning with the highest grades.

Kaolins

This term as commonly used, and it seems to the author the correct way to use it, refers to those white-burning clays of residual character,[1] which are composed mostly of silica, alumina, and chemically combined water, and have a very low percentage of fluxing impurities, especially iron. In this country they have been formed chiefly by the weathering of pegmatite veins, and in rarer instances from feldspathic quartzites,[2] limestone,[3] and talcose schists.[4] There are some other occurrences, as those of Edwards County, Texas, and the indianaite of Indiana,[5] whose exact origin does not seem satisfactorily proven.

In Europe they have been formed by the alteration (in most cases probably by weathering) of other rock types, especially granite and quartz-porphyry.

The mode of origin of kaolin, and changes accompanying same, have been discussed on another page (p. 8), and it need simply be repeated here that kaolins formed by weathering will grade downward into the parent rock, while the depth of those caused by fluoric action will depend on the depth of the parent rock and the extent of the path through it of the kaolinizing vapors.

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[1] The white-burning sedimentary clays found in the coastal plain area of the Southern Atlantic States are at times termed *kaolins*, but it would seem wiser, perhaps, to term these *plastic kaolins* to distinguish them from the residual ones.

[2] H. Ries, Private publication of the Kaolin Co., Cornwall, Conn.

[3] Wheeler, Mo. Geol. Surv., XI, p. 162, 1896.

[4] Hopkins, Ann. Rept. Pa. State College, 1898–99.

[5] Blatchley, Ind. Dept. Geol. and Nat. Res., XXIX, p. 55, 1904.

Most kaolins as mined are rather siliceous, but in their washed condition approach closely to the composition of kaolinite, from which it has been sometimes argued that kaolins are composed chiefly of kaolinite and quartz. The author himself held this view for some time, but now feels that it is not safe to make such a broad statement.

Fig. 36.—Map showing kaolin and ball-clay deposits of United States, east of the Mississippi River. (After H. Ries, U. S. Geol. Surv. Prof. Pap. 11, p. 284, 1903.)

The incorrectness of this theory becomes apparent if we examine any series of kaolin analyses, from which it can be seen that the alumina-silica ratio is often higher than that required for kaolinite, and this seems best accounted for on the supposition that some of the other hydrous aluminum silicates, such as pholerite or halloysite, are present.

Again, a washed kaolin might have as much as 20 per cent white mica, and yet on analysis show a composition approaching rather closely to that of kaolinite.

All of these minerals—kaolinite, pholerite, halloysite, and muscovite—are decomposed by treatment with hot sulphuric acid, and therefore reported in the rational analysis as clay substance. This is unfortunate, because mica is not refractory and should not therefore be grouped with the other three.

There is also the possibility that in some highly aluminous kaolins some aluminum hydroxide, such as bauxite or gibbsite, might be present.

Chemical composition.—The analyses shown on page 203 of both native and foreign kaolins, will give some idea of their composition. All of these are washed samples with the exception of No. I. A comparison of analyses I and II will therefore show the beneficial effects of washing.

It will be noticed that all of these analyses show a small percentage of alkalies, due probably to the presence of some undecomposed feldspar or muscovite.

Physical tests.—When tested physically they all show a low air-shrinkage, low tensile strength, are white-burning, and usually highly refractory. The following tests bring out these points well:

1. Kaolin from Harris Clay Company, Webster, N. C.—Works up with 42 per cent of water to a lean mass. Air-shrinkage, 6 per cent; fire-shrinkage at cone 9, 4 per cent; average tensile strength, 22 pounds per square inch; fuses about cone 33.[1]

2. Kaolin from Glen Allen, Mo.—Requires 23.2 per cent of water to work it up to a lean paste whose air-shrinkage is 4 per cent and fire-shrinkage, at 2500° F., 8.4 per cent; average tensile strength, 12 pounds per square inch; incipient fusion, 2200° F.; vitrification at 2500° F.[2]

3. Kaolin, Oak Level, Henry County, Va.—Water required, 48.4 per cent; plasticity and tensile strength, low; air-shrinkage, 1.6 per cent; fire-shrinkage, cone 9, 8 per cent, with absorption 36.08 per cent; fusion-point above cone, 27.

Distribution.—The known workable deposits of kaolin found in the United States are all located east of the Mississippi River, with the exception of those found in Missouri, Utah, and Texas. The last-named two are not worked. The distribution of those east of the

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[1] N. C. Geol. Surv., Bull. 13, p. 59, 1897.

[2] Mo. Geol. Surv., XI, p. 578.

Mississippi River is shown in Fig. 36, and the Missouri deposits in Fig. 56. Reference is made to their occurrence undei the state descriptions in Chapters VI and VII.

ANALYSES OF KAOLINS

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	62.40	45.78	46.28	73.80	46.50	72.30
Alumina (Al_2O_3)	26.51	36.46	36.25	17.30	37.40	18.94
Ferric oxide (Fe_2O_3)	1.14	.28	1.644	.35	.80	.40
Ferrous oxide (FeO)	....	1.08	....	....	....	....
Lime (CaO)	.57	.50	.192	....	tr.	.68
Magnesia (MgO)	.01	.04	.321	1.18	....	.39
Potash (K_2O)	.98	.25	1.69	2.49	1.1	.42
Soda (Na_2O)			.85	.20		
Titanium oxide (TiO_2)	....	....	....	....	....	....
Water (H_2O)	8.80	13.40	13.535	4.69	12.49	7.04
Moisture	.25	2.05	....	....	....	....
Total	100.66	99.84	100.762	100.01	98.29	99.57

	VII.	VIII.	IX.	X.	XI.
Silica (SiO_2)	45.44	46.38	48.26	46.87	47.71
Alumina (Al_2O_3)	40.30	39.76	37.64	38.00	36.78
Ferric oxide (Fe_2O_3)	.54	.79	.46	.89	....
Ferrous oxide (FeO)	....	....	....	....	....
Lime (CaO)	tr.	.44	.06	tr.	....
Magnesia (MgO)	tr.	.05	tr.	.35	....
Potash (K_2O)	tr.	1.80	1.56	1.22	2.58
Soda (Na_2O)	.38	.20			
Titanium oxide (TiO_2)	....	.28	....	....	....
Water (H_2O)	13.9	10.26	12.02	12.70	13.03
Moisture	....	....	....	....	....
Total	100.56	99.96	100.00	100.03	100.10

I. Webster, N. C. Crude kaolin. N. C. Geol. Surv., Bull. 13, p. 62, 1897.
II. Webster, N. C. Washed kaolin. Ibid.
III. Brandywine Summit, Pa. Hopkins, Pa. State Coll., App. Rept., 1898–99, p. 36.
IV. Upper Mill, Pa. T. C. Hopkins, Ann. Rept., Pa. State Coll., 1899–1900, p. 11.
V. West Cornwall, Conn. H. Ries, Anal.
VI. Glen Allen, Mo. Mo. Geol. Surv., XI, p. 562, 1896.
VII. Leaky, Edwards County, Texas. O. H. Palm, Anal.
VIII. Oak Level, Henry County, Va. Analyzed by Va. Geol. Surv.
IX. Cornwall, Eng.
X. Zettlitz, Bohemia. U. S. Geol. Surv., Prof. Pap. 11, p. 39, 1903.
XI. Coussac-Bonneval, France.

Kaolins after washing are used in the manufacture of white ware, porcelain, floor and wall tiles, paper manufacture, and as an ingredient of slips and glazes.

Ball-clay

This includes those white-burning plastic clays of sedimentary character which are extensively used as a necessary ingredient of white-ware mixtures in order to give the body sufficient plasticity and bonding power. They must therefore contain little or no iron oxide, and possess good plasticity and tensile strength. Refractoriness is desirable, but those imported vitrify at cone 8, while the native ones require a much higher heat for vitrification. Some ball-clays as those of Florida require washing before shipment to market.

Chemical composition.—The following table gives the composition of several American ball-clays, as well as that of an English ball-clay:

ANALYSES OF BALL-CLAYS

	I.	II.	III.	IV.	V.
Silica (SiO_2)	46.11	45.57	56.40	45.97	48.99
Alumina (Al_2O_3)	39.55	38.87	30.00	36.35	32.11
Ferric oxide (Fe_2O_3)	.35	1.14	....	1.08	....
Ferrous oxide (FeO)	....	....	....	....	2.34
Lime (CaO)	....	tr.	.40	1.14	.43
Magnesia (MgO)	.13	.11	tr.	1.09	.22
Potash (K_2O)	....	.16	3.26	1.84	3.31
Soda (Na_2O)	....	.00	2.01		.....
Titanium oxide (TiO_2)	1.20	1.30	....	....	....
Sulphur trioxide (SO_3)	.07	....	....	....	....
Water (H_2O)	13.78	14.10	7.93	12.36	9.63
Moisture	.....		.....	....	....
Total	101.19	101.25	100.00	99.83	97.03

I. Edgar, Fla. U. S. Geol. Surv., Prof. Pap. 11, p. 39.
II. Woodbridge, N. J. N. J. Geol. Surv., Fin. Rept. VI, p. 443.
III. Mayfield, Ky. U. S. Geol. Surv., Prof. Pap. 11, p. 39.
IV. Regina, Mo. Mo. Geol. Surv., XI, p. 566, 1896.
V. "Poole" clay, Wareham, Eng.

Physical characters.—The physical properties of some of the well-known ball-clays used in this country are as follows:

Edgar, Fla.—Very plastic; average tensile strength, 150 pounds per square inch; total shrinkage at cone 9, 15 per cent.

Woodbridge, N. J.—Water required, 33 per cent; plasticity, fair; air-shrinkage, 3.4 per cent; average tensile strength, 33 pounds per square inch. At cone 10, fire-shrinkage 16.6 per cent and absorption 0.22 per cent; fusion-point, cone 34.

Distribution.—The number of known localities in the United States at which ball-clays occur is small, and are shown in Figs. 36 and 55. They are obtained from the Tertiary (Florida, Kentucky, Tennessee) and Cretaceous (New Jersey) formations, and in residual deposits derived from Palæozoic limestones (Missouri).

Fire-clays.

The term fire-clay, properly speaking, refers to those clays capable of withstanding a high degree of heat, but it is unfortunately most loosely used by American clay-workers, and many plastic materials which have absolutely no claim to refractoriness are included under this head. It is to be greatly regretted that no standard of refractoriness has been adopted by producers and consumers of refractory clays in the United States, nor for that matter in Europe, although the term is probably less abused there than it is here. In the author's opinion no clay should be classed as a fire-clay unless its fusion point is higher than that of cone 27, and this agrees with the common usage of the German clay-workers.

In many parts of the United States it is common to grade both fire-clays and fire-bricks as No. 1 and No. 2, a practice which should be discouraged unless the term has some standardized meaning, which it lacks at the present time. Even in the same district a No. 1 clay or brick of one manufacturer may be no better than the No. 2 clay or brick of another manufacturer. It therefore seems reasonable to urge that unless the terms No. 1 and No. 2 refer to certain definite and accepted standards, they should be dropped, as they only lead to confusion.

One common misuse of the term *fire-clay* may also be referred to in this place. It is a prevalent custom in the United States to apply the term fire-clay to all clays or shales found underlying coal-beds. While it is true that in several States, such as Pennsylvania, Ohio, West Virginia and Kentucky, valuable fire-clays underlie the coals, still sometimes even in these States, and always in some others, as Michigan, clay or shale is found under the coal, which is not refractory by any means. There is at times nothing in the appearance of these under-clays to tell whether they are refractory or not.

Aside from refractoriness, which is the most important property of a fire-clay and the one possessed by all true ones, they vary widely, showing great differences in plasticity, density, shrinkage, tensile strength, and color. Since the resistance of a fire-clay to heat is governed primarily by its chemical composition and secondarily by its texture, it may be well to consider first the former property.

Chemical composition—Fire-clays contain practically all the substances usually determined by the ultimate analysis (p. 60), but in every good fire-clay the total percentage of certain fluxing impurities, such as ferric oxide, lime, magnesia, and alkalies, is small. This is necessarily the case, since, if the fluxing impurities were present in large quantities, the clay would fuse at comparatively low temperatures and could not be classed as refractory.

Effect of silica.—It is found, however, that clays running low in fluxes but high in silica may also show poor refractoriness. If we compare two fire-clays of low-flux contents, but high silica in one case and low silica in the other, it is found that, other things being equal, the high-silica clay is less refractory than the other. This indicates that a high percentage of silica, as well as a high percentage of the fluxes mentioned above, diminishes the refractoriness of the clay. We might, therefore, term the iron oxide, lime, magnesia, and alkalies low-temperature fluxes and the silica a high-temperature flux.

In any fire-clay some of the silica is combined chemically with the alumina and water, forming a hydrous aluminum silicate which for convenience of discussion we assume is kaolinite,[1] while the balance is probably there in the form of quartz.[2] If kaolinite alone is heated, its refractoriness is found to be high, for its fusion-point is the same as cone 36 of the Seger series, and the refractoriness of quartz or silica alone is nearly as high, but if these two minerals are mixed together in varying proportions, then the fusion-point of the mixtures will in every case be lower than that of either silica or kaolinite alone.

This fact was pointed out some years ago by Seger,[3] who made up a series of mixtures of alumina and silica, and kaolin and silica. In the former series of mixtures the quantity of alumina in each case was the same, but the amount of silica was increased. Starting with 1 part of alumina to 1 of silica by volume[4] (91.5 of alumina to 8.5 of silica by weight), a mixture, the fusion-point of which was the same as that of cone 37, he found that the refractoriness decreased until a mixture of 1 part alumina to 17 parts of silica (10 alumina to 90 silica by weight) was reached. The fusing-point of this mixture was cone 29. A further increase in the amount of silica caused the refractoriness to rise steadily. This shows that silica added to alumina in certain proportions acts as a flux at high temperatures.

If now silica is mixed with kaolinite in the same manner, a similar lowering of the refractoriness of the body takes place down to a certain point beyond which the fusion-point again rises. These experi-

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[1] It probably is in most fire-clays.

[2] There cannot be many silicate minerals, such as feldspar, mica, etc., in a fire-clay, otherwise the percentage of alkalies, magnesia, lime, and iron oxide would be higher than it usually is, so that the balance of the silica must be quartz.

[3] Seger, Gesammelte Schriften, p. 434, 1896. Amer. Ceram. Soc., Translation, I, p. 545.

[4] What is meant here is parts by volume which would not be the same as parts by weight, because the two substances have different specific weight5, hence 1 alumina to 1 silica per volume would be 91.5 per cent alumina to 8.5 silica by weight.

PLATE VII

FIG. 1.—Section showing fire-clay underlying coal-seam. The upper clay above coal is of impure character. (Photo loaned by Robinson Clay-product Company.)

FIG. 2.—Fire-clay underlying Lower Mercer limestone, Union Furnace, O. (Photo by B. S. Fisher.)

ments of Seger are shown graphically in Fig. 33, in which the horizontal lines represent the different cone numbers from 26 to 38 inclusive. The divisions on the lower line represent percentages of alumina measured above the line, 100 per cent being at the left end, and percentages of silica measured below the line, 100 per cent being at the right end. The solid curve represents the silica and alumina in a silica-alumina mixture, while the dotted curve represents the silica and alumina in silica-kaolin mixture. An inspection of these curves shows quite clearly how an increase in the percentage of silica up to a certain point causes a dropping of the fusion-point, but that a further increase in the silica contents raises it again, although not quite as high as it originally was.

It will be seen from a comparison of these two curves that the kaolinite-silica mixtures have lower refractoriness than the pure silica-alumina mixtures. This effect of silica has not always been understood by fire-brick manufacturers, many believing that sand added to the refractoriness of a clay in burning. While this is indeed true in the case of brick-clays, it is to be remembered that common brick is burned at a much lower temperature than that at which alumina and silica flux together.

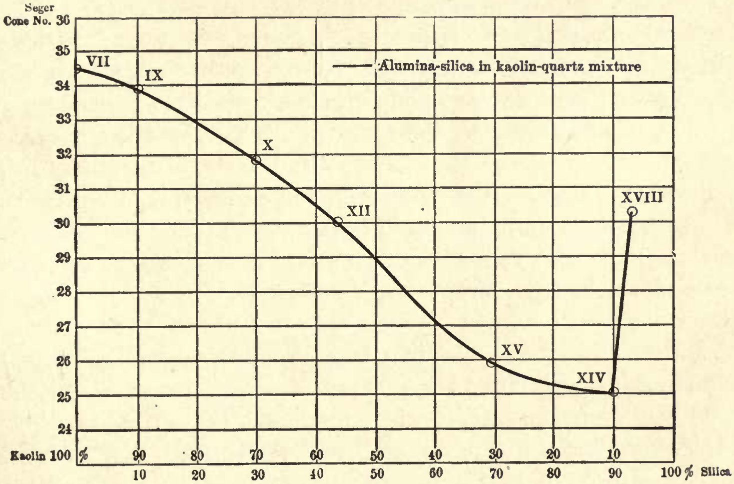

FIG. 37.—Diagram showing effects of silica on fusibility of kaolin. (After Ries, N. J. Geol. Surv., Fin. Rept. VI, p. 313, 1904.)

Recent tests made on a series of fire-clays from New Jersey[1] agreed with Seger's results in a general way but not exactly, the plotted fusion-

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[1] N. J. Geol. Surv., Fin. Rept., VI, p. 314, 1904.

points forming a curve on which corresponding points were somewhat lower than those on Seger's.

In order to test his experiments a series of mixtures of a white-burning clay (having practically the composition of kaolinite) and finely ground quartz were made up and their fusion-points tested in the Deville furnace. These results were plotted in a curve (Fig. 37), which in its general form agrees with that of Seger, but shows lower cones of fusion for corresponding mixtures. The results obtained with New Jersey clays seem to agree more closely with this curve than they did with Seger's. (Fig. 33.)

Effect of titanium.—It will be noticed that the percentage of titanium oxide has been determined separately in several of the analyses (p. 212). and from the quantity present it is believed to exert some influence. As has been mentioned under Titanium (p. 104), the presence of 2 per cent of titanium seems to lower the refractoriness a whole cone number, while 0.5 per cent lowered it half a cone when it was mixed with kaolin alone. Since titanium exerts an appreciable effect on the fusibility of a fire-clay, it should always be determined in the analysis.

Physical properties.—As mentioned above, the term *fire-clay* does not signify the presence of any other character than refractoriness, and fire-clays may therefore vary widely in their plasticity, shrinkage, texture, color, tensile strength, and other physical properties, all of which affect the behavior of the clay during the process of manufacture, but none of which can be used as a sure guide in determining its probable refractoriness. Color may be an aid under certain conditions, since pure white clays and light yellowish clays are often at least semi-refractory and sometimes highly refractory. Some fire-clays are tinged a deep yellow or yellowish red, as though they contained considerable iron oxide, and yet they have excellent heat-resisting power. If the clay is black or bluish black, there is no means of telling from mere inspection what its heat-resisting qualities are, for under these conditions both a clay with very little iron oxide and one with much might outwardly appear the same.

Plasticity has little or no direct relation to refractoriness, although Seger has pointed out that of two clays of unequal refractoriness the one of lower fire-resisting qualities may withstand the action of molten materials better if it is of high plasticity, as this makes it burn to a dense body at a comparatively low temperature. The result of this is that the pores are closed and the clay resists the corrosive action of a fused mass better than the more refractory clay, which does not burn dense at as low a temperature as the first one, and which, therefore, permits a molten mass to enter the pore-spaces between its grains.

Fire-clays are of variable tensile strength. Some of the highest grades show low tensile strength and often require a more plastic material to raise it, such an addition being sometimes necessarily done at a slight sacrifice of refractoriness.

Texture is a property of some importance, for, other things being equal, the coarser grained of two clays is usually the more refractory. The question often arises whether, in making up cones for testing the refractoriness of a fire-clay or fire-brick it should be ground up fine or not. In the writer's opinion, fine grinding will not effect its refractoriness, if there is uniformity of composition in both the fine and coarse parts. If, however, for example, the fine parts are highly aluminous and the coarse parts very silicious, then when the clay is heated, active fluxing between the clay and silica is prevented, and the clay fuses at a higher point than one might assume it would from the chemical analysis.

As an illustration of this, we may take the case of some New Jersey fire-brick, containing about 75% silica, which is present largely in the form of coarse quartz grains. These bricks when tested in the Deville furnace, fused at cone 33. If ground up to pass easily through a 100-mesh sieve, the refractoriness dropped to cone 27, because the alumina and silica were more intimately mixed and could flux more freely.

Analyses of fire-clays—The analyses given on pp. 211–212 show the composition of a number of fire-clays from various localities in the United States, and for additional ones reference should be made to the State descriptions.

ANALYSES OF FIRE-CLAYS

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	74.25	63.00	52.52	59.92	62.89	51.92
Alumina (Al_2O_3)	17.25	23.57	31.84	27.56	21.49	31.64
Ferric oxide (Fe_2O_3)	1.19	.46	.67	1.03	....	....
Ferrous oxide (FeO)	....	1.87	....	....	1.81	1.13
Lime (CaO)	.40	.44	.50	tr.	.38	.03
Magnesia (MgO)	tr.	.89	.19	tr.	.56	.44
Potash (K_2O) Soda (Na_2O)	.52	2.40 .29	.59	.67	2.52	.40
Sulphur trioxide (SO_3)	....	....	....	....	....	....
Titanic acid (TiO_2)	....	1.10	1.68	....	1.82	1.16
Water (H_2O)	6.30	6.45	11.68	9.70	7.58	13.49
Moisture	....	....	....	....	1.16	....
Total	99.91	100.47	99.67	98.88	100.21	100.21

ANALYSES OF FIRE-CLAYS—*Continued*

	VII.	VIII.	IX.	X.	XI.	XII.
Silica (SiO_2)	51.56	46.56	59.36	61.44	73.00	50.35
Alumina (Al_2O_3)	33.13	37.47	23.26	26.18	15.79	33.64
Ferric oxide (Fe_2O_3)	.78	tr.	3.06	.30	.63	.75
Ferrous oxide (FeO)	....	....	....	.36	....	....
Lime (CaO)	tr.	.112	.65	.12	1.29	....
Magnesia (MgO)	tr.	tr.	.42	....	1.53	tr.
Potash (K_2O)	tr.	.28	.63	.....	.10	.49
Soda (Na_2O)	tr.	.28		.02	.16	.09
Sulphur trioxide (SO_3)	....	....	.35	....	....	....
Titanic acid (TiO_2)	1.91	....	1.01	1.39	.43	.80
Water (H_2O)	12.50	13.03	10.20	9.07	5.76	11.75
Moisture			2.74	.77	....	2.13
Total	99.88	97.732	101.68	99.65	98.69	100.00

	XIII.	XIV.	XV.	XVI.	XVII.
Silica (SiO_2)	40.28	54.80	44.16	39.56	73.20
Alumina (Al_2O_3)	34.72	29.44	37.34	43.35	18.56
Ferric oxide (Fe_2O_3)	.84	1.70	1.28	2.57	.50
Lime (CaO)	.05	....	.25	.56	.29
Magnesia (MgO)	.04	....	tr.	.50	.52
Potash (K_2O)	tr.	.....	.53	.....	.36
Soda (Na_2O)	....	.....		.....	.38
Sulphur trioxide (SO_3)	tr.	....	.31		
Titanic acid (TiO_2)	1.15	.82	tr.	....	....
Water (H_2O)	12.39	8.84	14.60	13.09	5.93
Moisture	10.72	2.37	2.82	....	....
Total	100.19	97.97	101.29	99.63	99.74

I. Bibbville, Ala. Ala. Geol. Surv., Bull. 6, p. 152, 1900.
II. Mecca Parke County, Ind. Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 507, 1905.
III. Mineral Point, O. (Flint-clay). Mo. Geol. Surv., XI, p. 591, 1896.
IV. Salineville, O. (Flint-clay). Ohio Geol. Surv., VII, p. 221, 1893.
V. Lower Kittanning clay, New Brighton, Pa., 2d Pa. Geol. Surv., MM, p. 262.
VI. Bolivar flint fire-clay, Salina, Pa. Ibid., p. 259.
VII. Woodbridge, N. J. No. 1 fire-clay, N. J. Geol. Surv., VI, p. 441, 1904.
VIII. Boone Furnace, Ky. Coal measures, U. S. Geol. Surv., Prof. Pap. 11, p. 119.
IX. St. Louis, Mo. Mo. Geol. Surv., XI, p. 571, 1896.
X. Piedmont, W. Va. Mount Savage clay, W. Va. Geol. Surv., III.
XI. Athens, Tex. O. H. Palm, analyst.
XII. Golden, Colo. U. S. Geol. Surv., Mon. XXVII, p. 390.
XIII. Dry Branch, Ga. U. S. Geol. Surv., Bull. 315, p. 303, 1907.
XIV. Coal-measures clay, Utica, Ill. Ill. Geol. Surv., Bull. 4.
XV. White clay, Subcarboniferous, 5 m. s. e. Bonnieville, Ky. Ky. Geol. Surv., Bull. 6.
XVI. "Aluminite," Olive Hill, Ky., Carboniferous. Trans. Amer. Ceram. Soc., IX, p. 461, 1907.
XVII. White siliceous Tertiary clay, N. Dak. 4th Bien. Rept., Dak. Geol. Surv.

Occurrence and distribution.—Fire-clays may be of either residual or sedimentary origin, and of the two the latter are by far the most important commercially. This class is further subdivisible into plastic fire-clays and flint-clays. The former are plastic when wet, the latter are hard and flint-like, with a smooth, shell-like fracture and dense texture. They develop but little plasticity, even when ground fine, but are usually highly refractory. Flint-clays are found at a number of points in the Carboniferous of Pennsylvania, Ohio, Maryland, Kentucky, and West Virginia, where they occur often underlying coal-seams and in the same bed with the plastic clay, the two showing no regularity of arrangement, and often differing but little if at all in chemical composition. They are also known in the Cretaceous of Georgia, the Tertiary of Alabama, and the Cretaceous of Colorado. Their peculiar character has been a puzzling problem to geologists, but it seems probable that they may have been formed by a solution and reprecipitation of the clay by percolating water subsequent to its formation. A second type of flint-clay is that found occupying basins in Palæozoic limestones in Missouri (which see). Some flint-clays show a higher alumina content than is required for kaolinite, and they are thought to contain pholerite. Others may carry bauxite, and some of those of northeastern Kentucky carry alumina nodules.

In many States [1] fire-clays are often found underlying coal-beds, and on this account it has been suggested that their alkalies and other fluxing impurities have been abstracted by the roots of plants which grew in the swamps in which these clays were deposited, while the decay of these plants later gave rise to the coal-bed overlying the clay. This theory seems rather improbable, as in some States, such as Michigan and Alabama, the clays and shales underlying the coals always contain sufficient impurities to render them non-refractory. Furthermore, the extensive beds of refractory clay, found in the Tertiary-Cretaceous formations of the Atlantic and Gulf coastal plains, are very rarely associated with coal-beds.

We must, therefore, assume that these clays were either derived from rocks running low in fusible impurities, or else that these were removed by solution during the transportation and deposition of the clay particles.

In the United States fire-clays are widely distributed, both geologically and geographically. The most important occurrences are in the Carboniferous of Ohio, Pennsylvania, Kentucky, Indiana, Illinois, Maryland, West Virginia, and Missouri. Many other deposits are, however, found in the Cretaceous of New Jersey, Maryland, Georgia, South Carolina, Alabama, Texas, Iowa, Colorado, South Dakota, etc., and in the Tertiary of New Jersey, Georgia, South Carolina, Alabama, Texas, Arkansas, and California.

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[1] Ohio, Pennsylvania, Kentucky, Indiana, and West Virginia.

In Pennsylvania, Maryland, Alabama, and North Carolina some pre-Devonian ones occur, but they are of limited extent.

Uses.—The main use of fire-clays is for the manufacture of the various shapes of fire-brick, but in addition they are used wholly or in part in the manufacture of gas- and zinc-retorts, locomotive and furnace linings, crucibles, floor-tiles, terra-cotta, conduits, pressed and paving bricks, etc.

Glass-pot clays form a special grade used in the manufacture of glass pots and blocks for glass-tank furnaces. These require a clay which is not only refractory but burns dense at a moderately low temperature, so that it will resist the fluxing action of the molten glass.

It must possess good bonding power and burn without warping. Great care is necessary in the selection of the clay and the manufacture of the pot.[1]

In testing a glass-pot clay physical tests are of more value than chemical analyses. Glass-pot clay is obtained from both Pennsylvania and Missouri, but much is still imported from the Gross-Almerode district of Germany.

Stoneware-clays

Physical properties.—Stoneware is usually made from a refractory or semi-refractory clay, but at some small potteries a much lower grade of material is used. While the material is often as refractory as a clay used for fire-brick, it differs from it in burning to a very dense body at a comparatively low temperature. It should have sufficient plasticity and toughness to permit its being turned on a potter's wheel. A size of grain of from 0.002 to 0.01 of an inch for the non-plastic grains in stoneware clays has proved to be most suitable. Coarse sand renders the clay so absorbent that it will not hold its shape in turning.[2]

A tensile strength of 125 lbs. per square inch or over is desirable, and the clay should also show low fire-shrinkage, good vitrifying qualities, and yet sufficient refractoriness to make the ware hold its shape in burning. Concretionary minerals, such as iron or lime, which are liable to cause blisters, should be avoided. Most stoneware is now made from a mixture of clays, so as to produce a body of the proper qualities, both before and after burning.

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[1] Ries, U. S. Geol. Surv., Min. Res., 1901. Separate sheets.

[2] Ia. Geol. Surv., XIV, p. 233, 1904.

Chemical composition.—Orton[1] gives the following average of ten separate analyses of stoneware-clays in use in Ohio potteries:

Clay base	56.65
Sandy matter	37.45
Fluxing matter	4.44
Moisture	1.57
	100.14
Total silica	65.09

A high silica content was formerly considered essential in order to produce a successful salt-glaze, but this feature is of little importance now as other kinds of glazes are almost exclusively used.

The following analyses give the composition of stoneware clays from a number of different localities.

ANALYSES OF STONEWARE CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	67.10	71.94	67.84	57.20	64.26	68.3	60.34	69.23
Alumina (Al_2O_3)	19.37	17.60	21.83	24.82	22.95	20.1	20.55	18.97
Ferric oxide (Fe_2O_3)	2.88	2.35	1.57	3.25	1.28	1.0	3.53	1.57
Ferrous oxide (FeO)	......	......	......	1.42	......	tr.	.49	.55
Lime (CaO)	tr.	.62	.28	.73	.45	tr.	.38	.12
Magnesia (MgO)	.725	.56	.24	.13	.37	2.4	1.12	.36
Potash (K_2O)	.672	1.50	2.24	.93	1.96	tr.	2.89	2.27
Soda (Na_2O)	......	......	......	......	......	.6	.73	.33
Titanic acid (TiO_2)	......	......	......	......	......	1.2	.92	1.5
Water (H_2O)	6.08	5.27	5.9	8.25	6.74	6.6	6.42	5.46
Moisture	1.71	1.01	.8	2.10	2.05	......	2.35	......
Phosphorous acid (P_2O_5)	......	......	......	......	......	......	.55	......
Total	98.537	100.85	100.70	97.83	100.06	100.20	100.27	100.37

I. Thirteen miles from Fayette C. H., Fayette County, Ala. Ala. Geol. Surv., Bull. 6, p. 176, 1900.
II. Calhoun, Henry County, Mo. Mo. Geol. Surv., XI, p. 564, 1896.
III. Woodbridge, Sussex County, N. J. N. J. Clay Rept., 1878, p. 99.
IV. Lincolnton, N. C. N. C. Geol. Surv., Bull. 13, p. 78, 1897.
V. Akron, Summit County., O. Ohio Geol. Surv., VII, p. 94, 1893.
VI. Elmendorf, Bexar County, Tex. O. H. Palm, anal.
VII. Bridgeport, Harrison County, W. Va. W. Va. Geol. Surv., III, p. 162, 1906.
VIII. Huntingburg, Ind. Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 508, 1904.

Physical tests.—The following data will serve to illustrate the physical characters of some stoneware clays:

Calhoun, Henry County, Mo.—A very plastic, buff-burning clay requiring 16.5 per cent water; average tensile strength, 150 lbs. per sq.

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[1] Ohio Geol. Surv., VII, p. 95, 1893.

in.; air-shrinkage, 5.5 per cent; fire-shrinkage, 2.2 per cent; incipient fusion, 2100° F.; vitrification, 2300° F.; viscosity, 2500° F.[1]

Northport, Long Island, N. Y.—A yellow sandy clay requiring 25 per cent water, and having fair plasticity; average tensile strength, 25 pounds per square inch; air-shrinkage, 5.5 per cent.; fire-shrinkage, 6.5 per cent; nearly vitrified at 2300° F; viscous at cone 27. This is mixed with a more plastic clay for use.[2]

South Amboy, N. J.—No. 2 stoneware clay. Water required, 37 per cent; average tensile strength, 109 lbs. per sq. in.; air-shrinkage, 7 per cent; fire-shrinkage at cone 10, 9 per cent and absorption .24 per cent; viscous at cone 30.[3]

Athens, Henderson County, Tex.—Water required, 26.4 per cent; average tensile strength, 143 lbs. per sq. in.; air-shrinkage, 6.9 per cent. At cone 9, fire-shrinkage, 6 per cent; color, buff; absorption, 7.45 per cent; viscous at cone 30.[4]

It will be noticed that no examples are given from Ohio or Indiana, both important producers of stoneware clays, the reason for this being that no tests have been published.

Stoneware clays are used not only for the manufacture of all grades of stoneware, but also for yellow ware, art ware, earthenware, and more recently even for terra-cotta.

Terra-cotta Clays

Terra-cotta is made from many different kinds of clay, but most manufacturers of this material are now using semi-fire clays, or a mixture of these with a more impure clay or shale, since these give the best results at the temperatures (cone 6–8) usually attained in their kilns. Some are used because of their dense-burning character and bonding power, others because of a low shrinkage and freedom from warping, while absence of soluble salts is an important as well as desirable property in all.

Buff-burning clays are commonly chosen, partly because they burn to a hard body at the desired temperature, and there is little danger of overburning. The color of the body is of no great importance, since the final color is applied superficially. Very few terra-cotta manufacturers at the present day employ a low-grade clay.

The soluble salts are undesirable, because in drying they may come

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[1] Mo. Geol. Surv., XI, p. 575, 1896.

[2] N. Y. State Museum, Bull. 35, p. 821, 1900.

[3] N. J. Geol. Surv., Fin. Rept., VI, p. 459, 1904.

[4] Unpublished notes.

out through the color-slip, but they can be rendered insoluble, if necessary, by treating the clay with barium chloride or carbonate.

To give a tabulated statement of the properties of clays used for terra-cotta manufacture would involve listing a very large number. It may be of interest, however, to give the properties of a terra-cotta mixture used at a large Eastern factory, the tests being made on a soft green body, as tempered at the works. Its physical properties were as follows:[1]

Air-shrinkage, 4½ per cent; tensile strength, 97.5 lbs. per sq. in. Its behavior in burning was as follows:

	Cone 01.	Cone 5.	Cone 10.
Fire-shrinkage......	1.5%	4.8%	5%
Hardness...........	not steel-hard	nearly steel-hard	
Absorption..........	very absorbent	slightly absorbent	nearly impervious
Color...............	pale buff	gray buff	gray buff

In making terra-cotta the clay is not carried to the temperature last given, as there would be danger of its warping, but it is usually fired between cones 6 and 8, at which point this danger is greatly, if not entirely, diminished.

The table on page 219 giving the physical character of some of the New Jersey clays used for terra-cotta manufacture shows what a variety of materials are employed.[2]

Clays suitable for terra-cotta manufacture are widely distributed, but those mostly used in this country are the Cretaceous clays of New Jersey and the Carboniferous clays of Pennsylvania, Indiana, and Missouri.

Sewer-pipe Clays

Since sewer-pipes have to be vitrified in burning, they require a clay high in fluxes, and the clays employed are similar to those needed for paving-brick manufacture, so that the two products are sometimes made at the same factory from the same clay. Ordinarily, some fire-clay is mixed in with the vitrifiable material, to hold its shape better in burning. A high iron percentage is said to aid the formation of the salt-glaze with which the pipes are covered, but a high percentage of soluble salts is objectionable.

The following are analyses of sewer-pipe clays from various localities:

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[1] N. J. Geol Surv., Final Rept., VI, p. 270, 1904.

[2] Ibid

Analyses of Sewer-pipe Clays

	I.	II.	III.	IV.	V.
Silica (SiO_2)	57.10	55.60	63.00	59.96	57.52
Alumina (Al_2O_3)	21.29	24.34	23.57	15.76	21.76
Ferric oxide (Fe_2O_3)	7.31	6.11	1.87	7.72	3.41
Ferrous oxide (FeO)	....	....	.46	....	3.70
Lime (CaO)	.29	.43	.44	.60	.60
Magnesia (MgO)	1.53	.77	.89	.93	.88
Potash (K_2O)	3.44	3.00	2.40	3.66	3.57
Soda (Na_2O)	.61	.09	.29	....	.03
Titanium oxide (TiO_2)	....	....	1.10	....	.83
Water (H_2O)	6.00	6.75	6.45	7.70	7.27
Moisture	1.30	2.65	....	....	.86
Sulphur trioxide (SO_3)	....	....	....	.73	....
Phosphorus pentoxide (P_2O_5)	....	....	....	....	.14
Total	98.87	99.74	100.47	97.06	100.57

I. Shale, Canton, O. Ohio Geol. Surv., VII, p. 133, 1893.
II. Shale and fire-clay mixture. Ibid.
III. Underclay, Mecca, Parker County, Ind. Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 114, 1904.
IV. Laclede mine, St. Louis, Mo. Mo. Geol. Surv., XI, p. 570, 1896.
V. Kittanning clay. Ætna mine, New Cumberland, W. Va. W. Va. Geol. Surv., III, p. 219, 1906.

Table showing Physical Characteristics of some New Jersey Terra-cotta Clays

Locality	Water required in tempering, per cent.	Air-shrinkage, per cent.	Tensile strength, lbs. per sq. in.	Cone of firing.	Fire-shrinkage, per cent	Color.	Hardness.
G. H. Cutter, Woodbridge.	26	4.6	57	Cone 05	4	Clay red.	Nearly steel-hard
				Cone 1	9.4	Deep red.	Nearly impervious.
				Cone 5	12	Very deep red.	Impervious.
				Cone 14	......	....	Viscous.
Perth Amboy Terra-cotta Co., tendency to warp.	34	6.6	142	Cone 8	7.4	Buff.	....
				Cone 26	......	....	Vitrifies thoroughly.
Clay from Perrine's Pit, known as a stoneware clay.	37	7	100	Cone 01	6	Yellowish white.	Absorbent.
				Cone 1	6	Light buff.	Steel-hard.
				Cone 3	7.6	Buff.	....
				Cone 10	9	Gray buff.	Very dense.
				Cone 27	......	....	Incipient fusion.
J. W. Paxson & Co., Bridgeboro.	22	5.3	104	Cone 05	1.3	Pale red.	Barely steel-hard, absorbent.
				Cone 3	2.7	Light red.	Steel-hard, but absorbent.
				Cone 5	4.7	Dark red	Absorbent.
				Cone 8	6.7	Gray.	Vitrified.
Hylton's Pits, Palmyra.	20	5.3	65	Cone 05	1.3	Buff.	Absorbent, not steel-hard.
				Cone 5	1.3	Buff.	Absorbent, not steel-hard.
				Cone 8	2	Buff.	Steel-hard, absorbent.
				Cone 27	......	....	Well vitrified.
Adams Clay Mining Co., east of Woodmansie.	23.3	5	73	Cone 5	2.7	Dirty white.	Steel-hard, absorbent.
				Cone 8	2.7	Dirty white.	Steel-hard, absorbent.
				Cone 10	......	Gray buff.	Small fused specks of iron silicate.

It will be seen from the above table that the clays used are mostly of low tensile strength, and that when burned at the cone number (8), at which terra-cotta is usually fired, some burned quite hard, while others were still porous. The latter kind, it will be seen, show a low shrinkage.

The sewer-pipe clays in the Eastern and Central States are obtained chiefly from the Carboniferous formations, and to a small extent from the Devonian ones. The Cretaceous and Tertiary beds of the coastal plain States are not as a rule adapted to sewer-pipe manufacture, but in the Rocky Mountain region and Black Hills area some of the Cretaceous shales have good vitrifying qualities. Pleistocene clays are used only to mix in with the other materials.

Brick-clays

Common brick.—The clays or shales used for common brick are usually of a low grade, and in most cases red-burning. The main requisites are that they shall mold easily and burn hard at as low a temperature as possible, with a minimum loss from cracking and warping. Since many common clays or shales when used alone show a higher air- and fire-shrinkage than is desirable, it is customary to decrease this by mixing some sand with the clay or by mixing a loamy or sandy clay with a more plastic one.

Common-brick clays vary widely in their composition, but most of them contain a rather high percentage of fluxing impurities.

While the chemical composition is of importance in affecting the color-burning qualities and fusibility of the mass, the physical characters are even more important, since they affect not only the color in burning, but often exert an influence on the process of molding to be chosen.

The following analyses will serve to represent their range in composition:

ANALYSES OF BRICK-CLAYS

	I.*	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Silica (SiO_2)	66.67	71.50	42.28	68.62	52.30	56.50	88.71	18.62	56.81
Alumina (Al_2O_3)	18.27	13.86	8.26	14.92	18.85	19.31	4.88	3.23	20.62
Ferric oxide (Fe_2O_3)	3.11	4.78	3.84	4.16	6.55	5.89	2.00	1.26	6.13
Lime (CaO)	1.18	.56	13.05	1.48	3.36	1.00[a]	.30	41.30	.65
Magnesia (MgO)	1.09	.11	6.01	1.09	4.49	1.85[a]	.97	.42	.58
Potash (K_2O)	2.92	2.29	2.51	1.50	4.65	5.98	tr.	......	4.47
Soda (Na_2O)	1.30	.81	.49	1.86	1.35	......	tr.	......	......
Titanic acid (TiO_2)	.85	1.44	.05	......	......	......	.90	tr.	......
Water (H_2O)	4.03	4.61	22.07	3.55	5.30	9.47[b]	2.28	2.42	8.60
Carbon dioxide (CO_2)	......	......		......	3.04	......	......	32.50	......
Manganese dioxide (MnO_2)	......	......	......	.64	......	......	......	......	......
Moisture	......	......	......	2.78	......	......	......	......	1.64
Total	99.42	99.96	98.56	100.60	99.89	100.00	100.04	99.75	99.50

a. Determined as carbonate. *b.* Includes organic matter.

* For references see foot of table, page 221.

PHYSICAL PROPERTIES OF SOME OF THE PRECEDING

		I.	II.	III.	VI.	VII.
Per cent water required		22	20.9	19.8	32	20.9
Plasticity		Good	Good	High	Good	Low
Air-shrinkage		6	6.4	6.5	6	6.6
Average tensile strength, lbs. per sq. in.		108	89.6	316	105	117
Cone 010	Fire-shrinkage	....	0	.4	Incipient fusion.... 05 Vitrification.... 01 Viscosity...... 3	....
	Absorption	....	17.40	23.23		....
Cone 05	Fire-shrinkage	4.3	1.6	slightly swelled		0
	Absorption	7.88	15.08	22.63		11.77
Cone 1	Fire-shrinkage	8.6	5	2.7		0
	Absorption	.1	7.1	16.35		13.27
Color when burned		Red	Red	Cream	Red	Red

I. Pleistocene clay, Little Ferry, N. J. N. J. Geol. Surv., VI, 220, 1904.
II. Pleistocene clay, Richmond, Va. Va. Geol. Surv., Bull. II, p. 130, 1906.
III. Calcareous Pleistocene clay, Whitewater, Wis. Wis. Geol. and Nat. Hist. Surv., Bull., 1906.
IV. Loess, Guthrie Centre, Ia. Ia. Geol. Surv., XIV, p. 541, 1904.
V. Salina shale, Warners, N. Y. N. Y. State Mus., Bull. 35, p. 830, 1900.
VI. Carboniferous shale, Grand Rapids, Mich. Mich. Geol. Surv., VIII, Pt. I, p. 41, 1899.
VII. Pleistocene brick-loam, Texarkana, Tex. O. H. Palm, anal.
VIII. Seguin, Guadalupe County, Tex. O. H. Palm, anal.
IX. Residual clay, Greensboro, N. C. N. C. Geol. Surv., Bull. 13, p. 114, 1897.

Some pretty poor clays are at times used for common-brick manufacture, but this is due to the fact that common brick will not always bear the cost of transportation, and it is sometimes necessary to use the best material that can be obtained locally, even though it be not thoroughly satisfactory.

Common-brick clays are widely distributed, both geologically and geographically.

Two varieties of brick-clay, of common occurrence west of the Mississippi River, may be mentioned here.

Adobe.—This is a calcareous silty clay, common throughout the Southwestern States and much used for making sun-dried or adobe brick.

Analyses of some adobe soils, showing their calcareous character, are given on page 222.

Loess.—This name has been applied to extensive Pleistocene deposits, which are not unlike adobe, but regarding whose origin there has been much dispute, some claiming them to be of subaqueous origin, while others consider them to be æolian formations. The loess is a very common deposit throughout the Mississippi Valley, and much used for brickmaking. Analyses by Russell[1] are given in the second table on page 222.

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[1] Geol. Mag., VI, pp. 289 and 342, 1889.

Analyses of Adobe Soils

	I.	II.	III.
Silica (SiO_2)	58.19	19.24	66.69
Alumina (Al_2O_3)	11.19	3.26	14.16
Ferric oxide (Fe_2O_3)	2.77	1.09	4.38
Lime (CaO)	12.16	38.94	2.49
Magnesia (MgO)	.80	2.75	1.28
Potash (K_2O)	tr.	tr.	1.21
Soda (Na_2O)	.18	tr.	.67
Titanium oxide (TiO_2)	1.05	....	....
Water (H_2O)	2.00	1.67	4.84
Carbon dioxide (CO_2)	8.00	29.57	.77
Phosphorus pentoxide (P_2O_5)	....	.23	.29
Sulphur trioxide (SO_3)	....	.53	.41
Chlorine (Cl)	....	.11	.34
Organic matter	....	2.96	2.00
Total	96.34	100.35	99.53

I. Laredo, Tex. O. H. Palm, anal.
II. Salt Lake City, Utah. L. G. Elkins, anal. U. S. Geol. Surv., Bull. 228, p. 367, 1904.
III. Santa Fé, N. Mex. Ibid., p. 368.

Analyses of Loess

	I.	II.	III.	IV.
Silica (SiO_2)	72.68	64.61	74.46	60.69
Alumina (Al_2O_3)	12.03	10.64	12.26	7.95
Ferric oxide (Fe_2O_3)	3.53	2.61	3.25	2.61
Ferrous oxide (FeO)	.96	.51	.12	.67
Lime (CaO)	1.59	5.41	1.69	8.96
Magnesia (MgO)	1.11	3.69	1.12	4.56
Potash (K_2O)	2.13	2.06	1.83	1.08
Soda (Na_2O)	1.68	1.35	1.43	1.17
Titanic oxide (TiO_2)	.72	.40	.14	.52
Phosphorus pentoxide (P_2O_5)	.23	.06	.09	.13
Manganese oxide (MnO)	.06	.05	.02	.12
Carbon dioxide (CO_2)	.39	6.31	.49	9.63
Sulphur trioxide (SO_3)	.51	.11	.06	.12
Carbon (C)	.09	.13	.12	.19
Water (H_2O)	2.50[a]	2.05[a]	2.70[a]	1.14[a]
Total	100.21	99.99	99.78	99.54

[a] Contains H of organic matter dried at 100° C.

Pressed brick.—Pressed brick call for a higher grade of clay. The kinds now in use fall mostly into one of three groups, namely, 1, red-burning clays; 2, white-burning clays; 3, buff-burning clays, usually semi-refractory. The composition of a sample of these three types is given in the table at top of page 223.

The physical requirements of a pressed-brick clay are (1) uniformity

ANALYSES OF PRESSED-BRICK CLAYS

	I.	II.	III.
Silica (SiO_2)	68.28	63.11	65.78
Alumina (Al_2O_3)	18.83	23.30	14.79
Ferric oxide (Fe_2O_3)	2.60	2.23	8.03
Lime (CaO)	.70	.73	.54
Magnesia (MgO)	.13	.97	1.42
Potash (K_2O)	2.29	.93	2.82
Soda (Na_2O)		.49	.97
Titanium oxide (TiO_2)	.27	....	1.00
Water (H_2O)	6.47	7.81	4.98
Moisture	.76	....	....
Sulphur trioxide (SO_3)	....	.24	....

I. A clay used for white brick, Grover, N. C. N. C. Geol. Surv., Bull. 13, p. 81, 1897.
II. Hocking Valley, O., clay. L. E. Barringer, anal. Supplied by A. V. Bleininger.
III. Shale from Cayuga, Vermillion County, Ind. Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 503, 1904.

of color in burning, (2) freedom from warping or splitting, (3) absence of soluble salts, and (4) sufficient hardness and low absorption when burned at a moderate temperature. The air-shrinkage and fire-shrinkage, as well as tensile strength, vary within the same limits as common bricks.

Red-burning clays were formerly much used, but in recent years other colors have found greater favor, and the demand for the former has greatly fallen off. Buff-burning, semi-refractory or refractory clays are, therefore, much employed now, partly on account of their color and partly because coloring materials can be effectively added to them, for since the range of natural colors that can be produced in burning is limited, artificial coloring agents are sometimes used. Manganese is the one most employed.

The clays must necessarily burn hard at a moderate temperature, and in the case of red-burning clays the temperature reached may range

PHYSICAL PROPERTIES OF SOME NEW JERSEY CLAYS USED FOR FRONT BRICK.[1]

Formation.	Water required, per cent.	Air-shrinkage, per cent.	Average tensile strength, lbs. per sq. in.	Cone of firing.	Fire-shrinkage, per cent.	Absorption, per cent.	Color.
Raritan	32.00	5.0	65	Cone 1			Buff
				Cone 5	5.0	11.68	
				Cone 8	6.6	11.34	
Cohansey	23.17	7.5	282	Cone 1	2.8	8.09	Buff
				Cone 5	4.5	3.08	
				Cone 8	6.5	0.84	
Cohansey	37.50	5.5	196	Cone 8	9.1	4.01	Buff

[1] N. J. Geol. Surv., Fin. Rept., VI, p. 222, 1904.

from the fusing-point of cone 06 to 2, while for buff-burning clays it is commonly necessary to go to cone 7 or 8 to get a steel-hard brick, unless calcareous materials are employed, and these are not burned above cone 3, or even cone 1.

In the table at bottom of page 223 are given the physical characters of some New Jersey pressed-brick clays. The properties of a shale quarried at North Bluff, Kansas City, Mo.,[1] are: water required, 22.3; plasticity, high; air-shrinkage, 6.9 per cent; fire-shrinkage, 4.8 per cent; average tensile strength, 198 lbs. per sq. in.; incipient fusion, 1600° F.; vitrification, 1750° F.; viscosity, 1900° F.; color when burned, red.

Flashing.[2]—Many bricks used for fronts are often darkened on the edges by special treatment in firing, caused chiefly by setting them so that the surfaces to be flashed are exposed to reducing conditions, either at the end of the firing or during the entire period of burning. This color is superficial and may range from a light gold to a rich, reddish brown. The principle of the operation depends on the formation of ferrous silicate and ferrous oxide and their subsequent partial oxidation to the red or ferric form. This oxidation probably takes place during cooling, for if the kiln be closed so as to shut off the supply of oxygen, the bricks are found to be a light grayish tint.

The degree of flashing is affected (1) by the composition and physical condition of the clay, (2) the temperature of burning, (3) the degree of reduction, and (4) the rate of cooling and the amount of air then admitted to the kiln.

1. The percentage of iron oxide should not be large enough to make the brick burn red, but to produce buff coloration, and the clay should have sufficient fluxes to reduce the point of vitrification to within reasonable limits, thus facilitating the flashing. Clays high in silica are apparently better adapted to flashing than those low in silica and high in alumina. The condition in which the iron is present in the clay probably exerts some influence, that is, whether it is there as ferric oxide, ferrous silicate, concretionary iron, ferrous sulphide, or perhaps ferrous carbonate. Bleininger's experiments showed that of three clays which were used for flashing, all contained considerable quantities of iron soluble in acid. Some Eastern manufacturers are obliged to add magnetite ores to their clays, which are low in combined iron, and No. 2 fire-clays, which contain more iron than the finer grades, seem to give the best results. As to the effect of the physical condition of the clay, finer grinding seems to give more uniform flashing effects, and the reason that stiff-mud bricks

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[1] Mo. Geol. Surv., XI.

[2] A. V. Bleininger, Notes on Flashing. Trans. Amer. Ceramic Soc., II, p. 74.

flash better than dry-press ones is claimed by some to be due to vitrification taking place more easily in the former.

The following analysis gives the composition of a No. 2 fire-clay from Ohio used for flashed brick:

ANALYSIS OF AN OHIO NO. 2 FIRE-CLAY

Silica (SiO_2)	67.14
Alumina (Al_2O_3)	19.74
Ferric oxide (Fe_2O_3)	2.46
Lime (CaO)	0.53
Magnesia (MgO)	0.71
Potash (K_2O)	2.80
Soda (Na_2O)	0.43
Water (H_2O)	7.01
Total	100.82

In one case the green clay showed a total of 2.15 per cent of ferric oxide, of which 0.88 per cent was soluble in acid. The flashed surface of a brick made from this clay gave, on analysis, a total of 2.31 per cent of ferric oxide, of which 0.14 per cent was soluble in nitro-hydrochloric acid, thus indicating that during the burning most of the iron oxide had combined with silica, forming a ferrous silicate.

2. The temperature reached must be sufficient to cause a combination of the iron and silica, and, therefore, it varies with different clays, the combination being aided by the presence of fluxes.

If the kiln atmosphere is oxidizing during nearly the entire burning, with only a small period of reduction at the end, the temperature reached must be comparatively high in order to insure union of the iron and silica by fusion. If, however, a reducing fire is maintained during most of the burning, then the temperature need not be as high, because the clay will vitrify sooner. (See Fusibility, Chapter III.)

At one factory it had formerly been the practice to burn with an oxidizing fire to a high temperature, namely, from cone 11–12, and then to cause reducing conditions to take place in the kiln during the last five or six hours of the burn. This practice, however, was changed, it being found that by maintaining a reducing fire during the entire period following water smoking a lower temperature was sufficient.

3. The oxidation which causes the flashing probably takes place in the first twelve hours after closing the kiln, and can be regulated by a proper handling of the dampers.

In the experiments of Bleininger, already referred to, it was found that a reduction of air, equal to 20 per cent below that required for ideal oxidation and considered as 100, is usually sufficient to produce flashing.

By this is meant that "100 per cent of air represents theoretically ideal conditions, in which just enough air is present to consume all the combustible gases forming CO_2; less than 100 per cent of air corresponds to reducing conditions. For instance, if an analysis on calculation represents 90 per cent of air, it tells us that the gases are reducing to the extent of 10 per cent of air; similarly, 110 per cent shows an excess of air to the amount of 10 per cent."

While 100 per cent represents theoretically the amount of air required for perfect combustion, still in actual practice with coal-fuel the mixture of gases is not perfect, and it may be necessary to have more than 100 per cent of air present to bring about thorough oxidation.

4. As regards the rate of cooling, it was found that the longer the period of cooling from the maximum temperature down to approximately 700° C. the darker the flash under given conditions.

Enameled brick.—The clays used for these are similar to those employed in the manufacture of buff pressed brick. The enamel is, of course, an artificial mixture, but must conform to the clay body to avoid cracking or scaling off of the coat.

Paving-brick Clays

A considerable variety of materials is used for paving-brick manufacture, ranging from common surface-clays to semi-refractory ones, but those most frequently employed are impure shales, these being often found to give the desired vitrified body at not too high a temperature. Shales of this character have a wide geographical and geological distribution, but those most extensively worked are in the Carboniferous of Ohio, Pennsylvania, Indiana, and Illinois. In New York and Maryland Devonian shales have yielded excellent results, and in the Western States, such as Colorado, the Cretaceous shales are of importance in this connection.

Wheeler[1] gives the following range of composition of paving-brick clays:

RANGE OF COMPOSITION OF PAVING-BRICK CLAYS

	Minimum.	Maximum.	Average.
Silica (SiO_2)	49.00	75.00	56.00
Alumina (Al_2O_3)	11.00	25.00	22.50
Ferric oxide (Fe_2O_3)	2.00	9.00	6.70
Lime (CaO)	.20	3.50	1.20
Magnesia (MgO)	.10	3.00	1.40
Alkalies (Na_2O,K_2O)	1.00	5.50	3.70
Ignition, loss	3.00	13.00	7.00

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[1] Mo. Geol. Surv., XI, p. 456, 1896.

Williams[1] gives the following limits between which the different ingredients of Iowa paving-brick clays range:

RANGE OF COMPOSITION OF IOWA PAVING-BRICK CLAYS

	Maximum, per cent.	Minimum, per cent.
Silica (SiO_2)	74.58	58.56
Alumina (Al_2O_3)	22.33	8.28
Ferric oxide (Fe_2O_3)	5.75	2.88
Lime (CaO)	3.42	1.55
Magnesia (MgO)	3.47	1.22
Potash (K_2O)	1.15	.29
Soda (Na_2O)	1.79	1.08
Water (H_2O)	5.33	1.07
Carbon dioxide (CO_2)	2.23	1.73
Sulphur trioxide (SO_3)	1.85	1.28
Moisture	1.13	.28

The analyses show a rather high percentage of total fluxes.

Clays for paving brick should possess fair plasticity, since they are commonly molded by the stiff-mud process; they should have good tensile strength, and a range of not less than 250° F. between the points of incipient vitrification and viscosity.

Fireproofing and Hollow-brick Clays

The clay used for making hollow bricks and fireproofing vary with the locality. At not a few yards where red bricks are manufactured the red-burning surface-clays of Pleistocene age are employed. In New Jersey, where many thousand tons are annually produced to supply the New York and other large Eastern markets, a mixture of red-burning sandy clay and a small amount of low-grade fire-clay are chosen, while in the States of the Eastern and Central coal-measure areas, as in Pennsylvania, Ohio, Indiana, and Illinois, Carboniferous shales are widely used.

It is therefore difficult to lay down any fixed set of requirements for the raw materials of this class. This much can be said: They should have sufficient plasticity to flow smoothly through the peculiar shape of die used in making them; they should also possess fair tensile strength; burn to a good hard but not vitrified body at a comparatively low cone. Concretionary masses, if present, should be either removed or crushed.

The following analyses show well the composition of clays or shales used for this kind of ware:

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[1] Ia. Geol. Surv., XIV, p. 229, 1904.

ANALYSES OF CLAYS USED FOR HOLLOW BRICK AND FIREPROOFING

	I.	II.	III.
Silica (SiO_2)	52.22	57.57	51.95
Alumina (Al_2O_3)	29.43	21.70	18.34
Ferric oxide (Fe_2O_3)	2.78	2.26	7.56
Ferrous oxide (FeO)	......	4.11	....
Lime (CaO)	.88	.32	4.14
Magnesia (MgO)	.72	1.12	3.36
Potash (K_2O)	2.10	2.16	1.43
Soda (Na_2O)	.75	.33	2.69
Titanium oxide (TiO_2)	......	1.10	....
Water (H_2O)	11.10	6.78	7.39
Moisture		......	.42
Carbon dioxide (CO_2)	......	1.73	....
Sulphur trioxide (SO_3)	......	......	2.76

I. National Fireproofing Co., Keasbey, N. J. N. J. Geol. Surv., Final Report, VI, p. 282, 1904.
II. Underclay beneath Coal II, Cannelton, Ind. Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 338, 1904.
III. Representative shale-clay from Iowa. Ia. Geol. Surv., XIV, p. 232, 1904.

The physical tests of fireproofing clays shown on page 229 are given in the New Jersey Geological Survey report.[1]

The tabulation is not without interest, and shows a considerable variation in certain directions. The air-shrinkage shows little variation, but the tensile strength shows a great range. Of these different samples, Nos. 1, 2, and 6 are practically from the same bed. No. 5 is from the base of the Raritan series, and is one of the most dense-burning clays to be found in that section or even New Jersey. Most of these clays have to be burned to cone 01 before becoming steel-hard, the one exception being No. 5, which burns very hard at cone 05. They all burn red. The pyrite and limonite nodules are abundant in some of the layers, and in burning often fuse, swell, and spall off pieces of the ware.

Slip-clays

A slip-clay is one containing such a high percentage of fluxing impurities, and of such texture that at a low cone it melts to a greenish or brown glass, thus forming a natural glaze. It must be fine grained, free from lumps or concretions, show a low air-shrinkage, and mature in burning at as little above cone 5 as possible.

While easily fusible clays are not uncommon, all do not melt to a good glaze.

"A good slip-clay makes a glaze which is free from defects common to artificial glazes. It will fit a wide range of clays, and since it is a

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[1] N. J. Geol. Surv., Final Rept., VI, p. 280, 1904.

TESTS OF NEW JERSEY CLAYS USED FOR FIREPROOFING

Locality.	Water required to temper, per cent.	Air-shrinkage, per cent.	Average tensile strength.	Cone of firing.	Fire-shrinkage, percent.	Color.	Hardness
1. Perth Amboy, black clay, small lumps of pyrite and lignite	....	5	145	Cone 05	1.6	Gray red	Not hard.
				Cone 01	2	Red	Hard.
				Cone 3	2.9	Red	Hard.
				Cone 15 to 16	......	....	Viscous at 1440° C.
2. Perth Amboy district, similar to the preceding	....	5.5	112	Cone 05	2.5	Reddish	Not hard.
				Cone 01	3	Red	Hard.
3. Lorillard	....	6	238	Cone 05	2.6	Red	Fairly hard.
				Cone 01	4	Red	Hard.
				Cone 1	5	....	....
				Cone 13 to 14	......	....	Viscous at 1400° C.
4. Spa Spring, gritty clay, moderate plasticity	....	5.5	50	Cone 05	2.5	Red	Not hard.
				Cone 1	2.5	Red	Hard.
				Cone 3	3.4	Red	Hard.
				Cone 10	11.5	Speckled gray brown	Nearly vitrified.
5. Piscataway red clay, quite plastic	36	7	129	Cone 05	4	Deep red	Hard.
				Cone 01	10	Red	Vitrified.
				Cone 3	10.7	Deep red	Well vitrified.
6. South River, dark-gray clay, mica scales and organic matter	25		84	Cone 1	8	Red	Hard.
				Cone 5	10.7	....	Vitrified.
7. Shale from Port Murray	18.5	2	51	Cone 05	1.6	Pale red	Easily scratched.
				Cone 01	2.4	Deep pink	Scratched.
				Cone 1	4.6	Red	Scratched.

natural clay it will undergo the same changes in burning as the body on which it is placed. Artificial mixtures of exactly similar composition to the natural clays have failed to give the excellent results as to gloss or color that are attained by the natural clay."[1]

While several fair slip-clays have been found in different parts of the country, none have given thorough satisfaction except the Albany, N. Y., material, which is shipped to all parts of the United States for potters' use.

In applying the glaze to the ware the clay is mixed with water to a creamy consistency and applied to the ware either by dipping or spraying. Attempts have sometimes been made to lower the fusing-point of the slip by the addition of fluxing oxides.

The following are analyses of slip-clays:

ANALYSES OF SLIP-CLAYS

	I.	II.	III.	IV.	V.
Silica (SiO_2)	55.60	43.94	63.63	38.08	57.01
Alumina (Al_2O_3)	14.80	11.17	13.57	11.36	11.85
Ferric oxide (Fe_2O_3)	5.80	3.81	7.77	2.60	3.02
Lime (CaO)	5.70	11.64	2.55	23.70	9.56
Magnesia (MgO)	2.48	4.17	1.47	tr.	1.20
Potash (K_2O)	3.23	2.90	2.63	.58	.75
Soda (Na_2O)	1.07	.71	.88	1.60	2.01
Manganese oxide (MnO)	.14	......	......	......	......
Titanium oxide (TiO_2)	......	......	......	.70	1.13
Phosphorus pentoxide (P_2O_5)	.15	......	......	......	......
Water (H_2O)	5.18	3.90	4.75	3.06	4.00
Carbon dioxide (CO_2) and moisture	4.94	15.66	2.90	18.80	8.00
Total	99.09	97.90	100.15	100.48	98.53

I. Albany, N. Y. Ohio Geol. Surv., VII, p. 105, 1893.
II. Rowley, Mich. Ibid., p. 105.
III. Brimfield, O. Ibid., p. 105.
IV. Leon Creek near San Antonio, Tex. O. H. Palm, anal.
V. Alazan Creek near San Antonio, Tex. O. H. Palm, anal.

The use of slip-clays for glazing stoneware is decreasing each year, because an artificial white glaze is now usually preferred.

MISCELLANEOUS KINDS OF CLAYS

Clays Used when Burned

Gumbo-clay.—Under this name there are included certain fine-grained, highly plastic, tenacious clays of surface character, which are found at many points in the Western Central States. Their high shrinkage

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[1] Ia. Geol. Surv., XIV, p. 224, 1904.

and dense character prohibits their use for brickmaking, but they are found excellently adapted to the manufacture of railroad ballast.

Wheeler, in describing the Missouri occurrences,[1] states that they do not differ chemically from common brick, paving brick, sewer-pipe or other burnt clays, and "their peculiar value for burnt ballast is entirely a physical one." He gives the following variation in composition:

Silica (SiO_2)	55 –65
Alumina (Al_2O_3)	15 –20
Ferric oxide (Fe_2O_3)	5 – 7
Lime (CaO)	1 – 3
Magnesia (MgO)	.5– 2
Alkalies (Na_2O, K_2O)	2.5– 4
Water (H_2O)	6 –10
Fluxes	10 –15

Their physical properties range as below:

Water required	22–25 per cent.
Average tensile strength	270–410 lbs. per sq. in.
Air-shrinkage	8–10 per cent.
Fire-shrinkage	1–6 per cent.
Incipient vitrification	1600°–1700° F.
Complete vitrification	1750°–1850° F.
Viscosity	1900°–2000° F.

Retort-clay.—A dense-burning, plastic, semi-refractory clay used chiefly in the manufacture of gas-retorts and zinc-retorts. In New Jersey the term is often applied to stoneware-clays.

Pot-clay.—A clay used for the manufacture of glass pots, and consequently representing a very dense-burning fire-clay. In refractoriness it ranges from a highly refractory to a refractory clay.

Ware-clay.—A term sometimes used for ball-clays, especially in the Woodbridge, N. J., district.

Pipe-clay.—This is a term applied to almost any fine-grained plastic clay. Strictly speaking, it would refer to a clay used for making sewer-pipe.

Sagger-clay.—This is a term applied to clays which are used in a mixture for making the saggers in which the white ware and other high grades of pottery are burned. They are commonly rather siliceous in their character, although some may be used on account of their bonding power and freedom from grit to hold the more porous grades together. As far as the physical properties go the sagger-clays are not, therefore, represented by any one type. Their refractoriness varies from that of a refractory to a semi-refractory clay.

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[1] Mo. Geol. Surv., XI, p. 542, 1896. See also Ia. Geol. Surv., XIV, p. 534, 1904.

Wad-clay.—This is a low grade of fire-clay, which is used for grouting the joints between the saggers when they are set up in bungs in the kilns.

Portland-cement clay.—The use of clay or shale for Portland cement is the most important of what may be termed the minor uses of clay. Portland cement is essentially an artificial mixture of lime, silica, and alumina. The first of these is usually supplied by some form of calcareous material, such as limestone, marl, or chalk, while the other two are obtained by the selection of clay or shale, the mixture consisting approximately of 75 per cent lime carbonate and 25 per cent clay or shale.

Clays or shales to be used for Portland-cement manufacture should be as free as possible from coarse particles or lumps of sand, gravel, or concretions. These conditions are best met by the transported clays, since residual clays are frequently sandy or stony, and many glacial clays notably so. An examination of the analyses of clays used at different works in this country shows that the silica percentage ranges from 50 to 70 per cent; when calcareous clays are used it may fall below 50 per cent.

The analyses shown on page 233 give the composition of clays employed at a number of different localities.

It is not to be understood from what has been said above that the clays whose analyses are given can be used only for Portland-cement manufacture; indeed nearly all of them could be utilized for some kind of clay product.

Clays Used in Unburned Condition

Paper-clays.—These form a type of clay much used by paper manufacturers, and which are mixed in with the pulp fiber, so that the latter can enmesh a certain amount of the clay particles. The degree of plasticity of the clay seems to play an important rôle, since it is found that a given paper will often retain a much greater proportion of some clays than others, those of which the greatest quantity is retained being the most plastic. Sand is an undesirable constituent of paper-clay, for the reason that the sand-grains wear the wires of the screens through which the materials have to pass. It can often be eliminated from the clay by washing. Whiteness of color is a third essential, and must be a primary character of the clay.

The best grades of paper-clay are some imported washed kaolins, but large quantities of good paper-clay are also obtained from the Potomac formations of Georgia, and the Cretaceous and Tertiary ones of South

ANALYSES OF PORTLAND-CEMENT CLAYS

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	53.30	63.73	74.29	64.85	55.27	40.56
Alumina (Al_2O_3)	23.29	22.12	12.06	17.98	10.20	8.52
Ferric oxide (Fe_2O_3)	9.52	9.01	4.92	5.92	3.40	2.84
Lime (CaO)	.36	2.83	.41	2.24	9.12	20.94
Magnesia (MgO)	1.49	......	.68	1.40	5.73	1.32
Potash (K_2O)	1.36	.21	.76	....	....	1.97
Soda (Na_2O)	2.76		1.80	....	....	
Sulphur trioxide (SO_3)	....	....	....	....	....	....
Carbon dioxide (CO_2)	....	....	....	4.98	......	17.90
Water (H_2O)	5.16	....	....		......	5.95

	VII.	VIII.	IX.	X.	XI.
Silica (SiO_2)	57.98	61.09	54.30	61.92	55.27
Alumina (Al_2O_3)	18.26	19.19	19.33	16.58	28.15
Ferric oxide (Fe_2O_3)	4.57	6.78	5.57	7.84	
Lime (CaO)	1.75	2.51	3.29	2.01	5.84
Magnesia (MgO)	1.83	.65	2.57	1.58	2.25
Potash (K_2O)	....	1.8	....	3.64	
Soda (Na_2O)	....	1.36	....		
Sulphur trioxide (SO_3)	1.28	1.42	2.36	tr.	.12
Carbon dioxide (CO_2)	12.08	5.13			
Water (H_2O)					

I. Little Rock, Ark. Amer. Inst. Min. Eng., Trans., XXVII, 62.
II. Santa Cruz, Cal. Min. Indus., I, p. 52.
III. Bedford, Ind. Ind. Dept. Geol. and Nat. Res., 25th Ann. Rept., p. 328.
IV. Millbury, O. Mich. Geol. Surv., VIII, Pt. III, p. 229.
V. Syracuse, Ind. Ind. Dept. Geol. and Nat. Res., 25th Ann. Rept., p. 28.
VI. Bristol, Ind. U. S. Geol. Surv., 21st Ann. Rept., Pt. 6 (ctd.), p. 400.
VII. Yankton, S. Dak. Min. Indus., VI, p. 97.
VIII. Alpena, Mich. Mich. Geol. Surv., VIII, Pt. III, p. 227.
IX. La Salle, Ill. U. S. Geol. Surv., 20th Ann. Rept., Pt. 6 (ctd.), p. 544.
X. Catskill, N. Y. Supplied by company.
XI. Glens Falls, N. Y. Min. Indus., VI, p. 97.

Carolina. The Algonkian kaolins of Maryland, Delaware, and Connecticut, as well as the white residual Cambro-Silurian ones of southeastern Pennsylvania, have also been used for this purpose.

Many of these clays are, however, also utilized for the manufacture of clay-products, such as white earthenware, wall-tile, etc.

Mineral paint.—Certain clays and shales, when ground and mixed with oil, make a good grade of mineral paint. Their color in most cases is due to some form of iron oxide, or more rarely manganese. Ocher is often nothing more than a fine-grained ferruginous clay colored by limonite, and the same may be true of sienna.

Mineral paints made from clays and shales form a cheap and satisfactory form of pigment for application to wooden surfaces. The value of the material depends to a large extent on the shade of color, its texture, and the amount of oil that has to be mixed with it in order to get the proper degree of fluidity.

Ultramarine manufacture.—Washed kaolin or even very fine-grained white sedimentary clays are used in the manufacture of ultramarine to serve as a nucleus for gathering the coloring material. For this work the clay should be as low in iron or lime as possible, and an excess of silica is undesirable.

Polishing and abrasive materials.—Many clays exert a combined polishing and abrasive action, on account of the very finely divided grains of sand which they contain. The well-known Bath brick which has such an extensive domestic use for scouring steel utensils is simply a fine-grained siliceous clay, which is deposited during high tide along the banks of the Parrot River in England.

Some clay is used for bonding purposes in the manufacture of corundum-wheels. These are burned before use, so that the clay vitrifies and holds the corundum-grains together.

METHODS OF MINING AND MANUFACTURE

METHODS OF MINING

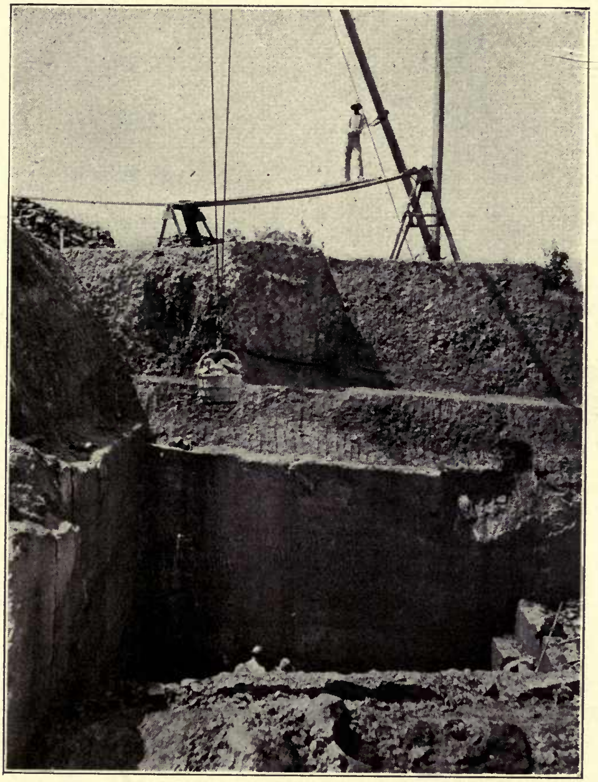
Prospecting for Clays

A knowledge of the facts given in Chapter I will, if borne in mind, be of much aid to the clay-worker in prospecting for clays, but several additional points may be mentioned by which beds of clay may be located.

Outcrops.—The presence of a clay-bed is usually detected by means of an outcrop. These exposures are commonly to be found on inclined surfaces, such as hilltops, or where natural or artificial cuts have been made. The washing out of gullies by heavy rains, the cutting of a stream valley, railroad or wagon-road cuts, all form good places in which to look for outcropping clay-beds. The newer the cut the better the exposure, for the sides of such excavations wash down rapidly, and a muddy-red surface-clay or loam will often run down over a bed of lighter colored clay beneath so as to completely hide it from view. If the cut is deep and freshly made the depth of weathering can frequently be determined.

Springs.—In many cases the presence of clay is shown by the occurrence of one or more springs issuing from the same level along some hill-slope. These are caused by waters seeping down from the surface (Fig. 38) until they reach the top of some impervious clay stratum,

PLATE VIII



Showing method of working clay in a rectangular pit. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 34, 1904.)

which they then follow to the face of the bank where they issue. The presence of springs, however, cannot be used as a positive indication of clay, for a bed of cemented iron sand, or even dense silt, may produce the same effect (Fig. 39).

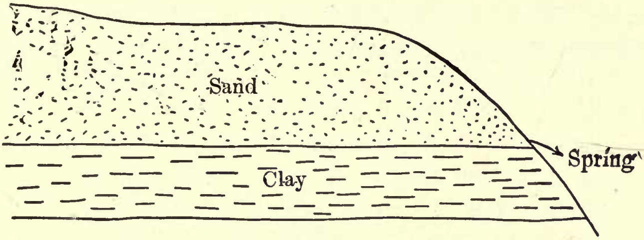


Fig. 38.—Formation of spring due to ground-water following a clay-layer.

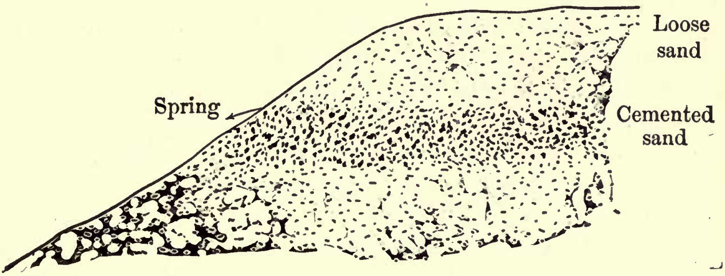


Fig. 39.—Formation of spring due to a layer of cemented sand.

Ponds.—In many regions covered by glacial drift, pools of water are often retained in depressions, because of the presence below of a water-tight bed of clay (Fig. 40). It does not necessarily indicate a thick deposit, for a very thin layer often holds up a considerable body of water. Such ponds may likewise in rarer instances be caused by ground-water seeping down from higher levels, even in the absence of clay.

Fig. 40.—Formation of a pond due to a clay-bed beneath a depression.

Vegetation.—Clay-deposits in some areas produce a different type of plant growth from other soils, but the character of the vegetation can only be used as a subordinate aid in the search of clay.

EXPLOITATION OF CLAY-DEPOSITS

The location of a clay-deposit is followed by a determination of its thickness, extent, character, and uses. The first two points and some facts bearing on the third are determined in the field; the behavior of the clay when mixed up and burned is found out by tests made in the laboratory or at some factory, and the information thus obtained indicates the commercial value of the material.

To determine the thickness and extent of the deposit a careful examination should be made of all clay outcrops in neighboring gullies, or other cuts on the property having the clay. Since, however, most clay-slopes wash down easily, it may be necessary to dig ditches from the top to the bottom of the cut or hillside in order to uncover the undisturbed clay-beds. In most cases, however, the cuts are not sufficiently close together and additional means have to be taken to determine the thickness of the deposit at intermediate points. Such data are sometimes obtainable from wells or excavations made for deep cellars, but the information thus obtained has to be taken on hearsay. Borings made with an auger furnish a more satisfactory and rapid means of determining the thickness of the clay-deposit away from the outcrop. A post-hole auger, cutting a hole of three to four inches diameter, can easily be used to a depth of 30 or 40 feet, while one of two inches diameter can be sunk to 100 feet without much difficulty.

From comparison of the data obtained from the bore-holes and outcrops, any vertical or horizontal variations in the deposit can usually be traced. Limonite concretions or crusts, if present in any abundance, are almost sure to be discovered, and even the dryness of the beds can be ascertained. Variations in the thickness of the bed and amount of stripping are also determinable. If small samples are desired for laboratory testing these can be taken from the outcrops and bore-holes, but if large samples are wanted from the intermediate points it is best to sink test-pits where the borings were made.

In some regions the clay-miners make use of an auger to guide them in their digging operations, this being often necessary on account of the rapid variations that may occur in any one deposit.

Adaptability of Clay for Working

Having determined the thickness, extent, and character of the clay there still remain several important points which have to be considered.

One of these is the amount of stripping, for if the clay is not of high grade it will not pay to remove much overburden unless the latter can be used. It is sometimes utilized for filling, where the factory is to be erected next to the bank, or for admixture with the clay, especially if the latter is too plastic or fat. In such event, however, the overburden should be free from pebbles, or if not it should be screened. Frequent neglect of this often injures the bricks. If the overburden is clean sand it can often be disposed of for foundry use, building or other purposes.

Drainage facilities must be looked out for, since dryness is essential for successful and economic working of the clay-bed. In some districts the clay is underlain by a stratum of wet sand, which should not be penetrated. In rare cases an underlying sand-bed is dry and may even serve for drainage purposes. If the clay-deposit lies below the level of the surrounding country, drainage will be more difficult than where the bed outcrops on a hillside, although in the latter case trouble may be and often is caused by springs.

Some banks contain several different grades of clay, and it then remains to see whether they are all of marketable character, or, if not, whether the expense of separating the worthless clay will overbalance the profit derived from the salable earth.

Transportation facilities are not to be overlooked, either for the raw clay or for the product, where the factory is located at the pit or bank. Long haulages with teams are costly, and steam haulage is far more economical when the output warrants it; but, even with the establishment of favorable conditions in every case, the successful marketing of the product is sometimes a long and tedious task, for many manufacturers hesitate to experiment with new clays.

Methods of Winning the Clay[1]

Clays and shales are commonly worked either as open pits or quarry workings or by underground methods. The open-pit method is practised at most localities where the deposit lies at or near the surface and there is little or no overburden to be removed. If the clay is soft and the quantity to be dug small picks and shovels are commonly used, but for more extensive operations plows and scrapers are cheaper and of greater capacity. In extensive works steam-shovels (Pl. XXVI, Fig. 1) are the best and most economical means, and capable of excavating even soft shales. They can be used with a face of 15 or 20 feet height, but have the disadvantage of mixing the clay from the top to the bottom of the bank.

In deposits of very tough clay or hard shale blasting is frequently

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[1] In this connection see J. K. Moore and H. R. Straight, Methods and Estimates of Cost of Handling Clay and Clay Materials, Clay Worker, XLVII, pp. 651 and 785, 1907.

necessary in order to loosen up the material. Since surface-waters often trickle through the soil until they reach a clay-surface and follow it, there is not infrequently a series of small springs emerging along the top of a clay-bank, and the water from these is usually diverted by means of properly constructed ditches. In addition to these ditches, however, it is commonly necessary to have additional ones on the ground at the base of the bank. If the bank is high, that is seventy-five feet or more and of soft clay, it is safer to work it in several benches or steps (Pl. XXXIII, Fig. 2) and not as a vertical face, for the latter will be apt to slide if the clay gets water-soaked. Neither should the factory be located close to the base of such a bank, where there is danger of slides, and the writer has seen several instances in which yards have been buried in this manner. The ease with which large masses of clay will sometimes cave or slide when softened with water was well illustrated recently at Haverstraw, N. Y., when a portion of a large cliff overlooking the clay-pits sank down, carrying many houses and people with it.

Where the clay is not of uniform quality from top to bottom, or when a number of layers of different kinds, as terra-cotta, fire-, and stoneware-clay are present, it is then necessary to strip off each one separately and place it in a storage pile by itself. This is notably the custom in the Woodbridge and Perth Amboy districts of New Jersey, and the practice followed there may be described in some detail, as the same method might be adopted in other parts of the coastal plain area.

In the area referred to the better grades of clay are generally dug by small pits. These are commonly square, and about ten to fifteen feet or more on a side (Fig. 41), and the depth is usually that of the thickness of the good clay in the bed. Around Woodbridge the miners commonly penetrate the No. 1 fire-clay or sometimes the extra sandy clay below, but the depth is oftentimes determined by the character of the ground and presence or absence of water underneath. Where there is danger of the pit caving in, the sides are sometimes protected in the weak parts by planking, held in place by cross-timbers.

The clay is dug by a gouge-spade, which differs from an ordinary spade in having a curved or semi-cylindrical blade, as well as a tread on its upper edge, to aid the digger in forcing it into the tough clay. A lump of clay dug by the pitman is termed a *spit*, and in taking out the material it is customary to dig over the area of the bottom of the pit to the depth of a spade and then begin a new spit. The thickness of any bed of clay, therefore, is always judged in spits.

Where a pit is dug so deep that it is not possible for the workman to throw or lift the lumps to the surface of the ground, a platform may

PLATE IX

FIG. 1.—Digging clay by means of open pits. At the top of the bank, in the background, a workman is driving a wedge into the clay in order to break it off The clay is hauled to the yards in carts. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 35, 1904.)

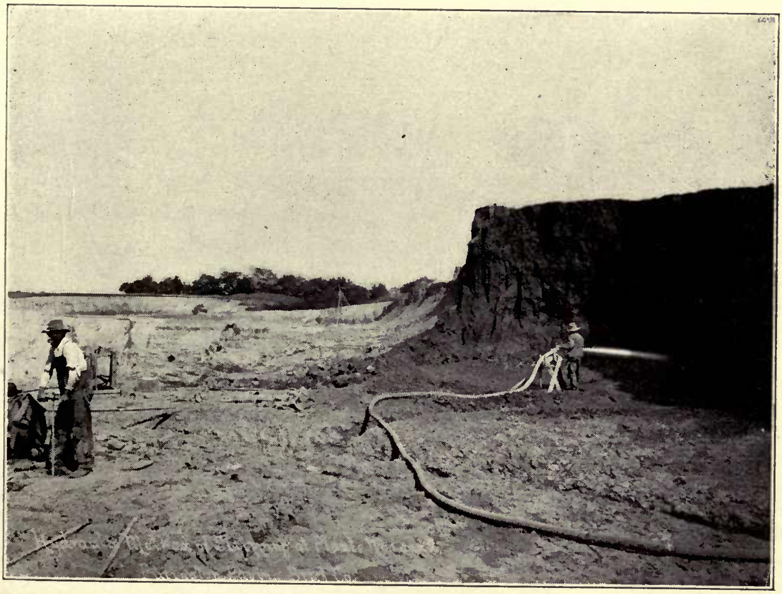

FIG. 2.—Removing the overburden from a shale-bed by hydraulicking. (Photo loaned by Illinois Geological Survey.)

be built in the pit half-way up its side, or else the clay is loaded into buckets (Pl. VIII) and hoisted to the surface by means of a derrick operated by steam- or horse-power. As soon as a pit is worked out a new one is begun next to it, but a wall of clay, 1 to 2 feet thick, is commonly left between the two. When the second pit is done as much as possible of this wall is removed. A platform of planking is laid on one side of the pit on the ground, and the clay thrown upon this, the different grades being kept separate.

When the clay lies above the ground- or road-level there is less trouble with water, and it is not necessary to work the clay in pits, although the general system of working forward in a succession of pit-like excavations or recesses is followed. In such banks the cart or car is backed against the face of the excavation and the clay thrown into it.

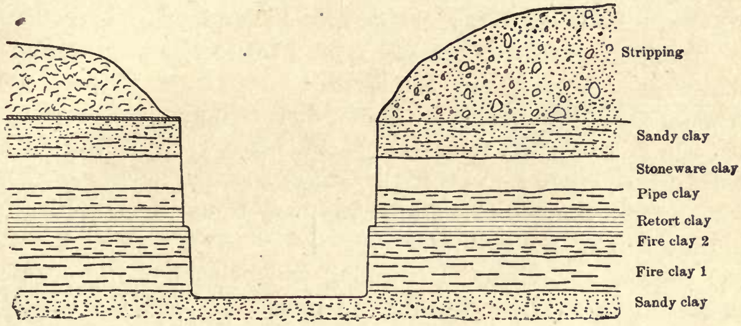

FIG. 41.—Section of pit working in Middlesex district. (After Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 33, 1904.)

Unless a number of pits are being dug at the same time, the output of any one deposit or of any one grade is necessarily small, since five or six different kinds are sometimes obtained from one pit. It would also seem that by this method any one grade of clay might show greater variation than if the excavations were more extended, for the reason that since clay-beds are liable to horizontal variation, the material extracted from one pit might be different from that taken from another farther on. Against this we may of course argue that the clays from different pits get mixed up on the storage pile.

As these pits are small and the time required for sinking one, namely, two or three days, is not very great, but little water runs in them, although in some much water comes from sand or other layers that are sometimes inter-stratified with the clay. The surface drainage is commonly diverted by means of ditches dug around the top of the pit. In some districts there is a bed of water-bearing sand underlying the lowest clay dug, and, as this is approached, hand-pumps have to be used to keep down the water until the last spit of clay is all taken out.

In digging a pit of clay, it is well to avoid discarding a clay of lower grade or mixing it with the dirt stripping, because it has no market value at the time. Careless handling of the medium-grade clays in the Woodbridge and Perth Amboy districts in the early days of their development has been the means of spoiling much clay that would now be salable.

Haulage.—If the distance from the bank to works or shipping-point is short, wheelbarrows or one-horse carts are used, but, if a longer haulage is necessary, it is more economical to lay light tracks and haul the clay in cars drawn by horses or small engines. Steam haulage is economical for a distance of perhaps not less than 1000 feet, and provided the locomotive is kept constantly employed.

When a pit is to be opened, the top dirt, stripping or bearing, as it is variously called, is first removed to some place where it will not have to be disturbed, in order to avoid the cost of a second moving, but, after one pit has been started, it is often customary to use the stripping from a new pit for filling the old one.

The cost of removing the stripping will depend on its character, whether hard or soft, the distance to be moved, and the possibility of its being used for any purpose, such as filling or grading. The methods of removal employed will also affect the expense. If the thickness of the overburden is considerable and a large quantity has to be removed, it is cheaper to dig it with a steam-shovel than by hand. Wheel-scrapers are also employed at times, and if the distance to the dump-heap is short the material can be carried there in the scraper. If the stripping can be used to mix with the clay it is sometimes dug with shovels and screened to free it from pebbles. A method tried at some localities is to remove the sandy or gravelly overburden by washing (Pl. IX, Fig. 2). This is done by directing a powerful stream of water from a hose against the face or surface of the gravel and washing it down into some ditch along which it runs off.

In selecting the site for a dump-heap, care should be taken not to locate it over any clay-deposit which is to be worked out later, but the presence or absence of such clay under the proposed dump can commonly be determined by a few bore-holes made with an auger.

Kaolin-mining.—Since most of the kaolin-deposits worked in the United States are long and narrow, a method often adopted consists in sinking a circular pit in the kaolin about 25 feet in diameter. As the pit proceeds in depth it is lined with a cribwork of wood (Pl. XXXIV, Fig. 1). This lining is extended to the full depth of the pit, which varies from 50 to 100 or even 120 feet. When the bottom of the kaolin has been reached the filling-in of the pit is begun, the cribwork being removed from the bottom upwards as the filling proceeds. If there is any overburden it is used for filling up the old pits. The kaolin is removed from the pit with a bucket-hoist, and as soon as one pit is filled a new one may be sunk in the same manner right next to it. In this way the whole vein is worked out, and, if the deposit is large, several pits may be sunk at the same time.

A somewhat unique method of mining is that practiced in the Cornwall, Eng., district where the material to be mined is a sandy kaolin of great depth. The method of working is described by J. H. Collins[1] as follows:

> "The depth of the overburden and the extent of the workable clay-ground having been sufficiently ascertained by pitting or boring (often by a combination of both methods), a shaft is sunk in the firm rock, near the clay which is to be worked, and to a depth of 15 or 20 fathoms. A cross-cut is put out from the bottom of the shaft into the clay-ground. This must be securely timbered where it approaches the clay-ground. The overburden having been removed and deposited at a convenient spot, a raise is put up vertically through the clay to the surface. In this is placed (vertically) a wooden launder, which reaches within a fathom or two of the surface, and is provided with lateral openings a foot or two apart, each of which is closed by a temporary wooden cover. This is called a 'buttonhole' launder. The shaft having been equipped with a suitable pump, work may be begun at once. The clay-ground, to a depth of a fathom or so around the buttonhole launder, is removed and a stream of water, pumped from the shaft or brought along from some other source, is made to flow over the broken ground, which is at the same time stirred up as may be necessary. The fine clay particles, held in suspension in the milky stream, pass down the launder and along the cross-cut to the shaft, whence they are pumped up for further treatment. The quartz-grains ('sand') and the coarser particles of mica, schorl (tourmaline), etc., are shoveled up from around the launder and trammed away to the waste-dump. As the depth of the workings increases, other 'buttonholes' are opened, the inclination of the clay 'stopes' being at the same time maintained by removing more overburden and by cutting away the margin of the pit.
>
> "The clay raised in suspension from the shaft by the pump is made to flow through a long series of shallow troughs called 'micas'; these are set nearly level, and the stream is divided again and again so as to lessen the rate of flow and to allow the fine sandy and micaceous particles to settle. Finally, the refined-clay stream is led into circular stone-lined pits, preferably from 12 to 18 ft. deep, where the clay settles to a creamy consistency, while the overflow of nearly clear water is conducted back to the clay-stopes, where it again serves for the washing process. The deposit in the 'micas' is swept out from time to time, an operation which

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[1] Min. Indus., XIII, p. 472, 1905.

occupies only a few minutes, after which they are again ready to receive the clay stream. The thickened clay from the pits passes to large stone-built or stone-lined tanks, which are from 5 to 8 ft. deep. In many cases they consist merely of two dry-built rubble walls placed as far apart as the depth of the tank and puddled between with waste sand, containing a little clay from some previous working. From the tanks, after further settlement, it is trammed into the kiln or 'dry.' The deposit in the micas is sometimes re-washed, so as to yield an inferior product, which is commercially sold as 'mica' or 'mica-clay.'

"*Carclazite*[1] varies much in productiveness; in obtaining one ton of fine clay the following by-products have to be dealt with: From 3 to 7 tons of sand, average 4 tons; 2 to 5 cwt. of coarse mica, average 3 cwt.; 1 to 3 cwt. of fine mica (mica clay), average 2 cwt.; ¼ to 1 cwt. of stones, mostly quartz, with, generally, much 'schorl' from the stony veins or branches. A cubic fathom of carclazite of good quality will yield about three tons of fine clay; on an average nearly half a cubic fathom of overburden must be removed in order to get it."

A somewhat similar method has recently been adopted to work the kaolin-deposits at West Cornwall, Conn., and the following description of it is given by A. R. Ledoux:[2]

"The kaolin-deposit of West Cornwall is an alteration *in situ*—that is, it is not sedimentary. A series of clay-veins, dipping about 50° from the vertical, lie between a foot-wall of limonite and a hanging-wall of gneiss and hornblende schist. The clay-veins alternate with veins or seams of more or less broken quartz and unaltered feldspar. The deposit, which occurs at a point about 600 ft. above the Housatonic River, was opened five years ago, and about 5000 tons of washed kaolin has been extracted from open pits and sold.

"Mr. Wanner conceived the scheme to disintegrate the kaolin *in situ* by means of jets of water under sufficient pressure, and floating the resultant product to the surface. To accomplish this result holes are drilled through the overlying gneiss, a pipe of 4-in. internal diameter is inserted into the bore and driven into the clay-body to within a few feet of the foot-wall. The wells in operation are from 50 to 198 ft. deep. Into this 4-in. pipe or 'casing' an interior pipe is inserted of 2-in. external diameter, leaving an annular space of 1 in. for the flow of the slip. The lower end of the internal pipe is provided with a mouthpiece with several nozzle-like openings for the exit of the water; the mouthpiece rests on the clay-body, and the interior pipe sinks gradually as the clay is removed until it rests on the foot-wall of the vein. For the operation of these 'hydraulics' a head of water equivalent to a pressure of from 40 to 60 lbs. per sq. in. is required, according to the nature of the vein-matter.

"Residual kaolin slacks more or less readily, according to the amount of sand and mica mixed with it. In the case in point, it has been found that a pressure of 40 lbs. is amply sufficient to cause the disintegration, the vein-matter contains 20 per cent and the slip, discharged by the hydraulics, from 60 to 75 per cent of pure kaolin. The purity of the discharged slip is inversely proportional to the velocity of the overflow.

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[1] A name applied to the kaolin.

[2] Amer. Inst. Min. Eng., Bi-monthly Bull., No. 9, p. 379, 1906.

"Observations made during the 1905 season's work have shown that the overflow contains from 5 to 10 per cent of solid matter. A discharge of 100 gal. per min. through the annular space of 9.42 sq. in. from a depth of 127 ft. yielded 5 per cent of solid matter, of which 75 per cent was pure kaolin, while a discharge of 200 gal. per min., through the same orifice from the same depth, gave a slip containing 10 per cent of solid matter but only 54 per cent of pure kaolin, the rest being finely divided quartz and mica.

"In addition to the lessening of the cost of extraction, the method described has effectually solved the transportation of the product to the railroad. Heretofore, the kaolin washed and dried at the mines was carted by teams over a difficult mountain road to West Cornwall, 4 miles distant. The fuel for the whole plant had to be hauled up the mountain the same distance. With slip issuing from the hydraulics of only 10 per cent of solid matter and sufficient fineness to pass through 100-mesh screens, the conveyance of the product through a pipe-line to the Housatonic Valley offers no difficulty, and the company now contemplates the erection of a new washing-plant adjacent to the river and railroad."

Underground workings.—This method may be resorted to when the clay-bed is covered by such a great thickness of overburden that its removal would be too costly. If the bed sought outcrops on the side of a hill, a tunnel or drift is driven in along the clay-bed, as shown in Pl. VII, Fig. 2, but in case no outcrop is accessible it is necessary to sink a vertical shaft (Fig. 53) until the bed of clay is reached, and from this, levels or tunnels may be driven along the clay-bed.

Underground methods are desirable, however, only under certain conditions, which may be enumerated herewith:

1. In the case of high-grade clays.

2. Where there is much overburden as compared with the thickness of the clay-deposit.

3. There should, if possible, be a solid dense layer overlying the clay stratum, otherwise the expense of timbering for supporting the roof may be too great. Timbering is nearly always necessary in underground clay-work. Where the clay is not inter-stratified between dense water-tight beds, it is often necessary to leave the upper and lower foot of clay to form a roof and floor.

4. The workings should be free from water, both on account of the cost of removing the same and because of the tendency of wet ground to slide.

5. The output is usually restricted, unless the workings underlie a large area, and can be worked by several shafts or drifts.

Soft clays are rarely worked by underground methods, but in Maryland, Indiana, Missouri, Pennsylvania, and a few other localities, the shaly clays associated with the coals are frequently mined by shafts, drifts, or slopes.

Some of the mines are lighted by electricity and also equipped with electric hoists, drills, and haulage.

Preparation of Clay for Market

Unless clay is to be used for higher grades of ware, it rarely requires much preparation to make it marketable, for, since the impurities in clay often run in streaks or beds, they can be avoided in mining. Large concretions, pyrite nodules, and lumps of lignite are often picked out by hand and thrown to one side. Where the impurities are present in a finely divided form and distributed throughout the clay, screening or hand-picking may be ineffective, and washing is necessary.

Washing.—The method of washing most commonly adopted is the troughing method, in which the clay, after being stirred up and disintegrated with water, is washed into a long trough along which it passes, dropping its sandy impurities on the way and finally reaching the settling-vats, into which the clay and water are discharged, and where the clay finally settles.

Details.—The disintegration of the clay is generally accomplished in washing-troughs. These consist of cylindrical or rectangular troughs, in which there revolves a shaft, bearing a series of arms or stirrers. The clay may be taken from the bank direct to the washer, or it may first receive a soaking in a pit to slake it. As the clay is put into the washer a stream of water is directed on it, and the revolving blades break up the clay so that it goes more readily into suspension. The water, with suspended clay, then passes out at the opposite end from which the water entered.

The troughing (Pl. X, Fig. 1) into which the material is discharged is constructed of planking and has a rectangular cross-section. Its slope is very gentle, not more than 1 inch in 20 feet usually, and its total length may be from 500 to 700 feet, or even 1000 feet. In order to economize space it is usually built in short lengths, which are set side by side, and thus the water and clay follow a zigzag course. The pitch, width, and depth of the troughing may be varied to suit the conditions, for at some localities it is necessary to remove more sand than at others. If the clay contains very much fine sand the pitch must be less than if the sand is coarse, since fine sand will not settle in a fast current. In the case of very sandy clays, it is customary to place sand-wheels at the upper end of the troughing. These are wooden wheels bearing a number of iron scoops on their periphery. As the wheel revolves the scoops pick up the coarse sand which has settled in the trough and, as the

PLATE X

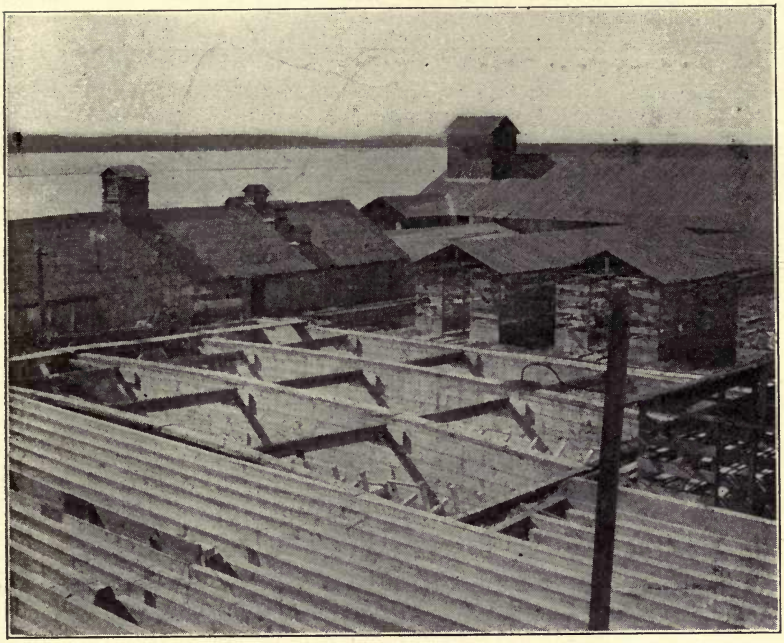

FIG. 1.—View showing portion of sand-troughs, settling-tanks, and drying-racks at a kaolin-washing plant. (After Ries, Md. Geol. Surv., IV, p. 270, 1902.)

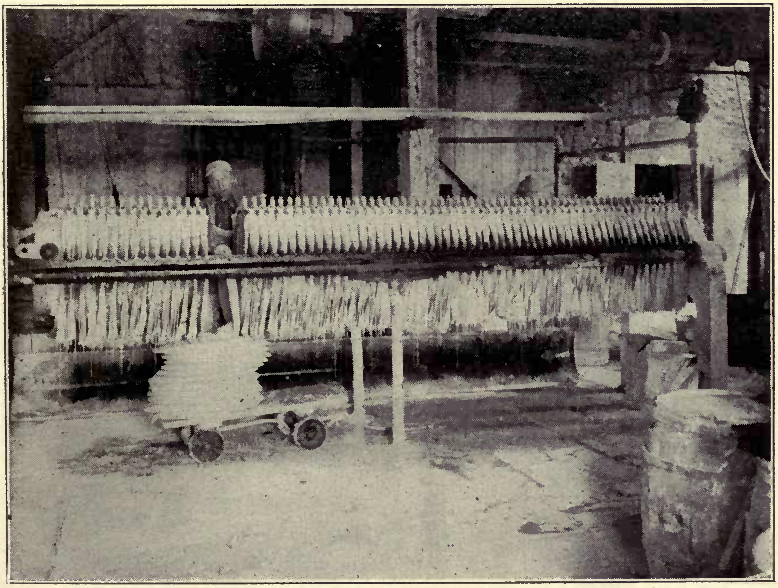

FIG. 2.—Filter-press for removing water from washed or blunged clays. The portion at the left end has been emptied and the leaves of clay taken from it are on the car. The workman is just removing a leaf of clay from the press. (After Ries, N. Y. State Mus., Bull. 35, p. 792, 1900.)

scoop reaches the upper limit of its turn on the wheel, by its inverted position it drops the sand upon a slanting chute, which carries it outside the trough.

By the time the water reaches the end of the troughing nearly all the sand has been dropped and the water and clay are discharged into the settling-tanks, passing first, however, through a screen of about 80 or 100 mesh. This catches any particles of dirt or twigs and thus keeps the clay as clean as possible.

The settling-tanks (Pl. X, Fig. 1) are of wood, usually about 4 feet deep, 8 feet wide, and 40 or 50 feet long. As soon as one is filled the water and clay are diverted into another. When the clay has settled, most of the clear water is drawn off, and the cream-like mass of clay and water in the bottom of the vat is drawn off by means of slip-pumps and forced into the presses (Pl. X, Fig. 2). These consist of flat iron or wooden frames, between which are flat canvas bags. The latter are either connected by nipples with the supply-tubes, or else there may be a central opening in all the press bags and frames, which, being in line, form a central tube when the press is closed up. By means of pressure from the pumps, the slip is then forced into the press, and the water is also driven out of it. When the water has been squeezed out the press is opened, and the sheets of clay are removed from the press cloths and sent to the drying-room or racks.

Washing is applied chiefly to kaolins, but is carried out to a less extent on fire-clays, glass-pot clays, and ball-clays.

Air separation.—This is a method of cleansing clays which has been rarely tried, yet, in some of the cases where it has been used, is said to have met with success. It is especially applicable to those clays from which it is necessary to remove simply coarse or sandy particles. The process consists, in brief, in feeding the dry clay into a pulverizer, which reduces it to the condition of a very fine powder. As the material is discharged from the pulverizer into a long box or tunnel, it is seized by a powerful current of air, which at once picks up the fine particles and carries them along to the end of the airway, where they are dropped into a bin. The coarser particles, which are too heavy to be picked up by the current, drop back and are carried through the pulverizer once more. Such a method would be especially applicable to kaolins that are free from iron, but probably would not be found adaptable to many of those containing ferruginous particles.

There are several forms of separators on the market. In the Raymond pulverizer and separator the material is pulverized in the lower part of the machine and then thrown upward, the finer particles being carried off by a fan to the discharge-hopper, the coarser ones falling back into the hopper.

THE MANUFACTURE OF CLAY PRODUCTS

Uses of Clay

Probably few persons have any conception of the many different applications of clay in either its raw or burned condition. These varied uses can be best shown by the following table, compiled originally by R. T. Hill[1] and amplified by the writer:

Domestic.— Porcelain, white ware, stoneware, yellow ware, and Rockingham ware for table service and for cooking; majolica stoves; polishing-brick, Bath brick, fire-kindlers.

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

Refractories.—Crucibles and other assaying apparatus; gas-retorts; fire-bricks; glass pots and blocks for tank-furnaces; saggers; stove and furnace bricks; blocks for fire-boxes; tuyères; cupola bricks; mold linings for steel castings.

Engineering.—Puddle; Portland cement; railroad ballast; water conduits; turbine-wheels; electrical conduits; road metal.

Hygienic.—Urinals, closet bowls, sinks, washtubs, bathtubs, pitchers, sewer-pipe, ventilating-flues, foundation-blocks, vitrified bricks.

Decorative. — Ornamental pottery, terra-cotta, majolica, garden-stands, tombstones.

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

METHODS OF MANUFACTURE

In the following pages it is intended to give a brief account of the methods of manufacture employed, so as to enable one to see what requirements a clay has to meet. The more important products are

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[1] Mineral Resources, U. S., 1891, p. 475, Washington.

taken up in the following order: Building- and paving-brick; sewer-pipe; drain-tile; hollow ware; conduits; fire-brick; roofing-tile; terra-cotta; floor- and wall-tile; pottery.

Building-brick and Paving-brick

Building-brick include common brick, face and pressed brick, enamel brick, and glazed brick, while paving-brick form a class by themselves.

Common brick include all those used for ordinary structural work, and are employed usually for side and rear walls of buildings, or, indeed, for any portion of the structure where appearance is of minor importance, although for the sake of economy they are sometimes used for front walls. They are often made without much regard to color, smoothness of surface, or sharpness of edges.

Face, front, or pressed brick include those made with greater care, and usually from a better grade of clay, much consideration being given to their uniformity of color, even surface, and straightness of outline. Red ones were formerly in great demand, but at the present time buff, white, and buff with manganese speckles are the most sought.

Enamel brick are those which have a coating of enamel on one or sometimes two sides. The body is usually a fire-clay.

Glazed brick differ from enamel brick in being coated with a transparent glaze instead of an opaque enamel. They are used more in Europe than in the United States.

The clays used for brickmaking have already been described (p. 220).

Manufacture of Brick

The methods employed in the manufacture of common and pressed brick are usually very similar, the differences lying chiefly in the selection of material, the degree of preparation, and the amount of care taken in burning. The manufacture of bricks may be separated into the following steps: preparation, molding, drying, and burning.

Preparation

In brickmaking some preparation of the clay is commonly necessary, since few clays can be sent direct from the bank to the molding-machine, although some common-brick manufacturers reduce the preparation process to a minimum.

Many clays are prepared by weathering, especially if they are to be used in the manufacture of pressed brick. This is done by distributing the clay over some flat surface in a thin layer not more than 2 or 3 feet in thickness and allowing it to lie there exposed to frost, rain, wind, and sun, which results in a slow but thorough disintegration or slacking. Iron nodules, if present, tend to rust, and are thus more easily seen and rejected, while pyrite, if present, may also decompose and give rise to soluble compounds, which form a white crust on the surface of the clay. Although some clays are prepared by weathering, yet in great part their disintegration is done by artificial means.

Crushers.—When the clay or shale is to be disintegrated or crushed, it is commonly done dry, and the machine employed varies with the character of the material. Hard shale is often disintegrated in a jaw crusher, which consists of two movable jaws that interact and are set closer together at their lower than at their upper ends.

Dry pans.—Where a soft shale or a hard, tough, dry clay is to be used, dry pans (Pl. XI, Fig. 1) are frequently employed. These consist of a circular pan in which there revolve two iron wheels on a horizontal axis. The wheels turn because of the friction against the bottom of the pan, the latter being rotated by steam-power, and in turning they grind by reason of their weight, which ranges from 2000 to 5000 pounds. The bottom of the pan is made of removable perforated plates, so that the material falls through as soon as it is ground fine enough. Two scrapers are placed in front of the rollers to throw the material in their path.

Disintegrators, which are sometimes used for breaking up clay or shale, consist of several drums, or knives on axles, revolving rapidly within a case and in opposite directions. As the lumps of clay are dropped into the machine they are thrown violently about between the drums and also strike against each other, thus pulverizing the material completely and rapidly. Their capacity is large, but much power is also required to drive them.

Rolls.—These are often employed for breaking up clay and pebbles, and where dry material is used they are quite effective; but if damp clay is put through them, as is done at some yards, the lumps are simply flattened out. The surface of the rolls is smooth, corrugated or toothed, or tapering, and the two rolls revolve in opposite directions and with differential velocities of from 500 to 700 revolutions per minute. In some the stones in the clay are crushed, in others they are thrown out, by reason of the construction of the machine.

All the machines mentioned above are used on dry or nearly dry clay, but there are several other types which are employed for wet clays

PLATE XI

Fig. 1.—Dry pan used for grinding hard clays, shale, and brick. (After H. Ries, N. Y. State Museum, Bull. 35, p. 765, 1900.)

Fig. 2.—Ring-pit for mixing clays. (After H. Ries, N. Y. State Museum, Bull. 35, p. 659, 1900.)

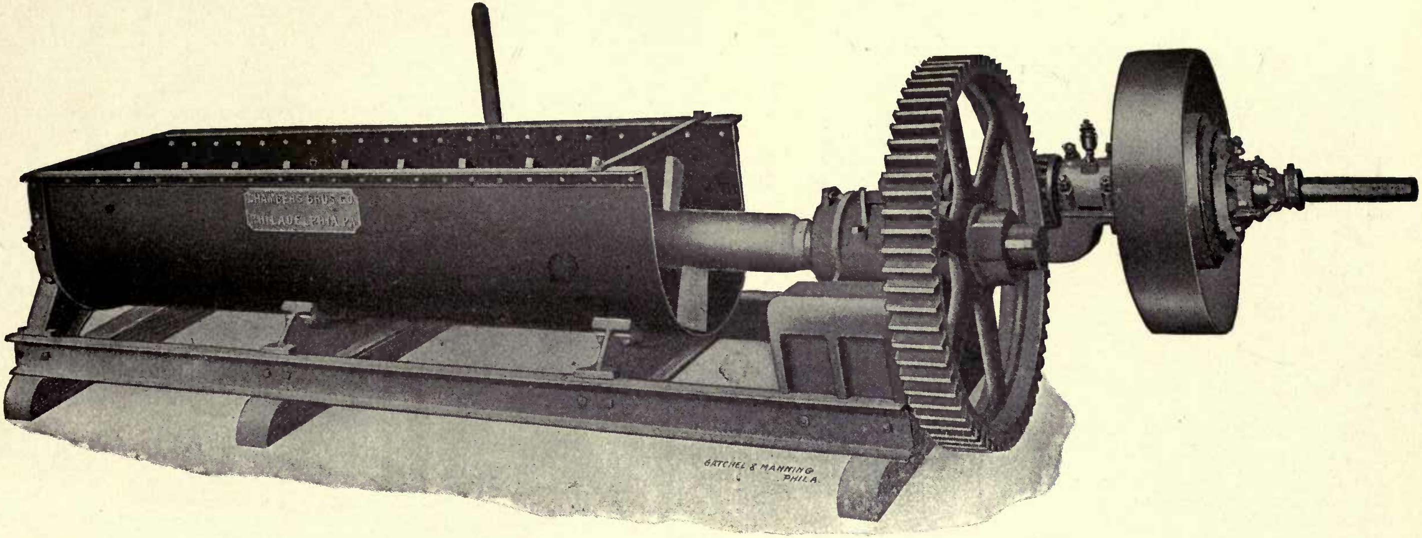

FIG. 42.—Pug-mill for tempering clay.

PLATE XII

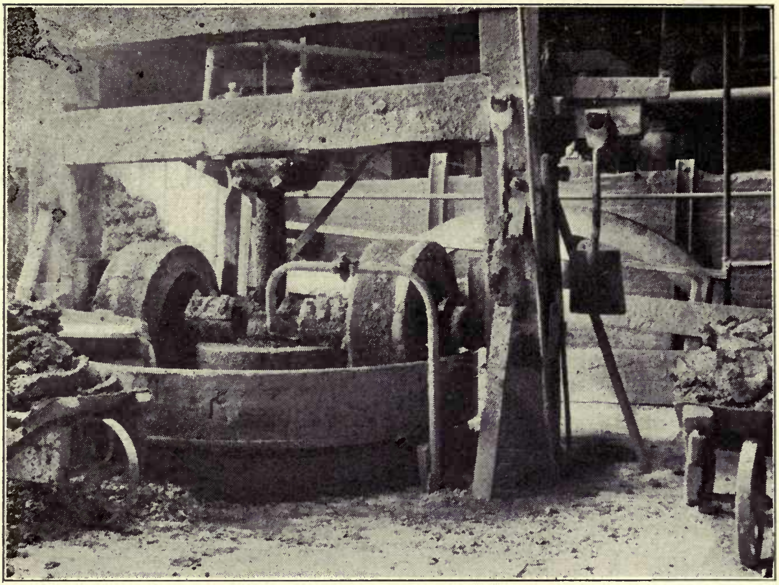

FIG. 1.—Wet pan for grinding and mixing clays or shales. (After H. Ries, Md. Geol., IV, p. 356, 1902.)

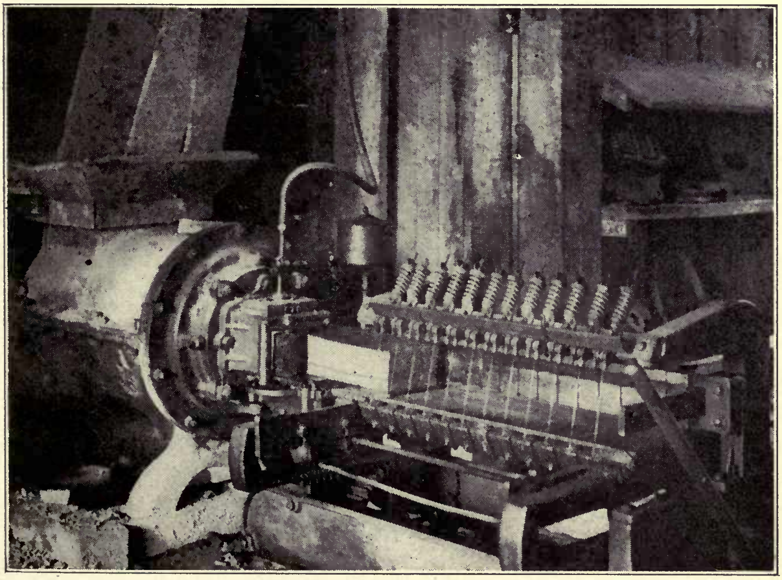

FIG. 2.—Cutting-table of stiff-mud brick-machine. (After H. Ries, N. Y. State Mus., Bull. 35, p. 662, 1900.)

only, and these in addition to breaking up the clay may also be used to mix it. The process is sometimes termed tempering.

Soak-pits.—Soak-pits, used at many small yards for preparing the clay, are simply pits in which the clay, with water added, is allowed to soak overnight.

Ring-pits.—Ring-pits (Pl. XI, Fig. 2), employed at many common-brick yards, are circular pits from 20 to 25 feet in diameter, about 3 feet deep, and lined with boards or brick. Revolving in this pit is an iron wheel, 6 feet in diameter, so geared as to travel around the pit in a spiral path, thus thoroughly mixing the mass. The tempering is accomplished usually in 5 or 6 hours, and one pit commonly holds enough clay for from 25,000 to 30,000 brick. Ring-pits are cheaper than pug-mills, but have a lower capacity and require more room. They are operated by either steam- or horse-power.

Pug-mills (Fig. 42) are semi-cylindrical troughs, varying in length from 3 to 14 feet, with 6 feet as a fair average. In this trough there revolves a horizontal shaft, bearing knives set spirally around it and having a variable pitch. The clay and water are charged at one end, and the blades on the shaft not only cut up the clay lumps, but mix the mass, at the same time pushing it towards the discharge end.

Pug-mills are thorough and continuous in their action, take up less space than ring-pits, and do not require much power to operate. They are used in connection with both stiff-mud and soft-mud machines.

Wet pans (Pl. XII, Fig. 1).—These are similar to dry pans, but differ from them in having a solid bottom. The material and water are put into the pan, and the clay is crushed and tempered at the same time. Where the clay contains hard lumps of limonite or pyrite nodules, a wet pan is superior to a pug-mill or disintegrator, for the charge is crushed and tempered in a few minutes, and can then be replaced by another one.

Molding

Bricks are molded by one of four methods, namely, soft-mud, stiff-mud, dry-press, and semi-dry-press, although in reality there is not much difference between the last two.

Soft-mud process.—In this method the clay, or clay and sand, are mixed with water to the consistency of a soft mud or paste and pressed into wooden molds. Since, however, the wet clay is sticky and likely to adhere to a wooden surface, the molds are sanded each time before being filled. Soft-mud bricks, therefore, show five sanded surfaces, and the sixth surface will be somewhat rough, due to the excess of clay being wiped off even with the top of the mold.

Soft-mud bricks are molded either by hand or in machines.

The soft-mud machine (Fig. 43) consists usually of an upright box of wood or iron, in which there revolves a vertical shaft bearing several blades or arms. Attached to the bottom of the shaft is a curved arm which forces the clay into the press-box. The molds, after being sanded, are shoved underneath the press-box from the rear side of the machine. Each mold has six divisions, and as it comes under the press-box the plunger descends and forces the soft clay into it. The filled mold is then pushed forward automatically upon the delivery-table, while an empty one moves into its place. As soon as the mold is delivered its upper surface is "struck" off by means of an iron scraper. Under favorable conditions soft-mud machines have a capacity of about 40,000 brick per day of ten hours, although they rarely attain this.

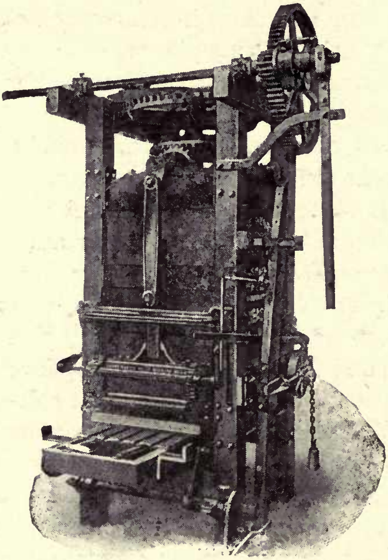

FIG. 43.—A soft-mud brick-machine.

The soft-mud process was the first method of molding employed, and is still largely used at many localities. It is adaptable to a wider range of clays than any of the others, and possesses the advantage of producing not only a brick of very homogeneous structure, but one that is rarely affected by frost action.

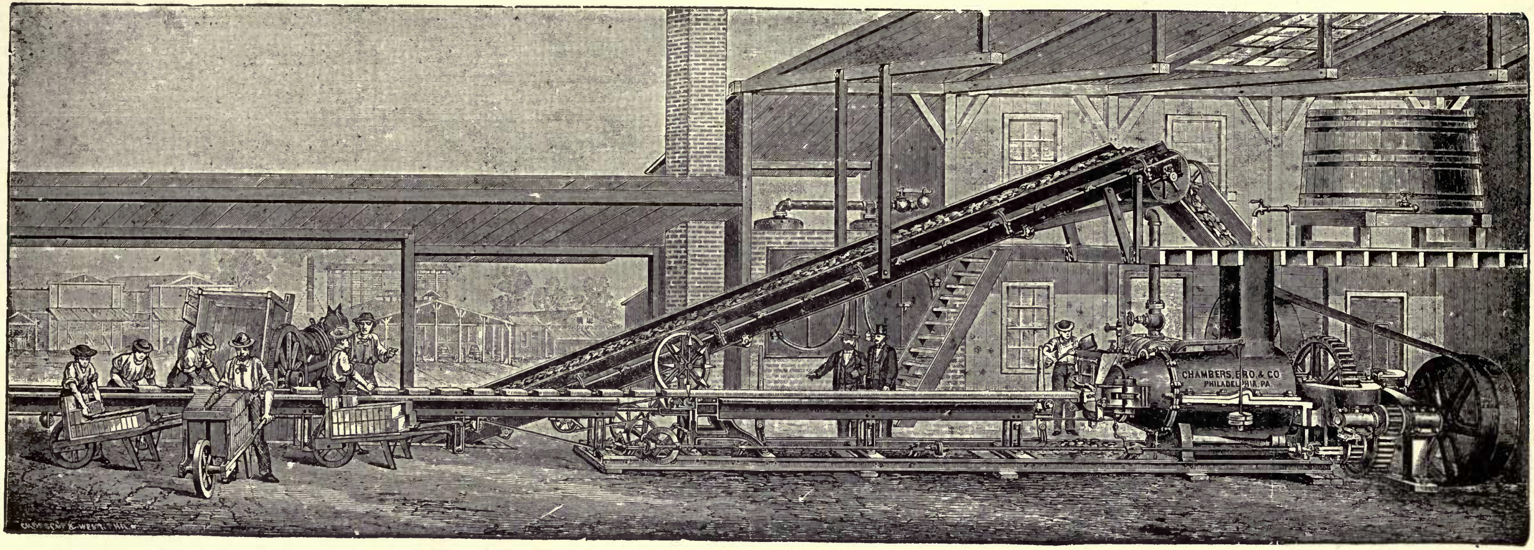

FIG. 44.—Manufacture of brick by stiff-mud process.

Stiff-mud process.—With this method (Pl. XII, Fig. 2, and Fig. 44.), the clay is tempered with less water and consequently is much stiffer. The principle of the process consists in taking the clay thus prepared and forcing it through a die in the form of a rectangular bar, which is then cut up into bricks. The most general form of the stiff-mud machine, known as the auger machine, is that of a cylinder closed at one end, but at the other end tapering off into a rectangular die whose cross-section is the same as either the end or the largest side of a brick. Within this cylinder, which is set in a horizontal position, there is a shaft, carrying blades similar to those of a pug-mill, but at the end of the shaft nearest the die there is a tapering screw. The die is heated by steam or lubricated by oil on its inner side, in order to facilitate the flow of the clay through it.

The tempered clay is charged into the cylinder at the end farthest from the die, is mixed up by the revolving blades, and at the same time it is moved forward until seized by the screw and pushed through the die. Since this involves considerable power, it results in a marked compression of the clay, and there is also some friction between the sides of the bar and the interior of the die, causing the center of the stream of clay to move faster than the outer portion. Excessive friction between die surface and clay is likely to cause the latter to tear on the edges, producing serrations like the teeth of a saw. The effect of the screw at the end of the shaft, together with the differential velocities within the stream of clay, also produces a laminated structure in the brick, which is often greatest in highly plastic clays, but is sometimes marked in clays of only moderate plasticity when machines of a particular structure are used.

The brick made in auger machines are either end-cut or side-cut, depending on whether the area of the cross-sections of the bar of clay corresponds to the end or side of a brick, and consequently the mouth of the die varies in size and shape. The auger machine is probably used more extensively at the present day than either the soft-mud or dry-press machine, especially for making paving-brick. It has a large capacity and can produce 45,000 or even 60,000 brick in ten hours, the output of the machine being sometimes increased by the use of double or even triple dies, though this is not a desirable practice.

As the bar of clay issues from the machine it is received on the cutting-table, where it is cut up into bricks.

The stiff-mud process is adapted mainly to clays of moderate plasticity. The stiff-mud brick, like the soft-mud ones, can be re-pressed, and many face brick are now made by this process.

Dry-press (Pl. XIII) **and semi-dry-press process.**—This process is commonly used for the production of front brick, but in some States is extensively employed even for common-brick manufacture. The clay is powdered and then pressed into steel molds in this nearly dry condition.[1] In order to prepare the clay for disintegration, it is usually stored in sheds for some time before being used, and is then broken up either in a disintegrator or a dry pan before passing to the screen, which is commonly from 12 to 16 mesh. The molding-machine consists of a steel frame of varying height and heaviness, with a delivery-table about 3 feet above the ground, and a press-box sunk into the rear of it. The charger is connected with the clay-hopper by means of a canvas tube, and forms a framework which slides back and forth over the molds. It is filled on the backward stroke, and on its forward stroke lets the clay fall into the mold-box. As the charger recedes to be refilled, a plunger descends, pressing the clay into the mold; but at the same time the bottom of the mold, which is movable, rises slightly, and the clay is subjected to great pressure, which may be repeated after a moment's interval. The plunger then rises, while the bottom of the mold also ascends, with the freshly molded bricks, to a level with the delivery-table. These are then pushed forward by the charger as it advances to refill the molds.

The faces of the mold are of hard steel and heated by steam to prevent adherence of the clay. Air-holes are also made in the dies to permit the air, which becomes imprisoned between the clay particles, to escape. If this were not done, the air in the clay would be compressed, and when the pressure was released, its expansion would tend to split the brick. At several localities in the United States an hydraulic dry-press machine is used, in which the gradually applied pressure is produced by a pair of hydraulic rams acting from above and below.

The advantages claimed for the dry-press process are that in one operation it produces a brick with sharp edges and smooth faces. Air-drying is eliminated, but there is still considerable moisture to be driven off in the kiln during the early stages of burning. When hard-burned, dry-pressed bricks are as strong as others, but on account of the method of molding they often show a granular structure.

The capacity of a dry-press machine is about the same as that of a soft-mud one, provided six bricks are molded at a time. Two- and four-mold machines are, however, also made. The initial cost of the

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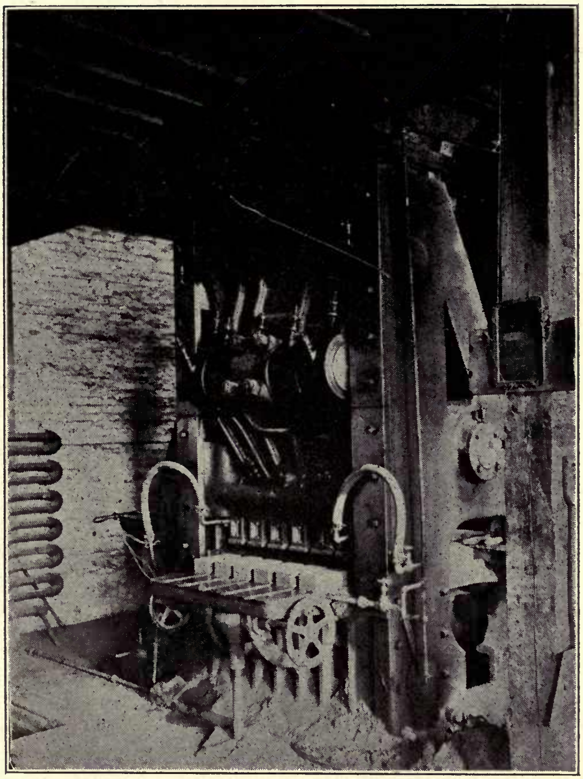
[1] The clay usually has 12 or 15 per cent moisture, so that the term dry-press is somewhat misleading.

PLATE XIII



Dry-press brick-machine. (After H. Ries, N. Y. State Mus., Bull. 35, p. 665, 1900.)

machinery is considerable, although this may be more than offset by the saving in drying.

Re-pressing.—Many soft-mud and stiff-mud brick that are to be used for fronts are improved in appearance and even in density[1] by re-pressing, an operation which smoothens the surface and straightens and sharpens the edges of the product, as well as sometimes increasing the strength.[1] A re-pressing machine is shown in Pl. XIV, Fig. 1.

The change in volume that occurs in a brick in re-pressing can be seen from the following measurements of a paving-brick:

Before re-pressing, $8\frac{3}{4}$ by $4\frac{3}{8}$ by $3\frac{1}{8}$ inches, $=119\frac{5}{8}$ cubic inches.
After re-pressing, $8\frac{11}{16}$ by $4\frac{3}{8}$ by $3\frac{7}{8}$ inches, $=109\frac{1}{4}$ cubic inches.

Drying

Bricks made by either the stiff-mud or soft-mud process have to be freed from most of their water of tempering before they can be burned.

Open yards.—These are used at most soft-mud brick-plants, and are simply smooth flat floors of earth or brick, on which the bricks are dumped as soon as molded, and allowed to dry in the sun. At some yards the drying-floor is partly covered.

Pallet driers.—These are covered frames for holding the boards or "pallets" on which the bricks are dumped from the mold at the machine. They are used at many soft-mud yards and even some stiff-mud plants, and possess the advantage of cheapness, large capacity, economy of space, and protection against rain.

One disadvantage of the above method is that the driers can not be used in cold weather. Dampness in summer may also interfere with them, and therefore sunlight and wind are usually the most favorable weather conditions. Some clays are quite susceptible to air-currents, however, and crack easily when exposed to them.

Drying-tunnels.—Many brickmakers dry their product by this method, especially if they continue in operation throughout the year. With this system the bricks, after molding, are piled on cars, which are run into an artificially heated tunnel (Fig. 45). Several of these tunnels are generally constructed side by side, and the green bricks are run in at the cooler end, and pushed along slowly to the warmer end, where they are removed, this passage through the tunnel requiring commonly from 24 to 48 hours. The tunnel driers used at different localities differ chiefly in the manner in which they are heated, the following methods being employed:

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[1] N. J. Geol. Surv., VI, p. 260, 1904. It should be emphasized that re-pressing does not increase the crushing strength in every case.

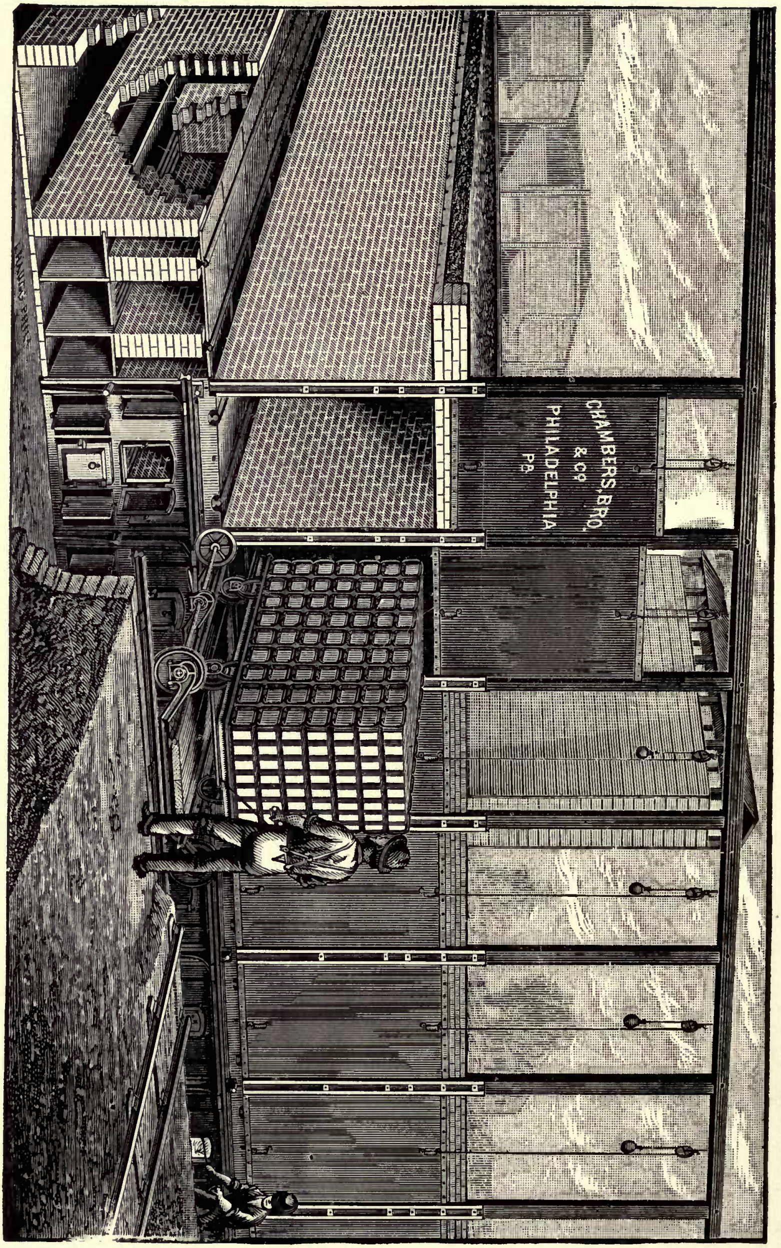

Fig. 45.—Tunnels for drying bricks and other structural clay products.

1. Parallel flues underneath and heated by fireplaces at one end. 2. By steam heat, the pipes being laid on the floor or sides of the tunnel or both. 3. By hot air, the latter being supplied from cooling-kilns, or by passing the outer air over steam-coils before it is drawn through the tunnel by natural draft or fan. If the air is too hot, cooler air is mixed with it before it enters the drier. The temperature to which tunnels are heated varies, and in most cases is not over 120° C. (250° F.).

Floor driers.—Floor driers are used at some brick-works, although their application is more extended at fire-brick works. They are made of brick, and have flues passing underneath their entire length, from the fireplace at one end to the chimney at the other. Such floors are cheap to construct, but the distribution of the heat under them is rather unequal, and a large amount of labor is required to handle the material dried on them.

In some cases drying-racks are set up on the top of the kiln.

Burning

Kilns.—Bricks are burned in a variety of kilns, ranging from temporary structures, which are torn down after each lot of brick is burned (Pl. XIV, Fig. 2), to patented or other permanent forms of complicated design. They are built on one of two principles, either up-draft or down-draft. In the former the heat from the fire-boxes at the bottom passes directly into the body of the kiln and up through the wares, escaping from suitable chimneys or openings at the top. In the latter the heat from the fire-boxes is conducted first to the top of the kiln chamber, by means of suitable flues on the interior wall, and then down through the wares, being carried off through flues in the bottom of the kiln to the stack (Pl. XV, Fig. 2). The down-draft system is growing in favor, as the burning can be regulated better. Furthermore, since the bricks at the top receive the greatest heat, and those at the bottom the least, there is less danger of the bricks in the lower courses being crushed out of shape if heated too high.

The amount of heat required for burning brick will vary with the clay and the color, density or degree of hardness desired, the same clay giving different results when burned at different temperatures. Common bricks are rarely burned any higher than cone 05, and usually not above cone 010, while pressed brick are frequently fired to cone 7 or 8, because the clays generally used have to be burned to that point to render them hard.

Up-draft kilns.—The simplest type of kiln with rising draft is known as the "scove-kiln" (Pl. XIV, Fig. 2, and Pl. XV, Fig. 1), which is in use at many yards making common brick, and is of a temporary character.

The bricks are set in large rectangular blocks from 38 to 54 courses high, depending on the kind of clay. In building up the mass a series of parallel arches is left running through the mass from side to side, and with their centers about two feet apart. After the bricks are set up they are surrounded by a wall two courses deep of "double-coal" brick, and the whole outside of the mass daubed with wet clay to prevent the entrance of cold air during burning. The top of the kiln is then closed by a layer of bricks laid close together and termed the platting. Kilns of this type involve little cost except the labor of building. They are, however, adapted only to common brick, and are not capable of being heated to a high temperature.

The so-called Dutch kilns are a slight improvement over the scove-kilns, since they have permanent side walls, and so yield somewhat better results, for they heat up better and admit less cold air.

Many common brick and nearly all front brick, however, are burned in kilns that are walled and roofed, with a door at each end for filling and emptying. They are, therefore, far more reliable, capable of better regulation, attain higher temperatures, and are both up-draft and down-draft. The fuel used is sometimes wood, but mostly coal, not a few manufacturers employing anthracite in part. With coal, the fuel is sometimes placed on grate-bars or on the floor of the hearth. In plan they are either rectangular or circular. The bricks are set in much the same way as in the others.

Down-draft kilns.—In these the heat from the fires is conducted first to the top of the kiln-chamber by means of suitable flues on the inner wall of the kiln, and then down through the ware, being carried off through flues in the bottom of the kiln to the stack. With this system the burning can be regulated better, and there is less loss from cracked and overburned brick. Furthermore, since the bricks at the top receive the greatest heat, and those at the bottom the least, there is less danger of the bricks in the lower courses being crushed out of shape. Down-draft kilns are either circular or rectangular in form. The latter, which have greater capacity and are more economical of space, are employed commonly for burning brick, while the former are preferred for drain-tile, sewer-pipe, or stoneware.

There are a number of different types of down-draft kilns, which differ in the arrangement and structure of the flues, arrangement of the fire-place, etc.

Continuous kilns (Pl. XVI, Fig. 2).—These were originally designed to utilize the waste heat from burning. Many types have appeared, some of which are patented, but the principle of all is the same. It consists essentially in having a series of chambers arranged in a line,

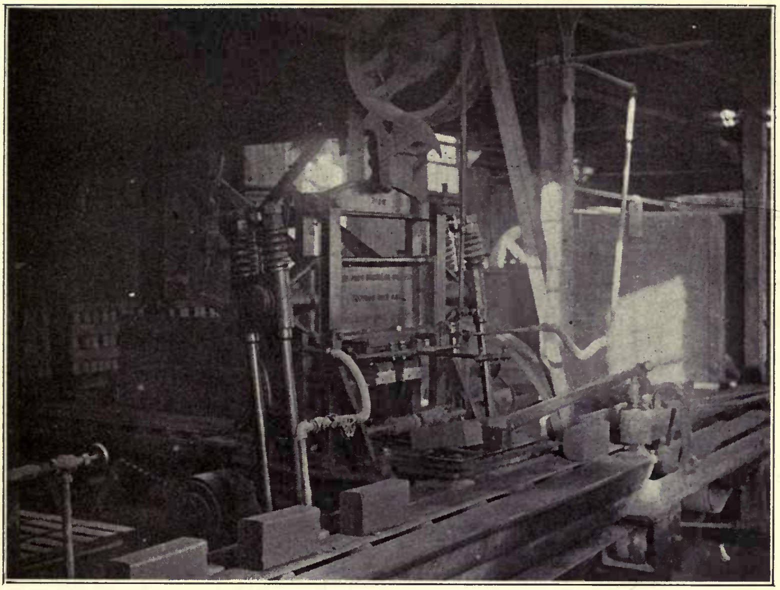

FIG. 1.—A steam-power re-press. The bricks on the belt are being brought from the stiff-mud machine. (Photo by H. Ries.)

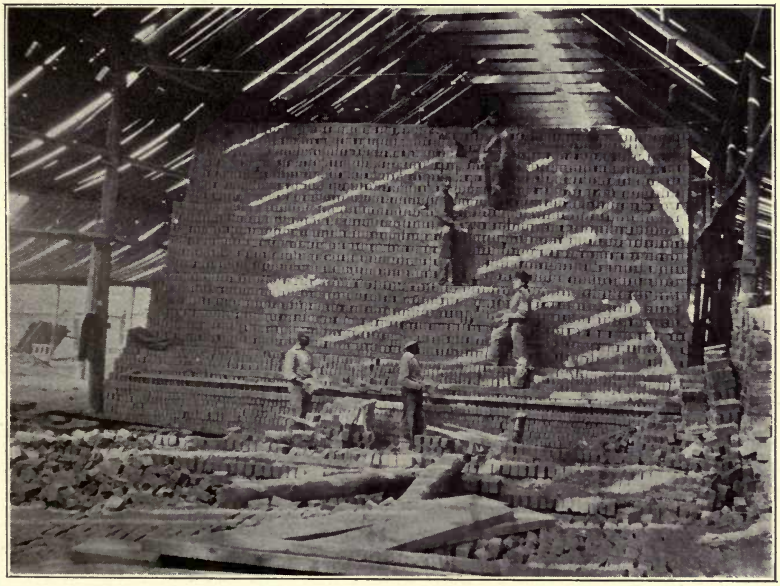

FIG. 2.—Setting brick for a scove-kiln. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 240, 1900.)

circle, or oval, and connected with each other and also with a central stack by means of flues. Each chamber holds about 22,000 bricks. In starting the kiln, a chamber full of bricks is first fired by means of exterior fire-boxes, and while the water-smoke or steam is passing off the vapors are conducted to the stack, but as soon as this ceases the heat from the chamber first fired is conducted through several other chambers ahead of it, before it finally passes to the stack. In this manner the waste heat from any chamber is used to heat the others. When any one compartment becomes red hot, fuel in the form of coal-slack is added through small openings in the roof, which are kept covered by iron caps.

As soon as one chamber has reached its maximum temperature, the next two or three ahead of it are being heated up, while those behind it are cooling down. A wave of maximum temperature is therefore continually passing around the kiln. It is thus possible to be burning brick in certain chambers, filling others, and emptying still others, all at the same time, making the process a continuous one. Continuous kilns are employed in many states for burning common brick with considerable success.

Sewer-pipe Manufacture

While some works use a soft clay for sewer-pipe, the largest factories in the United States, namely, those located in Ohio, run chiefly on shale, to which a certain amount of refractory clay is sometimes added. The material therefore requires crushing before tempering. Dry pans (p. 254) are used for this purpose. The ground-clay is then screened and mixed in pug-mills (p. 261),wet pans (p. 261), or chaser-mills (p. 303).

Sewer-pipes are made in a special form of press (Figs. 46 and 47, and Pl. XVII, Fig. 1) consisting of two cylinders, connected with a continuous piston and placed one above the other. The upper is the steam and the lower the clay cylinder. The size ratio of these two cylinders varies from 1 : 2 to 1 : 3.[1] "The piston is propelled by the admission of steam to the upper cylinder, giving it a downward movement which presses the clay through a die at the bottom of the lower cylinder. The action is then intermittent, the piston receding when it has reached its length of stroke and a supply of clay is needed.

"The clay previously prepared and in plastic condition is brought to the press on a moving belt. Each time the piston recedes, the cylinder

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[1] Beyer and Williams, Ia. Geol. Surv., XIV, p. 214, 1904.

is filled with clay by throwing this belt into motion. The die which forms the pipe consists of a central bell or core and outer die, the space between the core and die determining the thickness of the wall of the pipe. By changing the dies the various sizes of sewer-pipe are made. It has been found of advantage to have the issue, or the distance through which the clay must travel between the dies, compressed to its maximum thickness, quite long. J. E. Minter[1] recommends an issue of not less than three inches for dies smaller than eight inches

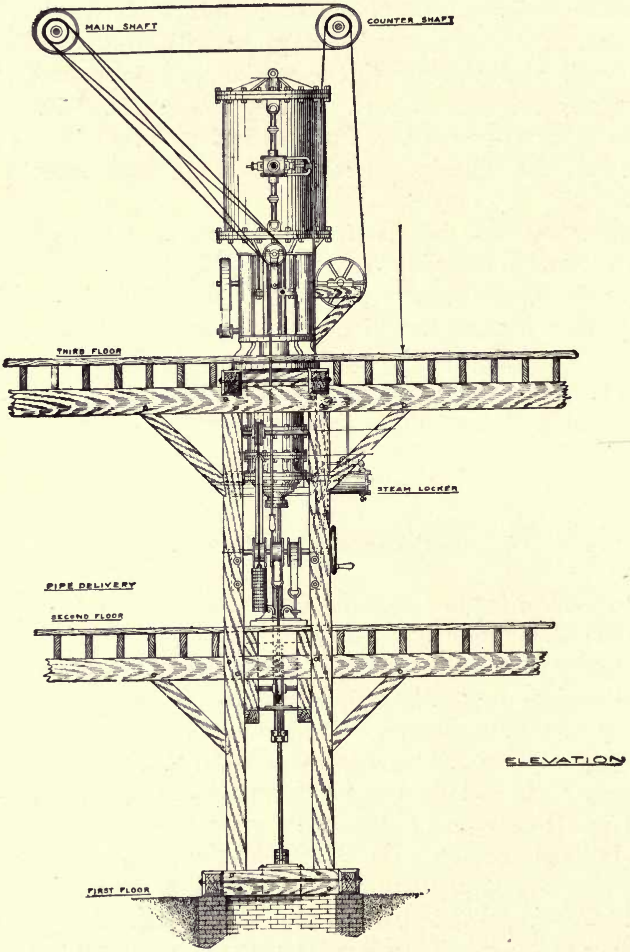

FIG. 46.—Side elevation of a sewer-pipe press.

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[1] Brick, XVIII, No. 1, p. 48.

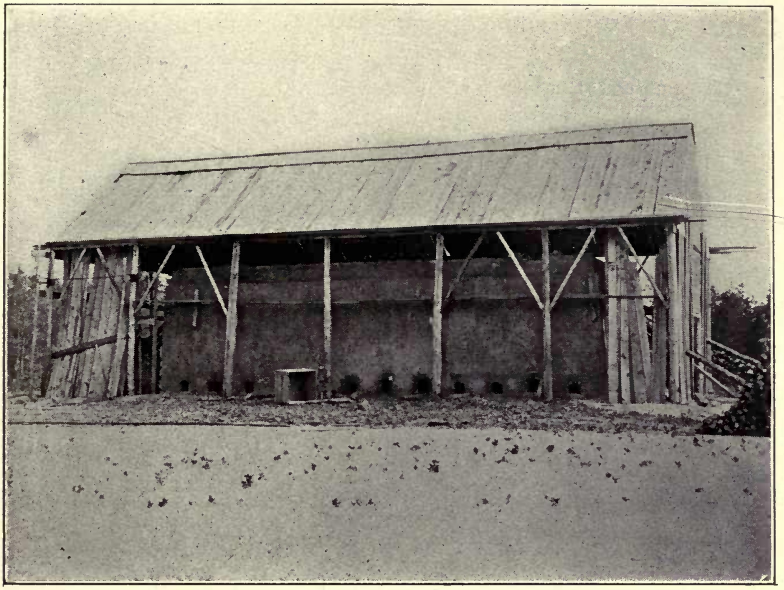

FIG. 1.—Side view of a scove-kiln for burning common brick, exterior daubed over with wet clay. The firing-holes are shown at bottom of one side. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 240, 1904.)

FIG. 2.—Down-draft kilns. (Photo loaned by Robinson Clay-product Co.)

FIG. 1.—Interior view of circular down-draft kiln. (Photo loaned by Robinson Clay-product Manufacturing Co.)

FIG. 2.—Haight continuous kiln. (After H. Ries, N. Y. State Mus.. Bull. 35, p. 679, 1900.)

and not below four inches for dies over eight inches in diameter. The basis for this recommendation is that where the issue is short, blebs of air imprisoned in the clay will remain and are apt to form blisters on the pipes, while with a long issue the air will back upwards through the loose clay and escape in the direction of least resistance rather than remain in the clay."

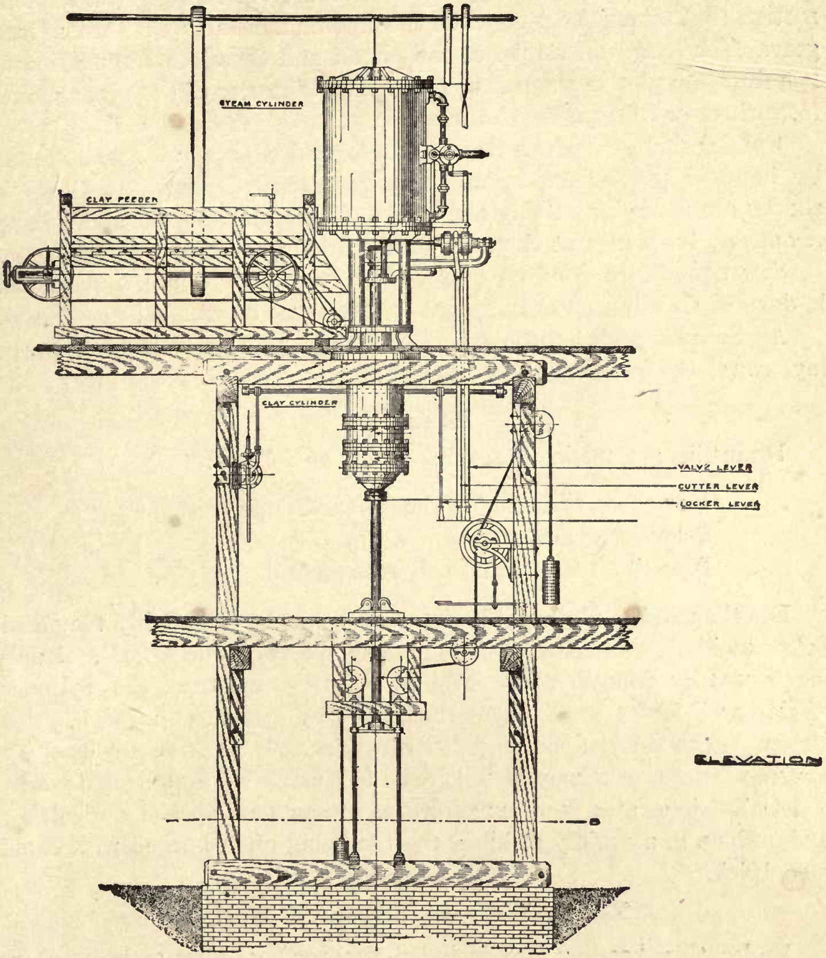

Fig. 47.—Front elevation of a sewer-pipe press.

Beneath the die is the pipe-table which receives the pipe as it issues from the cylinder. The table is supported by a vertical rod which is kept in perfect alignment with the center of the cylinder. The table is raised and lowered by weights which may be so adjusted as to counter-balance. After the pipe is forced out the desired length it is cut by hand, by wire, or automatically by means of a power cutter, the last consisting of a knife edge in the lower part of the cylinder, extending down through core, which is thrust out and given a circular motion that severs the pipe when the cutting mechanism is thrown into gear. The length of stroke of the piston and therefore the maximum length of the pipe is about four feet. The diameter of the pipes ranges from three or four inches to three feet.

Special shapes, such as traps, sockets, and elbows, are usually made by hand in plaster molds, and require careful drying. At times Y shapes are made by cutting one straight piece on the slant and joining it onto a pipe with wet clay. T's are made in a similar manner.[1]

Sewer-pipes are dried on floors, heated by steam-pipes, and burned in down-draft kilns. For burning they are stood on end and salt-glazed.

All defects, such as iron spots, blisters, imperfect glazing, or warping, cause the product to be placed among seconds.

Drain-tile

Drain-tile are made in several styles as follows:

Horseshoe-tile, of horseshoe-shaped cross-section.
Sole-tile, cylindrical with a flat base.
Pipe-tile, with cylindrical cross-section.

For the making of drain-tile the clay should be thoroughly tempered before molding, this being commonly done in a pug-mill (p. 261). Molding is usually done in some form of stiff-mud machine, the cylinder of clay as it issues from the die being cut up into the desired lengths. Drying is commonly done on pallet-racks (p. 269), such as are used for common bricks, or it may also be done in tunnels. The burning, which is usually done at a low temperature, presents no special difficulties, and is done in a variety of kilns, the tile being often burned with common brick.

Hollow Ware for Structural Work

Under this heading are included fireproofing, terra-cotta lumber, hollow blocks and hollow bricks. These are all hollow (Pl. XVII, Fig. 2), being molded through a stiff-mud die and may contain one or more cross webs or partitions to give them strength. *Fireproofing*

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[1] Traps and bends can also be made on press by use of special dies having a slide by which flow of clay from one side to another is regulated. This works well with a plastic clay.

is the term applied to those forms used in the construction of floor-arches, partitions, and wall-furring for columns, girders, and other purposes in fireproof buildings. *Terra-cotta lumber* is a form of fireproofing that is soft and porous, owing to the addition of a large percentage of sawdust to the clay. The former burns off in the kiln, thus leaving the material so soft and porous that nails can be driven into it. It is used chiefly for partitions. *Hollow blocks* are used for exterior walls, in both fireproof and non-fireproof buildings. They are of rectangular outline. *Hollow brick* are like hollow blocks in form, but no larger than ordinary building-bricks.

A number of different shapes and sizes of fireproofing are made, and while the majority of them agree in being 12 inches long the other two dimensions may vary. Thus of the blocks which are 12 inches long, the other dimensions may be 6 by 3 in., 6 by 4 in., 6 by 5 in., 6 by 6 in., 6 by 7 in., etc., or perhaps 3 by 8 in., or 3 by 12 in., etc. A large number of the fireproof shapes made are for floor-arches, and in such cases the architect commonly specifies the depth of the arch, while the width of the blocks is governed by the width of the span. The weight of the arch will depend on its depth.

Thus,	6-inch	floor-arches	weigh	about	25	pounds	per	square	foot.
	7 "	" "	"	"	28	"	"	"	"
	10 "	" "	"	"	35	"	"	"	"
	12 "	" "	"	"	42	"	"	"	"
	3 "	book-tile	"	"	15	"	"	"	"
	3 "	partition-tile	"	"	15	"	"	"	"
	6 "	" "	"	"	21	"	"	"	"
	8 "	" "	"	"	28	"	"	"	"
	2 "	wall furring	"	"	8.5	"	"	"	"
	3 "	" "	"	"	10.5	"	"	"	"
	2 "	column covering	"	"	13	"	"	"	"
	3 "	" "	"	"	15	"	"	"	"

The cost of fireproofing is commonly figured by the ton.

Hollow blocks are usually made in 8-inch lengths, but vary in their other dimensions, being 4 by 16 in., 6 by 16 in., 8 by 16 in., 10 by 16 in., 12 by 16 in., etc. They are used quite extensively in the Central States, but not so much in the Eastern ones. Hollow blocks are made with either smooth, corrugated, or ornamental surfaces.

Sizes 8 by 4 by 16 in. are sold for about $0.07 each, and 8 by 8 by 16 in. at $0.10 each. Hollow bricks are often used for the interior course of exterior walls, and the plaster can be laid directly on them without the use of lathing.

In some States shales are used for making hollow ware, while in others plastic clays are employed. Calcareous clays are undesirable as being unsuited to the production of a vitrified ware.

The clays used for making fireproofing have been referred to on p. 227.

Manufacture.—The method of preparation used for making hollow blocks or fireproofing is essentially the same as that employed in the manufacture of stiff-mud bricks. Shales are sometimes first ground in a dry pan (p. 254) or disintegrator (p. 254) and then screened, followed by mixing in a pug-mill (p. 261), or a wet pan (p. 261) may do the combined work of crushing and tempering. Molding is done in a stiff-mud machine (p. 265), care being necessary to have the clay sufficiently plastic to permit its flowing freely from the die and prevent tearing on the corners or edges.

The die is of a special type, which emits a hollow tube with cross-partitions, and the cutting-table is likewise sometimes of a specialized type, so designed that as the brick reaches the end of the table it is turned to an upright position to facilitate handling.

Hollow blocks and fireproofing are dried on racks (p. 269) in tunnel-driers (p. 269), or even on heated floors, the last being the method most commonly used.

When hot floors are used they are heated by steam-pipes passing under them or around the walls of the drying-room.

In burning any of these shapes they are stood on end, and the smaller ones are sometimes burned in the same kilns with brick.

Williams[1] gives the following advantages for hollow blocks:

Lightness.—Sufficient strength, to insure a large factor of safety in any common building construction. Amount of clay required from one third to one half that necessary for solid brick. Smaller expense of transportation due to decreased weight of product. Full protection against dampness and temperature. Possibility of terra-cotta decoration on exterior of block.[2]

Conduits

Manufacture.—Conduits form a line of clay-products, the use of which has greatly increased in the last few years. These are hollow blocks of varying length, having sometimes several cross-partitions and rounded edges, and are used as pipes for electrical cables and wires

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[1] Ia. Geol. Surv., XIV, p. 213.

[2] See E. G. Durant. Hollow Building-blocks. Published by American Clay-working Machinery Co., Bucyrus, O. (No date.)

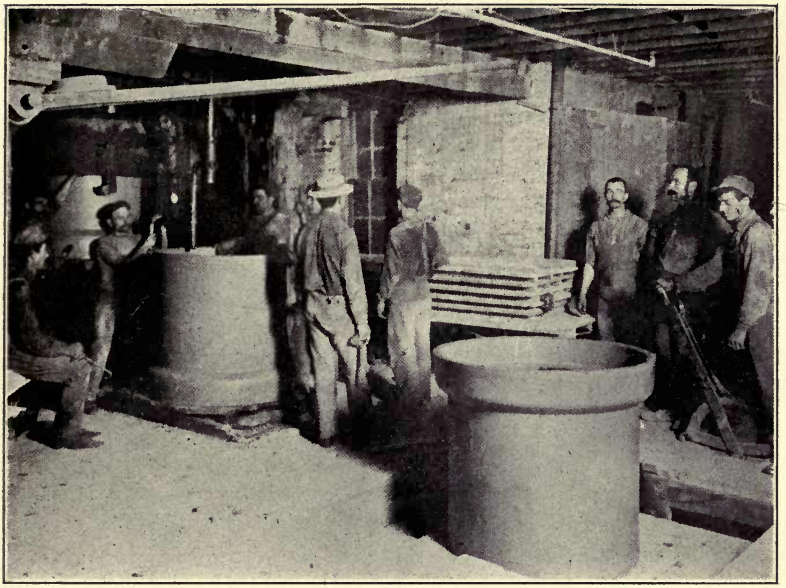

FIG. 1.—Molding 30-inch sewer-pipe in pipe-press. (Photo loaned by Robinson Clay-product Co.)

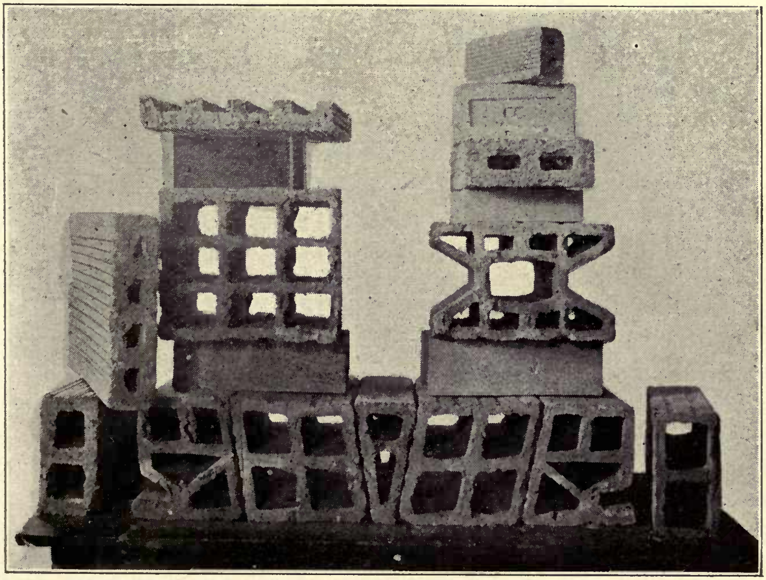

FIG. 2.—Some forms of fireproofing made by stiff-mud machine. (Photo by C. M. Doyle in N. Y. State Museum, Bull. 35, p. 775, 1900.)

below ground. On this account they have to be hard-burned with dense body, and are salt-glazed.

The clays used are similar to those employed for making fireproofing, although they are somewhat more carefully selected with regard to plasticity and freedom from pyrite and limonite lumps. They must also burn dense at a moderate temperature.

The clays are prepared in essentially the same manner as for hollow blocks, and are molded in auger stiff-mud machines. They are then removed from the cutting-table on a pallet and placed on a stand, where the ends are trimmed smooth before the pieces are taken to the drying-floor or drying-tunnel. In drying, the conduits are stood on end. The burning is commonly done in down-draft kilns, between cones 8 and 9, although some manufacturers burn lower than this. The average shrinkage that takes place in a long conduit is about as follows:[1] Length, freshly molded, 39 inches; length, air-dried, 37½ inches; length, burned, 35 inches.

There has been a great demand for conduits in many cities during the last few years, many being used in New York City especially, in the construction of the rapid-transit subway, and some large plants are run almost exclusively on this line of work.

Conduits are also occasionally made at the fireproofing factories.

Fire-brick

Most fire-brick makers employ a mixture of several grades of clay, to which there is added a certain percentage of ground fire-brick or even coarse quartz. These ingredients are sometimes ground in a dry pan (p. 254) or disintegrator (p. 254), then screened, and tempered in a pug-mill (p. 261). At some plants a wet pan (p. 261) combines the crushing and tempering operation. Where soft clays exclusively are used, the tempering is occasionally done in a ring-pit (p. 261).

Fire-bricks were originally molded entirely by hand, and some manufacturers still cling to this method, but many now employ the soft-mud (p. 261) or stiff-mud machine (p. 265). In all these methods the brick requires re-pressing after it has been drying for a few hours. A few works manufacture dry-press (p. 266) brick, and for some purposes these may be desirable, but they are not regarded as altogether satisfactory. Drying is generally done on brick floors, heated by flues passing underneath them, but some manufacturers prefer drying-tunnels (p. 269).

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[1] N. J. Geol. Surv., Final Rept., VI, p. 284, 1904.

Most fire-brick makers burn their brick in down-draft kilns, but there is a remarkable difference in the temperature reached, this in the United States ranging from cones 5 to 14.

Fire-bricks are made in many different shapes, and vary greatly in their density, hardness, and texture, according to the conditions under which they are to be used. For abrasive resistance they must be hard, to resist corrosion they must be dense, while, for resistance to high heats and changes of temperature, porosity and coarseness are of importance.

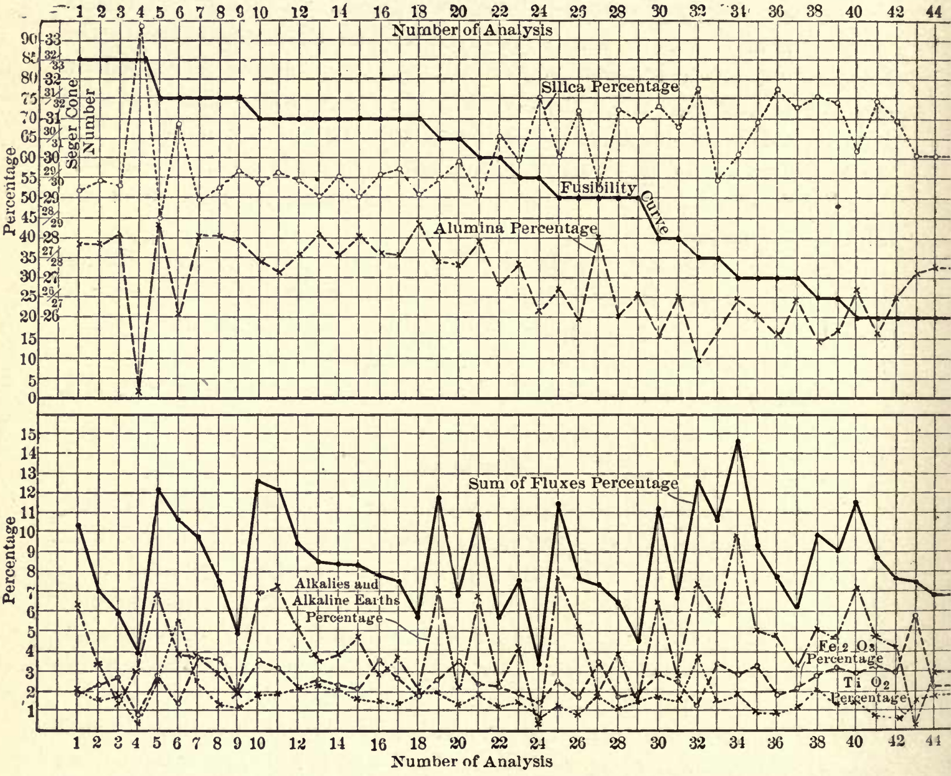

FIG. 48.—Graphic representation of composition and fusibility of some domestic fire-brick. (After Weber.)

The influence of texture and composition on refractoriness has been well set forth by the experiments by Weber,[1] which are graphically illustrated in Fig. 48.

From these tests he concluded that the refractoriness of a fire-brick depends on the total quantity of fluxes present, the silica percentage, and the coarseness of grain.

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[1] Trans. Amer. Inst. Min. Eng., Sept., 1904.

below ground. On this account they have to be hard-burned with dense body, and are salt-glazed.

The clays used are similar to those employed for making fireproofing, although they are somewhat more carefully selected with regard to plasticity and freedom from pyrite and limonite lumps. They must also burn dense at a moderate temperature.

The clays are prepared in essentially the same manner as for hollow blocks, and are molded in auger stiff-mud machines. They are then removed from the cutting-table on a pallet and placed on a stand, where the ends are trimmed smooth before the pieces are taken to the drying-floor or drying-tunnel. In drying, the conduits are stood on end. The burning is commonly done in down-draft kilns, between cones 8 and 9, although some manufacturers burn lower than this. The average shrinkage that takes place in a long conduit is about as follows:[1] Length, freshly molded, 39 inches; length, air-dried, 37½ inches; length, burned, 35 inches.

There has been a great demand for conduits in many cities during the last few years, many being used in New York City especially, in the construction of the rapid-transit subway, and some large plants are run almost exclusively on this line of work.

Conduits are also occasionally made at the fireproofing factories.

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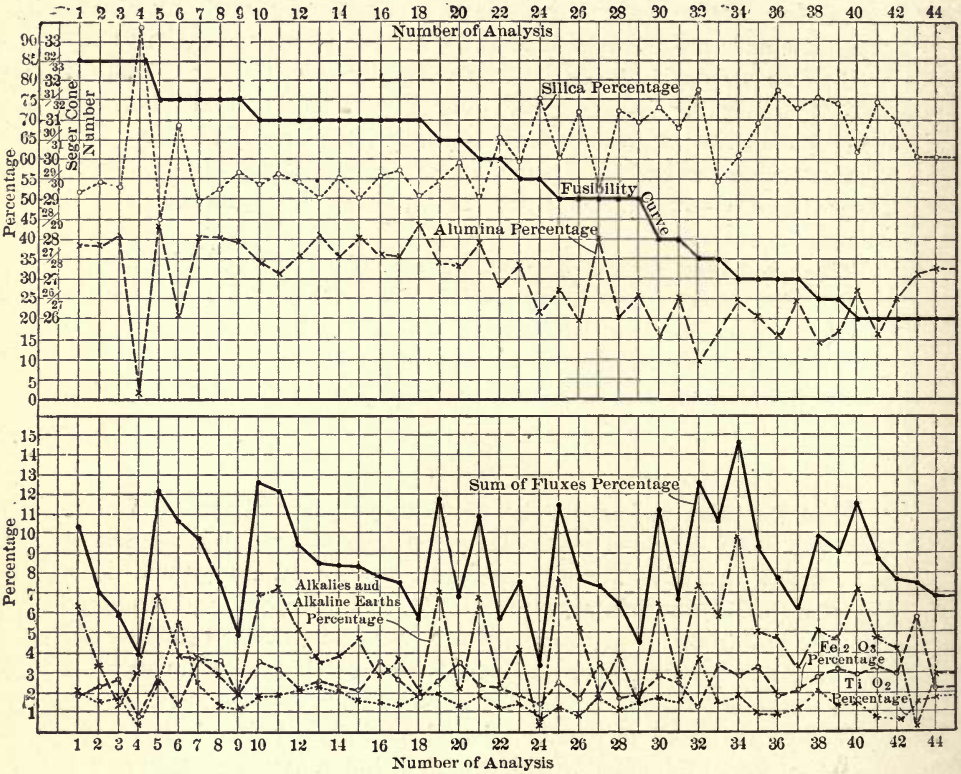

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[1] Trans. Amer. Inst. Min. Eng., Sept., 1904.

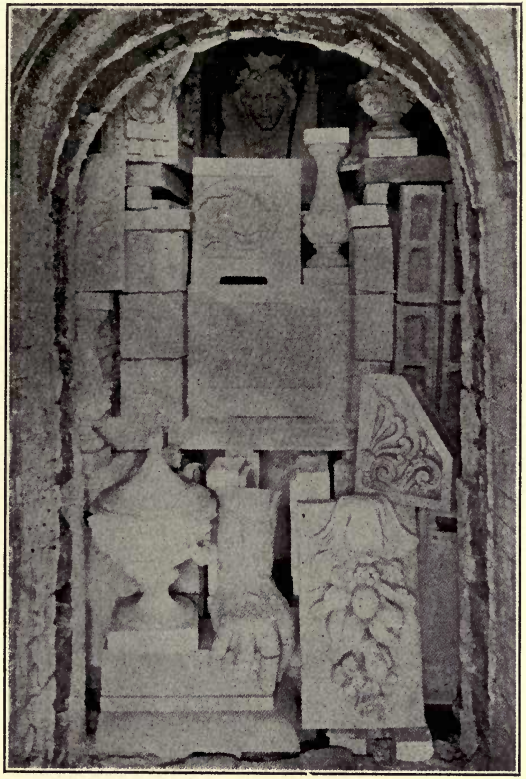

FIG. 1.—Interior view of terra-cotta kiln, showing method of setting ware for burning. (After Ries, N. Y. State Mus., Bull. 35, p. 763, 1900.)

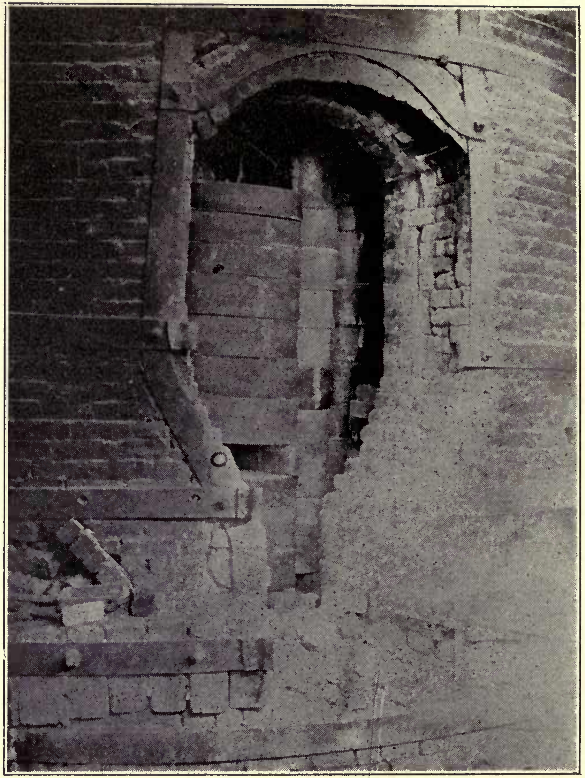

FIG. 2.—Partial interior view of a pottery-kiln, showing saggers in which white wares are burned. (Photo by H. Ries.)

PLATE XIX

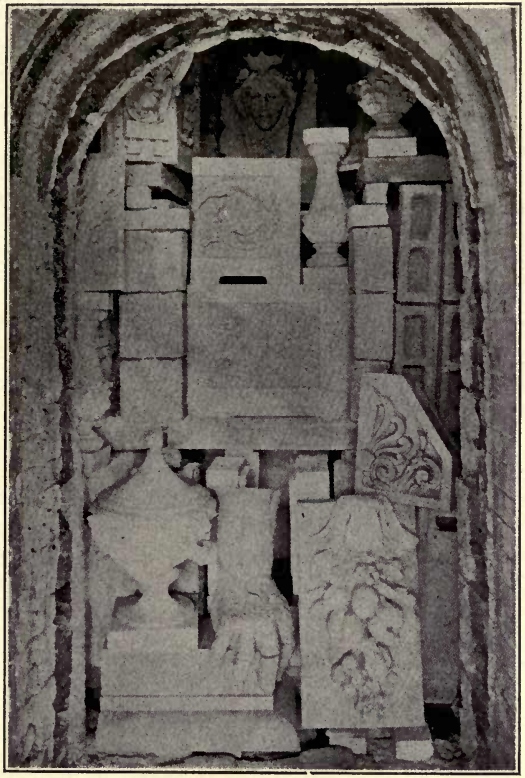

Fig. 1.—Interior view of terra-cotta kiln, showing method of setting ware for burning. (After Ries, N. Y. State Mus., Bull. 35, p. 763, 1900.)

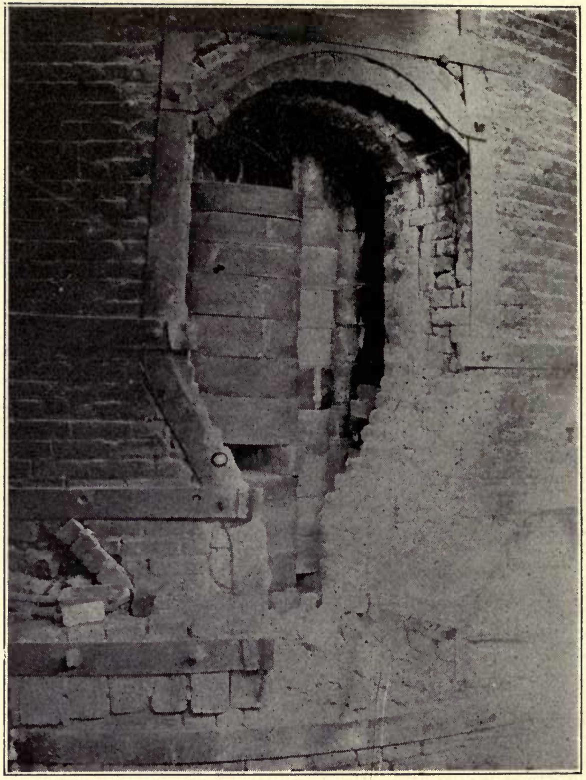

Fig. 2.—Partial interior view of a pottery-kiln, showing saggers in which white wares are burned. (Photo by H. Ries.)

slip which is to form the surface coating is sprayed on it, thus forming a thin layer over all the surface, and also being somewhat absorbed by the body. The slip, which is commonly a mixture of kaolin, ball-clay, quartz, and feldspar (or other fluxes) to which the proper coloring ingredients are added, forms an impervious layer on the surface of the terra-cotta, and also produces the color effect on the ware. It is sometimes of such composition as to burn to a dull enamel. Full-glazed terra-cotta is but little made in the United States, but the demand for matt-glazed or semi-dull glazed terra-cotta has greatly increased in the last two years. This effect was first produced by sand-blasting a full-glazed surface, but proved unsatisfactory, and at present the best plants are covering such ware with a regular matt-glaze.

Terra-cotta is commonly burned in circular down-draft kilns, whose diameter ranges from 15 to 25 feet, the kilns being of the muffle type. That is to say, they have a double wall through which the gases of combustion pass, and do not come in contact with the ware, which becomes heated by radiation from the walls of the muffle. The different pieces are set in the kiln surrounded by a framework of tiles and pipes of fire-clay (Pl. XIX, Fig. 1), so that during the burning no object has to bear any weight other than its own. The total shrinkage in drying and burning is commonly about 8 per cent, and the ware is never burned to vitrification. Some terra-cotta manufacturers burn at as low a cone as 02, but the majority probably reach cones 6 or 8.

Floor-tile

Under this heading are included tile of a variety of shapes and colors which are used for flooring. On account of the conditions under which they are used they should possess sufficient hardness to resist abrasive action, sufficient transverse strength to resist knocks, and sufficient density to prevent excessive absorption of water. White tiles show little or no absorption, but some of the other colors soak up from 1 to 5 per cent of moisture, or perhaps even more.[1]

Great care is necessary in the selection of raw materials for floor-tile as the clays used must be such that they will not form surface cracks after being air-pressed. The clay should also be free from any tendency to warp or split in burning and furthermore the manufacturer must aim to adjust his mixtures for facing and backing in case they are different. Clays used for floor-tile should also be as free from soluble salts as those used for the manufacture of pressed brick or terra-cotta,

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[1] N. J. Geol. Surv , Fin. Rept., VI, p. 287, 1904.

although, as pointed out by Langenbeck[1] soluble lime salts may come from the coloring materials used. Thus the manganese and umber used for chocolates, brown and black, are seldom free from gypsum.

Purdy[2] has suggested the following classification of floor-tiles:

Face-tile. . . .	Vitreous	White Colored	Prepared facing body on a common clay backing.
	Porous	Clay Colors	
Tesseræ.	Vitreous	White Colored	Solid bodies formed into geometric shapes.
	Encaustic	Clay Colors	

Floor-tile when white are commonly made of a mixture of white-burning clays, flint, and feldspar. Buff-colored tiles and artificial ones are usually made from fire-clays, while red tiles are often made from a red-burning clay or shale. A certain amount of flint and feldspar is generally added to the clay to regulate the shrinkage or degree of vitrification in burning.

Floor-tiles are always molded by the dry-press process in hand-power machines, the raw material being first carefully ground and mixed.

In burning tiles they are placed in saggers and burned in down-draft kilns.

The face-tiles include the plain or Alhambra 6×6 tile strips of various sizes, such as 6×3 and 6×1½ used as body tile, and are most generally made with a prepared facing body backed by a common body, the latter being ground in a dry pan to a 16-mesh powder.

In the manufacture of these plain tiles the face of the die is covered to the required thickness with the required facing body and the rest of the die filled up with backing clay, after which the pressure is applied.

For making inlaid tile a brass cell frame of the same depth as the facing body is used, and consists of a framework of brass strips arranged so as to form the outline of the colors making the pattern. The framework is placed in the mold and the colored clays sifted into their proper divisions. This is done by using a sieve so perforated as to expose only certain cells, and the exposed cells being filled with the facing mixture of the desired color. This means, of course, that it is necessary to use as many sieves as there are colors in the design. The cell frame is then lifted out and the die is filled with a clay backing.

In making tesseræ the body is solid, namely, made entirely from

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[1] Chemistry of Pottery, p. 155.

[2] Trans. Amer. Cer. Soc., VII, p. 95, 1905.

one body mixture. The vitreous tesseræ[1] are porcelains, so compounded as to develop the greatest toughness or resistance to wear under feet that is consistent with the texture of the body and the brilliancy of the colors demanded by the trade.

Encaustic tesseræ tiles have for their base buff- and red-burning clays. Since the iron in these is mainly present as free oxide, it is impossible to burn such tiles to vitrification without destroying the color.

Wall-tile

These are quite different from floor-tile in the character of body and style and decoration. The body is made of white-burning clay and is not burned to vitrification, but on the contrary is usually just hard enough to resist scratching with a knife. It is therefore very porous.

Wall-tile are molded in dry-press machines and burned first in saggers in a biscuit-kiln. They are then glazed and fired in a muffle-kiln at a much lower temperature. Many different shades, colors, and styles of decoration are now produced. In some cases the decoration is applied by a relief design impressed on the surface of the clay during molding, in others different colored glazes are used, or a considerable variation can be obtained in the shades of one color by varying the thickness of the glaze over different parts of the tile. Print-work and hand-painting also are employed at times to ornament the ware.

Pottery

Classification.—Under the term of pottery there is included a great series of products for ornamental or domestic use, ranging from the common red earthenware flower-pot to the highly artistic and delicate porcelain vase. The different kinds may be defined as follows:

Common earthenware, made from the lower grades of plastic clays, and having a porous body, usually of red but sometimes cream color, and as a rule not glazed. Decoration is given to it by relief designs, produced during the molding process, or more rarely by painting or glazing.

Yellow or Rockingham ware, covering wares made of semi-fire clays or fire-clays, and having a porous buff-colored body, which is covered with a glaze.

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[1] Purdy, op. cit., p. 101.

[2] If the surface of the tile is to be decorated with modeled embossments, the body is worked up to a plastic condition and formed in plaster molds, after which the surface decoration can be applied.

Majolica and Fayence.—Both these terms are rather loosely used, but a definition recently suggested by S. G. Burt[1] gives fayence as pottery in which the colored clay body is covered with a clear glaze, and majolica as pottery in which the colored clay body is concealed with an opaque enamel.

Stoneware, made of vitrifiable clays, often of semi-refractory character, and having a vitrified body, often of bluish color but never white. The surface is glazed.

White ware, including those products having a white or nearly white porous body, usually covered with a glaze. There are several trade varieties of this known as C. C. ware, white granite ware or ironstone china, semi-vitreous ware, semi-porcelain, and china. Some of these differ at times in name only. Theoretically they differ in the whiteness and degree of vitrification of the body.

Porcelain.—The same materials are in general used for porcelain as for white-ware, but great care has to be exercised in their selection; the proportions are also such as to produce a vitrified and translucent body. Porcelain which is fluxed by feldspar is termed spar china, while that fluxed by calcined bones is termed bone china. The temperature of burning porcelain is often much higher than that of white-ware, although some porcelains of more fusible composition may be fired as low as cone 4.

Belleek, or eggshell-ware, is a porcelain of unusual thinness and delicacy. *Parian-ware* is a term applied to white, unglazed porcelain, so-called from its resemblance to Parian marble.

The technology of the lower grades of pottery is comparatively simple, but for the manufacture of white ware or porcelain the successful completion of the product calls for skill, intelligence, and good materials.

There was a time when whiteware mixtures and glazes of the proper quality could be obtained only after long and tedious experimenting and the expenditure of much time and money, and while many potters are still groping in the dark, the day of this cut-and-try method can be said to have passed. Modern ceramic technology has worked wonders and a knowledge of it proves invaluable to the progressive potter in aiding him to work out the proper combinations of body and glaze. It enables him to adjust them if they do not agree, or to find out often in a comparatively short time where the trouble lies when failures occur.

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[1] Trans. Amer. Ceram. Soc., VI, p 109, 1904.

To take advantage of the facts and principles of ceramic technology does not so much require a very profound knowledge of chemistry as a good technical training, and the potter who seeks and grasps these ceramic principles will advance rapidly, while, on the other hand, he who rejects them and carefully guards some elementary facts as imaginary secrets of great value does himself a positive injury. Freedom of discussion has proven an invaluable aid in other technical branches, and there is no apparent reason why it should not do the same for the pottery industry. The subject of ceramic technology in America has been behind that of Europe for many years, although it is now coming forward with rapid strides.

Manufacture of Pottery

In making pottery there are certain steps that are common to all grades of ware, but the care of preparation and the number of steps are increased in the manufacture of the higher grades.

The different steps may be grouped as follows:

- Preparation
  - Weathering
  - Grinding
  - Washing by sedimentation
  - Blunging and filter-pressing
  - Ball-mills
- Tempering
  - Chaser-mills
  - Pug-mills
  - Hand-wedging
  - Wedging-tables
- Molding
  - Throwing
  - Jollying or jiggering
  - Pressing
  - Casting
- Drying
- Biscuit-burning
- Dipping
- Glost-burning
- Decorating

Preparation

Weathering and grinding.—For the commoner grades of pottery, such as red earthenware and often even for stoneware, the clay or shale are used as they come from the bank or mine.

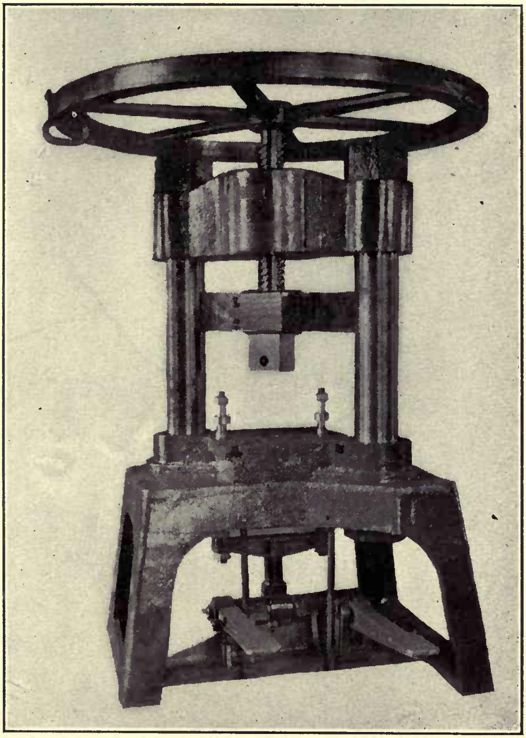
Weathering is sometimes resorted to in order to soften the clay and disintegrate it, so that it can be more readily washed, or to facilitate mixing it when washing is omitted. Shales are sometimes crushed without being weathered.

Washing.—For the higher grades, such as white ware and porcelains, the raw clay is washed in order to free it from sand or other heavy and coarse impurities.

Blunging and filter-pressing.—The blunger consists of a circular vat in which there revolves two arms with stirring-rods attached. In this the clay mixture and water become thoroughly stirred and mixed, after which the contents of the blunger are run through a fine screen of 100 or 150 meshes to the inch into a cistern, from which it is pumped to the filter-press (p. 214 and Pl. X, Fig. 2). The pressed clay then goes to a pug-mill after which it is further wedged before use. This process of preparation is now used by nearly all potteries of any size, except those manufacturing common earthenware. For glazed earthenware bodies it means simply washing, blunging, screening, and filter-pressing the clay body, but for white-ware bodies a somewhat more elaborate system of treatment is necessary, since these carry kaolin, ball-clay, quartz, and feldspar, which must be intimately mixed.

Ball-mills.—Ball-mills are employed in the preparation of clay in the manufacture of some of the finer grades of wares, where fine grinding and intimate mixture of ingredients is especially important. They consist of a hollow cylinder that rotates on a horizontal axle and into which the clay to be ground is admitted through an opening at one side or end. The machine is charged with the clay and balls (which fill about one third of the volume of the cylinder), the latter being of porcelain or water-worn Iceland-flint pebbles. The material is pulverized by abrasion or rubbing friction between these balls as they are caused to move upon each other by the rotation of the cylinder. There are two principal types of ball-mills which may be designated as the intermittent and the continuous. The former are those which are run with a given charge until the requisite degree of fineness is attained, when this is removed and another charge put in. This class of apparatus may be used to grind either in the dry or wet state. The latter or continuous class includes the more improved types of ball-mills for turning

PLATE XX



Bergstrom & Bass Tile-press.

out a large product of very finely dry-ground materials. They are so arranged that the raw ingredients are fed in at one end of the rotating cylinder and gradually work their way towards the other end, becoming finer and finer until they are discharged in the desired state of comminution, when the opposite end of the drum is reached. The continuous ball-mill is in use very little, if at all, in this country, but is rapidly coming into use in Germany. The periodic mill is used to some extent by potteries in this country.

Tempering

Chaser-mills, which may be regarded as a form of wet pan, are sometimes used at the stoneware factories. They consist of a circular iron pan in which there revolves a frame bearing two narrow iron wheels, 30 to 36 inches in diameter. As this frame revolves the wheels, by means of a gearing, travel around the pan in a spiral path. The clay and water are placed in the pan and the action of the wheels grinds and cuts it up, the tempering taking from one to two hours. The action of such a machine is quite thorough, but considerable power is required to operate it. Their use has been largely discontinued since the introduction of the blunger and filter-press.

Pug-mills and hand-wedging.—The washed clays or mixtures of clays as they come from the filter-press are tempered in a vertical or horizontal pug-mill, which is similar in its action to that described under Brick (p. 261). This is then followed by hand-wedging in order to render the clay perfectly homogeneous and free from air-bubbles. This latter operation consists in taking a large lump of the pugged clay, cutting it in two, bringing the two parts together with force, and then kneading the reunited lumps, this treatment being repeated a number of times.

Wedging-tables.—Kneading-tables are used at some factories for working the clay by machine instead of wedging it by hand. Although much used abroad, their introduction into this country has been rather restricted. The machine consists of a circular table about 6 feet in diameter, the upper surface of which slopes outward. On this are two conical rolls, 20 to 30 inches in diameter and about 8 inches wide. These rolls have corrugated rims, and are attached to opposite ends of a horizontal axis, having a slight vertical play. The clay is laid on the table, and as the rolls travel around on it the clay is spread out into a broad band. A second axle carries two other pairs of rolls of the same shape but smaller size, which travel around in a horizontal plane. These rolls press the band of clay together again. In this way the clay is subjected to alternating vertical and lateral pressure and all air-spaces are thus closed. The rolls make 10 to 12 revolutions per minute, and the machine kneads 2 to 3 charges of 700 pounds per hour.

Molding

After the clay has been properly tempered, the next step in the process of manufacture is molding. As indicated above, this is done in four different ways, the clay having first been thoroughly kneaded, usually by hand, in order to insure its complete homogeneity and freedom from all air-bubbles.

Throwing is done by the potter taking a lump of clay and placing it on a rapidly revolving horizontal disk and gradually working it up into the desired form (Pl. XXI). After being turned the object is then detached from the wheel by running a thin wire underneath it. Only articles with a circular cross-section and thick walls can be formed in this manner, since they have to hold their shape under their own weight. Throwing represents the earliest methods of the potter, and is much used still at small factories, but in the larger ones it has been mostly superseded by the next process.

Jollying or jiggering is a more rapid method than turning, and the clay for this purpose is tempered to a softer consistency. The jolly is a wheel fitted with a hollow head to receive the plaster mold, the interior of which is the same shape as the outside of the object to be molded. A lump of clay is placed in the revolving mold and shaped into the proper form, first by means of the fingers and lastly by means of a template or so-called "shoe" attached to a pull-down arm, which is brought down into the mold. Cups, jars, jugs, and the larger flower-pots are molded in this manner. A modification of this method termed "pressing" is used for the smaller sizes of flower-pots. This consists of a revolving steel mold, with a steel plunger of the shape and size of the interior of the pot. The tempered clay is first put through a plunger-machine, from which it issues in the form of columns, which are cut up by wires into a number of pieces, each containing just enough clay for making a pot of the desired size. These lumps of clay are then placed one at a time in the mold, and the latter raised by means of a lever, until the plungers fit into it, thus pressing the clay into the mold. The bottom of the mold is movable, so that as the mold is lowered the bottom rises and pushes out the pot. Such machines have a large capacity, and are now used at most flower-pot factories.[1]

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[1] Fire-clay crucibles are sometimes molded by this method.

A modification of jollying, used for making plates and saucers, consists in having a plaster mold, the surface of which has the same shape as the interior or upper surface of the plate to be formed. The potter's assistant takes a piece of clay of the desired size, and pounds it to a flat cake, called a "bat," which is laid on the mold; he then shapes the other side or bottom of the plate by pressing a wooden template of the proper profile against it as it revolves.

Pressing.—Ewers and vessels of oval or elliptical section are usually made by means of sectional molds, consisting of two or three pieces, the inner surface of which conforms to the outer surface of the object to be molded. A slab of clay is laid in each section and carefully pressed in, the mold put together, and all seams smoothed with a wet sponge. After drying for a few hours the parts of the mold are lifted off. Clocks, lamps, water-pitchers, and similar articles are made in this manner.

Casting.—This consists in pouring a clay-slip into a plaster mold which absorbs some of the water, and causes a thin layer of the clay to adhere to the interior surface of the mold. In order to produce a slip with less water some alkaline salt is added to the mixture. When the layer on the inner surface of the mold is sufficiently thick, the mold is inverted and the remaining slip is poured out, the mold being removed in a few hours. This method is extensively used in making thin porcelain ornaments, as well as many white-ware objects. It is also employed for making belleek.

The forming of pottery by casting is much more extensively done in Europe than in the United States.

Drying

This, of necessity, often has to proceed rather slowly, especially if the ware is of complicated shape. The ware is usually dried first in an open room, and then removed to the heated green-ware dry-room.

Subsequent steps

Up to this point, the method of treatment has been much the same, except for the blunging of white ware or porcelain mixtures. From the drying stage on, the methods of treatment of the different kinds of ware diverge somewhat.

Common red earthenware, such as flower-pots, is usually burned at a low heat, often not above the melting-point of cone 010, and the kilns used are generally rectangular or circular up-draft ones. The ware after burning is quite porous and not steel-hard.

If to be decorated this can be done by incised designs, the application of relief decoration, or by covering it with a glaze of easy fusibility.

Yellow and Rockingham ware.—In making this the clay is first burned to develop the body, after which it is glazed and then fired a second time to develop the glaze, the process in this respect being similar to that employed for white ware, and the ware being placed in saggers to protect it from the flames and dirt. The glazes are artificial mixtures which melt to a glass at a lower temperature than that required to burn the body.

Stoneware.—In this class of product the body and glaze are developed together, so that after drying the objects are ready to have the glaze applied. A type sometimes used is some form of natural glaze or slip-clay (see p. 228), which melts to a brown glass at a temperature at which the body of the ware is nearly vitrified.

For application the slip-clay is mixed with water to a creamy consistency and the ware dipped in it. Although slip-clays have been found at a number of localities in the United States, that obtained from Albany, N. Y., continues to be the most satisfactory and is shipped all over the country. The amount of slip-clay required even by a factory of moderate size is not very large, so that the annual domestic consumption of this kind of clay is limited.

Salt-glazing represents the simplest form of glazing a ware, and is applied more often to sewer-pipe than stoneware. When the wares are to be salt-glazed they are placed in the kiln, unprotected from the flames. As soon as the kiln has reached its highest temperature, the salt is put in the fireplaces, one or two shovelsfull at a time, at regular intervals, so that the addition of the salt may extend over several hours. When the salt is placed in the fires the heat volatilizes it, and the vapors in passing up through the kiln unite with the clay, forming a glaze on the surface of the ware. Many clays are capable of taking a good salt-glaze, but some take a poor one, and others do not glaze at all.

From experiments made by L. E. Barringer[1] it seems that a clay may be either too aluminous or too siliceous to be successfully salt-glazed, but that, if the process of salt-glazing is properly carried out, clays in which the proportion of silica to alumina is more than 4.6 to 1 and less than 12.5 to 1 are capable of receiving a glaze. The degree

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[1] Trans. Amer. Cer. Soc., IV, p. 223.

of fineness of the free silica in the clay makes little difference. The finer the sand the lighter the color of the glaze.

Barringer also found that, contrary to what was usually supposed, a considerable quantity of soluble salts, as much as 3 per cent, can be present in a clay without seriously interfering with the salt-glazing when conducted at cone 8.

Bristol glazes, representing a third type, are an artificial mixture of fluxes, kaolin, ball-clays, and flint. They can be produced in a variety of colors, and white, due to zinc or tin, is a common one. This is the type of glazing generally used on stoneware.

The burning of stoneware is carried out in up-draft or down-draft kilns, and the cone reached varies in different localities, but where fire-clays or semi-fire clays are employed it ranges probably from 6 to 8.

White ware and porcelain.—Both of these are made from artificial mixtures, consisting of kaolin, ball-clay, quartz, and feldspar, and the materials used are selected with a view to their white-burning qualities.

The kaolin supplies white color and refractoriness but is low in plasticity, and to supply this deficiency ball-clay is added. Quartz serves to diminish the shrinkage, and feldspar or calcined bones as a flux.

Porcelain in which spar is the flux is termed hard, feldspar or true porcelain, and shows a bluish-white color by transmitted lights, while that which is fluxed in part by calcined bones or lime phosphate is termed bone china and shows a yellowish color by transmitted light.

The proportions in which these several substances are used are commonly kept secret by the potter, but enough has been published to show the general mixtures.

In the molding of white and porcelain wares jiggering and pressing are extensively employed, and the burning is done in much the same manner as in yellow ware.

Saggers, which are oval or cylindrical receptacles made of fire-clay with a flat bottom, about 20 inches in diameter and a height usually of about 8 inches, are used for protecting the ware in the kilns.

The saggers are filled with unburned ware and set one on top of the other (Pl. XIX, Fig. 2), so that the bottom of one forms a cover for the one below it, the joint between the two being closed by a strip of "wad"-clay. The use of these saggers is to protect the ware from the smoke, gases, and ashes of the kiln-fire. The chief requisite of a sagger-clay is that it shall stand more heat than the ware placed in it, and repeated firing and cooling, as well as handling without breaking. Saggers are generally made from a plastic, refractory clay, with the maximum admixture of grog, i.e., ground old saggers, broken fire-brick, etc. The kilns are usually of the circular up-draft type having a diameter of from 10 to 18 feet. Down-draft kilns are but little used for burning white ware in the United States, although in Europe the down-draft method of burning has superseded the up-draft. The temperature reached in burning varies. White ware is commonly burned at from cones 8 to 9, while the porcelain may be fired as high as cones 12 to 16. Since the color of ferrous iron is less noticeable than ferric iron the fires should be reducing during at least the last part of the firing, and the kiln is then cooled down as rapidly as possible to prevent the oxidation of whatever iron may be in the clay.

For all pottery ware, except hard or feldspar porcelains, the body is first burned in the biscuit-kiln, then glazed and burned a second time in the glost-kiln. For white ware the biscuit-burn is done at perhaps cones 8 to 9, while the glost-burn at about 2 to 6. For yellow and Rockingham ware, fayence and majolica, the biscuit-burn ranges between cones 2 to 8, while the glost is from cones 07 to 03. For porcelain the biscuit-burn is about cone 2, while the glost-burn is at a higher heat, and in this country ranges probably from cones 11 to 13.

The glazes for white ware and porcelain are complex compounds of an artificial character. They consist of a mixture of acids and bases combined according to a definite formula, in such proportions that they will melt to a glass at the temperature reached in burning. A glaze thus produced must furthermore agree with the body in its shrinkage and coefficient of expansion, in order to prevent various defects, such as crazing, shivering, peeling, etc. A discussion of the composition and methods of calculating glaze formulas hardly lies within the province of this work, and those wishing to become acquainted with this subject are referred to a most excellent little manual of Ceramic Calculations issued by the American Ceramic Society.[1]

The glazes used on white ware are usually fritted first. That is, the ingredients of the glaze after mixing are melted either in a frit-kiln or a sagger, broken up and ground wet, together with certain added materials. This glaze mixture is then of a cream-like consistency and the biscuit ware is dipped into it (Pl. XXII). In the glost-kiln this thin coating of glaze melts to a glassy layer and covers the body entirely. White-ware glazes commonly owe their easy fusibility to borax

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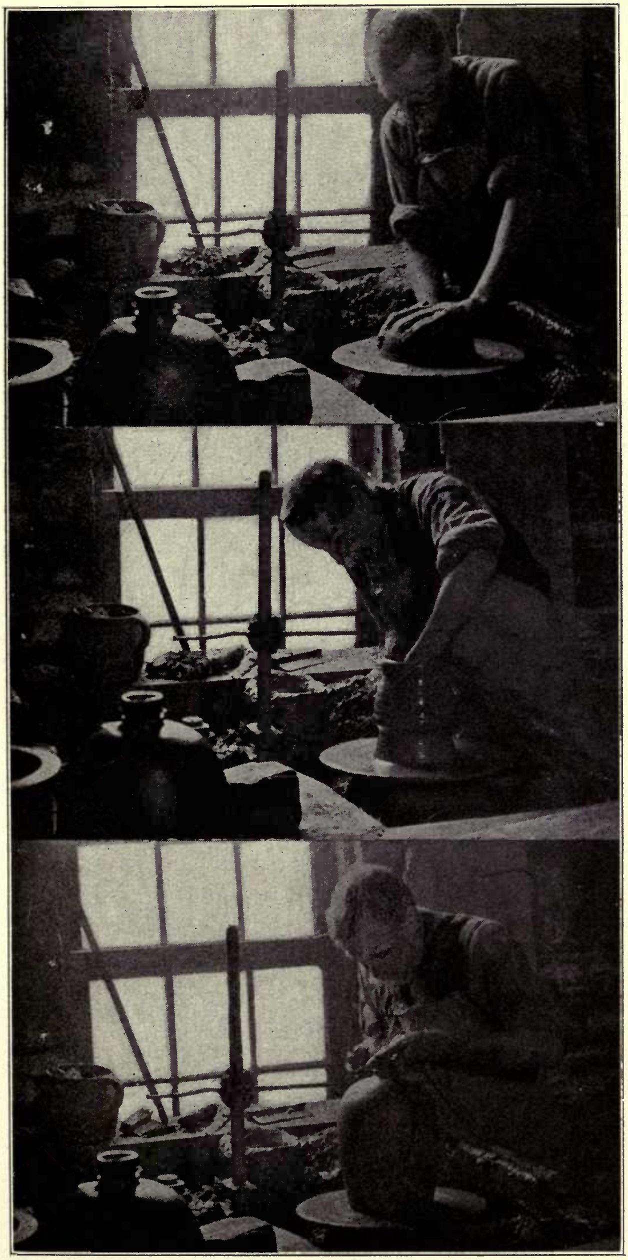
[1] Purchasable for $1.00 from Ed. Orton, Jr., Sec'y, Columbus, Ohio.

PLATE XXI



Views illustrating the process of turning jars. (Photo by H. H. Hindshaw Md. Geol. Surv., IV, p. 358, 1902.)

and lead, while those used on porcelain contain no lead, and require a higher heat for maturing.

White ware and porcelain are often elaborately decorated, either under or over the glaze, but the form of decoration most often seen is print-work. This is done by printing a copper-plate design on special paper, and applying this to the surface of the ware. After being allowed to stand for a few hours the paper is washed off, but the ink of the design is retained on the surface of the ware. The colors are then fixed by firing in a muffle-kiln at a dull-red heat. The print-work is sometimes "filled in" and elaborated by brush-work, or, on better grades of ware, the entire design may be hand-painted. The more delicate colors as well as gold have to be applied over the glaze as they are destroyed by hard-firing. With chromolithography a soft and ornamental multicolored design can be produced at one operation, but it is but little used in this country, although productive of beautiful effects.

Electrical porcelain.[1]—This forms a separate branch of the clay-working industry. These insulating fixtures are made of a mixture of white-burning clays, feldspar, and flint. Articles like wiring-fixtures, knobs, cleats, receptacles, attaching plugs, and switch bases are molded dry-press. Porcelain used for high-tension insulation, as is necessary for oil-switches, transmission lines and transformers, is formed by the wet process, as this gives a ware of greater density and higher insulating value. The wares in this country are burned mostly between cones 10 and 12, but some are fired at lower cones. The electrical porcelain is usually glazed.

Sanitary ware is made sometimes from the same clay bodies as white ware, but the body is usually vitrified or nearly so, and is glazed. The ware is formed by hand in plaster molds, and great care has to be exercised in drying and burning.

Bathtubs and washtubs.—These are commonly made from buff-burning clays, such as are used in terra-cotta manufacture, and covered with both a white slip and a glaze. The lining is usually vitrified, but not the body, and they are termed porcelain lined. The pressing, drying, and burning of such a large object as a bathtub requires much care and time. The pressing is done by hand in large plaster molds, and the wares are burned commonly at from cones 9 to 10, or perhaps slightly higher. A finished bathtub may commonly weigh from 500 to 800 pounds, according to size and shape.

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[1] L. E. Barringer, Porcelain for Electrical Purposes, General Electric Review, March 1908.

CHAPTER V

DISTRIBUTION OF CLAY IN THE UNITED STATES

ALABAMA—LOUISIANA

Introduction.—In this chapter and the two following ones it is proposed to describe briefly the occurrence, properties, and uses [1] of the clays found in the different States. While it is thought that the more important facts are grouped here, still there may be some who wish to obtain additional details, which they can do by looking up the references given at the end of the discussion of each State.

A grouping of the clays according to geologic formations has been adopted partly because the subject is treated mainly from the standpoint of the economic geologist, and partly because it admits of greater uniformity in mode of presentation. For the benefit of those who would prefer a grouping by kinds, the index has been made as complete as possible, in order to enable them to find the data for which they are searching.

Statistics of Production.—Doubtless few people realize the importance of the clay-working industry in the United States, and yet this is not so surprising, since clay has less popular attraction than many other mineral products, such as gold, silver, etc. A casual glance, however, at the annual figures of production will probably speedily convince one that clay is to be classed among the foremost mineral products of the country, being outranked only by coal and iron.

The statistics of production for 1904, as published by the United States Geological Survey, were the latest available at the time the first

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[1] This refers to their use for the manfacture of clay-products.

edition was published. As those for 1907 appeared as the second edition was being printed they have also been added.

VALUE OF CLAY-PRODUCTS OF THE UNITED STATES IN 1904

Product.	Value.	Per cent of total production.
Common brick	$51,768,558	39.51
Vitrified paving-brick	7,557,425	5.77
Front brick	5,560,131	4.24
Fancy or ornamental brick	845,630	.65
Drain-tile	5,348,555	4.08
Sewer-pipe	9,187,423	7.01
Architectural terra-cotta	4,107,473	3.14
Fireproofing	2,502,603	1.91
Hollow blocks	1,126,498	.86
Tile, not drain	3,023,428	2.31
Fire-brick	11,167,972	8.52
Miscellaneous	3,669,282	2.80
Red earthenware	756,625	.58
Stoneware	3,411,025	2.60
Yellow and Rockingham ware	290,819	.22
C. C. ware	854,389	.65
White granite and semi-porcelain	10,836,117	8.27
China	1,583,513	1.21
Bone china, delft, and belleek	162,500	.12
Sanitary ware	3,585,375	2.74
Porcelain electrical supplies	1,431,452	1.09
Miscellaneous pottery	2,246,455	1.72
Total	$131,023,248	100.00

CLAY MINED AND SOLD IN THE UNITED STATES IN 1904

Kind.	Value.
Kaolin	$304,582
Paper	276,381
Slip	11,942
Ball	142,028
Fire	1,306,053
Stoneware	83,904
Miscellaneous	195,272
Total	$2,320.162

VALUE OF CLAY PRODUCTS OF THE UNITED STATES IN 1907
(From U. S. Geol Survey.)

Product.	Value.	Per cent of total production.
Common brick	$58,785,461	36.99
Vitrified paving-brick	9,654,282	6.07
Front brick	7,329,360	4.61
Fancy ornamental brick (including enameled brick)	1,279,416	0.81
Drain tile	6,864,162	4.32
Sewer-pipes	11,482,845	7.22
Architectural terra-cotta	6,026,977	3.79
Fireproofing	3,162,453	1.99
Hollow blocks	1,088,165	0.68
Tile, not drain	4,551,881	2.86
Stove lining	627,647	0.40
Fire-brick	14,946,045	9.40
Miscellaneous (brick and tile)	3,000,201	1.89
Red earthenware	845,465	0.53
Stoneware	4,280,601	2.69
Yellow and Rockingham ware		
C. C. ware	13,913,680	8.75
White granite and semi-porcelain		
China, bone china, delft, belleek	1,930,669	1.22
Sanitary ware	4,863,222	3.06
Porcelain electrical supplies	2,613,771	1.65
Miscellaneous pottery	1,696,066	1.07
Total	$158,942,369	100.00

CLAY MINED AND SOLD IN THE UNITED STATES IN 1907

Kind.	Value.
Kaolin	$340,311
Paper	293,943
Slip	37,925
Ball	195,515
Fire	2,054,698
Stoneware	136,576
Brick	112,003
Miscellaneous	277,577
Total	$3,448,548

ALABAMA

The clay-deposits of this State are distributed over a wide range of geologic formations, whose characters are briefly referred to below.

Archæan and Algonkian

The rocks of this age, which underlie a roughly triangular area of the eastern part of the State, consist of granites, gneisses, and schists,

PLATE XXII

Dipping biscuit ware into the glazing-tubs. (Photo by H. Ries.)

all of which have, by surface decay, furnished a residual clay, usually of ferruginous character. In the schist areas, however, there are not a few pegmatite veins, whose decomposition has resulted in the formation of kaolin. Such occurrences are found near Milner, Pinetucky, and Micaville, Randolph County, and Stone Hill in Cleburne County, but they are all undeveloped, owing to lack of railroad facilities. The Alabama kaolins in their crude condition are rather siliceous, highly refractory, and burn to a very white color.

Cambrian and Silurian

The clays obtained from these formations are either residual deposits or are concentrates from these, which have been carried by surface-waters down into sinks and other depressions. While the Silurian rocks contain some shaly members they are not, so far as known, used for brickmaking, but the residual clays which are usually impure are extensively employed for this purpose. At certain localities, such as at Gadsden, Kymulga, Peaceburgh, and Oaxanna, white clays occur surrounded by the impure ones, and those found in Cherokee County have been used for fire-brick manufacture.

Lower Carboniferous

Although occupying a number of small areas in the northern portion of the State no clays of economic value have been noted from these. In Will's Valley, however, it carries an important bed of white clay, which is also found farther north near the State line. The white clay, which is known locally as chalk, and has an aggregate thickness of about 40 feet, is worked near the State line about Eureka station, and thence southward for two miles.

Coal-measures

These occupy a large triangular area in the northern part of the State, but since a great portion of the region is remote from the railways, whatever shales or clays it may contain have been but little developed. The most important deposits are the under-clays found in some of the coal-fields, which have been employed for making pottery, as at Jugtown, Fort Payne, Rodentown, etc. The shales are also used in some parts of the State for making vitrified brick, especially at Coaldale and North Birmingham. No fire-clays have thus far been found in the coal-measures.

Cretaceous

This contains the most important clay-deposits in the State, but most of the beds have thus far been found in one member, namely, the Tuscaloosa. This consists usually of yellow and grayish sands, with smaller beds of pink and light-purple sands thinly laminated, dark-gray clays holding many leaf impressions, and gray lenses of massive clay which vary in color. The formation occupies a belt of country extending from the northwest corner of the State around the edges of the Paleozoic formations to the Georgia State line at Columbus, attaining its greatest width at the northwestern boundary of the State. The purer clays have as yet been found only in the northern part of this area, in Fayette, Marion, Franklin, and Colbert counties, and the adjoining parts of Mississippi, but the following section from 12 miles east of Tuscaloosa affords a good idea of the character of the deposits.

SECTION 12 MILES EAST OF TUSCALOOSA, ALA.

	Feet.	In.
1. Purple massive clays	5	
2. Ferruginous sandstone crusts	6–8	
3. Variegated clayey sands	10	
4. Purple clays with sand partings	10	
5. Ferruginous crusts	1	
6. Laminated, gray and yellow sandy clay	6–8	
7. Lignite with pyrite nodules	2	6
8. Dark-gray massive clays	6	8
9. Covered	1	8
10. Purple clay	—	

This section shows great vertical variation and a similar one may occur horizontally. Nevertheless, the formation contains not a few deposits of workable size, which are employed for stoneware and common earthenware, as at Sulligent, Tuscaloosa, etc. In Colbert County the Tuscaloosa formation carries fire-clays, and other deposits are known near Woodstock and Bibbville, A curious white siliceous clay occurs near Chalk Bluff and Pearce's Mill, Marion County, but it has not been utilized.

Tertiary

The Tertiary formations underlie the southern third of Alabama, and while it is known that they contain extensive deposits of clay, these have been but little investigated. The most promising occurrences of clay in this section are in the Grand Gulf formation (Pliocene) which, according to Dr. E. A. Smith, overlies unconformably most of the older Tertiary beds. A siliceous clay, resembling flint-clay in appearance, is found in abundance in Choctaw, Clarke, Conecuh, and other counties. Its analysis is given in the appended table.

Pleistocene

Over much of the coastal plain in the second bottoms of the rivers there is a great extent of yellow loam suitable for brickmaking, which corresponds to the Columbia loams of the Northern States.

Division of Clays by Kinds

China-clays.—The only kaolins are those occurring chiefly in Randolph County.

Fire-clays.—The fire-clays of Alabama come from four geologic horizons, namely: (1) The Cambrian and Silurian limestone formations of the Coosa Valley region, seen at Peaceburgh, Calhoun County, Oaxanna County, and Rock Run, Cherokee County; (2) the cherty limestone of the Lower Carboniferous formations of Will's Valley, seen at Will's Valley and Valley Head, Dekalb County; (3) the Tuscaloosa formation of the Lower Cretaceous, occurrences being known at Bibbville and Woodstock in Bibb County, Hull station and Tuscaloosa in Tuscaloosa County, Potter's Mills in Marion County, and Pegram in Colbert County; (4) the Lower Tertiary formation, Choctaw County.

Pottery-clays.—These are found at a number of localities, including Blount County; Rock Run, Cherokee County; Fort Payne, Dekalb County; Coosada, Elmore County; Bedford and Fernbank, Lamar County; Tuscaloosa, Shirley's Mill, Fayette County; Pegram, Colbert County.

Brick-clays.—Many deposits are found in all parts of the State.

In the following table there are given a number of physical tests and chemical analyses of Alabama clays. Additional ones will be found in Reference 4, on page 321.

CHEMICAL ANALYSES OF ALABAMA CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	67.95	51.90	82.04	61.55	74.25	60.90	72.20	72.40	66.45	
Alumina (Al_2O_3)	20.15	35.00	12.17	20.25	17.25	18.98	17.42	14.86	18.53	
Ferric oxide (Fe_2O_3)	1.00	0.99	trace	7.23	1.19	7.68	2.40	7.64	2.40	
Lime (CaO)	1.00	0.23	trace	trace	0.40	trace	trace	0.20	1.50	
Magnesia (MgO)	trace	0.10	0.327	0.98	trace	trace	trace	0.40	1.25	
Alkalies	1.87	0.55	0.60	2.25	0.52	trace	0.56	....	trace	
Water (H_2O)	....	....	....	6.19	6.30	12.46	7.40	5.05	8.68	
Moisture	....	....	....	....	....	0.90	0.12	0.65	0.78	
Loss on ignition	8.00	11.30	4.325							

PHYSICAL TESTS OF ALABAMA CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Per cent water required for mixing	37.5	25	35	20	22.6	45	33	39	26	36
Average tensile strength	143	20	5–6	40	102	100	106	55	30	100
Air-shrinkage, per cent	8	5	....	1½	6½	12.5	10	6	5	11
Fire-shrinkage, per cent	7	8	2	5	3½	6.5	4	11	10	7
Incipient fusion	2250°	2250°	2400° F.	2000°	2300°	1900°	2000°	2000°	2150°	2100°
Vitrification	....	Cone 30	Cone 27	2250°	Cone 27	2100°	2200°	2150°	2300°	2300°
Viscosity	Cone 27	....	....	....	....	2300°	2400°	2300°	2500°	Cone 27
Color when burned	cream-white	....	yellow	red	buff	red	buff	red	yellowish white	red
Plasticity	....	....	lean	moderate	good	fat	....	....	....	fair

Localities of Clays in Preceding Table

No.	Locality.	Geological Age.	Uses.
I.	Gadsden	Cambro-Silurian	Not worked
II.	Peaceburg	" "	" "
III.	Eureka	Lower Carboniferous	" "
IV.	Birmingham	Coal-measures	" "
V.	Bibbville	Lower Cretaceous	" "
VI.	Bedford	" "	" "
VII.	Shirley's Mills	" "	" "
VIII.	Bexar	" "	" "
IX.	Pegram	" "	" "
X.	Tuscaloosa	" "	" "

Nos. I–X from Bull. 6, Ala. Geol. Survey.

References on Alabama Clays

1. McCalley, H., Report on the Valley Regions of Alabama (Palæozoic strata): Clays. In two parts. I. The Tennessee Valley Region, Ala. Geol. Surv., p. 68, 1896.

2. Ibid., II. The Coosa Valley Region, p. 84, 1897.

3. Mell, P. H., Jr., The Southern soapstones, kaolin, and fire-clays and their uses, Amer. Inst. Min. Eng., Trans., X, p. 318, 1882.

4. Ries, H., The Clays of Alabama, Ala. Geol. Surv., Bull. 6, p. 220, 1900.

5. Smith, E. A., The Clay Resources of Alabama and the industries dependent on them, Eng. and Min. Jour., LXVI, p. 369, 1898.

6. Smith, E. A., Geological relations of the clays of Alabama, Ala. Geol. Surv., Bull. 6, pp. 69–113, 1900.

7. Butts, C., Clays of the Birmingham District, Ala. U. S. Geol. Surv., Bull. 315, p. 291, 1907.

ARKANSAS

In the Mesozoic regions of Arkansas there are found a great variety of clays. Those occurring within the Tertiary region are said to have been used for the manufacture of pottery, while kaolin is said to occur in Pike, Pulaski, Saline, and Ouachita counties, but the beds are rarely over 2 feet in thickness. The Pulaski deposits are the only true kaolins of those mentioned.

On the Hotsprings (Ref. 3) reservation the Palaeozoic shales have, by decay and leaching in place, yielded a series of light-colored siliceous clays. They form beds of variable thickness, sometimes interbedded with sandstones. These clays have been worked outside the reservation on Cedar Mountain, near Mountain Valley, P. O., and shipped to Chicago for use in making art pottery. Only analyses are available, and these give little information regarding their physical properties:

	I.	II.
Silica (SiO_2)	70.31	74.55
Alumina (Al_2O_3)	17.27	13.68
Ferric oxide (Fe_2O_3)	1.35	1.27
Lime (CaO)	.23	.20
Magnesia (MgO)	.91	2.03
Potash (K_2O)	3.51	3.84
Soda (Na_2O)	.26	.10
Titanic acid (TiO_2)	1.00	.73
Ignition	4.36	3.63
Moisture	.88	.77
	100.08	100.80

Brick-clays are abundant in the Pleistocene formations. The shales associated with the Carboniferous coals should also prove of value for the manufacture of clay-products. According to Branner they occur in great abundance between Little Rock and Fort Smith.[1]

The following analyses are given by Branner in the paper referred to above.

ANALYSES OF ARKANSAS CLAYS

	I	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Silica (SiO_2)	53.30	62.36	58.43	51.3	63.07	48.34	76.33	75.99	45.28
Alumina (Al_2O_3),	23.29	25.52	22.50	24.69	23.92	34.58	16.04	16.12	37.39
Ferric oxide (Fe_2O_3)	9.52	2.16	8.36	10.57	1.94	1.65	1.24	1.35	1.71
Lime (CaO)	.36	.51	.32	.32	.23	.81	By diff. .99	1.45	1.83
Magnesia (MgO)	1.49	.29	1.14	.63	trace	trace			.29
Potash (K_2O)	1.36	1.90	2.18	2.18	1.15	.44			
Soda (Na_2O)	2.76	.66	1.03	.72	1.08	1.26			
Water (H_2O)	5.16	5.32	6.87	9.11	7.07	12.94	5.40		13.49
Total	97.24	98.72	100.83	99.52	99.46	100.02[2]	100.00	94.91	99.99

I. Clay-shale from railroad cut at south end of upper bridge, Little Rock.
II. Decayed shale from Iron Mountain Railroad cut, at crossing of Mt. Ida road, Little Rock.
III. Clay-shale from Nigger Hill, Little Rock.
IV. From S. E. ¼ of S. W ¼, Sec. 31, 10 N., 23 W.
V. Benton, Hick's bed, 2 S., 15 W., Sec. 12.
VI. Benton, Howe's pottery.
VII. John Foley's, 13 S., 24 W, Sec. 18, N. E. ¼ of S. E. ¼.
VIII. Climax pottery, 15 S., 28 W., Sec. 5, W ½ of S. E. ¼.
IX. Kaolin, 1 N., 12 W., Sec. 36, Tarpley's.
I–IV, Carboniferous; V–IX, Tertiary. Branner, Ref. 1.

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[1] Branner, Amer. Inst. Min. Eng., Trans., XXVIII, p. 42, 1897.

[2] TiO_2 1.56.

PLATE XXIII

Fig. 1.—Pit of Carboniferous shale near Birmingham, Ala. (Graves photo.)

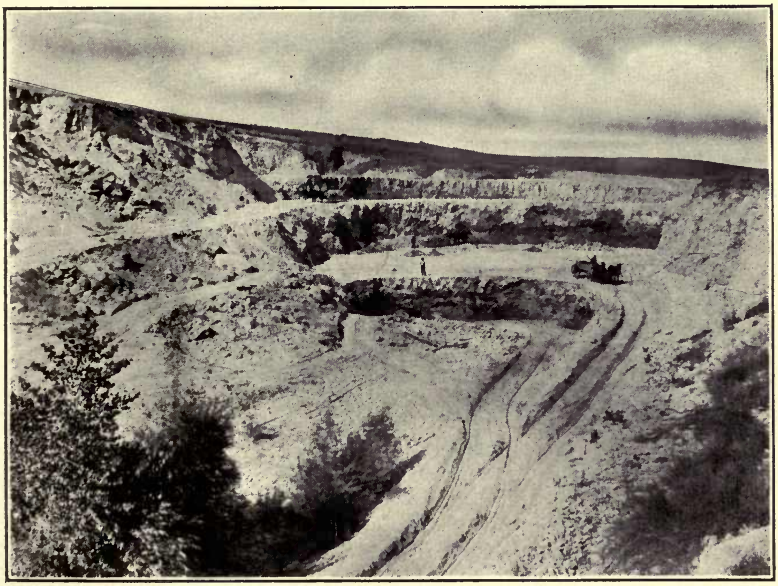

Fig. 2.—Tertiary clays (Ione formation) used for brick, terra-cotta, etc., Lincoln, Calif. (Photo loaned by Gladding, McBean & Co.)

References on Arkansas Clays

1. Branner, J. C., Cement Materials of Southwestern Arkansas, in Amer. Inst. Min. Eng., Trans., XXVII, p. 42, 1897.

2. Annual Report of State Geologist for 1888, Pt. V, p. 11. Gives numerous analyses.

3. Eckel, E. C., Clays of Garland County, Ark., U. S. Geol. Surv., Bull. 285, p. 407, 1906. See also Geol. Atlas Folios, Nos. 122, 154, 119.

ARIZONA

The clay resources of this State have been but little developed.

Ransome[1] states that clay for use in a mixture to line converters is obtained from near the Czar fault in the Copper Queen mine, and has been formed by decomposition or alteration of the Obrigo limestone.

Common brick-clays are used locally at a few points.

CALIFORNIA

Published information regarding the properties of the California clays is very meager, although many scattered references are to be found in the annual reports of the California State Mineralogist, especially the 7th to 13th.

Residual clays are derived from many of the formations occurring within the State, and are occasionally worked for common brick.

Of the sedimentary clays, those belonging to the Ione formation of the Neocene, extensively developed in the Great Valley, are the most important, but unfortunately they are exposed in only a few places.

Lindgren[2] states that the white clays of this formation are frequently well suited to pottery manufacture, and the clay industry has been extensively developed around Lincoln, Placer County. Similar beds are found at many places in the Cosumnes area, but they are not worked.

The white Ione clays have also been extensively dug to the northwest of Ione and above Carbondale, to be used in making coarse pottery. A variegated clay of good quality has been quarried at Valley Springs and shipped to Stockton for making pottery.[3]

A belt of clays is also said to extend in a general west of north and east of south direction from Elsinore on the south to Corona on the

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[1] U. S. Geol. Atlas, Folio No. 112, p. 17.

[2] U. S. G. S., Geol. Atlas, Folio 5.

[3] Turner, U. S. Geol. Survey, Geol. Atlas, Folio 11.

north. These have been dug for the factories at Elsinore, Corona, and Los Angeles.[1]

At Los Angeles the Tertiary clays are used locally for brick and flower-pots.

The Lincoln locality, although the smallest of the three important ones, is extensively worked; the Carbondale area contains probably the best grades of clay, but the Elsinore-Corona belt affords a greater variety.

References on California Clays

1. Anon., Industrial Materials of California, Calif. State Mining Bureau, Bull. 38, 1906.

2. Johnson, W. D., Clays, Calif. State Mineralogist, 9th Ann. Rept., 287, 1890.

3. Ries, H., The Clay-working Industry of the Pacific Coast States, Mines and Minerals, XX, p. 487, 1900.

4. See scattered notes in Annual Reports of California, State Mineralogist, up to the 13th.

COLORADO

The clay-bearing formations of Colorado which have been thus far examined or developed are chiefly Cretaceous, Tertiary, and Quaternary.

Mesozoic

The Cretaceous and Tertiary beds are well exposed along the eastern edge of the Rocky Mountains, where they have been worked for some years.

In the Denver Basin, which is the most important, the clays are derived from the Denver, Laramie, Fox Hills, and Dakota formations, but the second and third are comparatively unimportant.

The Dakota formation in the Denver Basin carries beds of fire-clay which occur as non-continuous bands, 5 to 15 feet thick, and several hundred feet in length, in the argillaceous shales which separate the two or three heavy layers of sandstones that constitute the bulk of the formation, and forms the hogbacks around Golden (Pl. XXIV, Fig. 2). The fire-clays, some of which fuse at cone 33, are bluish-gray or black in color, the impurities consisting of sand laminæ, and iron oxide resulting from the decomposition of pyrite.

The Golden clay enjoys a high reputation for fire-brick and assayer's materials. Fire-clays also exist in the Laramie in connection with the coal, but these are of inferior quality and irregular thickness.

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[1] Bull. 38, Calif. State Min. Bureau, 1906.

PLATE XXIV

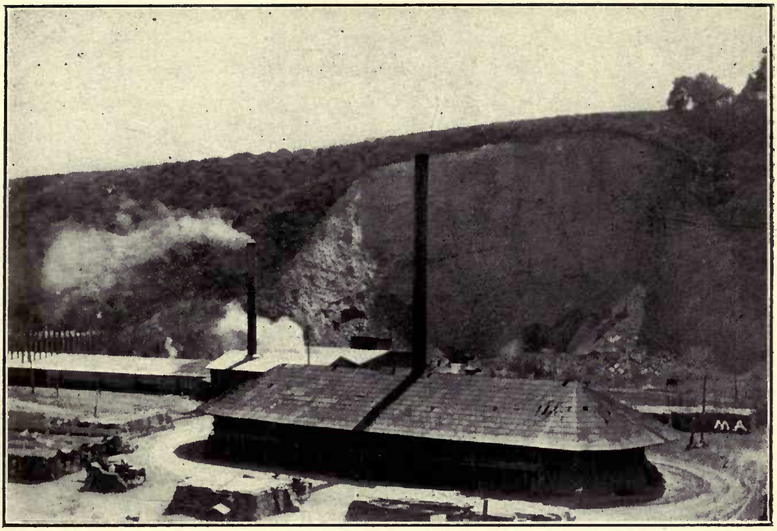

FIG. 1.—Tertiary clays used for common brick, Los Angeles, Calif. (From Bull. 38, Calif. State Min. Bur.)

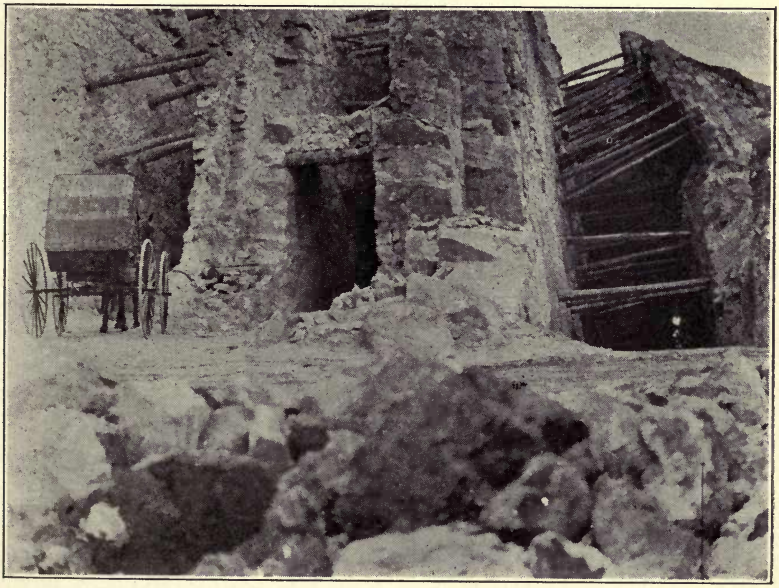

FIG. 2.—View of fire-clay pits, Golden, Colo. The good clay has been taken out, the worthless sandy beds left standing. (Photo by H. Ries.)

The Dakota clays form a more or less continuous strip from Boulder southward through Golden, Platte Canon, Colorado City and beyond, swinging thence westward toward Canon City. They are also found in the region southwest, south and southeast of Pueblo.

Golden, Platte Canon, Colorado City, Canon City, have all produced considerable quantities.

The distribution of the Dakota formation is shown in the following Geologic Atlas Folios, issued by the U. S. Geological Survey: 36, Pueblo; 68, Walsenburg; 135, Nepesta. See also report by N. H. Darton on Geology and Underground Water Resources of the Central Great Plains, U. S. Geol. Surv., Prof. Pap. 32, 1905.

The Benton shales overlying the Dakota carry beds of plastic shale at Golden which are adapted to stoneware and sewer-pipe manufacture, but elsewhere are of little importance.

The clays in the western and southwestern part of the State have received but little attention. In the Durango-Gallup coal-field area (Ref. 6) heavy clay shale deposits occur in the Mancos and Lewis formations of the Upper Cretaceous, and thinner beds in the Mesaverde and Laramie formations, but the first two include the greater part of the thick shale formations of the area. The Mesaverde formation also carries semi-refractory fire-clays associated with the coals and sand-stones.

The Mancos shale has been used for pressed brick at Durango. It burns red, but contains limestone concretions which have to be removed in quarrying. Its analysis is given in the table below.

The Mesaverde fire-clays occur in the coal measures between Durango and Mancos, as do also the Mancos shales. In Rages Basin, southwest of Durango, there are thick outcrops of the Lewis shale, and it is continuously exposed (but not worked) as far as the La Plata River in the vicinity of Fort Lewis.

Tertiary clays and shales are also found in this region, but remain undeveloped.

The upper half of the Fox Hills formation carries an abundance of slightly arenaceous clays suitable for structural materials, and these have been worked at both Golden and Valmont.

At Boulder, Boulder County, the Pierre shales of the Cretaceous afford an excellent supply of material for common, pressed, and paving brick, but the material seems to vary in its physical properties from place to place (Ref. 2). The Carlisle shale has been worked at La Junta for red dry-pressed brick.

Pleistocene

The loess is used at many points in eastern Colorado for making common brick, and many brick-yards around Denver are supplied with it. At other localities alluvial clays are easily obtained.

Analyses of Colorado Clays

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	50.35	63.309	46.61	63.22	48.87	76.56
Alumina (Al_2O_3)	33.64	14.38	37.20	24.72	12.26	8.30
Ferric oxide (Fe_2O_3)	.75	6.27	.15	.43	4.44	.38
Ferrous oxide (FeO)	....	.859	....	....	* .07	....
Lime (CaO)	....	1.81	.44	.30	10.06	.12
Magnesia (MgO)	trace	2.57	.25	.13	3.82	.24
Potash (K_2O)	.49	1.28	1.23	trace	1.76	trace
Soda (Na_2O)	.09	2.19			.55	
Titanic acid (TiO_2)	.80	....	....	.68	....	.60
Water (H_2O)	11.75	5.223	13.65	8.63	†16.39	4.40
Moisture	2.13	2.05	.47	1.36	1.27	1.26
Organic matter	....	....	....	.40	‡ .45	8.31
Total	100.00	99.941	100.00	99.87	99.94	100.17

† Includes CO_2. ‡ SO_3.

I. A typical Golden fire-clay, U. S. G. S., Mon. XXVII, p. 390.
II. Pierre shale, Lee yard, Boulder, Boulder County, U. S. G S., Bull. 265, p. 74.
III. Edgemont, Jefferson County, } U. S. G. S., 16th Ann. Rept., Pt. IV, pp. 554–565.
IV. Pueblo, Pueblo County,
V. Durango. U. S. G. S. Bull. 315. p. 296, 1906.
VI. Dakota fire-clay, Nepesta quadrangle. U. S. Geol. Atl. Folio, 135.

References on Colorado Clays

1. Eldridge, Cross and Emmons, Geology of Denver Basin, U. S. Geol. Surv., Mon. XXVII, p. 387, 1896.

2. Fenneman, N. M., Geology of Boulder District, Colo., U. S. Geol. Surv., Bull. 265, p. 72, 1905.

3. Geijsbeek, S., Colorado Clays, Clay-worker, XXXVI, p. 424; also Whiteware Possibilities of Colorado Raw Materials, Trans. Amer. Ceram. Soc., VIII, p. 98, 1906.

4. Ries, H., The Clays and Clay Industry of Colorado, Trans. Amer. Inst. Min. Eng., XXVII, p. 336, 1898.

5. Ries, H., U. S. Geol. Surv., 18th Ann. Rept., Pt. V (ctd.), p. 1131, 1897.

6. Shaler, M. K., and Gardner, J. H., Clay Deposits of the Western Part of the Durango Gallup Coalfield of Colorado and New Mexico, U. S. Geol. Surv., Bull. 315, p. 296, 1906.

CONNECTICUT

The clays at present worked in this State are confined to the central lowland portion of the State, and to West Cornwall in Litchfield County.

Residual Clays

At West Cornwall, Litchfield County (Pl. XXV, Fig. 1), there is a deposit of kaolin, which has been formed by the weathering of a bed of feldspathic quartzite, but has been protected from glacial erosion, partly because of its location in a hollow, and partly because of its being interbedded with harder quartzites. It is of white color, and sandy or granular texture. The deposit which has a length of at least 1000 feet dips southeastward at a rather steep angle and is worked by forcing water down through pipes and washing out the clay, which is then brought up in suspension and floated down to the settling-tanks. This clay is sold to potters and paper manufacturers. An analysis of the washed material is given below.

Pleistocene

Nearly all of the workable clay-deposits of Connecticut are of this age, and were deposited either in estuaries at a time when the land stood at a lower level, thus allowing the water to occupy some of the valleys entering Long Island Sound, or else they were laid down in lakes, formed by the damming of the valleys by glacial drift. The valley of the Quinnipiac depressed below sea-level, became a long, deep estuary in which the fine clay derived from the material in and under the ice was deposited.

The Milldale, Berlin, Middletown, and Cromwell clays are lake-deposits.

The central Connecticut clays are grouped by Loughlin into five areas, as follows:

Northern area, the largest in the State and including the brick-yards in and north of Hartford. The clay is a blue or sometimes red deposit of highly plastic character, alternating with layers of fine quicksand.

This area extends from King's Island to eastern Rock Hill County. At Hartford it lies chiefly west of the river and is 4 to 5 miles in width, thence it extends northeastward to South Windsor, where east of the river its width is 2 to 5 miles. Its thickness varies from a few feet

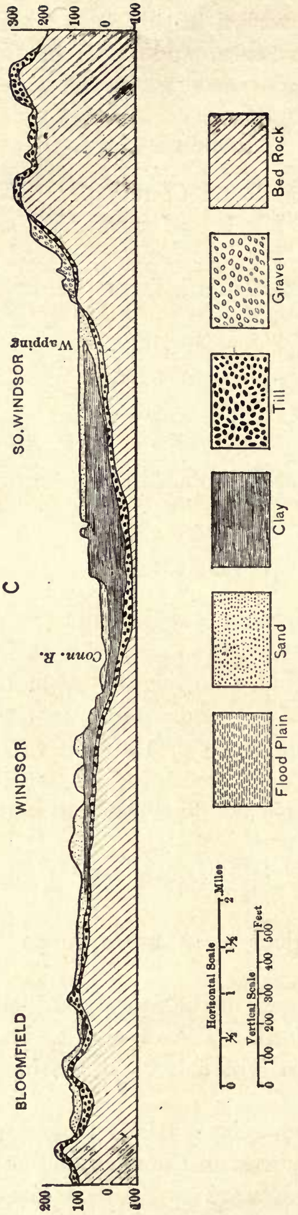

FIG. 49.—Section across Connecticut Valley, showing relations of the clays and other Pleistocene deposits. (After Loughlin, Conn. Geol. and Nat. Hist. Surv., Bull. 4, p. 12, 1905.)

to as much as 95. At most points the clay is overlain by a varying thickness of red or yellow sand.

Clayton area, a small area of reddish clay, having a depth of not less than 15 or 20 feet and overlain by coarse sand.

Berlin area, a brownish-red clay-deposit in the valley of the Sebeth River between Berlin and Middletown.

Quinnipiac area, including the clays extending from North Haven southward into New Haven. The clay is similar to that of the Berlin region, and is usually overlain by several feet of peat. Its measured thickness ranges from 6 to 30 feet.

Milldale area. This is the smallest of the worked deposits. In character the material is similar to the others.

All of these Pleistocene clays are used chiefly for the manufacture of common brick, although a small quantity of the drain-tile and earthenware is also produced. The stoneware and fire-brick manufactured in Connecticut are from New Jersey clays.

The following analyses are taken from Loughlin's report referred to below.

ANALYSES OF CONNECTICUT CLAYS

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	47.50	52.73	50.33	55.27	58.02	56.75
Alumina (Al_2O_3)	37.40	22.25	27.06	20.52	17.93	17.54
Ferric oxide (Fe_2O_3)	0.80	3.14	2.29	5.34	4.89	4.92
Ferrous oxide (FeO)	....	4.55	2.62	1.55	1.24	0.93
Lime (CaO)	trace	1.48	1.22	2.21	3.42	4.18
Magnesia (MgO)	....	3.20	3.34	2.80	1.92	2.34
Soda (Na_2O)	1.10	2.22	1.78	2.82	3.33	3.40
Potash (K_2O)		4.28	4.40	3.43	3.06	3.16
Water (H_2O)	12.48	1.12	1.42	1.37	0.99	1.24
Moisture	....	4.91	5.24	5.06	5.36	6.28
Clay substance	99.00					
Quartz	1.00					
Clay base	....	34.15	47.36	34.04	28.75	27.82
Non-fluxing impurities	....	46.86	36.69	48.18	53.55	53.99
Fluxes	......	18.87	15.65	18.15	17.86	18.93

I. West Cornwall, kaolin, H Ries, anal.
II. S. Windsor, Conn., East Windsor Hill Brick Co.
III. Newfield, Tuttle Bros.
IV Berlin, Berlin Brick Co.
V North Haven, I. L. Stiles & Sons.

References on Connecticut Clays

1. Loughlin, G. F., The Clays and Clay Industries of Connecticut, Conn. Geol. and Nat. Hist. Surv., Bull. 4, 1905.

2. Sheldon, J. M. A., Concretions from the Champlain Clays of the

Connecticut Valley, 45 pp., 1900, Boston, Mass.; Abstracted in Amer. Jour. Sci., 4th ser., Vol. 11, p. 397, 1901.

DELAWARE

The clay resources of this State are of comparatively little importance, nor has much been published regarding them. In the northwestern part, along the Pennsylvania boundary, there are deposits of kaolin similar to those found in southeastern Pennsylvania. The product is washed before shipment.

The Potomac beds of the coastal plain area are said to contain stoneware and fire-clays, which have been dug at two localities not far from Wilmington.

DISTRICT OF COLUMBIA

According to Darton[1] there is an abundance of brick-clay around Washington and much of it is used, in fact large areas have been dug over in the immediate vicinity of the city. The materials employed are chiefly loams belonging to the Columbian formation, but the sandy clays of the Potomac beds are also used.

FLORIDA

The clays of Florida are mostly surface deposits of Tertiary and Pleistocene age, and occur chiefly in the northern part of the State, the majority of them being more or less sandy in their character, and adapted to little else than common brick. They have been worked to some extent around Jacksonville, and also at a few other localities. While most of these are ferruginous, calcareous ones are also known, and have been noted from several localities as 18 miles southwest of Tallahassee, and one half mile southeast of Jackson Bluff. Their composition is given below.

The ball-clays are the most important ones found in the State. These are white-burning, plastic, sedimentary clays, of high refractoriness, which are much used by the white-ware potteries. The clay occurs at several points in northcentral Florida (Fig. 36), and the different areas may represent portions of a formerly continuous bed. It consists of a mixture of white clay and quartz pebbles, the latter forming 65 to 75 per cent of the entire mass. A section measured in the pit at Edgar[2] gave:

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[1] U. S. Geol. Atlas, Folio No. 70, Washington, D. C.

[2] See Reference 2 below.

Top-soil	8	ft.
Impure upper clay	8–10	"
White clay	25	"
Green clay	——	

The thickness of the green clay is not exactly known, but at some localities it appears to rest on limestone. An extensive belt of ball-clay also occurs along the Palatlakaha River south of Leesburg, and at Bartow Junction.

On page 335 are given analyses of both the calcareous clays and the ball-clays.

Analyses of Florida Clays

	I.	II.	III.	IV.
Silica (SiO_2)	35.95	30.83	46.11	45.39
Alumina (Al_2O_3)	13.23	15.40	39.5	39.19
Ferric oxide (Fe_2O_3)	1.27	1.40	.35	.45
Lime (CaO)	15.00	13.78	....	.51
Magnesia (MgO)	5.40	7.50	.13	.29
Alkalies (Na_2O, K_2O)	....	undet.	....	.83
Water (H_2O)	10.55	7.16	13.78	14.01
Carbon dioxide (CO_2)	18.50	20.14	....	....
Sulphur trioxide (SO_3)	....	....	.07	....
Total	99.90	96.21	99.94	100.67

I. Calcareous clay, Leon County, H. Ries, anal.
II. Calcareous clay, near Jackson Bluff on Ocklocknee River, H. Ries, anal.
III. Washed clay from Palatlakaha River.
IV. Washed clay from Edgar, C. Langenbeck, anal.
I–IV from U. S. Geol. Surv., Prof. Pap. 11, p. 83.

References on Florida Clays

1. Memminger, C. G., Florida kaolin-deposits, Eng. and Min. Jour., LVII, p. 436, 1894.

2. Ries, H., The Clays of Florida, U. S. Geol. Surv., 17th Ann. Rept., Pt. III, p. 871, 1898.

3. Ries, H., See Florida, U.S. Geol. Surv., Prof. Pap. 11, p. 81, 1903.

GEORGIA

This State is divisible geologically into three areas, namely: (1) A northwestern area, underlain by shales, limestones, and sandstones of Palæozoic age; (2) a broad central belt of pre-Cambrian rocks, such as granites and gneisses; (3) a southeastern belt, in the coastal plain region composed largely of unconsolidated sedimentary rocks of Cretaceous, Tertiary, and Pleistocene age.

Palæozoic Area

This belt includes the counties of Polk, Floyd, Bartow, Gordon, Murray, Whitfield, Catoosa, Chattooga, Walker, and Dade, and while the rocks in this area range from Cambrian to Carboniferous inclusive, the residual clays derived from them are all somewhat similar. The shales are often calcareous, with the exception of the Carboniferous ones. The residual clay-deposits, which are chiefly adapted to common-brick manufacture, are often of considerable extent, and generally ferruginous character, but here and there contain pockets of white clay which may be suitable for fire-brick; those derived from the limestones often contain cherty nodules.

Pre-Cambrian Belt

This covers an area of about 12,000 square miles, and consists of granites, gneisses, schists, marbles, and in places pegmatite veins, of which the last should afford kaolin. Residual clays are abundant throughout the region, and the wash from them may form secondary deposits in the valleys.

Coastal Plain Region

This region includes that portion of the State lying to the southeast of a line drawn through Augusta, Macon, and Columbus, and coinciding approximately with the fall line (Fig. 50).

Within this area the formations range from Cretaceous to Pleistocene and carry many clay-deposits of variable character, ranging from easily fusible ferruginous clays to snowy white ones (Pl. XXV, Fig. 2) of high refractoriness. The form of most of these is rather irregular (a characteristic of most coastal plain clays), the majority being lens shaped, and surrounded by sand or sandy clay.

The Cretaceous formations (Refs. 5 and 6) carry the most valuable clays found in Georgia, and extend across the State in a northeast-southwest direction (Fig. 50*a*), lying in contact with the metamorphic and crystalline rocks of the Piedmont plateau on the northwest. To the southeast they pass under the later formations.

The Cretaceous shows its greatest development in west central Georgia, between the Ocmulgee and Chattahoochee rivers, its total thickness being about 2500 feet (Veatch). East of the former river, the Lower (?) Cretaceous is exposed, but it is narrow and partially covered by tongues of Eocene and local deposits.

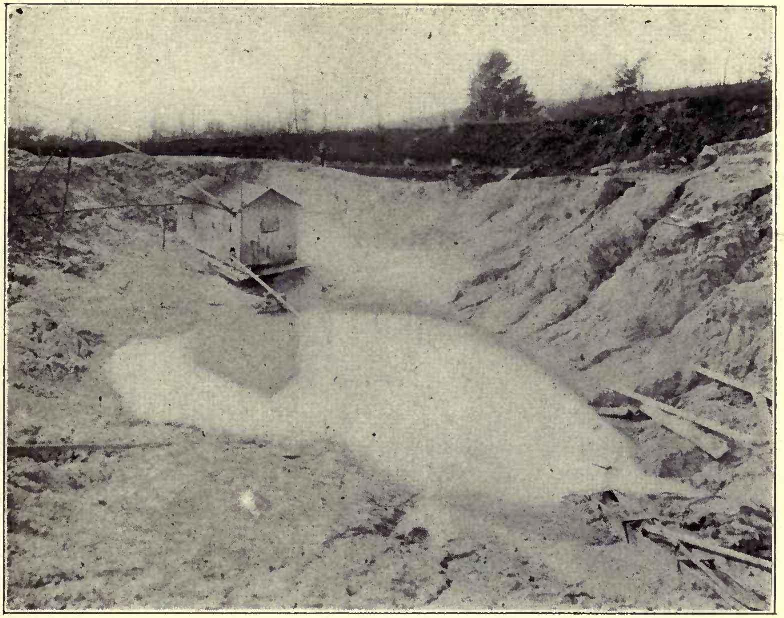

FIG. 1.—Kaolin-pit at West Cornwall, Conn. (Photo loaned by The Kaolin Company.)

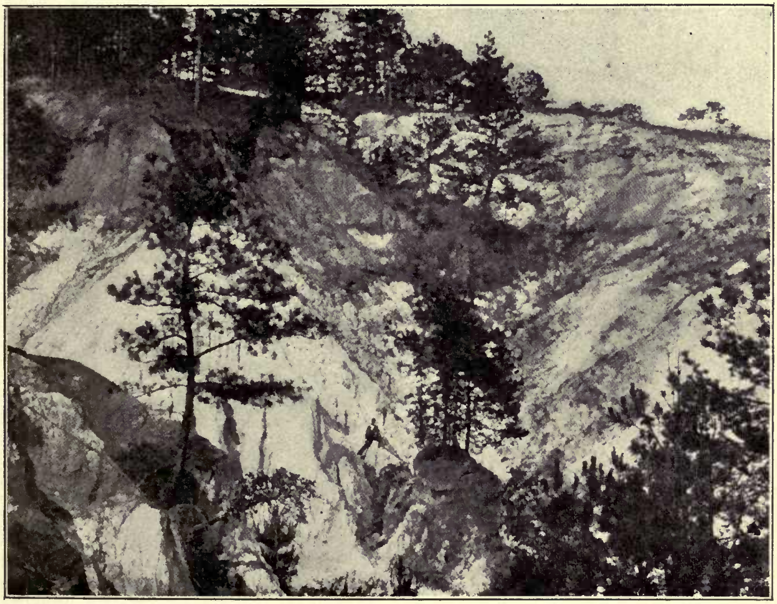

FIG. 2.—White clay and sands of Cretaceous age, overlain by Tertiary beds, Rich Hill near Knoxville, Ga. (After G. E. Ladd, Ga. Geol. Surv., Bull. 6A, p. 32, 1898.)

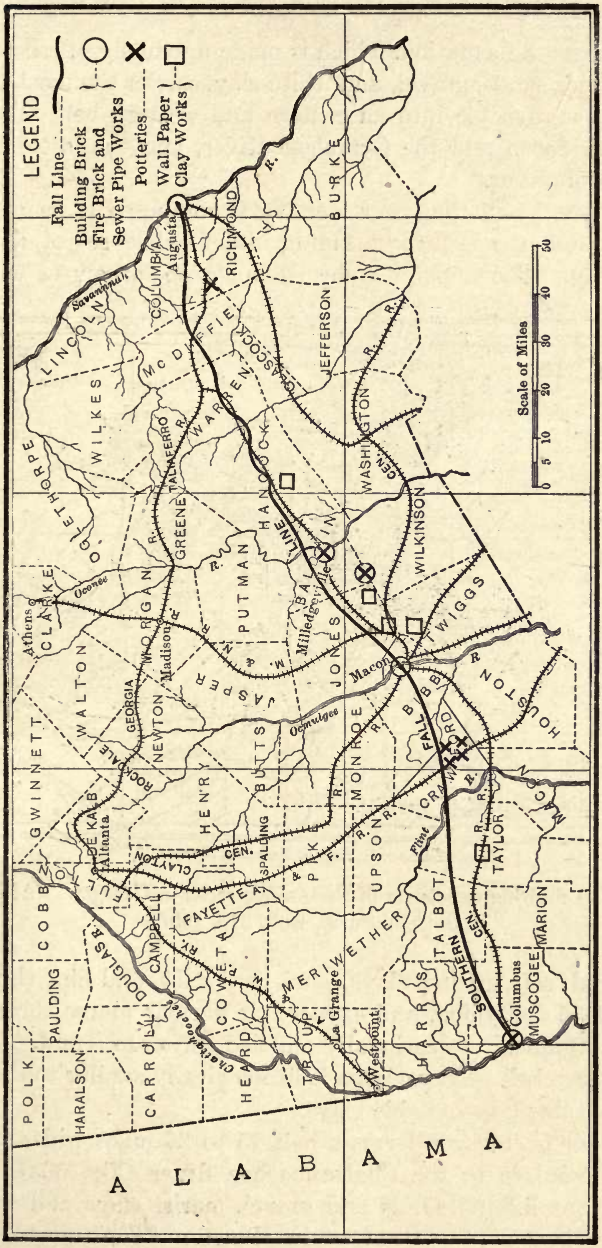

FIG. 50.—Map showing the clay-deposits and the location of the clay industries along the southern fall line in Georgia. (After Ladd, Ga. Geol. Surv., Bull. 6A, p. 80, 1898.)

Two divisions are recognized, the Lower or Tuscaloosa or Potomac and the Upper.

The Tuscaloosa formation, which is made up chiefly of cross-bedded quartz and mica sands, gravel, and white-clay, carries the most valuable deposits. It is divisible into an eastern and western belt, the former lying east of Macon and the Ocmulgee River, and the latter between Macon and Columbus.

In the eastern belt the lower member is composed of coarse clayey gravel and sand, the latter containing ill-defined lenses of white-clay of high purity. The upper member is made up largely of white and cream colored, soft, gritless clays, semi-hard ones, and flint clays. The beds are 10-35 feet thick, and exposed at various places throughout a distance of 90 miles. Occasionally mottled clays are found.

FIG. 50*a*.—Map showing exposures of Cretaceous rocks in Georgia. (After Veatch, U. S. Geol. Surv., Bull. 315, 1907.)

The western belt of Tuscaloosa is lithologically similar to the eastern one, but contains less valuable clays.

The Upper Cretaceous forms a belt 15 to 25 miles wide, extending from the Ocmulgee to the Chattahoochee River (Fig. 50*a*). It consists of unconsolidated sands and gravel, marls, clays and limestone, carrying no clays of value except in Houston County, where white-clays occur in great quantity.

The Dry Branch district of Central Georgia is the most important, the white clays mined there being shipped without washing. McIntyre and Gordon are also important localities. The clays are used in the manufacture of paper, pottery, tiles, fire-brick, etc.

Veatch describes them as varying from soft white, through semi-hard and punky ones, to very hard flint-like clays. The punky ones, which harden slightly on exposure to the atmosphere, are sawed into blocks for building purposes.

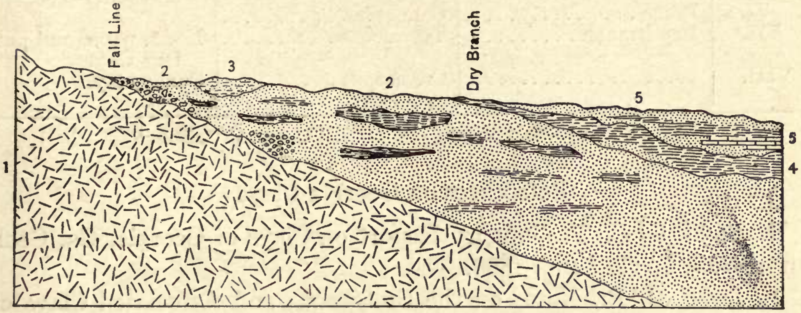

Fig. 50*b*.—Section through formations in Dry Branch region of Georgia. 1. Igneous and metamorphic rocks; 2. Lower Cretaceous (Tuscaloosa); 3. Tertiary outlier; 4. Clay bed mined at Dry Branch; 5. Tertiary strata, Middle Eocene (Claiborne). (After Veatch, Econ. Geol., III, No. 2, 1908.)

Analyses and Physical Tests of Georgia Clays

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	41.20	52.82	46.17	52.68	46.62	77.60	40.28	43.57
Alumina (Al_2O_3)	38.60	26.17	39.13	14.64	38.28	10.90	34.72	39.34
Ferric oxide (Fe_2O_3)	1.45	9.46	0.45	0.28	1.02	2.25	0.84	0.72
Lime (CaO)	......	trace	0.18	7.08	0.18	......	0.05	
Magnesia (MgO)	0.30	1.08	0.11	1.71	......	0.63	0.04	0.10
Potash (K_2O)	0.09	2.71	0.51	4.23	0.05	1.83	trace	0.10
Soda (Na_2O)	0.02	0.20	0.63		0.08	0.23	trace	0.05
Water (H_2O)	16.35	7.00	Ign. 13.08	Ign. 11.24	Ign. 13.64	...... 4.70	12.39	14.10
Moisture	0.35	0.23	0.57	8.7	0.72	0.20	10.72	0.89
Titanic oxide (TiO_2)	1.95	with Al_2O_3	......	......	......	1.98	1.15	1.61
MnO	......	......	......	......	......	......	trace	
Tensile strength	......	......	25	213	24			
Air-shrinkage	......	......	0.8	25	8			
Fire-shrinkage	......	......	......	6	2			
Cone of fusion	......	......	36		35			
Specific gravity	......	......	1.76	.9–1.2	1.69 to 1.75			
Color when burned	......	......	......	buff yellow				

ANALYSES AND PHYSICAL TESTS OF GEORGIA CLAYS—*Continued.*

No.	Locality.	Geological Ages	Uses.
I.	Flowery Branch	Silurian	Not worked.
II.	Near Cartersville	Oostanaula series	
III.	Griswoldville	Potomac clay	
IV.	Fitzpatrick	Tertiary	Not worked.
V.	Steven's pottery	Potomac	Fire-brick, pottery and sewer-pipe.
VI.	Rome	Columbia	
VII.	Dry Branch	Tuscaloosa	No. 1, paper and pottery clay.
VIII.		Cretaceous	Punky clay.

I. to VI from Refs. 1 and 3. VII. and VIII, Refs. V.

References on Georgia Clays

1. Ladd, G. E., Preliminary Report on Clays of Georgia, Ga. Geol. Surv., Bull. 6A, 204 pp., 1898.

2. Ladd, G. E., Notes on the Cretaceous and Associated Clays of Middle Georgia, Amer. Geol., XXIII, p. 240, 1899.

3. Spencer, J. W., The Palæozoic Group, Ga. Geol. Surv., 1893, p. 276.

4. See also U. S. Geol. Surv., Geol. Atlas Folios relating to Georgia.

5. Veatch, O., Kaolins and Fire-clays of Central Georgia, U. S. Geol. Surv., Bull. 315, p. 303, 1907.

6. Veatch, O., The Kaolins of the Dry Branch Region, Georgia, Econ. Geol., III, No. 2, Mar.–Apr., 1908.

ILLINOIS

The clay materials of this State are obtainable from the Ordovician, Lower Carboniferous, the Coal-measures, Cretaceous, Tertiary and Pleistocene.

Little of economic value was published by the former geological survey, but the present one has extended investigations under way. The distribution of the geologic formations is shown in Fig. 50*c*.

Ordovician

So far as known this is of little importance, but the Cincinnati shale. outcropping in Daviess and Boone counties, may prove of value for the manufacture of brick, hollow-brick, and perhaps earthenware, since the same material has been successfully used in Iowa, and tested with good results in Wisconsin.

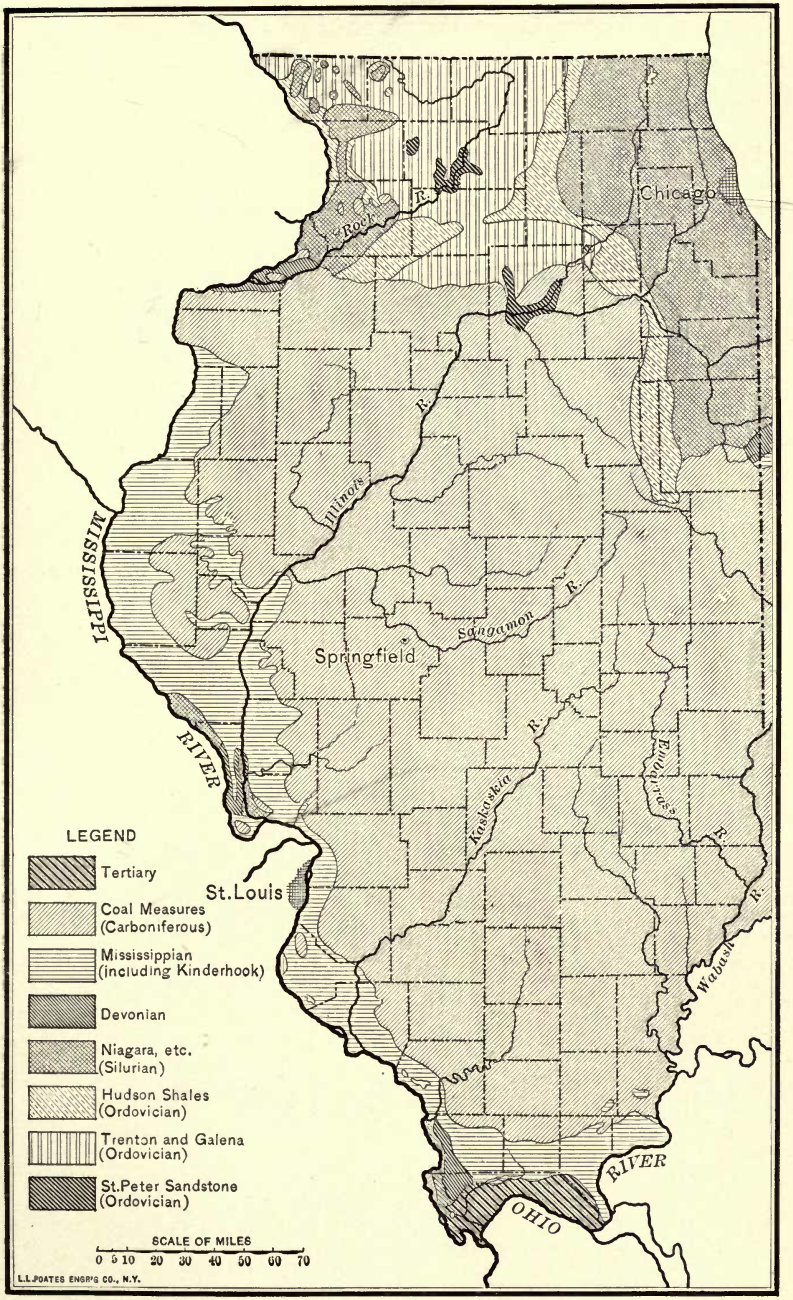

FIG. 50*c*.—Map of Illinois, showing distribution of geologic formations. (After Ill. Geol. Surv., Bull. 4, 1907.)

Lower Carboniferous or Mississippian

This is said to carry a few deposits of non-plastic siliceous fire-clay in Pope and Massac counties. (Ref. 2.)

Coal-measures

These underlie a large area in central, eastern and southern Illinois, within a line passing from Hampton in Rock Island County to the junction of the Kankakee and Iroquois rivers, thence southward to near Chatsworth in Livingston County and eastward to the Indiana boundary.

The coal-measures consist of a series of coal-beds, shales, sandstones, and clays, those underlying the coal being sometimes of a refractory character. Owing to the nearly horizontal position of the beds, mining is usually carried on by shaft, although at several localities, as Galesburg, etc., great outcrops of shale occur.

Unfortunately, most of the published information regarding these Carboniferous clays and shales is not of recent character, although they form the basis of an active clay-working industry, and are much used for paving-brick around Galesburg, Ill. A number of localities are mentioned by Worthen in the old report of the Geological Survey of Illinois (see below). Several analyses and fusion tests published by the present survey are given below.

ANALYSES OF ILLINOIS FIRE-CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	71.58	64.88	65.14	55.96	54.80	56.28	68.12	58.06
Alumina (Al_2O_3)	18.31	21.54	21.53	29.47	29.44	26.68	20.08	26.57
Ferric oxide (Fe_2O_3)	1.51	1.86	1.59	1.57	1.70	3.24	1.76	1.23
Titanium oxide (TiO_2)	1.40	1.26	1.60	1.60	0.82	1.28	1.16	0.14
Volatile	5.27	6.83	7.37	8.25	8.84	10.28	6.31	9.84
Moisture	1.41	2.58	1.62	1.41	2.37	1.74	1.19	4.62
Total	99.48	98.95	98.85	98.26	97.97	99.50	98.62	100.46
Cone of fusion	28	28	29	31 ?	30+	22+	30	29+
Burned at 1120° C.	Porous buff	Hard buff	Porous lt.buff	Porous lt. buff				

I. Potter's clay, Round Knob, Massac County.
II. W. Kortie farm, Massac County. Ripley formation.
III. IV. } Clays from near Monmouth, used in stoneware manufacture. Coal measures.
V. Utica Fire Brick Co., Utica, La Salle County. Coal measures.
VI. Pioneer Fire Proofing Co., Ottawa, La Salle County. Coal measures.
VII. Drake, Green County. Coal measures.
VIII. Clay from fault fissure between St. Louis limestone and Mansfield sandstones.
I–VIII. Bull. 4, Ill. State Geol. Surv., 1907.

PLATE XXVI.

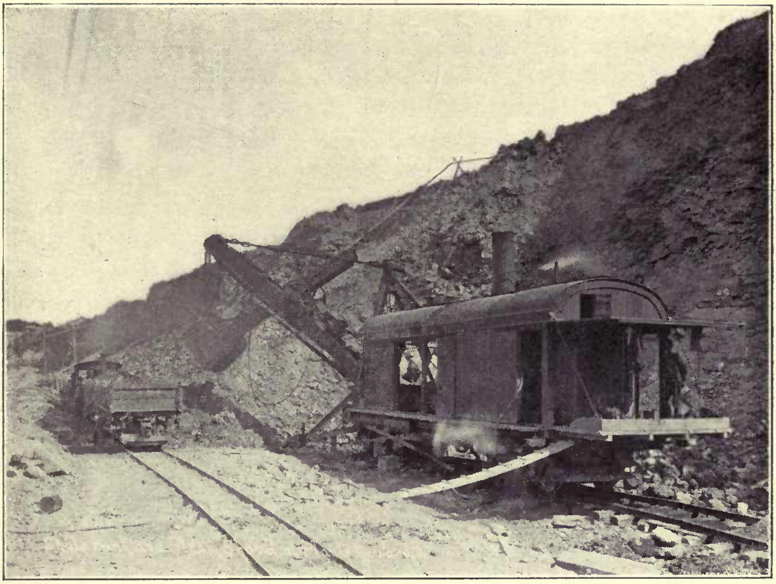

FIG. 1.—Carboniferous shale used for paving-brick. Galesburg Ill. The excavating is done with a steam-shovel. (Photo loaned by Ill. Geol. Surv.)

FIG. 2.—View in Knobstone shale-pit, Crawfordsville, Ind. (After Blatchley, Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., 1895.)

Cretaceous Tertiary

The Cretaceous Tertiary clays (Ref. 2) occur in a small area in the extreme southern part of the State (Fig. 50*c*), being a portion of the Gulf Embayment area, which extends across the border from Kentucky. The clay is light colored, white or cream, but varies to buff, brown, chocolate and slate. It is bedded and interstratified with sands. Immediately above the Tertiary fire-clays, there is usually a prominent band of brick-red clay and sand, 1 to 3 feet thick, and this in turn is overlain by a thin bed of cherty gravel. The fire-clay and its associated red clay outcrops in all the counties in which the Tertiary occurs, but Round Knob, Massac County, is the only place where it has been worked. Although these clays are commonly regarded as Tertiary, some may belong to the Ripley formation of the Cretaceous.

Pleistocene

These form a most abundant source of brick- and tile-clays in many parts of the State. Around Chicago these clays are lake-deposits of considerable extent, but they are highly calcareous and often pebbly. They form the basis of a large local brick industry, and the smoother ones have been used for drain-tile and even roofing-tiles. In other parts of the State the clays are found either in the glacial drift or underlying terraces along the broader rivers, especially the Illinois.

The sandy loess-clay is much used at many points.

References on Illinois Clays

1. Leverett, F., The Illinois Glacial Lobe, U. S. Geol. Surv., Mon. XXXVII. Describes distribution of drift, but is not a paper of economic character.

2. Purdy, R. C., and De Wolf, F. W., Preliminary Investigation of Illinois Fire-clays, Ill. State Geol. Surv., Bull. 4, p. 131, 1907.

3. Worthen, A. H., Reports on Economic Geology of Illinois, Ill. Geol. Surv., I, II, III.

INDIANA

The Ordovician, Silurian, Devonian, and Carboniferous contain extensive shale-deposits, but only the last have thus far proven of commercial value.

Ordovician

The Ordovician rocks outcrop only in the southeast corner of the State, and there are often covered by a thin drift layer. The only shales are the Hudson River, but these are too calcareous to use, and of no value even when weathered.

Silurian

The beds of this age underlie a large area in eastern and northcentral Indiana, but carry few shales, and these are of no value.

Devonian

The Devonian beds underlie a great area, extending northwest and southeast through central part of State, but offer little promise to the clay-worker, as they are usually too bituminous.

Mississippian or Lower Carboniferous

The rocks of this age afford residual clays and shales.

Residual clays.—Since a large part of the Mississippian area occurs in the driftless region, the residual clays derived from underlying limestone and sandstones are available, and occur at many points in Monroe, Lawrence, Orange, Harrison, and Floyd counties, as well as parts of the adjoining ones, so that they form the most important source of the brick- and tile-clays worked in these counties.

Shales.—Those of the Knobstone formation (Fig. 51) are important and destined to become prominent in the future, although they have been neglected in the past. Indeed they are next to the coal-measure shales, the most important in the State. According to Blatchley (Ref. 3) the Knobstone shale forms the surface-rock of a strip of territory 3 to 38 miles wide on the eastern side of the Lower Carboniferous area, extending from the Ohio River southwest of New Albany in a west of north direction to a point a few miles south of Rensselaer, Jasper County.

While the formation is often covered by a heavy mantle of drift, many excellent exposures have been formed by the cutting of the larger streams, as along the West White River near Martinsville; along Sugar Creek, above and below Crawfordville, and along Shawnee Creek south of Attica. Many additional outcrops have been found in other counties within the belt occupied by these shales.

The Knobstone formation consists of blue-gray shales, shaly sandstones, and sandstones, with rarely a little limestone. Nodules of siderite are not uncommon.

These shales are utilized at New Albany for stiff-mud and dry-press brick; it is also possible that they could be used for sewer-pipe when admixed with some of the Carboniferous under-clays.

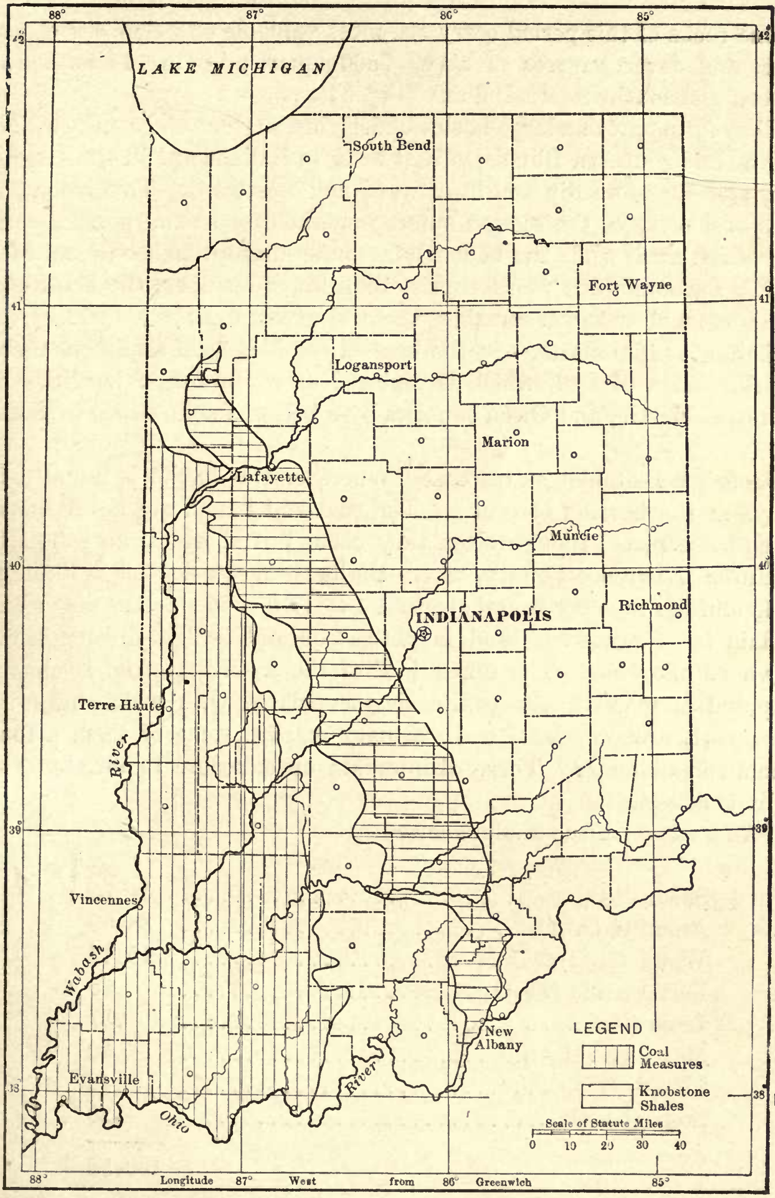

FIG. 51.—Map of Indiana, showing areal distribution of coal-measure shales and Knobstone shales. (Adapted from map compiled by Hopkins.)

Carboniferous

The rocks of this period carry the most valuable clay-deposits of the State, and cover an area of about 7500 square miles in 14 counties of western and southwestern Indiana (Fig. 51).

They form part of a large basin, underlying western and southwestern Indiana and southern Illinois, so that those in Indiana are on the eastern edge, and therefore dip southwestward and westward. This being so, the lowest rocks of the section outcrop on the eastern and northeastern edge of the area, while the higher lying ones outcrop farther westward.

The Carboniferous rocks consist of a lower member, the Mansfield sandstone, and an upper member, the coal-measures.

Kaolin or indianaite.—At the base of the Mansfield sandstone there is a thin seam of coal, which is replaced at a number of localities in Lawrence, Martin, and Owen counties by a bed of kaolin called indianaite.

Professor Blatchley states that "Wherever this kaolin is found it is always at the horizon of coal I. The coal and kaolin are never found at the same place, though often they occur but short distances apart. At Huron, Lawrence County, where the best-known deposit is located, the kaolin lies in a horizontal stratum 4 to 11 feet in thickness, which is overlain by a sandstone, and in places contains a light-green mineral known as *allophane.* The upper half of the kaolin stratum is chiefly composed of massive snow-white clay associated with which, near its upper part, are occasional concretionary masses, some of them a foot or more in diameter. These disintegrate on exposure to air, but the kaolin is non-plastic.

"An analysis of the kaolin showed:

Silica (SiO_2)	44.75
Alumina (Al_2O_3)	38.69
Water (H_2O)	15.17
Ferric oxide (Fe_2O_3)	.95
Lime (CaO)	.37
Magnesia (MgO)	.30
Potash (K_2O)	.12
Soda (Na_2O)	.23
	100.58

"While of high purity, this clay is not now used, although at one time it was made into alum sulphate for sizing paper."

There has been much discussion regarding the origin of this kaolin, and while two theories have been advanced to explain its formation, both acknowledge its residual character, and that of the inclosing rocks, as sedimentary.

E. T. Cox[1] argued that the kaolin occupied the position of a limestone bed, and that carbonated waters, acting on the latter, replaced the limestone with kaolinite. Thompson[2] seconded this theory, but added the belief that the surface-water had leached the alumina and silica from the overlying sandstones.

Lesquereaux, on the other hand, believed that the kaolin was formed by the burning-out of coal-beds, a view in which Ashley concurred.

Although the author is not personally acquainted with the region, it seems to him that there are certain marked objections to the latter theory. The burning-out of the coal would probably produce sufficient heat to cause some dehydration of the kaolin, whereas there is no evidence of this. In just what way the kaolin resembles baked fire-clay is not mentioned.

It is not necessary to suppose any complex chemical reactions in order to derive kaolin from limestone. A calcareous rock, containing aluminous matter very low in impurities, might easily yield a mass of kaolin by simple leaching, and residual limestone clays of rather high purity are known in Missouri and also Virginia.

Coal-measure clays and shales. — The Coal-measures include a series of coals, clays, shales, and sandstones (Fig. 52), and are found in a number of counties in the southwestern part of the State (Fig. 51).

Ashley[3] has divided them vertically into eight divisions designated by Roman numerals, these divisions being based on the position of some principal coal-beds or horizons, the type section occurring in Clay and Vigo counties. The Mansfield sandstone found in general along the eastern edge of the coal-field forms division I, and the main-worked coals, clays, and shales occur above it stratigraphically.

A part of a typical vertical section showing the arrangement of the different strata of the coal-measures and their relation to each other is given by Blatchley (Ref. 3) as follows:

	Feet.	Inches.
1. Soil- and surface-clay	5	2
2. Sandstone, massive or shelly	2	8
3. Blue compact shale	27	0
4. Coal VII	4	10
5. Fire-clay	6	2

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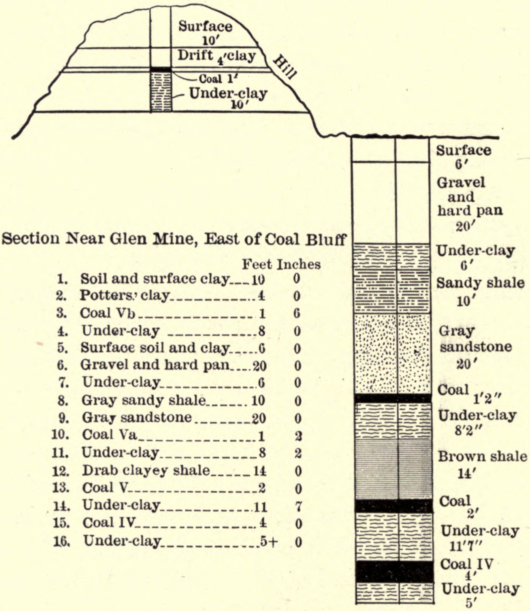
[1] Sixth Ann. Rep. Geol. Surv. of Ind., 1874, p. 15.

[2] Ind. Dept. Geol. and Nat. Hist., 15th Ann. Rep., p. 37, 1886.

[3] Ind. Dept. Geol. and Nat. Res., 23d Ann. Rept., 1899.

		Feet.	Inches.
6.	Drab siliceous shale	18	0
7.	Limestone	3	8
8.	Black bituminous shale	2	4
9.	Coal VI*b*	..	8
10.	Fire-clay	5	6
11.	Sandstone	13	0
12.	Dark-gray shale	11	2
13.	Coal VI	6	3
14.	Hard impure bluish fire-clay	11	0
15.	Sandstone	21	0
16.	Blue limestone	11	0
17.	Black slaty bituminous shale	5	4
18.	Coal V	5	2
19.	Fire-clay	4	8



Section Near Glen Mine, East of Coal Bluff

		Feet	Inches
1.	Soil and surface clay	10	0
2.	Potters' clay	4	0
3.	Coal Vb	1	6
4.	Under-clay	8	0
5.	Surface soil and clay	6	0
6.	Gravel and hard pan	20	0
7.	Under-clay	6	0
8.	Gray sandy shale	10	0
9.	Gray sandstone	20	0
10.	Coal Va	1	2
11.	Under-clay	8	2
12.	Drab clayey shale	14	0
13.	Coal V	2	0
14.	Under-clay	11	7
15.	Coal IV	4	0
16.	Under-clay	5+	0

FIG. 52.—Section near Glen Mine, Coal Bluff, Ind., showing association of coals, under-clays, etc. (After Blatchley, Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., p. 183, 1905.)

The fire-clays (Nos. 5, 10, 14, and 19) are almost universal accompaniments of the overlying coal-seams. They are usually one to six feet thick, and are a soft homogeneous clay, whitish or gray in color, highly plastic, and often of excellent refractoriness. At times, however, these under-clays are composed of a hard, bluish, siliceous clay with more or less pyrite and other impurities.

No. 14 is of this character, and similar clays usually occur beneath coals III and V, but those below coals II, IV, VI, and VIII are often of excellent quality.

The blue, gray, and drab shales (Nos. 3, 6, and 12) make up the greater part of the Coal-measure rocks of Indiana, and include the most valuable clay-deposits found in the State. When freshly exposed they are usually hard, but weather down easily to a plastic clay.

The relations of the shales, clays, and coal are such that the three can often be mined by one shaft.

The coal-measure clays and shales are worked for a variety of purposes, including pressed and paving brick, fireproofing, sewer-pipe, stoneware and fire-brick.

At Brazil, Clay County, which is a most important clay-working center, the following section is instructive.

	Feet.	Inches.
1. Soil and yellow clay	12	0
2. Bowlder clay, blue	7	0
3. Gray clayey shale	33	0
4. Coal V	2	3
5. Under-clay (potters' clay)	3	2
6. Blue clayey shale	19	0
7. Bituminous fossil shale	1	6
8. Coal IV	3	6
9. Under-clay	5	4

No. 9 and an overlying shale are used for sewer-pipe, flue-linings, wall-coping, etc. No. 3 is also used for a variety of purposes.

The best deposits of unworked shales and clays for making vitrified bricks lie just east of Mecca, Parke County; west of Montezuma, Parke County; west of Terra Haute, and near Riley, Vigo County.

Pleistocene Clays

These are soft, plastic clays, found at the surface or at no great distance below it, and, while occurring over a large part of the State, they are especially important in the northwestern part of Indiana, and on this account have been made the subject of a special report. (Ref. 1.)

In this region three classes are distinguishable, namely, drift-clays or "hard-pans," alluvial clays, and silty or marly clays.

The drift-clays are the most common type, forming a large percentage of the unstratified morainic material, but they are usually too impure and calcareous for making anything but common brick and tile.

The alluvial clays form larger deposits along the lowlands and second bottoms of the large streams of northwestern Indiana, having been formed during periods of overflow, and in some places showing a thickness of 30 to 90 feet.

The silty or marly clays resemble those of the preceding class very closely, but differ in having been deposited in bays, lakes, or harbors in quiet water. These clays are usually finer grained than the alluvial ones, thinly laminated, and often highly calcareous, so that they produce a buff product. They are an important source of brick and tile material in Benton, Newton, Jasper, Starke, Lake, Porter, Laporte, and St. Joseph counties.

In other parts of the State there are many scattered deposits of surface-clays used for brick and tile, while south of the terminal moraine in southwestern Indiana there are many deposits of loess which are available for the same purpose.

The analyses on pages 355 and 356 are given by Blatchley (Ref. 3) as representative of the different types of Indiana clays and shales.

References on Indiana Clays

1. Blatchley, W. S., Clays and Clay Industries of Northwestern Indiana, Rept. of Indiana State Geologist for 1897, p. 106.

2. Blatchley, W. S., Preliminary Report on the Clays and Clay Industries of the Coal-bearing Counties of Indiana, Ind. Dept. of Geol. and Nat. Res., 20th Ann. Rept., p. 23, 1896.

3. Blatchley, W. S., The Clays and Clay Industries of Indiana, Ind. Dept. Geol. and Nat. Res., 29th Ann. Rept., pp. 13–658, 1904.

4. See also scattered references in the other annual reports of this survey.

Analyses of Indiana Clays

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	59.77	58.83	65.78	67.65	55.09	83.44
Alumina (Al_2O_3)	20.60	22.84	14.79	19.97	20.76	10.36
Ferric oxide (Fe_2O_3)	2.22	5.13	8.03	0.72	3.00	0.27
Ferrous oxide (FeO)	3.70	1.44	....	....	4.01	0.28
Lime (CaO)	0.64	0.49	0.54	0.48	1.51	0.36
Magnesia (MgO)	1.98	1.56	1.42	0.59	1.18	0.14
Potash (K_2O)	3.10	4.18	2.82	1.75	2.36	0.03
Soda (Na_2O)	0 85	0.63	0.97	2.29	0.34	0.71
Titanic acid (TiO_2)	0.80	0.70	1.00	1.01	1.20	1.29
Carbon dioxide (CO_2), etc.	0.90	....	0.26	3.04	....	....
Water (H_2O)	4.53	5.22	4.98	5.96	7.01	3.15

	VII.	VIII.	IX.	X.	XI.	XII.
Silica (SiO_2)	69.23	65.25	59.64	63.88	70.60	66.11
Alumina (Al_2O_3)	18.97	17.30	19.14	17.85	13.89	13.78
Ferric oxide (Fe_2O_3)	1.57	2.30	3.39	5.38	2.83	5.35
Ferrous oxide (FeO)	0.55	....	4.20	....	3.56	....
Lime (CaO)	0.12	0.50	0.26	0.38	0.60	1.67
Magnesia (MgO)	0.36	0.20	2.31	1.47	0.50	1.78
Potash (K_2O)	2.27	1.56	3.53	3.98	2.76	2.11
Soda (Na_2O)	0.33	0.98	0.80	1.29	1.60	1.15
Titanic acid (TiO_2)	1.50	....	1.05	0.91	0.43	....
Carbon dioxide (CO_2), etc.	....	6.50	0.35	....	0.51	....
Water (H_2O)	5.46	5.40	4.36	4.99	3.19	6.34

	XIII.	XIV.	XV.	XVI.	XVII.
Silica (SiO_2)	71.20	72.56	50.56	50.47	44.75
Alumina (Al_2O_3)	18.56	10.44	13.11	12.77	38.69
Ferric oxide (Fe_2O_5)	1.34	7.45	2.98	2.44	0.95
Ferrous oxide (FeO)	0.15	0 43	2.32	2.52	....
Lime (CaO)	0.14	0.82	7.87	8.17	0.37
Magnesia (MgO)	0.52	1.09	5.06	5.22	0.30
Potash (K_2O)	0.32	2.05	3.74	3.70	0.12
Soda (Na_2O)	1.26	0.73	0.70	0.73	0.23
Titanic acid (TiO_2)	0.88	0.31	1.00	1.45	....
Carbon dioxide (CO_2), etc.	....	....	9.62	9.80	....
Water (H_2O)	6.30	4.54	2.76	3.14	15.17

RATIONAL ANALYSES OF THE PRECEDING

	I.	II.	III.	IV.	V
Quartz	26.04	22.81	34.34	28.29	20.90
Feldspathic detritus	8.37	8.30	12.58	34.77	2.03
Ferrous carbonate	2.37	....	....	....	6.46
Magnesium carbonate	....	....	0.50	....	1.13
Clay substance	63.22	68.89	52.58	36.94	69.48

	VI.	VII.	IX.	X.	XI.
Quartz	46.33	39.36	25.57	17.93	56.65
Feldspathic detritus	39.28	1.67	6.86	42.03	16.63
Ferrous carbonate	....	....	....	....	1.07
Magnesium carbonate	....	....	0.67	....	0.08
Clay substance	14.39	58.37	66.90	40.04	25.57

LOCALITIES OF THE PRECEDING

No.	Location.	Geological Age.
I.	Mecca, Mecca Coal and Mining Company	Carboniferous shale
II.	“ “ “ “ “ “	“ “
III.	Cayuga, Cayuga Brick and Coal Company	“ “
IV.	Mecca, Mecca Coal and Mining Company	Coal-measures under-clay
V.	Cayuga, Cayuga Brick and Coal Company	“ “ “ “
VI.	W. Montezuma, Burns & Hancock	“ “ “ “
VII.	Huntingburg, Bockting Bros.	“ “ “ “
VIII	Huntingburg, C. Fuchs	“ “ “ “
IX.	Blue Lick	Knobstone shale
X.	New Albany	“ “
XI.	Martinsville, Branch & Sons	“ “
XII.	Terre Haute	Alluvial
XIII.	Princeton	Surface Loess
XIV.	Four miles south of Bloomington	Residual
XV.	Hobart	Pleistocene
XVI.	Michigan	Pleistocene
XVII.	Indianaite, Huron, Dr. Gardner	Residual

INDIAN TERRITORY[1]

The greater part of the Cherokee and Creek nations and the northern part of the Choctaw nation contains extensive deposits of clays of Pennsylvanian age, which are very similar to the brick- and tile-clays of southeastern Kansas, and the presence of gas in that region will warrant the development of extensive industries. In the western part of the Chickasaw nation the country is underlain with red clay of the Permian red

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[1] From note supplied by Professor C. N. Gould. See also U. S. Geol. Surv. Atlas Folios; 122, Tahlequah; Muscogee, 132; Winslow, 154. Since these descriptions were written Indian and Oklahoma territories have joined, forming the State of Oklahoma.

beds, the same as that found in Oklahoma, while in the southern part of the Choctaw and Chickasaw nations the clay is of Lower Cretaceous age, similar to that in central Texas.

Probably the best clay in Indian Territory so far discovered is from the formation known as Sylvan Shale of Silurian age, which outcrops in various places in the Arbuckle Mountains in the eastern part of the Chickasaw nation. A company is now engaged in developing the clay-products at Oolite, where plants are being erected for the manufacture of brick, tile, sewer-pipe, fireproofing, and cement.

IOWA

Every great rock formation of Iowa, except one, the Sioux quartzite contains more or less important clay- or shale-deposits, but the different ones represent a wide range of structural characters and physical or chemical properties, these variations occurring sometimes within the same formation.

Cambrian

Saint Croix sandstone.—This carries a few shale-beds which outcrop in portions of Allamakee and Clayton counties, but nothing is known regarding their economic value.

Ordovician

Galena-Trenton.—Although essentially a limestone formation, this nevertheless contains a few beds of shale, which may be adaptable to pottery manufacture. The best exposure is on Silver Creek, Makee township, Allamakee County. Concretions and fossils are apt to render this shale worthless.

Maquoketa shale.—This, the oldest shale formation of importance in the State, forms a narrow, sinuous band from Jackson County on the south to Winneshiek and Howard counties. The shale is divisible into two groups, the upper consisting of a plastic clay, with occasional limestone layers, while the lower is of lean fissile shales, with some earthy, fossiliferous beds. They are mostly red-burning, but may at times be quite calcareous, and though their chief use is for common brick, they have also given excellent results for earthenware manufacture and hollow brick.

Silurian

The beds of this system are practically devoid of shale-deposits.

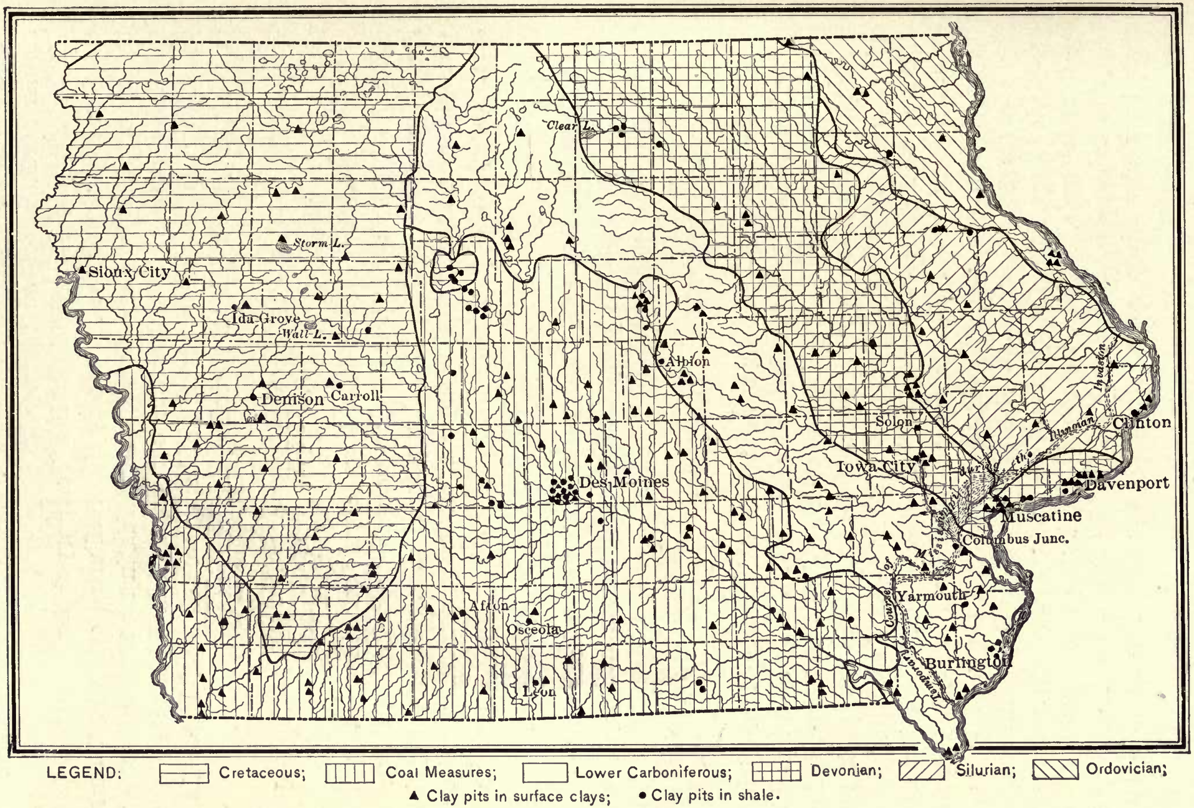

FIG. 53.—Map of Iowa, showing distribution of clay-bearing formations and location of clay and shale-pits. (After Beyer and Williams, Ia. Geol. Surv., XIV, 1904.)

PLATE XXVII

Fig. 1.—Carboniferous shale for paving-blocks near Veedersburg, Ind. (After Blatchley, 29th Ann. Rep., Ind. Dept. Geol. and Nat. Res., p. 80.)

Fig. 2.—Cretaceous shale, Sioux City, Ia. (After Williams, Ia. Geol. Surv., XIV, p. 518, 1904.)

Devonian

The lower argillaceous beds, known as the Independenc outcrop in limited measure in Cedar, Linn, and Buchanan counties, but are of no economic importance.

The upper shales, which are typically developed along Lime Creek in Cerro Gordo and Floyd counties, and at Rockford and Mason City are of much greater value. Owing to a variable lime-content the clays burn either light red or cream, but in either case have yielded good results in the manufacture of common and hollow brick and drain-tile. The shales are too fusible to take a salt-glaze.

Carboniferous

Practically all of the great formations of the Carboniferous contain clays of importance, but those of the Kinderhook and Coal-measures are especially important. According to Beyer and Williams, "Rocks referable to the Carboniferous comprise the indurated rocks over nearly one half of the surface of the State. The system may be divided into two parts: (1) the Lower Carboniferous beds, which are prevailingly calcareous in character, and (2) the Upper Carboniferous, in which arenaceous and argillaceous deposits predominate, with important limestone bands in the upper portion. The latter division contains all of the workable coal in the State. On account of the abundance of raw material suitable for the manufacture of clay wares and cheap fuel, the Upper Carboniferous or Coal-measures constitute the most important formation to the clay-worker in the State.

"The Lower Carboniferous comprises a belt averaging from thirty to forty miles in width, and extending diagonally across the State from Kossuth and Winnebago counties on the north to Des Moines and Lee counties on the south. Narrow strips have been laid bare by the lower courses of the Skunk and Des Moines rivers, and unimportant detached areas appear in Story and Webster counties. Three stages represent the Lower Carboniferous in Iowa, namely, the Kinderhook, Augusta, and Saint Louis."

Kinderhook.—The shales of this formation are specially prominent in Des Moines and Lee counties; they are red- or brown-burning and used for common brick.

Augusta.—These shales are of little importance except in Lee County, and even there are rather calcareous.

Coal-measures

The rocks of this age cover nearly one third of the State and carry a great range of argillaceous beds grouped as (1) argillaceous, (2) arenaceous, (3) carbonaceous or bituminous, and (4) calcareous varieties. These grade into each other both vertically and horizontally. Although the coal-measures are present in ninety-nine counties of the State, the clay-shales are utilized for making clay-products in but sixteen. The argillaceous shales are often found underlying the coal-seams, and are not uncommonly of refractory character, but the calcareous ones contain too much limey matter to be of great value. Those beds of the Coal-measures prominent along the Des Moines River contain argillaceous, bituminous, and arenaceous shales, while in the beds most prominent along the Missouri River the calcareous members are more prominent.

It is difficult to generalize regarding the clays of this series, but at any one point it is not uncommon to find several grades of clay ranging from common brick-clay to fire-clay in the same section. The shales are worked at a number of points, among which Van Meter, Dallas County; Des Moines, Polk County; Ottumwa, Wapello County; and Fort Dodge, Wapello County may be mentioned. The clays are worked either as open pits or undergound mining and the products include common and pressed brick, paving-brick, hollow blocks, drain-tile, stoneware, and fire-bricks. Analyses of these are given on a later page.

Cretaceous

The Cretaceous of Iowa consists of a lower sandstone and shale series, the Dakota, and an upper series of interbedded sandstones, shales, and marly limestones. These rocks cover approximately the northwestern third of the State, shale-beds of this age being known in Sioux (Pl. XXVII, Fig. 2), Plymouth, Woodbury, Sac, Calhoun, and Montgomery counties.

The shales show about the same textural and chemical range as the Carboniferous ones, but on the whole are more siliceous.

At Red Oak, Montgomery County, both white stoneware and fire-brick are made, and it has been suggested that washing might render the clay available for glass-pot manufacture. Other products from these shales are paving and common brick.

FIG. 1.—Loess-bank, Muscatine, Ia. (After Williams, Ia. Geol. Surv., XIV, 1904.)

FIG. 2.—Bank of (Devonian) shale used for paving-brick, Cumberland, Md. (After H. Ries, Md. Geol. Surv., IV, p. 454, 1902.)

Pleistocene

Covering all of the State, with the exception of a small area in the northeastern corner, is a thick mantle of glacial deposits which range in thickness from zero up to three or four hundred feet. The glacial drift is composed of a heterogeneous mass of bowlder beds, gravel, and sand-deposits, and more rarely beds of clay, which, owing to a natural washing process which they have undergone, are sufficiently plastic to be molded into clay wares. They often suffer, however, from the presence of lime pebbles or stones, and even if free from these are still unsatisfactory because of their high shrinkage, which causes a loss due to checking in drying and burning. A few of the drift-sheets, however, contain clays of satisfactory character for brick manufacture.

Loess.—Associated with the drift-sheets and of far greater economic importance are the massive structureless deposits of loess. (Pl. XXVIII, Fig. 1.) These consist of clays or clayey silts, which form a mantle over about two thirds of the area of the State, affording an inexhaustible supply of brick material.

This occurs beyond the borders of the drift-sheets and even overlapping them. It covers more than one half the surface of the State and shows great irregularity in thickness, being over one hundred feet thick along the Missouri River. It affords an exhaustless supply of material suitable for the manufacture of brick by the soft-mud, stiff-mud, or dry-press process, and moreover is a very cheap clay to work.

Of the several types of loess recognized in the State, the "gumbo" is noteworthy. This is a thoroughly oxidized and leached red clay which on drying breaks up into a number of angular fragments. In the southern part of the State the gumbo is gray or drab in color. Its peculiarity is its excessive shrinkage which precludes its use for the manufacture of brick, but makes it admirably adapted to the manufacture of burned-clay ballast.

The chemical composition of a number of representative Iowa clays and shales is given in the table on page 366.

References on Iowa Clays

1. Beyer, S. W., Origin and Classification of Iowa Clays, Clay Record, XX, No. 3.

2. Beyer, Weems and Williams, The Clays of Iowa, Ia. Geol. Surv., XIV, 1904. Additional analyses in Vol. XVII.

3. Youtz, L. A., Clays of the Indianola Brick, Tile, and Pottery Works, Ia. Acad. Sci. Proc., III, p. 40, 1896.

Analyses of Iowa Clays

ULTIMATE ANALYSES

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	67.50	61.59	73.43	63.78	58.56	75.85	58.05	77.39
Alumina (Al_2O_3)	15.75	21.01	11.94	19.78	22.33	10.73	23.05	5.16
Ferric oxide (Fe_2O_3)	4.80	4.79	3.83	5.75	2.87	1.43	3.83	2.40
Lime (CaO)	2.57	3.58	1.00	1.55	3.60	1.00	0.30	3.65
Magnesia (MgO)	1.57	2.16	0.86	1.22	1.44	0.49	2.04	3.13
Potash (K_2O)	0.95	0.52	0.05	0.54	0.29	0.24	0.90	1.44
Soda (Na_2O)	1.56	1.13	0.95	1.20	1.08	0.70	2.04	2.79
Comb. water (H_2O)	3.22	4.51	4.33	2.92	7.11	6.38	8.10	1.46
Carbon dioxide (CO_2)	with moist.	......	0.90	with moist.	with moist.	with moist.		
Sulphur trioxide (SO_3)	with moist.	0.95	1.65	with moist.	with moist.	with moist.	0.86	1.44
Moisture	2.88	0.42	0.63	3.88	2.98	3.18	0.96	0.13

	IX.	X.	XI	XII.	XIII.	XIV.	XV.	XVI.
Silica (SiO_2)	58.33	47.40	28.82	66.44	51.95	44.39	68.22	67.92
Alumina (Al_2O_3)	15.54	22.20	10.37	12.64	18.34	13.72	10.21	11.76
Ferric oxide (Fe_2O_3)	3.84	12.40	3.76	4.00	7.56	7.80	2.87	6.72
Lime (CaO)	9.42	0.70	19.14	4.02	4.14	7.88	3.90	1.63
Magnesia (MgO)	3.03	1.10	5.40	1.80	3.26	6.05	3.16	1.18
Potash (K_2O)	1.19	3.10	5.38	1.14	1.43	1.56	0.58	1.87
Soda (Na_2O)	1.76	0.50	7.41	1.90	2.69	5.29	1.68	1.92
Comb. water (H_2O)	3.47	7.90	16.24	5.83	7.39	12.18	1.52	5.36
Carbon dioxide (CO_2)	2.02	......	......	......	......	......	5.86	
Sulphur trioxide (SO_3)	1.10	2.40	3.01	......	2.76	......	1.45	
Moisture	0.42	2.10	0.43	2.33	0.42	0.89	0.62	1.49

RATIONAL ANALYSES

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Clay	52.85	56.79	41.47	61.57	57.40	38.20	68.20	24.92
Quartz	25.99	19.63	55.29	20.53	31.17	51.10	25.81	51.39
Feldspar	15.80	21.96	3.24	13.47	4.38	7.62	5.99	19.64
Carbonates and sulphates of Ca + Mg	5.36	1.62	......	4.43	7.05	3.08	......	4.05

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
Clay	64.47	74.90	68.20	38.80	47.08	40.61	19.72	39.90
Quartz	18.67	12.70	21.75	36.36	41.45	28.00	40.29	40.28
Feldspar	11.13	8.81	4.98	24.84	6.98	4.62	25.74	19.82
Carbonates and sulphates of Ca + Mg	5.73	3.59	5.12	......	4.49	26.77	14.25	

LOCALITIES OF THE PRECEDING

No.	Locality.	Geological Age.	Uses.
I.	Flint Brick Co., Des Moines....	Coal-measures	Paving- and building-brick
II.	Iowa Brick Co., Des Moines....	" "	Paving-brick, builders, and hollow ware, bottom
III.	" " " "	" "	Ditto, top
IV.	Flint Brick Co., Des Moines....	" "	Paving-brick; green-brick mixture
V.	Capital City Brick Co., Des Moines	" "	Brick and tile
VI.	J. Holman, Sargent's Bluff....	Cretaceous	Common, face, paving-brick, sidewalk brick
VII.	Corey Pr. Br. Co., Lehigh......	Coal-measures	Pressed face brick and ornamentals
VIII.	Granite Br. Co., Cascade.......	Kinderhook	Common and paving brick
IX.	Cream City B. & T. Co., Rockford	Devonian	Brick and tile
X.	Boone Br. & T. Co., Boone.....	Coal-measures	Paving, hollow ware, common brick
XI.	Clermont....................	Maquoketa	Brick and tile
XII.	Storm Lake..................	Drift	Drain-tile
XIII.	Mason City..................	Devonian	Brick and tile
XIV.	Edgewood....................	Maquoketa	Brick and tile
XV.	Council Bluffs................	Loess (Mo.)	Soft-mud, stiff-mud, and pressed brick
XVI.	Gladbrook..................	Inland Loess	Pressed brick

These analyses are all from Vol. XIV, Ia. Geol. Surv., and have been kindly selected as representative by Professor I. A. Williams.

KANSAS

This State probably contains an abundance of clays of low and medium grade, but they have not as yet been systematically investigated. The formations yielding them are of Carboniferous, Permian, Triassic, Cretaceous, Tertiary, and Pleistocene age.

Carboniferous

The Coal-measures underlie a rather extensive area in eastern Kansas, and consist of alternating strata of limestones, shales, and sandstones, with occasional coals. These beds dip gently to the westward, so that any one bed passes under the overlying ones if traced in that direction.

The shales of this series are mostly red-burning and at different localities have been found adapted to the manufacture of common and pressed brick, drain-tile, vitrified brick, and more recently even for roofing-tile and stoneware. They were first worked at Atchison in 1887, but since then factories have been opened up at Topeka, Pittsburg, Chanute, Coffeeville, etc. Those at Cherryvale are found immediately underlying the Independence limestone, while the beds worked at Iola overlie the Iola limestone. At Lawrence the beds utilized occupy a position near the middle of the Lawrence shales and right under the Oread limestone.

The coal-measure shales of southeastern Kansas are ideally located, because of the supply of natural-gas fuel. The Permian outcrops to the west of the coal-measures being found particularly in the Flint Hills area, and Haworth states that the shales are purer than those of the coal-measures.

Triassic

These occur in abundance, as at near Kingman, and Prosser states that they have been used for paint.

Cretaceous

The Dakota shales are well exposed near Salina, Dickinson County, but so far as known have not been utilized to any extent.

Pleistocene

The surface-clays are widely distributed over Kansas, but are chiefly important in the eastern portion. The gumbo clay, dug in many of the river valleys has been burned in large quantities for railroad ballast.

References on Kansas Clays

1. Grimsley, G. P., Kansas Mineral Products, Eleventh Bien. Rept., Kas. Board of Agric., 1897–98, p. 507, 1898.

2. Haworth, E., Annual Bulletins on Mineral Resources of Kansas, issued by Univ. Geol. Survey, as follows: 1899, p. 57; 1900 and 1901, p. 60; 1902, p. 40; 1897, p. 81; 1898, p. 61.

3. Hay, R., Geology and Mineral Resources of Kansas, Eight Bien. Rept., State Agric. Board, 1891–92, p. 54, 1893.

4. Prosser, C. S., Clay-deposits of Kansas, U. S. Geol. Surv., Min. Res. for 1892, p. 731, 1894.

5. Schrader, F. C., and Haworth, E., Clay Industries of the Independence District, U. S. Geol. Surv., Bull. 260, p. 546, 1905.

KENTUCKY

Kentucky possesses a great variety and valuable series of clays, but no detailed systematic investigation of them was ever completed by the old Geological Survey. Scattered references to them are found in its reports, and a large number of chemical analyses were published.[1] The present Geological Survey of Kentucky has begun a systematic investigation and has already published several preliminary bulletins. (See references 5, 6, 7, 8, 9.)

Within the State there are found a series of geologic formations, ranging from the Ordovician to the Pleistocene. Some of these contain deposits of soft plastic clays or shales, others carry flint-clays, while still others yield clays only as a result of surface weathering.

A section across the State from east to west shows that the formations are not highly folded as they are farther eastward, but that they are rather flat, having a comparatively gentle dip, so that in any one area where two formations are exposed the older or the lower of the two may have been laid bare as the result of erosion.

The Ordovician occupies an irregularly shaped area in the north central part of the State, and is bordered on the eastern and western sides by a strip of Silurian, while the Devonian rocks surround the latter on the east, west and south, forming a narrow, irregular patch, whose exact distribution can best be seen from an examination of a geologic map of the State.[2]

The Lower Carboniferous is found in both the eastern and western half of the State, forming an irregular band extending southwestward from opposite Portsmouth, O., through Lewis, Rowan, Menifee, Powell and Rockcastle counties, and then broadening considerably. It is exposed through the central part of the State as far westward as the western boundary of Hart County, where it splits, the one portion spreading northwestward to Meade County, and the other fork extending through the southern part of the State to the Tennessee River and then north to the Ohio.

The Middle Carboniferous rocks underlie two large areas of more or less solid outline. One of these areas is the eastern part of the State, and extends from the West Virginia and Virginia borders northwest and west to the Lower Carboniferous boundary. The second area forms a large, more or less rectangular patch, in the western part of the State, reaching along the Ohio River from Skillman, in Hancock County, to

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[1] Ky. Geol. Surv., Chem. Analyses, A., Pts. I, II and III.

[2] See map issued by Ky. Geol. Surv. in 1908.

Blackburn in Union County. South of these points this area extends approximately as far as the northern boundary of Christian, Todd, Logan and Warren counties. From the southeastern corner of the area a branch extends eastward, over most of Edmonson and Grayson counties. The Tertiary area occupies that portion of the State between the southern boundary and the Tennessee and Ohio rivers. In this area there are some small strips of Cretaceous in Marshall and Calloway counties and some broad patches of Pleistocene along the Ohio River.

Ordovician[1]

The Ordovician rocks supply residual clays, derived chiefly from the limestones, and of prominence in the Blue Grass region. They are probably well adapted to the manufacture of red brick and perhaps common earthenware. Shales occur in both the Cincinnati and the Hudson groups, but may be calcareous and perhaps better adapted to the manufacture of Portland cement than bricks.

Silurian

The Silurian rocks contain a number of shale formations, but their economic value has not been systematically investigated. A number of individual occurrences have been recently described by Foerste (Ref. 7). The Estill, Lulbegrud and Plum Creek formations appear to be promis-

ANALYSES OF SILURIAN SHALES

	I.	II.	III.	IV.
Silica (SiO_2)	49.90	58.82	54.33	54.48
Alumina (Al_2O_2)	18.15	18.14	19.44	18.90
Ferric oxide (Fe_2O_3)	5.57	4.83	5.00	5.64
Lime (CaO)	4.02	0.91	1.88	2.50
Magnesia (MgO)	3.32	1.74	2.22	1.71
Potash (K_2O)	5.32	4.71	5.15	4.67
Soda (Na_2O)	.33	.36	.31	.38
Titanic acid (TiO_2)	.93	1.25	1.13	1.12
Sulphur trioxide (SO_2)	trace	.12	.39	trace
Loss on ignition	9.94	6.12	7.80	7.86
Moisture	2.45	1.98	2.20	1.69
Total	99.93	98.98	99.85	98.95

I. Panola, Madison County. Plum Creek formation.
II. Irvine, Estill County. Lulbegrud formation.
III. Panola, Madison County. Estill formation.
IV. Crab Orchard.
I–IV from A. F. Foerste, Ky. Geol. Surv., Bull. 6, 1905.

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[1] See Ky. Geol. Surv., reports on Oldham County, p. 19; Kenton County, p. 133. Jefferson County, p. 50; and Chem. Analyses, Pt. I, 1884, pp. 34 and 76.

ing. None of them are fire-clays, but the possibility of utilizing them for brick, sewer-pipe and Portland cement is suggested.

The analyses on the preceding page will give some idea of their composition, no physical tests having been published.

Devonian

Little has been published regarding the value of the Devonian shales, but it is probable that the weathered outcrops at least would serve for making common brick.

Carboniferous

Lower Carboniferous.—The beds of this age are found in both the eastern and western parts of the State, and include several deposits of clays and shales. In east central Kentucky, Foerste calls attention (Ref. 6) to a great mass of clays at the base of the Waverly series, known as the Linietta clay, and occupying about the same horizon as the Bedford clay of Ohio. It is more siliceous than the Crab Orchard clay, but not only makes as good a brick, but also sewer-pipe and paving-brick. The Upper Waverly is shale-bearing, but nothing much is known of its economic value. J. H. Gardner (Ref. 8) has recently called attention to a series of promising clays in the Lower Carboniferous area, on the eastern rim of the western coalfield, and including the counties of Hardin, Hart, Larue, Taylor, Edmonson and Grayson.

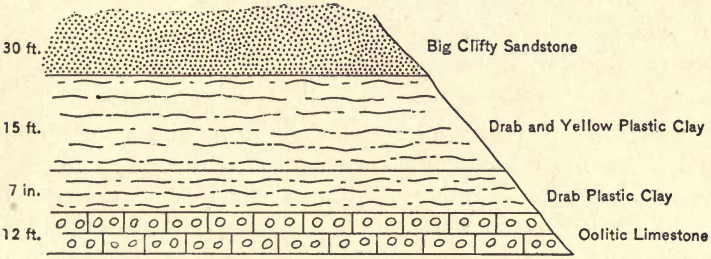

Fig. 53*a*.—Section showing occurrence of Sub-carboniferous clays in Kentucky. (After Gardner, Ky. Geol. Surv., Bull. 6, 1905.)

The beds, which include both plastic clays (sometimes refractory), and a white clay called "kaolin," are found in the various divisions of the Lower Carboniferous, but chiefly the upper ones. Fig. 53*a* shows their mode of occurrence. Grayson and Hardin appear to be the only two of the counties mentioned in which the white clay is absent.

Analyses of the plastic clays and kaolins are given below:

ANALYSES OF LOWER CARBONIFEROUS CLAYS

	I.	II.	III.	IV.
Silica (SiO_2)	54.07	48.09	44.16	43.64
Alumina (Al_2O_3)	22.60	34.66	37.34	34.57
Ferric oxide (Fe_2O_3)	5.04	.78	1.28	2.01
Lime (CaO)	.28	.27	.25	.99
Magnesia (MgO)	.50	.23	tr	.10
Potash (K_2O)	4.61	.74	.53	.81
Soda (Na_2O)		.30		
Titanic acid (TiO_2)	.93	.25	tr	tr
Sulphur trioxide (SO_3)	.27	.....	.31	.53
Loss on ignition	6.86	12.68	14.60	15.66
Moisture	4.62	2.39	2.82	2.71
Total	99.78	100.39	101.29	101.02

I. Plastic clay, J. B. Isaac place, 4 mi. s. e. of Bonnieville.
II. "Kaolin," P. Moss place, Bonnieville, Hart Co.
III "Kaolin," 5 mi. s. e. of Bonnieville.
IV. "Kaolin," Hibernia, Taylor Co.
I-IV. from Bull. 6, Ky. Geol. Surv., 1905.

The "kaolins" are believed by Gardner to be of marine origin, because: (1) they are interstratified with other sedimentary formations; (2) they at times show banding; (3) in one county at least they contain fossils; and (4) they are sometimes underlain by a thin stratum of Chester coal, which in turn rests on a fire-clay. The only other possible origin is a replacement one, which he does not consider probable. There are a number of occurrences of these white clays but none are worked.

A somewhat unique occurrence is that of siliceous clays along fault lines between the St. Louis limestones and cherts on one side, and the Chester quartzites on the other. The clay is supposed to result from the decomposition of the siliceous limestones and quartzites by circulating waters. These deposits have been noted at Marion and Sheridan, Crittenden County, Smithland, etc. (Ref. 5).

Coal-measures.—The coal-measures will undoubtedly be found to contain the most valuable clays of the State, those of the eastern coal-field having yielded especially valuable supplies. Very little systematic work has been done on them, or at least the results of it have not been published.

Pottsville.—In northeastern Kentucky an important clay bed occurs in the Pottsville formation (Ref. 13), and is regarded as the equivalent of the famous Sciotoville clay of Ohio. The clay lies a few feet above the Greenbrier (Lower Carboniferous) limestone, or at times may rest directly upon it. At Olive Hill, where it is extensively worked, the following section is seen (Ref. 13).

SECTION AT OLIVE HILL, CARTER COUNTY, KY.

	Feet.	Inches.
1. Coal	...	2–6
2. No. 3 clay	1–9	...
3. Drab-flint clay	1–9	...
4. "Semi-hard" clay	1–5	...
5. "Pink-eye"	3	...
6. Blue shale	...	18–20
7. Iron ore	...	4–8
8. Top of Lower Carboniferous limestone.		

The one seam may thus yield several varieties of clay. No. 3 is the most important, while No. 4, which is plastic, is similar to that found with the Ferriferous Limestone.

FIG. 53b.—Map of Northeastern Kentucky, showing flint-clay area. (After Greaves-Walker, Trans. Amer. Ceram. Soc., IX, 1907.)

Another clay horizon, which occurs directly under the Homewood sandstone, has been opened up at Ashland.

Greaves-Walker (Ref. 11) states that the flint-clay can be traced over the counties of Greenup, Carter, Lewis, Rowan and Elliott (Fig. 53b), thus underlying an area of not less than 200 square miles. It does not form a continuous bed, but rather lenticular masses, which grade into the plastic fire-clays and less pure clays. The deposit ranges from 3 or 4 up to 30 feet.

ANALYSES OF FIRE-CLAYS FROM NORTHEASTERN KENTUCKY

	I.	II.	III.	IV	V.
Silica (SiO_2)	43.82	43.76	58.34	39.56	47.08
Alumina (Al_2O_3)	39.67	40.21	33.34	43.35	36.12
Ferric oxide (Fe_2O_3)	1.09	.53	1.02	2.57	2.08
Lime (CaO)	1.43	.88	.72	.56	.86
Magnesia (MgO)	.11	.06	.36	.50	
Loss on ignition	11.96	14.12	6.13	13.09	13.75
Total	98.08	99.56	99.91	99.63	99.89
Cone of fusion	33	35–36	34–35	36	33

I. Semi-flint clay, Burnt House Mine, Olive Hill.
II. No. 1 flint clay. Burnt House Mine, Olive Hill
III. Sandy or high silica flint clay. Replaces No. II around the outer edges of the lens-shaped deposits.
IV. "Aluminite." Olive Hill.
V. No. 2 plastic clay, Burnt House Mine, Olive Hill.
I–IV. Trans. Amer. Ceram. Soc., IX, p. 461, 1907.

Allegheny.—An important fire-clay lies in the horizon of the ferriferrous limestone, and from 10 to 40 feet above the Homewood sandstone (Ref. 12). The clay, which is plastic, is worked at Willard, Ashland, Catlettsburg, etc. It is used mainly for fire-brick, and to some extent for pottery.

A number of references to the Coal-measure clays and shales are found in the reports of the old Kentucky Geological Survey, but little is known regarding them.[1]

Cretaceous

Clays of low refractoriness, dark or bluish color, and interbedded with sharp, fine-grained sands, occur in the western part of the State, and have been worked at Pottertown, east of Murray (Ref. 3).

Tertiary

The most important development of Tertiary clays is found in the Jackson Purchase region, lying immediately west of the Tennessee River. These were referred to in great detail in a special report issued by the

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[1] Ky. Geol. Surv., Eastern Coal Field, 1884, pp. 30, 32, 33, 43, 140–141, 201; also U. S. Geol. Surv., Geol. Atlas, Folio 47, London Sheet.

former Kentucky Geological Survey[1] (also Ref. 9, 3), and a number of analyses given. The materials include a variety of drab clays, siliceous clays and white or light colored plastic clays, which still remain largely undeveloped, indeed most of those mined are shipped out of the State. Of the many known occurrences (see Refs. 9 and 3) there may be specially mentioned the heavy beds of white clay from east of Wickliffe, Ballard County, and those around Hickman and Columbus. Crider states that the largest output comes from Pryorsburg, where beds over 100 feet thick have been proven, including white, ball and sagger clays, as well as others used for insulators and decorated tile.

The Irvine clays, of probable Tertiary age, form the basis of an important pottery industry in Madison County. They have been worked around Waco, etc., and used for stoneware, roofing, tile, drain-tile and brick. Some are buff-burning.

Pleistocene

Alluvial deposits, suitable for making common brick, are to be looked for along many of the river valleys.

The following table gives the analyses of some of the clays said to be of Tertiary age:

ANALYSES OF KENTUCKY TERTIARY CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	85.18	74.10	61.68	56.98	62.68	75.55	59.50	63.76
Alumina (Al_2O_3)	10.26	16.46	28.50	32.16	25.88	16.75	24.96	19.36
Ferric oxide (Fe_2O_3)	1.12	2.70	1.68	2.16	2.90	1.19	.72	2.59
Lime (CaO)	trace	.35	.10	trace	trace	trace	.32	.40
Magnesia (MgO)	.06	.18	.13	.20	.31	.14	.39	.82
Potash (K_2O)	.95	.55	1.15	.83	1.14	1.09	1.93	2.86
Soda (Na_2O)	.14	.13	.82	.11	.92	.21	.28	.47
Titanic acid (TiO_2)	......	......	......	......	......	......	......	1.25
Sulphur trioxide (SO_3)	......	......	......	......	......	......	......	trace
Loss on ignition	2.27	5.50	5.92	7.54	6.14	5.04	11.87	5.85
Moisture	......	......	......	......	......	......	......	2.27
Total	99.98	99.97	99.98	99.98	99.97	99.97	99.97	99.63

I. White siliceous clay, bluffs north of Columbus, Hickman County. P. 89.
II. Hickman, Fulton County. Bluish joint clay. P. 87.
III. White clay, Morris', east of New Providence, Calloway County. P. 100.
IV. White clay, Howard's, Bell City, Graves County. P. 100.
V. Three miles west of Lynnville, Graves County. P. 100.
VI. Panther Creek, east of Mayfield, Graves County. P. 100.
VII. Three miles south of Paducah, McCracken County. P. 112.
VIII. Waco, Madison County. P. 166.
All from Bull. 6, Ky. Geol. Surv., 1905. The page is given after each.

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LOUISIANA

The workable clays of Louisiana (Ref. 1) are all of transported character and post-Tertiary age. Three distinct types of clay are worked in Louisiana, and each of these is characteristic of that portion of the State in which it occurs.

The first, and oldest, is the Columbian mottled-gray clay of southeastern and southwestern Louisiana. It constitutes the "pine flats" of the coast, and the so-called "second bottoms" of the coastal plain These clays have been worked at a number of points, especially along the Pearl, Chefuncte, and Sabine rivers.

"The second group includes clays of later Columbian age, skirting, though lying 30 to 50 feet above, the alluvial valley of the modern Mississippi River. Upon the eastern bank they form a continuous bluff from the Mississippi State line to Baton Rouge, thence bear southwestward to near Lake Mauripas as an escarpment bordering the modern Mississippi alluvium. Upon the immediate front, and extending some two or three miles back from the river, these yellow and somewhat loamy clays are covered by the brown loam or loess, and in such position have not been worked." But at Baton Rouge, where the loam has been largely removed, they are extensively dug for common brick.

Clays of similar character and geologic age form a somewhat interrupted escarpment on the western side of the present Mississippi Valley. These clays have been worked at Markville, Washington, and New Iberia, and utilized for tile, common brick, and dry-pressed brick. The heaviest and perhaps best of these deposits are found in West Carroll, Richland, and Franklin parishes.

The third group includes a series of pocket-like deposits in the modern alluvium of the Red River.

Near Shreveport, and further north in the bluffs of Caddo and Bossier parishes, are outcrops of lignite shales which may be of value.

References on Louisiana Clays

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CHAPTER VI

MAINE—NORTH CAROLINA

MAINE, NEW HAMPSHIRE, AND VERMONT

THE larger portion of these three States is underlain by either pre-Cambrian crystalline rocks or metamorphosed Palæozoic formations, consequently little clay is to be looked for in these. Covering the entire surface of these States, however, is a mantle of Pleistocene deposits, mostly glacial drift, which is employed at many places for the manufacture of bricks, as it often contains clayey members. None of the deposits are refractory, and indeed they may often be quite calcareous. The glacial clays are found in the till or have accumulated in hollows, but in addition to these are to be found in a series of estuarine deposits, represented by the clay-beds that have been formed in the larger valleys during a depression of the land in Pleistocene time. The subsequent uplift of the surface, and their erosion by streams, has left the clays as terrace deposits along the valleys. Deposits of this character are commonly more persistent and thicker than the preceding type of drift-clay.

In the Penobscot Bay region of Maine (Ref. 3) yellow, gray, and blue-gray clays of marine origin are found between sea-level and the 125-foot contour, and extending farthest inland along rivers and tidal estuaries. They are frequently from 15 to 35 feet deep, and sometimes even more. Their main use is for common brick. The following analyses are given by Bastin:

ANALYSES OF MAINE BRICK CLAYS

	I.	II.	III.
Silica (SiO_2)	62.80	62.33	61.59
Alumina (Al_2O_3)	17.36	17.70	19.10
Ferric oxide (Fe_2O_3)	4.40	5.19	7.53
Ferrous oxide (FeO)	2.00	1.72	
Lime (CaO)	.88	1.00	1.68
Magnesia (MgO)	1.58	1.53	1.87
Potash (K_2O)	3.05	2.41	
Soda (Na_2O)	1.48	2.38	
Titanic acid (TiO_2)	.87	.79	
Ignition	4.39	3.81	5.51
Moisture	1.31	1.11	
Total	100.12	99.97	97.28

I. Clay from brickyard. Thomaston, Me.
II. Hayden Point, nr. S. Thomaston, Me.
III. Brick-clay, near Rockland, Me.
I–III. U. S. Geol. Surv., Bull. 285, p. 30.

An extensive series underlies the terraces along the eastern shore of Lake Champlain, where they reach a height of several hundred feet above sea-level. These Pleistocene clays are mostly of value only for making common brick and drain-tile, although the smoother ones could be employed for red earthenware.

A rather important series of residual clays is found in Vermont in connection with limonite and manganese deposits. They have been recorded from Brandon, Monkton, and Bennington, as well as in Shaftsbury, Wallingford, Plymouth, and Chittenden. Some of these are of white color, and although now used chiefly for paper manufacture, have also been tried for the manufacture of porcelain, stoneware, and fire-brick. The following analyses show the composition of one from Forestdale, Vt.

ANALYSES OF VERMONT KAOLINS

	I.	II.
Silica (SiO_2)	53.70	48.91
Alumina (Al_2O_3)	35.12	39.99
Ferric oxide (Fe_2O_3)	0.06	0.33
Lime (CaO)	trace	0.34
Magnesia (MgO)	trace	.....
Loss on ignition	10.55	8.92
Alkalies, by difference	0.57	1.51
Total	100.00	100.00

I. J. N Nevius anal.
II. H. Carmichael, anal.

A decomposed talcose schist known as "fire-clay" is worked near Rutland, and used for patent wall-plaster, stove-lining, etc.

References on Maine and Vermont Clays

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MARYLAND

The Maryland clay-deposits (Ref. 5) occur in formations ranging from Algonkian to Pleistocene, and the several formations of each system are each more or less limited to one of the three topographic provinces into which the State is divisible, as follows (Fig. 53*c*):

Coastal Plain area, containing Pleistocene, Tertiary, Jura-Trias, and some of the Algonkian formations; bounded approximately on northwest by a line passing through Wilmington, Baltimore, and Washington.

Piedmont Plateau region, containing Palæozoic, Mesozoic, and pre-Cambrian formations. The first two yield shales, while the third gives a series of residual clays which may at times be of value. This region extends from the western boundary of the coastal plain to the Appalachian Mountains.

Appalachian region, consisting of parallel mountain ridges composed of upturned Palæozoic strata. These are largely Devonian and Carboniferous shales which are abundant in Allegany and Garrett counties.

Algonkian Clays

These are exclusively of residual character and usually highly ferruginous; there are, however, in Cecil County a number of scattered kaolin-deposits derived from feldspathic gneiss, and one near Northeast has been worked to some extent for use in paper manufacture. A second pit has been worked near Dorsey station in Howard County and used in fire-brick making.

The impure, ferruginous residuals, which have been derived from a variety of rocks and are all red-burning, vary in thickness, and except in the case of limestone residuals invariably pass by slow gradation into the parent rock below. They are widely distributed in the Piedmont area. A broad belt of limestone clay is prominent in Washington County.

Silurian Shales

Most of these occurrences have no value for brick manufacture, unless they have at least partly weathered to residual clays. One good deposit occurs near the cement-works at Pinto, Allegany County.

Devonian Shales

These are represented in Allegany and Garrett counties by a great series of shales, sandy shales and shaly limestones. In some cases the shales have been so altered by folding that they develop little or no plasticity when ground and mixed with water, while at other times they are of excellent value for the manufacture of clay-products. The most important member is the Jennings shale, which is well exposed east of Cumberland and has been used for the manufacture of a red vitrified brick.

Carboniferous Shales

These are found in the western part of the State in Garrett County and western Allegany County. The important clay-bearing formations, together with their characteristics, are as follows:

Mauch Chunk.—A red shale with interbedded reddish sandstones, which at times weathers down to a plastic clay. The outcrops flank the ridges of western Allegany and eastern Garrett counties, but the beds are not worked.

Pottsville.—This, the only one of the Carboniferous formations which has been commercially exploited in Maryland, contains a valuable deposit of fire-clay. The bed, which is known as the Mount Savage fire-clay, underlies the Mount Savage coal, and has already been opened up at several points on Savage Mountain, west of Frostburg, Mount Savage, and Ellerslie respectively. Outcrops have also been found near Blaine and at Swallows Falls. The bed sometimes contains flint-clay and sometimes plastic shale, the two occurring irregularly.

Allegheny.—This outcrops on the eastern side of the George's Creek coal-basin high up on the western slope of Dans and Little Allegheny mountains. It contains many beds of shale, but none are worked, and it is doubtful if many could be used for clay-product manufacture.

Conemaugh.—The shales of this member are usually argillaceous, and sometimes associated with coal.

There are other shaly formations, but none except those mentioned seem promising.[1]

Cretaceous and Jura-Trias Clays

The clay-deposits of these two ages underlie large areas in eastern Maryland and are perhaps the most important clay series in the State. They are divisible into the following groups in

Upper Cretaceous.......	Rancocas Monmouth Matawan	
Lower Cretaceous.......	Raritan Patapsco	Potomac Group.
Jura Trias...............	Arundel Patuxent	

The Upper Cretaceous deposits of Maryland are a continuation of

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[1] For distribution, see Reports on Allegany and Garrett counties issued by Maryland Geological Survey.

similar beds in Delaware and New Jersey and cross the State from northeast to southwest, being especially developed in Cecil, Kent, Anne Arundel, and Prince George counties. In Maryland, however, these deposits carry but little clay. Those of the Potomac Group or Lower Cretaceous are of much importance, and consist of a series of sand, sandy clays, and gravels which have been deposited at different periods and under various conditions, the result being that the most unlike materials pass into each other horizontally. The characters of the several subdivisions of the Potomac together with their uses are as follows:

Patuxent.—This is best developed in the upper valleys of the Big Patuxent and Little Patuxent rivers and is sometimes found resting on the crystalline rocks of the Piedmont Plateau. It is traceable as a narrow, irregular, and sometimes broken belt from Cecil County on the northeast across Harford, Baltimore, Anne Arundel, and Prince George counties to the border of the District of Columbia. The Patuxent at times contains beds of refractory clay, the best occurrences having been noted around Baltimore and near Sewell in Harford County. The clays, which commonly show low tensile strength and low air- and fire-shrinkage, have been used with much success for admixture with the more plastic Arundel clays in the manufacture of terra-cotta.

Arundel formation.—Although highly developed in Anne Arundel County, the deposits of this horizon can be traced as a broken belt from Cecil County to the District of Columbia. The deposits form a series of large and small lenses of clays bearing carbonate iron ore (Pl. IV, Fig. 1) which have commonly been deposited in old depressions in the surface of the Patuxent formation. They vary considerably in size, ranging from a few feet up to 125 feet, and are usually made up of a blue, often siliceous clay of good plasticity but not high tensile strength. Cecil, Harford, Anne Arundel, Howard, Prince George, and Baltimore counties all contain many beds of Arundel clay. They are mostly red-burning and so their chief use has been for the manufacture of common and pressed brick, but some has been dug near Baltimore for making sewer-pipe and common pottery, in fact refractory clay is at times found and used for terra-cotta.

Patapsco formation.—The type exposures of this are on the shores of the Patapsco River, although the formation extends across the State. The clays are chiefly bright colored, mottled materials, which are often surrounded by sand-deposits. At the base of the formation there is often a bed of bluish stoneware clay, which is worked in Cecil County.

Raritan formation.—The beds in this formation are predominatingly sandy, and although at times they contain lenses of clay they are of far less importance than those in New Jersey.

Tertiary Clays

An important bed of red clay of Tertiary age extends from the South River southwestward, showing many outcrops, especially along the Western and Charles branches of the Patuxent, at Upper Marlboro in the Potomac Valley, in Prince George County, etc. It is a somewhat fine-grained plastic clay, at least 20 feet thick, and burns to a good hard red body, but is not worked, although it could be used for pressed brick.

Pleistocene

This overlies the earlier formations of the coastal plain, and in some cases extends up on the rocks of the Piedmont Plateau, forming a mantle of sandy clay, loam, and gravel of varying thickness. The loams, which belong to the Columbia formation, are very extensive and form an abundant source of brick material, being much used for this purpose around Baltimore.

Occasionally the Pleistocene carries stoneware clays, as along Chesapeake Bay south of Bodkin Point.

The physical properties and chemical composition of clays from the different formations are given below, all of them being taken from Volume IV of the Maryland Geological Survey.

Analyses of Maryland Clays

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	70.25	56.15	75.40	69.40	59.70	68.30
Alumina (Al_2O_3)	17.71	33.295	16.73	19.70	27.00	21.27
Ferric oxide (Fe_2O_3)	4.10	0.59	1.27	2.00	2.10	1.43
Lime (CaO)	0.70	0.17	0.35	0.20	0.60	0.52
Magnesia (MgO)	0.40	0.115	0.90	0.60	0.52	0.80
Alkalies (Na_2O,K_2O)	1.76	—	0.50	0.62	1.96	0.20
Ignition	4.80	9.68	5.30	7.85	8.20	7.55
Total	99.72	100.00	100.45	100.37	100.08	100.07

	VII	VIII.	IX.	X.	XI.	XII.
Silica (SiO_2)	72.50	55.65	61.00	46.10	58.60	67.50
Alumina (Al_2O_3)	17.00	30.53	26.36	38.05	28.71	17.20
Ferric oxide (Fe_2O_3)	1.50	0.97	0.83	1.05	3.22	6.70
Lime (CaO)	0.35	0.75	0.21	0.39	0.40	0.45
Magnesia (MgO)	0.60	0.60	0.10	0.60	0.35	—
Alkalies (Na_2O,K_2O)	1.10	0.20	trace	—	0.63	1,76
Ignition	6.50	12.30	11.60	12.95	8.90	5.90
Total	99.55	101.00	100.10	99.14	100.81	99.51

LOCALITIES OF THE ABOVE

No.	Locality.	Geological Age.	Uses.
I.	Bottom shale, brick works, Cumberland, Allegany County	Devonian	Paving-brick
II.	Flint-clay, Mount Savage, Allegany County	Carboniferous	Fire-brick
III.	Baldwin's sand-pit, Raritan River, Anne Arundel County	Raritan	Not worked
IV.	Bodkin Point, Anne Arundel County	Pleistocene	" "
V.	Baltimore, Baltimore County	Arundel	Brick
VI.	Link's pit, south of Baltimore, Baltimore County	Arundel	Terra-cotta
VII.	Carpenter Point, Cecil County	Patapsco	Stoneware
VIII.	Northeast, Cecil County	Algonkian	Kaolin
IX.	Flint-clay, Swallows Falls, Garrett County	Carboniferous	Not worked
X.	Shale, Swallows Falls, Garrett County	"	" "
IX.	Upper Marlboro, Prince George County	Eocene	" "
XII.	Residual limestone clay, Williamsport, Washington County	Pleistocene	Bricks

PHYSICAL TESTS OF MARYLAND CLAYS

	I.	II.	III.	IV.	V.	VI.
Per cent water required	19	30	40	19	22.5	23
Air-shrinkage, per cent	4	6	11	4	6	6
Fire-shrinkage	5	4	9	6	9	10
Aver. tens. strength, lbs. per sq. in.	55	40	223	65	77	110
Cone of incipient fusion	01	8	05	3	1	01
Cone of vitrification	4	27+	2	8+	6	8
Cone of viscosity	7	—	7	—	10	12
Plasticity	lean	good	high	fair	good	high

	VII.	VIII.	IX.	X.	XI.	XII.
Per cent water required	20	30	18	20	25	35
Air-shrinkage, per cent	2	6	1.5	5	4	9
Fire-shrinkage	4	4	12.5	3.5	5	11
Aver. tens. strength, lbs. per sq. in.	10	40	20	100	15	132
Cone of incipient fusion	27	8	10	3	27+	05
Cone of vitrification	—	27+	27	8	—	6
Cone of viscosity	—	—	—	10+	—	10
Plasticity	lean	fair	lean	fair	lean	fair

Localities of the Above

No.	Locality.	Geological Age.	Uses.
I.	Savage Mountain, Allegany County....	Mauch Chunk	Not worked
II.	Bodkin Point, Anne Arundel County..	Pleistocene	“ “
III.	Two miles south of Bodkin Point, Anne Arundel County................	“	“ “
IV.	One-half mile south of Harman, Anne Arundel County................	Raritan	Dry-pressed brick
V.	Link-pit, Baltimore, Anne Arundel County........................	Arundel	Terra-cotta
VI.	Near Elkton, Cecil County...........	Patapsco	Stoneware
VII.	Leslie, Cecil County.................	Residual	Stove-lining
VIII.	Northeast River, Cecil County........	Patapsco	Not worked
IX.	Northeast, Cecil County..............	Residual	Paper-clay
X.	Shannon Hill, Cecil County..........	Patapsco	Not worked
XI.	Dorsey, Howard County.............	Residual	Fire-brick
XII.	Upper Marlboro, Prince George County.	Eocene	Not worked

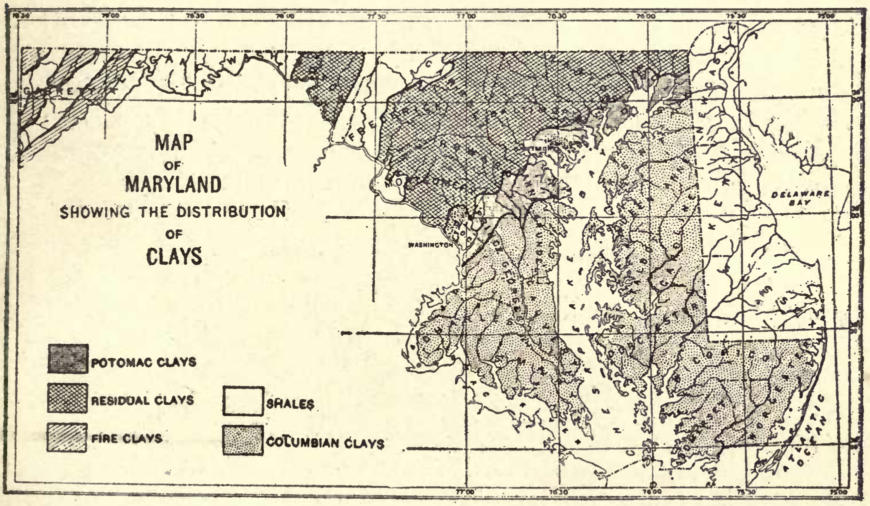

Fig. 53*c*.—Map of Maryland, showing the distribution of clays. (After Md. Geol. Surv.)

References on Maryland Clays

1. Bibbins, A., Md. Geol. Surv., Report on Cecil County.

2. Cook, R. A., The Manufacture of Fire-brick at Mount Savage, Maryland, Amer. Inst. Min. Eng., Trans., XIV, p. 698, 1886.

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MASSACHUSETTS

Most of the clays dug in the State are obtained from the Pleistocene formations, while comparatively small amounts are taken from the Cretaceous and Tertiary strata, and residual clays are rare.

Residual Clays

Two deposits of white residual clay or kaolin have been recorded from Massachusetts. One of these is at Blandford, Hampden County; the other is 4 miles south of Clayton, Berkshire County. The first has originated by the decomposition of a pegmatite vein in mica-schist, and has a width of nearly 100 feet.[1] It has been used for the manufacture of white brick and terra-cotta. The second has been derived from feldspathic quartzite or gneiss, and in its crude state is lean and sandy. The following analyses represent the composition of washed samples of the Blandford (1), and of Clayton (II) materials.[2]

Analyses of Massachusetts Kaolins

	I.	II.
Silica (SiO_2)	52.03	50.00
Alumina (Al_2O_3)	31.76	44.00
Ferric oxide (Fe_2O_3)	trace	.....
Ferrous oxide (FeO)	.....	1.00
Lime (CaO)	trace	.024
Magnesia (MgO)	.54	.....
Alkalies (Na_2O, K_2O)	trace	1.24
Water (H_2O)	15.55	.....
Total	99.88	96.264

Residual clays are known in Essex County, but are of no commercial value. One bed of fine white kaolin derived from felsite occurs on the west side of Kent's Island, Newbury. Another mass is found in South Lawrence, but neither have been worked, as they are too small.

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[1] Crosby, Technol. Quart., III, 1890.

[2] This evidently represents the composition of the burned clay. The analyst is unknown.

Cretaceous and Tertiary Clays

The Cretaceous and Tertiary beds form a thick series of clays and sands, well exposed in the Gay Head cliffs. The clay-deposits are pockety, owing partly to the frequent changes of conditions during deposition, and partly to their subsequent disturbance by the ice of the continental glacier as it advanced southward. These clays have been used to a slight extent for bricks, and somewhat for souvenir pottery.

Pleistocene Clays

These form the most important clay resource of the State, but contain no high-grade materials. They are extensively developed on the islands of Martha's Vineyard, Nantucket, and in southeastern Massachusetts on Cape Cod, but most of these are not well adapted to brick manufacture, as they vary too much in burning.

The true glacial clays are found and worked at many points. (Ref. 6.) Some of these were formed in estuaries, others in pools under or in front of the ice, while still others occur in the morainal drift and represent ground-up rock-flour. In the region south and east of a line from the mouth of the Merrimac River to Stonington, Conn., they are not found above an elevation of 100 feet. Around Boston these glacial clays are well developed in the estuaries of the Charles, Mystic, and Saugus rivers north and west of Boston. The clays are bluish, plastic, and very fine, but may at times contain bowlders or scattered pebbles.

Similar clays are extensively worked along the Mystic River at Medford; at Cambridge and Belmont on the Charles River; at Holyoke and South Hadley on the Connecticut; and at Taunton on the Taunton River. They are used chiefly for common-brick manufacture. There are but few published analyses of Massachusetts clays. Of the two given below, No. I is a glacial clay from West Cambridge, J. Card, analyst,

Analyses of Massachusetts Clays

	I.	II.
Silica (SiO_2)	48.99	57.50
Alumina (Al_2O_3)	28.90	31.21
Ferric oxide (Fe_2O_3)	3.89	....
Lime (CaO)	7.1	0.19
Magnesia (MgO)	3.66	0.20
Alkalies (Na_2O, K_2O)	4.73	0.40
Water (H_2O)	3.31	9.83
Total	100.58	99.33

and No. II a red clay from south end of Gay Head section. (7th Ann. Rept., U. S. Geol. Surv., p. 359.)

In Essex County, in which brickmaking began over 200 years ago, Pleistocene surface-clays are much used for bricks and pottery. They are of variable thickness, some exceeding thirty feet in depth, and are worked at Danversport, Haverhill, Beverly, and Salem. Some of the deposits are excavated below sea-level.

It is interesting to note the variety of products made from these common surface-clays, for they include common and pressed brick, fireproofing, and earthenware. A fine pottery is made at Newburyport from a mixture of local clay and Ohio clays.

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MICHIGAN

The clays of Michigan are derived from two types of deposits, namely, (1) Palæozoic shales and (2) Pleistocene clays. The former belong to the Silurian, Devonian, and Carboniferous.

Silurian

Hudson River. This formation carries a number of beds of shale, but most of these are either too gritty or too calcareous to be used for the manufacture of clay-products.

Devonian

Hamilton shales.—These outcrop around Alpena, but have not been used in the manufacture of clay-products, although their chemical composition seems to show that they may be promising.

Marshall series.—The shales of this formation are very extensive and are well developed around East Jordan, where the mellowed outcrops form a very tough plastic clay and are used in the manufacture of brick. They form a promising clay resource, but one objection to them is the occasional high content of soluble salts.

Carboniferous

The Carboniferous shales found in Michigan belong in the coal-measures, and are found interbedded with the coal-seams and sandstones. Three types were noted, namely, (1) a light-gray shale often underlying the coal and erroneously called fire-clay. (2) A black fine-grained, brittle shale, and (3) a dark grayish-black shale. The last two usually overlie the coal-seam. The shales are found associated with the coals in the different mines around Saginaw, Owosso, Corunna, St. Charles, Verne, Bay City, and Sebewaing. When ground up and mixed with water most of these shales give a plastic mass, but one whose tensile strength is usually low. They have been found in several places sufficiently plastic to be molded in a stiff-mud brick-machine, and used to make paving-brick or sewer-pipe. They usually vitrify around cones 3 and 4 and become viscous anywhere from cones 5 to 11. The coal and the shales form a basin northeast of Saginaw, which has a diameter of about 50 miles. The outcrops are found chiefly around the edge of the basin, and in the center the shales are not only at a considerable depth below the surface but there is usually a heavy covering of glacial drift or lake-deposits at many points.

Michigan shales.—The rocks of this series form a belt from 10 to 20 miles wide surrounding the coal-measure rocks in the lower peninsula. They are best exposed at Grand Rapids, where they form a bed from 6 to 10 feet thick overlying a gypsum deposit, but additional exposures occur in Huron and Arenac counties, as well as along the Cass River in Tuscola County. From laboratory tests it is found that the Michigan shales are usually more fusible than those of the coal-measures and that they burn to a good red color, although they may in some cases contain an abundance of soluble salts. Samples of them taken from the weathered outcrops show considerable plasticity. These shales have been worked for the manufacture of brick at Grand Rapids.

Coldwater shales.—The deposits of this series are very extensive, and have been opened up in quarries at Bronson, Union City, and Coldwater and on the northeast side of the coal-measure area, they are well exposed near Forestville (Pl. XXIX, Fig. 1) on Lake Huron. Many beds of this shale series will no doubt be found to be well suited for the manufacture of clay-products, for samples tested show that they vitrify at about cone 2 and become viscous at cone 5.

Pleistocene

The clays of this age are divisible into three groups, namely, lake-deposits, river-deposits, and moraine-deposits. All of these are very calcareous, except the river-clays which are less so, but show a high amount of grit. In many cases the lake-clays have been leached in their upper portions and, being freed from lime, these beds nearer the surface tend to burn red. The lake-clays are extensively developed at Detroit, Port Huron, South Haven, Marquette, Saginaw, and Escanaba, and are often found as much as 50 or 60 feet above the present lake-level. These Pleistocene clays are usually fine-grained, nearly always calcareous, and fuse at a low temperature. Their tensile strength commonly ranges from 150 to 170 pounds per square inch. The morainal clays form irregular masses in the terminal moraine and are worked at Ionia (Pl. XXX, Fig. 1) and Lansing. Their physical properties are similar to those of the lake-deposits. The river-clays are less extensive. No clays of a refractory nature have thus far been found in the State. At Rowley in Ontonagon County there is found a very fine-grained calcareous clay which has been used as a slip.

Analyses of Michigan Clays and Shales

	I.	II.	III.	IV.	V.
Silica (SiO_2)	55.30	44.30	56.50	53.44	55.95
Alumina (Al_2O_3)	14.20	23.72	19.31	24.80	17.43
Ferric oxide (Fe_2O_3)	3.62	7.68	5.89	0.76	7.67
Lime (CaO)	0.30*	1.11	1.00*	0.25	2.14*
Magnesia (MgO)	2.61†	1.50	1.85†	....	1.55†
Potash (K_2O)	2.15	2.00	5.98	20.75	2.86
Soda (Na_2O)					
Carbon dioxide (CO_2)	....	2.36	....		
Water (H_2O)	21.82	17.64	9.47		12.40
Organic +					

* = $CaCO_3$. † = $MgCO_3$.

PLATE XXIX

Fig. 1.—Coldwater (Carboniferous) shales at White Rock, near Forestville, Mich. (After H. Ries, Mich. Geol. Surv., VIII, Pt. I, p. 44, 1900.)

Fig. 2.—Carboniferous shale used for paving-brick, Flushing, Mich. (After H. Ries, Mich. Geol. Surv., VIII, Pt. I, p. 29, 1900.)

ANALYSES OF MICHIGAN CLAYS AND SHALES—*Continued*

	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	61.09	54.62	44.15	41.86	52.92
Alumina (Al_2O_3)	19.19	12.82	10.00	10.70	12.25
Ferric oxide (Fe_2O_3)	6.78	2.00	4.08	5.02	6.45
Lime (CaO)	2.51	13.68	24.64*	14.33*	13.84*
Magnesia (MgO)	0.65	4.25	1.50†	2.81†	3.55†
Potash (K_2O)	3.16	12.01	1.55	2.80	3.35
Soda (Na_2O)					
Carbon dioxide (CO_2)	......		....	14.50	
Water (H_2O)	5.13		12.13	8.00	7.14
Organic +	SO_3 1.42	....	1.95		

* = $CaCO_3$. † = $MgCO_3$.

PHYSICAL TESTS OF MICHIGAN CLAYS AND SHALES

	I.	III.	IV.	V.	VIII.
Per cent H_2O required for mixing	20	32	21	....	18
Tensile strength	55–65	105	125–139	80–95	
Plasticity	fair	good	good	....	high
Air-shrinkage, per cent	4	6	7	7	6
Fire-shrinkage, per cent	6	10	9	....	6
Incipient fusion, cone	1	05	03	05	05
Vitrification, cone	4	01	2	01	2
Viscosity, cone	9	3	5	2	3–4
Color when burned	red	red	red	deep red	buff

LOCALITIES OF THE ABOVE

No.	Locality.	Geological Age.	Uses.
I.	Saginaw	Coal-measures	Not worked
II.	Grand Ledge	Carboniferous	Sewer-pipe
III.	Grand Rapids	Michigan series	Common brick
IV.	Coldwater	Coldwater series	" "
V.	East Jordan	Devonian	Brick, Portland cement
VI.	Alpena	Hamilton shale	Portland cement
VII.	Marquette	Quaternary (lake)	Not worked
VIII.	Ionia	" (glacial)	Brick
IX.	Lansing	" "	Red and white brick, white tile
X.	Rockland	" (lake)	Slip-glazing

All of the above are taken from Vol. VIII, Pt. I, of the Michigan Geological Survey.

References on Michigan Clays

1. Fall, D., Marls and Clays in Michigan, Mich. Miner, III, No. 11, p. 11, 1901, and Mich. Geol. Surv., VIII, Pt. III, p. 343, 1903.

2. Ries, H., Clays and Shales of Michigan, Mich. Geol. Surv., VIII, Pt. I, 1900.

3. Russell, I. C., The Portland Cement Industry of Michigan, U. S. Geol. Surv., 22d Ann. Rept., Pt. III, p. 629, 1902.

MINNESOTA

The clays of this State can be divided into two groups, namely, (1) residual clays and (2) transported clays.

Residual Clays

These have been derived from either crystalline rocks or limestones. Crystalline rocks are abundant in certain parts of the State, but whatever clays may have been formed from them have been largely removed by glacial erosion. Deeply decayed granitic gneisses are, however, exposed at a few places in the Minnesota Valley, as, for example, at Redwood Falls, but the deposits appear to be of little value. Limestone residuals occur in the "driftless area" of southeastern Minnesota, but they are overlain by the loess, and the two are worked together for brick manufacture.

Transported Clays

Pre-Cambrian

Argillaceous slates of Kewaatin age have been worked for making dry-press brick at Thompson, thirty miles southwest of Duluth; but the enterprise has not been highly successful, although the plant was in operation in 1904.

Ordovician

Shales of this age are found only in the southeastern quarter of the State, and are well exposed in the Minnesota river bluffs near St. Paul. The shales are usually interstratified with limestones, and may themselves be calcareous, so that only certain beds can be used. These, however, have been successfully worked at St. Paul for pressed-brick manufacture.

Cretaceous

The Cretaceous beds are probably the most valuable clay resource of the State, but unfortunately the only important occurrence occupies but a very limited area near Red Wing (Pl. XXX, Fig. 2), where it has been worked for some years to make an excellent grade of stoneware. Other deposits are known in the western half of the State, but are deeply covered by drift as well as being of poor quality.

FIG. 1.—Deposit of calcareous glacial clay, Ionia, Mich. (After H. Ries, Mich. Geol. Surv., VIII, Pt. I, p. 52, 1900.)

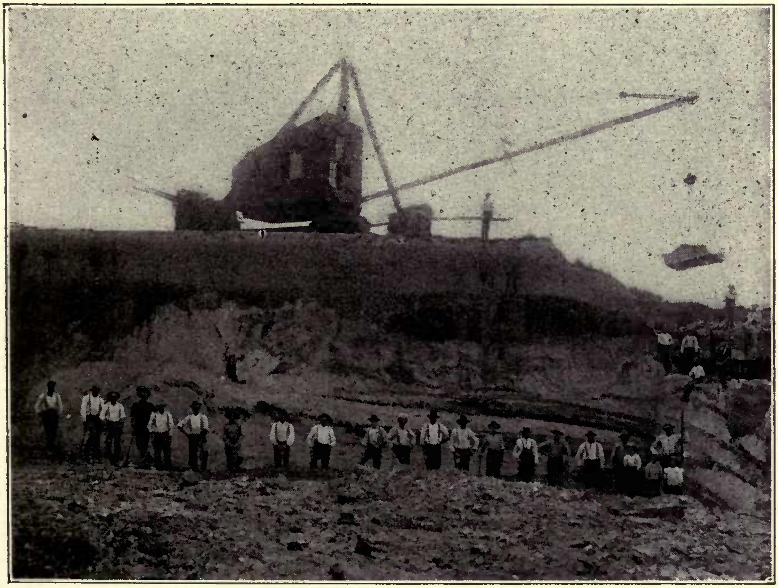

FIG. 2.—Cretaceous stoneware-clay, Red Wing, Minn. (Photo loaned by Red Wing Stoneware Co.)

Pleistocene

Glacial clays, represented by till-deposits, lake-deposits, or stream-deposits, are of importance in Minnesota, for common-brick manufacture at least. They are either red- or cream-burning, depending on the predominance of iron or lime.

Representative of the first of these three subtypes are the deposits near Princeton, Mille Lacs County. Those of the second, which were probably of interglacial age, occur near the eastern border of the State, a specially important one being worked at Wrenshall, Carlton County. The third subtype, which includes river silts deposited during the withdrawal of the ice, is prominent in two areas, namely, along the present Minnesota River from Shakopee to New Ulm and along the Mississippi River from Minneapolis to Little Falls. In both cases the worked clays underlie terraces bordering the present river channels. They are extensively worked at Chester and Minneapolis.

Loess-deposits.—Most of the clays worked on a small scale belong to this type, but all are not true loess accumulations. In this class belong the Red River Valley clays, worked at Moorhead and East Grand Forks.

ANALYSES OF MINNESOTA CLAYS

	I.	II.	III.	IV.
Silica (SiO_2)	69.84	60.31	59.72	73.34
Alumina (Al_2O_3)	23.07	23.77	30.00	14.75
Ferric oxide (Fe_2O_3)	0.48	7.96	.....	5.45
Lime (CaO)	0.11	2.5	0.82	0.28
Magnesia (MgO)	0.14	1.75	0.51	0.05
Potash (K_2O)	trace	2.42	....	trace
Soda (Na_2O)				
Water (H_2O)	6.35	....	10.34	4.71
Total	99.99	98.71	101.39	98.58

I. Red Wing, Goodhue County J. H. Rich sewer-pipe works.
II. Minneapolis, McLeod County. M. C. Madsden, anal.
III. Ottawa, Lesueur County. Ottawa Brick Co.
IV. Mankato, Blue Earth County. Minn. Geol. Surv., 1872.

References on Minnesota Clays

1. Berkey, C. P., Origin and Distribution of Minnesota Clays, Amer. Geol., XXIX, p. 171, 1902.

2. Winchell, A., County descriptions in the series of Final Reports, Vols. I, II, and IV of the Minn. Geol. and Nat. Hist. Surv.

3. Winchell, N. H., Brick Clays, Minn. Geol. and Nat. Hist. Surv., Miscel. Pub., No. 8, 1881.

MISSISSIPPI

The clay-bearing formations of Mississippi include the Devonian, Sub-carboniferous, Cretaceous, Tertiary and Quaternary, and form perhaps the most important mineral asset of the State. The general distribution of the clay-bearing formations is indicated on the map (Fig. 53*d*). All of these are not of equal importance. Both the Devonian and the Sub-carboniferous carry beds of shale, but they do not appear to have been worked.

Of the Cretaceous formations the Tuscaloosa is the most valuable, and in its lower portion at least is made up largely of plastic clays of varying grades, which have been used to a small extent for common stoneware and fire-brick (Ref. 1).

The Selma chalk, though carrying no beds of clay, yields a residual one, which is used for brick-making.

The Tertiary contains three important clay-bearing divisions, viz., the Wilcox, Jackson and Grand Gulf.

The Wilcox is the most valuable, and contains a wide variety of plastic materials, ranging from coarse, sandy clays, which could be used for sand-lime brick, to white pottery clays, such as those found at Holly Springs and Oxford. These have been developed mainly in the central portion of the Wilcox area, where they form part of a belt coming from Tennessee, and extending southward to Winston County. A thriving local stoneware industry has been built up upon them (Ref. 2).

The Jackson beds of the upper Eocene carry vast deposits of calcareous clay, as yet but little utilized, while in the Grand Gulf formation there are both siliceous and plastic clays.

The younger formations of the Quaternary furnish an abundance of sandy brick and tile clays.

The analyses on p. 400 have been selected by Prof. Logan as typical ones:

References on Mississippi Clays

1. Crider, A. F., Geology and Mineral Resources of Mississippi, U. S. Geol. Surv., Bull. 283, p. 49, 1906.

2. Eckel, E. C., Stoneware Clays of Western Tennessee and Northern Mississippi, U. S. Geol. Surv., Bull. 213, p. 382.

3. Hilgard, E. W., Report on the Geology of Mississippi, p. 244, 1844.

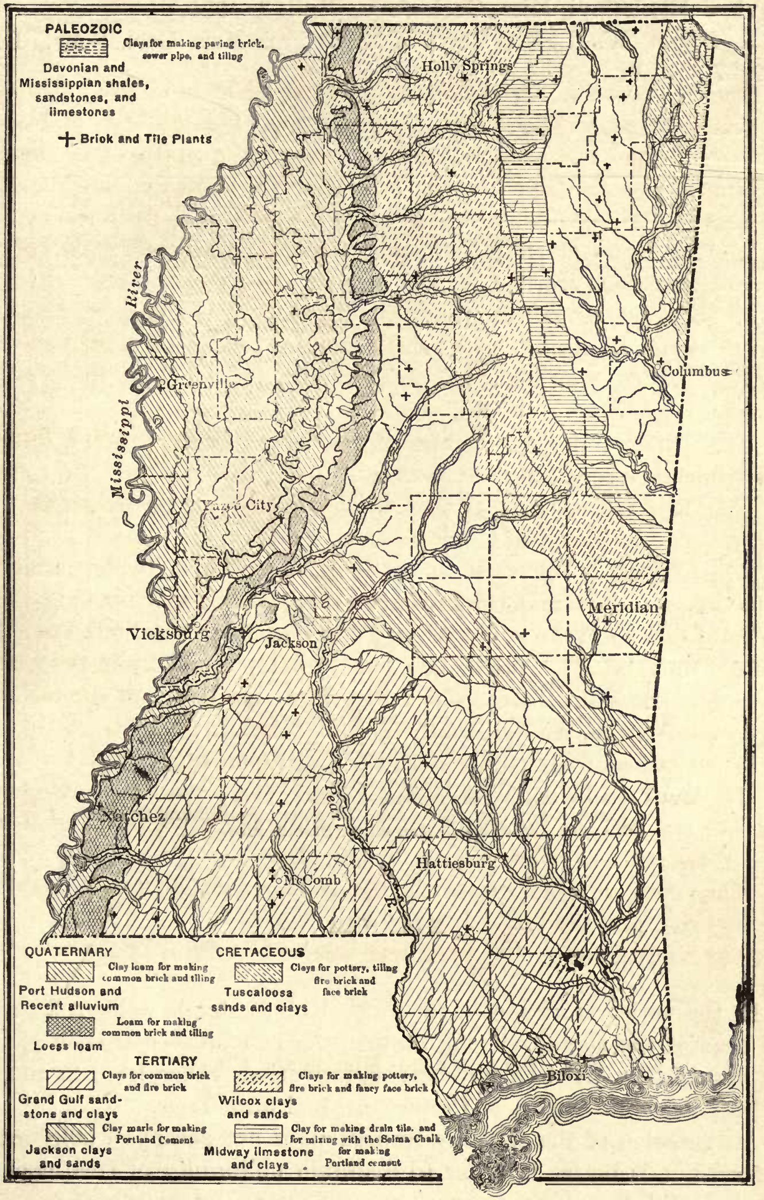

Fig. 53*d*.—Map of Mississippi showing the geologic age and distribution of the clay-bearing formations. (After W. N Logan, Miss. Geol. Surv., Bull. 2.)

4. Logan, W. N., and Hand, W. F., Preliminary Reports on the Clays of Mississippi, Miss. Geol. Surv., Bull. 3, 1905.

5. Logan, W. N., The Clays of Mississippi, Miss. Geol. Surv., Bull. 2, 1907.

ANALYSES OF MISSISSIPPI CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Silica (SiO_2)	74.45	71.67	77.57	75.11	71.13	67.72	59.22	60.00	63.35
Alumina (Al_2O_3)	11.62	8.10	7.25	10.70	9.12	10.86	10.30	27.80	13.70
Ferric oxide (Fe_2O_3)	3.38	7.90	6.25	5.50	7.75	5.51	4.70	.75	7.90
Lime (CaO)	1.69	.90	.50	.60	.42	.85	1.68	1.38	.80
Magnesia (MgO)	.94	.94	1.90	.47	.63	.70	1.18	.00	.60
Sulphur trioxide	.43	.62	.17	.....	.08	.54	.23	.20	.34
Loss on ignition	4.23	4.85	3.70	3.20	4.92	8.01	7.00	8.20	6.50
Moisture	2.81	2.15	2.13	1.81	4.95	4.25	10.06	.69	6.02
Total	99.55	97.13	99.47	97.39	99.00	98.44	94.37	99.02	99.21
Clay substance	29.39	20.49	18.34	27.07	23.07	27.47	.....	70.45	34.66
Free silica	60.89	62.15	69.05	62.53	60.41	12.77	.....	17.35	47.24
Impurities	8.44	10.36	8.82	6.57	8.88	7.00	.....	2.33	9.64
Total shrinkage, per cent	6⅔	....	6⅔	.....	10	8	15	.....	8
Tens. strength, lbs. per sq. in.	115	100	60	72	87	75	187	.....	133
Water required, per cent	19	20	15	18	.....	17	27	.....	16

I. Yazoo alluvium (buckshot clay), Clarksdale.
II. Yazoo alluvium (sandy).
III. Brown loam, Columbia formation, Pontotoc.
IV. Loess, Batesville.
V. "Joint clay," Lafayette formation, Aberdeen.
VI. Brick clay, Jackson formation, Jackson.
VII. Siliceous clay, Claiborne formation, Vaiden.
VIII. Pottery clay, Wilcox formation, Wilcox.
IX. Residual clay from Selma chalk formation, Agricultural College.
Nos. I–IX from Miss. Geol. Surv., Bull. 2, 1907.

MISSOURI

In the variety of its clays Missouri (Ref. 6) stands well up towards the head of the clay-producing States. As can be seen from a glance at the map (Fig. 54), the clay-bearing formations range from Cambrian to Pleistocene, exclusive of Cretaceous, and Jura-Trias.

A discussion of the clays by formations is not perhaps wholly satisfactory, but is better in order to maintain uniformity of treatment as far as possible.

FIG. 54.—Map of Missouri, showing distribution of clay-bearing formations, and location of clay-pits. (Adapted from Wheeler, Mo. Geol. Surv., XI, p. 48, 1896.)

Palæozoic Limestone Clays

These consist of four kinds, namely, kaolins, flint-clays, ball-clays, and stoneware-clays.

Kaolins.—The Missouri kaolins occur south of the Missouri River (Fig. 55) and are separable into three districts. These, together with the formations in which the kaolin occurs, are:

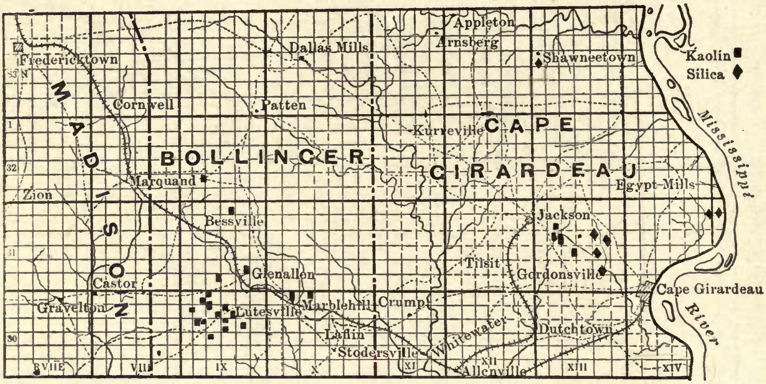

FIG. 55.—Map showing distribution of Missouri kaolins. (After Wheeler, Mo. Geol. Surv., XI, p. 200, 1896.)

Southeastern district of Cape Girardeau, Bollinger, and Howell counties, in Ordovician and Cambrian limestones.

Central district of Morgan and Cooper counties, in Ordovician limestone.

Southwestern district of Aurora and Lawrence counties, in Mississippian limestone.

According to Wheeler, the kaolins appear to be the insoluble fine residual matter left by the removal by solution of heavy beds of limestone. Only those of the southeastern district have been worked, and these to but a limited extent. The output has been sold for use in the manufacture of white ware, paper, or kalsomine, and Glen Allen is the most important locality.

Flint-clays.—These are compact, dense, flinty clays with a conchoidal fracture, which are found filling pockets or basins in limestone. The deposits range from 50 to 200 feet in diameter and 15 to 50 feet in depth, while between the limestone wall and the clay there is usually a sheet of sandstone several feet thick (Fig. 56). The pockets are thought by Wheeler to be old sink-holes in limestones that have become filled by aluminous matter being washed into them, but he further suggests that since this they have been slightly altered chemically by leaching with a recrystallization of the kaolinite; indeed, their remarkable freedom from impurities and high alumina content are puzzling features.

The flint-clays occur in the eastern-central portion of the State (Fig. 54), at a distance of 40 to 140 miles west of St. Louis, along the Wabash, Rock Island, Missouri Pacific, and Frisco railroads; but although the clays occur in sub-Carboniferous and Ordovician limestones, they were possibly formed in Cretaceous times.

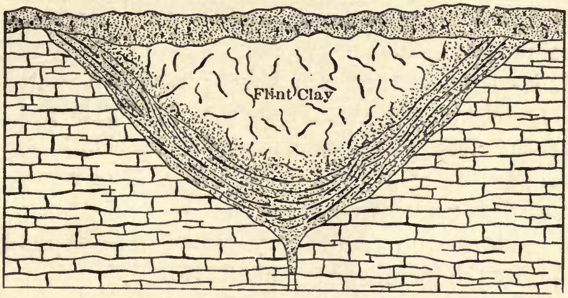

Fig. 56.—Section of a Missouri flint-clay deposit. (After Wheeler, Mo. Geol. Surv., XI, p. 202, 1896.)

The flint-clays show the following properties: hardness, 2.5 to 3.5; specific gravity, 2.33 to 2.45; slaking qualities, none; plasticity, very low; tensile strength, 10 to 38 lbs. per sq. in.; air-shrinkage, 2.5 to 3.5 per cent; fire-shrinkage, 9 to 14 per cent; incipient fusion, about 2300° F., but unaffected at 2700° F. and able to withstand 3000° F. Average composition: SiO_2, 45.8 per cent; Al_2O_3, 40 per cent; H_2O, 14.2 per cent. Their silica-alumina ratio has led Wheeler to suggest that they contain pholerite rather than kaolinite, or at least a mixture of the two. Flint-clay bricks have high powers of heat resistance, but low abrasive resistance. They work well in the arch of an open-hearth furnace or in the checkerwork of a regenerator.

Ball-clays.—These appear to have been derived by the weathering of flint-clays.

Stoneware-clays.—These have a similar origin to the flint-clays, but are less pure and have not been consolidated by secondary chemical changes. They are of local extent, and are found in rocks ranging from the Lower Carboniferous down to the Cambrian, but the Burlington and Trenton limestones appear to be the most favorable situations.

Coal-measures

The Coal-measures of Missouri contain two important series of deposits, namely, plastic fire-clays and impure shales.

Plastic fire-clays.—All of the Missouri plastic fire-clays occur in the Carboniferous, at the base of the Coal-measures, and are found in the eastern part of the State in two different basins known respectively as the St. Louis and Mexico areas. The former is on the western edge of the eastern interior coal-field, and the latter on the eastern edge of the western interior field.

In the St. Louis basin there are several beds of clay and shale, but only the St. Louis fire-clay seam is refractory. This has an average thickness of 6 to 8 feet, with a sandstone floor, a thin bituminous coal-roof, and is worked by shafts (Pl. XXXI, Fig. 1) or adits. It is hard when fresh, but disintegrates on exposure.

A special grade known as pot-clay comes from a purer and more uniform seam near the middle or top of the bed.

The St. Louis clay is coarse-grained, often carries pyrite, and although high in iron, still the latter is uniformly distributed and finely divided. The range of physical properties of this clay is given by Wheeler as follows: average tensile strength, 80 to 150 lbs. per sq. in.; air-shrinkage, 6 to 9 per cent; fire-shrinkage, 4 to 8.5 per cent; vitrification at 2300° to 2450° F.; viscosity, 2500° to 2700° F. This clay is much used for glass pots, zinc-retorts, and gas-retorts. It also makes a durable fire-brick if not exposed to excessive heat, as its fusion-point does not exceed cone 30 or 31.

The average composition of seven clays was as follows:

AVERAGE COMPOSITION OF ST. LOUIS FIRE-CLAY

	Mine-run.	Washed.
Combined silica (SiO_2)	32	32
Free silica (SiO_2)	30	25
Alumina (Al_2O_3)	24	24
Ferric oxide (Fe_2O_3)	1.9	1.85
Ferrous oxide (FeO)	1.2	1.00
Lime (CaO)	.7	.7
Magnesia (MgO)	.3	.2
Potash (K_2O)	.5	.55
Soda (Na_2O)	.2	.10
Sulphur (S)	.3	.18
Sulphur trioxide (SO_3)	.35	.40
Water (H_2O)	10.5	10
Moisture	2.7	3
Total fluxes	5.5	4.8

The Mexico clay includes one bed which is worked at Fulton, Mexico, and Vandalia. It ranges from 6 to 40 feet in thickness, but only the

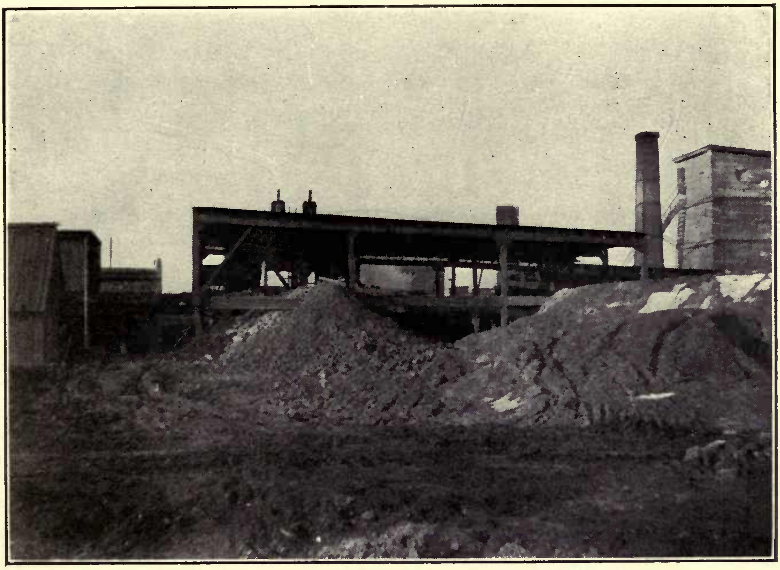

FIG. 1.—Photo of shaft-house and crushing-house at fire-clay mine, St. Louis. (Photo by L. Parker.)

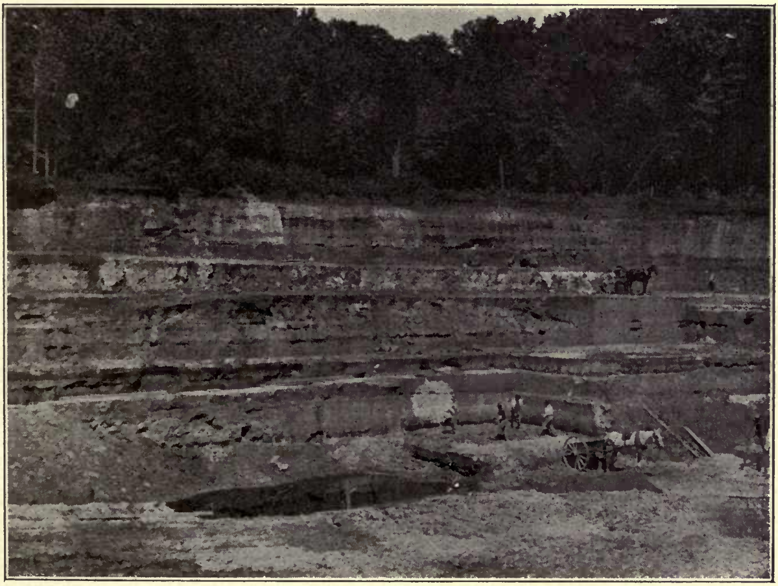

FIG. 2.—Pit of Raritan (Cretaceous) clays, Woodbridge, N. J. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 340, 1904.)

lower 6 to 12 feet are worked, and this through shafts. The range of physical properties is given by Wheeler as follows: Average tensile strength, 40 to 80 lbs. per square inch; air-shrinkage, 4 to 5 per cent; fire-shrinkage, 6 to 7 per cent; vitrification, 2400° to 2500° F.; viscosity, 2600° to 2700° F. The average composition is also given by Wheeler as follows:

Silica (SiO_2)	52.00
Alumina (Al_2O_3)	33.00
Ferric oxide (Fe_2O_3)	1.5
Lime (CaO)	.5
Magnesia (MgO)	.7
Alkalies (Na_2O, K_2O)	12.00
Total fluxes	3.4

Stoneware-clays.—Those found in the coal-measures are the most important known in the State, including many clay- and shale-beds, the most extensive of which are found in Henry County. They have been much used by potteries in Kansas as well as other portions of the West and Southwest. The so-called fire-clays of the barren coal-measures are usually impure, and consequently fusible and likely to blister or give a dark body after burning. The true fire-clays have also been used to some extent for stoneware.

Impure shales.—Many excellent beds of these are found in the coal-measures. They are all impure, but are eminently useful for making paving-brick, sewer-pipe, drain-tile, roofing-tile, terra-cotta, brick, and hollow ware, but they are not usually pure enough for refractory goods, stoneware, or white ware, and their main use has been for paving-bricks. Nearly all of them make a fair grade of brick by any process of molding, but the majority have to be finely ground or weathered.

In their physical properties the range is: average tensile strength, 50 to 250 lbs. per sq. in., usually between 125 and 175 lbs.; water required for tempering, 16 to 25 per cent; air-shrinkage, 4 to 8 per cent; fire-shrinkage, 1 to 10.6 per cent, but usually 4 to 6 per cent; incipient fusion, 1500° to 1700° F.; vitrification, 1700° to 1900° F.

The range of chemical composition is given by Wheeler as:

Silica (SiO_2)	50–75
Alumina (Al_2O_3)	10–27
Ferric oxide (Fe_2O_3)	3–10
Lime (CaO)	.5–2
Magnesia (MgO)	.5–2
Alkalies (Na_2O, K_2O)	3–4
Water (H_2O)	5–12
Total fluxes	10–15

Tertiary

The Tertiary beds occupy a small area in the southeastern corner of the State. They contain much clay admirably adapted to stoneware manufacture and which is dug to supply local potteries. An important deposit is known at Commerce.

Pleistocene

Pleistocene clays are widely scattered over the State, and form the main supply of material for common brick, although a few are sufficiently pure and plastic for stoneware manufacture.

Three types are recognizable:

1. **Loess-clays,** confined mostly to the neighborhood of the larger streams, especially the Missouri and Mississippi. They are yellow to brown in color, unstratified, and often of columnar structure. Their thickness is considerable, 75 to 100 feet being common along the lower Missouri, while at the Iowa line they have a thickness of 200 feet. The loess extends from 3 to 10 miles back from the streams, and appears to get stronger as the distance from the rivers increases, this change interfering with its being worked by the mud process. It is, however, the most valuable of the surface-clays.

2. **Glacial clays,** of varying character, confined to the counties north of the Missouri River and rarely over 50 feet thick. The material is usually very strong, red-burning, and often contains bowlders of concretions, but occasionally shows beds of better clay suitable for stoneware or drain-tile.

3. **Alluvial clays,** found along the present streams, and of little importance.

The tables on pp. 361, 362 give the analyses and phyical tests of a number of Missouri clays which may be regarded as representative.[1]

References on Missouri Clays

1. Keyes, C. R., The Geological Occurrence of Clay, Mo. Geol. Surv., XI, p. 35, 1896. 2. Keyes, C. R,. Distribution and Character of Missouri Clays, Min. Indus., VI, p. 127, 1897. 3. Ladd, G. E., Notes on Certain Undescribed Clay Occurrences in Missouri, Science, n. s., III, p. 691, 1896. 4. Ladd, G. E., Mo. Geol. Surv., Bulls. Nos. 3 and 5. 5. Seaman, W. H., Zinciferous Clays of Southwestern Missouri, Amer. Jour. Sci., iii, XXXIX, p. 38. 6. Wheeler, H. A., Clay-deposits, Mo. Geol.

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[1] These were selected for the writer by Professor H. A. Wheeler.

Surv., XI, 1896. 7. Wheeler, H. A., Clays and Shales (Bevier sheet), Mo. Geol. Surv., IX, sheet rept. No. 2, p. 57, 1896. 8. Wheeler, H. A., Fire-clays of Missouri, Amer. Inst. Min. Eng., Bimonthly Bull., Jan., 1905. 9. Orton, Jr., E., The Kaolin Deposits of Bollinger County, Mo., Trans. Amer. Ceram. Soc., IX, p. 62, 1907. 10. Fenneman, N. M., Clay Resources of the St. Louis District, Mo., U. S. Geol. Surv., Bull. 315, p. 314, 1907. 11. Mühlhäuser, O., Tonindustrie-Zeitung, 1903, p. 606. Abs. of a series of articles published in Zeitschr. ang. Chem.

Analyses of Missouri Clays

ULTIMATE ANALYSES

	I.	II.	III.	IV.	V.	VI.	VII.	VIII
Silica (SiO_2)	55.12	72.30	54.90	74.39	43.82	71.94	54.80	72.00
Alumina (Al_2O_3)	30.71	18.94	18.03	12.03	38.24	17.60	23.73	11.97
Ferric oxide (Fe_2O_3)	1.51	0.40	6.03	4.06	0.23	2.35	8.67	3.51
Lime (CaO)	0.54	0.68	2.88	1.50	1.93	0.62	0.64	1.80
Magnesia (MgO)	trace	0.39	1.10	1.52	......	0.56	2.23	1.35
Potash (K_2O) Soda (Na_2O)	1.37	0.42	3.40	3.01	0.73	1.51	3.80	3.25
Moisture	......	......	6.72	......	......	1.01	......	......
Comb. water	10.56	7.04	6.90	3.17	14.94	5.27	6.00	6.42

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Silica (SiO_2)	49.04	65.01	61.19	59.36	60.70	73.92	43.56
Alumina (Al_2O_3)	34.85	19.30	15.48	23.26	18.22	11.65	41.48
Ferric oxide (Fe_2O_3)	0.71	4.91	5.49	3.06	7.58	4.74	0.35
Lime (CaO)	1.33	1.40	1.95	0.65	2.68	1.45	0.45
Magnesia (MgO)	1.04	0.40	1.56	0.42	trace	0.60	
Potash (K_2O) Soda (Na_2O)	0.85	2.60	2.82	0.63	3.67	3.13	0.20
Titanic oxide (TiO_2)	......	......	......	1.01	......	......	......
Sulphur trioxide (SO_3)	......	......	......	0.35	......	......	......
Moisture	......	1.03	3.11	2.74	......	2.18	......
Comb. water	12.33	5.51	9.02	10.20	7.77	3.08	14.05

Physical Tests of Missouri Clays

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Size of grain	C.*	V.F.	V.F.	C.	V.F.	V.F.	V.F.	F.
Aver. tensile strength, lbs. per sq. in.	62	12	380	131	8	150	115	151
% H_2O for plasticity	14.8	23.2	22.3	17.2	15.1	16.5	21.5	18.4
Plasticity	lean	lean	very plastic	lean	very lean	plastic	plastic	lean
Air-shrinkage, per cent	4.4	4.0	9.6	5.7	3.1	5.5	5.9	5.1
Fire-shrinkage, per cent.	6.4	8.4	1.4	4.3	11.6	2.2	2.8	5.7
Speed	R.	S.	S.	R.	S.	S.	V.S.	R.
Incipient fusion, degs. F.	2200	2200	1600	2000	2350	2100	1500	2000
Complete fusion, degs. F.	2400	2500	1750	2000	2700	2300	1700	2200
Viscosity, degrees F.	2600	......	1900	2300	2700	2500	1900	2200
Specific gravity	2.46	1.89	2.01	2.09	2.85	2.34	2.37	2.17

* C. = coarse; V.F. = very fine; F. = fine; S = slow; R = rapid; V.S. = very slow.

PHYSICAL TESTS OF MISSOURI CLAYS—*Continued*

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Size of grain	V.F.	C.	V.F.	C.	C.	C.	F.
Aver. tensile strength, lbs. per sq. in.	198	92	273	78	177	173	13
% H_2O for plasticity	23.4	18.4	23.1	15.0	20	17.1	15.2
Plasticity	plastic	slightly lean	very plastic	lean	plastic	plastic	very lean
Air-shrinkage, per cent	7.7	5.2	8.0	6.3	5.3	5.3	2.4
Fire-shrinkage, per cent	9.8	3.5	1.5	5.4	8.3	5.5	8.9
Speed	S.	R.	V.S.	R.	R.	R.	S.
Incipient fusion, degs. F.	1800	1850	1650	2250	1700	1800	2400
Complete fusion, degs. F.	2100	2050	1800	2450	1900	1950	2700
Viscosity, degrees F.	2400	2250	1950	2650	2100	2050	2750
Specific gravity	1.69	2.41	2.05	2.41	......	1.98	2.39

LOCALITIES OF THE PRECEDING

No.	Locality.	Geological Age.	Uses.
I.	Mexico	Coal-measures	Fire-brick
II.	Glen Allen	Residual	White ware
III.	Norborne	Pleistocene	Railway ballast
IV.	Jefferson City	Coal-measures	Red brick
V.	Leasburg	....	Fire-brick
VI.	Calhoun	Coal-measures	Stoneware
VII.	Kansas City	"	Paving-brick
VIII.	" "	"	Red brick
IX.	De Soto	Residual	White ware
X.	Moberly	Coal-measures	Paving-brick
XI.	St. Peter's	Pleistocene	Railway ballast
XII.	St. Louis (Evens and Howard)	Coal-measures	Fire-brick
XIII.	Prospect Hill, St. Louis	"	Roofing-tile
XIV.	St. Louis (Hyd. Pr. Co.)	"	Red brick
XV.	Truesdale (Kelley's pit)	"	Fire-brick

MONTANA

Montana has never assumed prominence as a producer of clay products, and there is but little published information on the clays of that state, although the presence of good ones will no doubt be demonstrated when the demand for them develops.

Common brick clays are known to occur in many parts of the State, but the only fire-clay district of importance which has been developed is that lying in the eastern part of Cascade County.

In this region the Kootenai formation of the lower Cretaceous is known to carry important deposits of refractory clay, which have been worked at Belt and Armington, small coal-mining towns lying in the northwestern part of the area.

The section of the Kootenai formation in this area shows about 450 ft. of sandstones and shales. Near the center of the section is a bed of fire clay which was formerly mined, while about 100 feet above the base of the section is a bed of plastic clay, which is now extracted in considerable quantities. Although the clay is found at a number of points, it does not represent a continuous deposit. Moreover the beds, while appearing horizontal to the casual observer, are bent into a series of very gentle folds and also broken in places by small faults, having a throw of from 5 to 15 feet.

The plastic clay is shipped to Anaconda where it is used for the manufacture of fire bricks to supply the large smelters at that locality.

The following analyses, given by Fisher, represent the composition of the plastic fire clay.

ANALYSES OF FIRE CLAYS FROM BELT REGION, MONTANA

	I		II.
Silica (SiO_2)	55.38		53.70
Alumina (Al_2O_3)	30.86		27.20
Ferrous oxide (FeO)	0.86	Ferric oxide (Fe_2O_3)	5.00
Lime (CaO)	0.40		tr.
Magnesia (MgO)	1.03		tr.
Ferric sulphide (FeS_2)	2.23		....
Soda (Na_2O)	0.26		....
Potash (K_2O)	1.04		2.90
Sulphur trioxide (SO_3)	....		0.30
Moisture	0.84		....
Ignition loss	6.86		10.00
Total	99.82		99.10

I. Analysis of clay worked by Anaconda Copper Mining Co. at Armington, and sampled by C. A. Fisher.

II. Analysis of clay from same district supplied by Anaconda reduction works.

References on Montana Clays

Fisher, C. A., Clays in the Kootenai Formation near Belt, Montana, U. S. Geol. Surv., Bull. 340, 1908.

NEBRASKA

According to E. H. Barbour (Ref. 1), this State contains an abundance of clays, the most important being found in the Carboniferous and Dakota Cretaceous formations, while others occur in the Tertiary and Quaternary.

Carboniferous

The rocks of this formation (Ref. 2) occupy a V-shaped area in southeastern Nebraska, with the apex in the vicinity of Blair, and the base along the Kansas-Nebraska line from a point near Wymore to the

Missouri River. The Carboniferous, including the Permian, consists of massive grayish-yellow limestones, interstratified with clays, shales, and an occasional layer of coal. "The clays are usually of a dull-blue color interbedded with streaks of red and buff-colored sands, but there are also thin layers of disintegrated limestone, calcite concretions, and sand. . . .

"Frequently these thick deposits of clay form prominent bluffs along either side of the valley for some distance, especially where the clay is protected from erosion by some overlying layer of a somewhat harder material, such as limestone. . . . There are also many other available clay-banks along the Platte and Missouri rivers, notably at Nebraska City, where extensive brick-works are in operation, utilizing the clays of the Carboniferous for vitrified paving-brick. Terra-cotta ware has also been made here. Other localities where the clays are well exposed, and in some cases worked, are Minorsville, Peru, and Table Rock." Nearly all of the best deposits along the Missouri River in southeastern Nebraska are located along the Nebraska City branch of the Burlington and Missouri Railroad.

Cretaceous

The Dakota formation rests stratigraphically on top of the Carboniferous, with an unconformity between. The surface underlain by it is on the west and northwestern sides of the Carboniferous area, forming a strip about 30 miles wide and 200 miles long. It also forms a belt along the Missouri River north of the Carboniferous area. The formation consists of a series of shales and sandstones, but the latter, owing to their higher resistance to erosion, stand out more prominently, so that the mellowed outcrops of the shales are less noticeable. These shales vary from a sandy material of yellowish-brown color to highly plastic clays, the different beds showing a great variety of colors. Lens-shaped layers of sandstone are, however, not uncommon in the shale. These Dakota clays are available at many localities, and are said to have given excellent results for both pottery and brick manufacture.

Loess and Alluvium

The great bulk of brick made in Nebraska are manufactured from loess and alluvium (Ref. 3). The loess, or "bluff-deposit" as it is commonly called, consists of a light buff-colored loam, of generally uniform texture, but containing some shells. It is found over about half the area of the State.

The alluvium or valley-wash is a dark-colored soil of very fine texture, with interbedded layers of fine sand and gravel, and is being deposited at the present time in narrow strips along nearly all the large streams in the State.

References on Nebraska Clays

1. Barbour, Nebr. Geol. Surv., I, p. 202, 1903.

2. Gould, C. N., and Fisher, C. A., Ann. Rept. Neb. State Board of Agric. for 1900, pp. 185.

3. Fisher, C. A., Ann. Rept. Neb. State Board of Agric. for 1900, p. 181.

NEW JERSEY

Nearly all of the larger geological formations in the State contain deposits of clay, but the important ones belong to the following: Ordovician, Triassic, Lower Cretaceous, Upper Cretaceous, Miocene and Pliocene of Tertiary and Pleistocene.

Cambrian and Ordovician

The Cambrian and Ordovician rocks include beds of limestones and shales with some beds of sandstone and quartzite, and occur chiefly in Warren and Sussex counties in the great Kittatinny Valley, but are found also at a few other localities. Southwest of the terminal moraine (Fig. 57) the limestone yields a sticky yellow residual clay with flints, and that worked near Beattystown is of this character. The shale, also, where found south of the moraine is often deeply weathered, and at Port Murray is utilized for the manufacture of fireproofing. There it is found to be red-burning, of low plasticity, and fusing about cone 1.

Triassic

The Triassic or Newark series consists chiefly of red shales and sandstones with masses of trap-rock, and forms a belt extending across the State between the Highlands on the northwest and Cretaceous on the southeast. In places the shale has disintegrated to a sandy clay-soil, which has been used locally for common brick, but the fresh shale has in most cases been found too sandy to make into clay-products, although at one point, Kingsland, the shales have been used with apparent success. They burn to a hard red brick, but fuse at a low cone, and are not highly plastic.

FIG. 57.—Map of New Jersey showing distribution of important clay-bearing formations. (Adapted from map by Kümmel and Knapp, N. J. Geol. Surv. Fin. Rept., VI, 1904.)

FIG. 1.—Clay-loam deposit of shallow character, west of Mount Holly, N. J. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 122, 1904.)

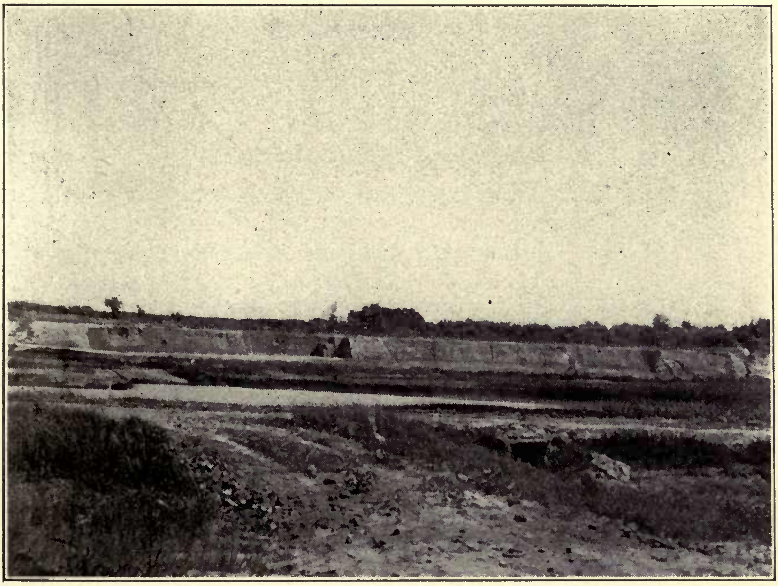

FIG. 2.—Pleistocene brick-clay, Little Ferry, N. J. (After H. Ries, N. J. Geol. Surv., Fin. Rept., VI, p. 374, 1904.)

Cretaceous

The New Jersey Cretaceous is divisible into three parts, which, beginning at the bottom, are: 1. Clay series of Lower Cretaceous; 2. Clay-marl series of Upper Cretaceous; and 3. Glauconitic marl series (see Fig. 57). Of these three, the first contains many important clay-deposits, the second some clays of economic value, but the third is of no interest in the present discussion.

Lower Cretaceous clay series.—This was termed the Raritan or Plastic Clay series by Dr. Cook (1878) and consists of a number of beds of clay, sand, and even gravel. The clays show great variety, ranging from nearly white or steel-blue fire-clay of high quality to black sandy clays containing varying amounts of pyrite, and useful only for common-brick manufacture. A similar variation is found in the sand-beds. A peculiar feature of the Raritan series is the rapid alternation of strata, so that the clays often change suddenly, both vertically and horizontally, much as shown in Fig. 3. This fact often makes it uncertain whether two pits sunk within a short distance of each other will yield the same kinds of clay.

Nothwithstanding these frequent changes in character and the impossibility of establishing divisions in the Raritan series, which can be accurately identified at widely separated intervals, it is possible, nevertheless, to recognize certain divisions, whose general features are sufficiently persistent to permit their being traced throughout the region of Middlesex County in which the beds have been so extensively worked. In other areas these subdivisions do not seem to hold.

The boundary between the upper part of the Raritan clays and the overlying clay marls is easily recognized, the upper bed of the former being a loose sand or sandy clay, while the lower bed of the latter is a glauconitic clay, black when fresh, but rusty brown when weathered, and often fossiliferous. Underlying the Raritan beds is the Triassic shale.

The Raritan series occupies a broad belt (Fig. 57) extending from Raritan Bay across the State to Trenton and Bordentown, and a much narrower strip along the Delaware River to Salem County. Over most of its outcrop across the State it is covered by later formations.

In the Middlesex County area the Raritan is divisible into nine members, which, beginning at the bottom together with their characters, are as follows:

1. Raritan clays. This member carries both a fire-clay and potter's

clay. The former is usually drab, but sometimes mottled or black, and generally quite sandy. It is dug around Sand Hills, and sparingly at Woodbridge and Mill Brook. Its main use is for fire-brick, and its refractoriness is usually about cone 27. The potter's clay is a white or bluish-white clay of variable color and composition. It is worked east of Martin's Dock and south of Metuchen.

2. No. 1 fire-sand, a bed of quartz-sand.

3. Woodbridge clays. This, the most important member of the Raritan series, consists of an upper bed of black, laminated sandy clay, and a lower bed of fire-clay. The laminated clay is red-burning, plastic, and contains more or less lignite and pyrite; it is extensively worked for the manufacture of fireproofing, common brick, conduits, etc., and large pits have been opened in it around South River, Sayreville, and other points.

The fire-clay ranges from a fine-grained clay of high plasticity and high refractoriness (cone 35) to sandy clays of lower grade fusing at cone 27. It can be stated in general that the bed is less refractory at the southwest end. This clay is used in the manufacture of fire-brick, pressed brick, retorts, stoneware, and as an ingredient in fireproofing and conduits. A small amount dug near Woodbridge is sufficiently white-burning and refractory for white-ware manufacture.

4. No. 2 sand. Included in this sand formation are two important beds whose names are somewhat misleading, namely, the feldspar and kaolin beds. The *feldspar* is a coarse feldspathic sand or gravel with more or less decomposed feldspar and pellets of white clay, while the *kaolin* is not in any sense such, but is a micaceous quartz-sand.

5. South Amboy fire-clay. This outcrops chiefly south of the Raritan River between Sayreville and South Amboy, but is also found at several points north of it. It is generally a white, light blue, or red-mottled clay, ranging from 15 to 30 feet in thickness, and varying greatly in its quality. Its refractoriness is moderate.

6. No. 3 sand.

7. Amboy stoneware-clay. An important bed of stoneware-clay, best exposed southeast of South Amboy. Like the other members it is of variable character, but the better grades are used for stoneware.

8. Laminated sands of little value.

9. Cliffwood lignitic sands and clays. These form a series of beds of massive black clay and gray-black laminated sands and clays, which often carry lignite and pyrite. They are extensively exposed in the brick-pits around Cliffwood and along Cheesequake Creek, and are all red-burning.

The other Raritan areas, around Trenton, Burlington, Bordentown, Bridgeboro, etc., afford clays of refractory character, but it is not possible to correlate the sections with those of Middlesex County. The Raritan formation is by far the most important clay-bearing formation in New Jersey containing as it does such a wide range of materials. Even a hasty consideration of the uses to which they are put indicates in a measure what a wide range of materials must be contained within the limits at the Raritan strata, for among the products made from these clays are common brick, fireproofing, drain-tile, conduits, terra-cotta, front brick, fire-brick, stoneware, earthenware, tubs, and sinks, foundry materials, paper filling, etc. The physical tests and chemical analyses on pp. 372 and 374 will serve to give a good idea of their character.

Clay-marl series. — The outcrops of this series extend from the shores of Raritan Bay across the State in a southwest direction to the Delaware River north of Salem, forming a belt varying in width from 2½ to 8 miles. Its base is marked by a glauconitic sandy clay which weathers to a characteristic cinnamon-brown, indurated earth. The top is emphasized by the passage of a bed of loose reddish sand with quartz grains of pea size into a compact greenish marl. At many points a fossil bed 1 to 4 feet thick is present. Five members are recognizable as follows:

1. Black, sandy, often glauconitic clay, weathering cinnamon-brown.
2. Black, non-glauconitic clay, weathering to chocolate.
3. Varicolored sands.
4. Black laminated sand and clay, strongly glauconitic to the southwest.
5. Red quartz-sand. Top.

Both Nos. 1 and 2 are important sources of brick- and sometimes tile-clay, the former being worked near Camden, Keyport, Hightstown, etc., and the latter near Matawan, Kinkora, Maple Shade, Camden, etc. Indeed, the two are sometimes worked in the same or adjoining banks.

Tertiary

The Tertiary clay-deposits occur in scattered areas lying to the southeast of the Lower Cretaceous belt. They are beds of irregular form, with a tendency towards basin-shaped structure. Owing to the almost universal mantle of sand over this region and the flatness of the surface, prospecting for the deposits is rendered more or less difficult.

The clay-deposits recognized in the recent work of the New Jersey Geological Survey are the Cohansey, Alloway, and Asbury clays. The

Cohansey is really a sand formation, but carries many lenses of clay which average 8 to 10 feet in thickness. They occur in the southern portion of the State, in Ocean and Atlantic counties, in southern Burlington, Camden, and Gloucester counties, and in Central Cumberland counties. Deposits have been worked at Rosenhayn, Millville, May's Landing, Woodmansie, Whitney's, etc. The clays are white, yellow, chocolate, and black, and sometimes even lignitic. Many are buff-burning and semi-refractory, on which account they are much sought after for the manufacture of buff bricks and terra-cotta.

The Alloway clay, which extends from near Swans Mills, Gloucester County, to a point 2 miles south of Alloway in Salem County, is a light-brown clay, of great toughness and high plasticity. Where weathered it contains many joints often filled with iron crusts, which greatly diminish its value. The Alloway clay is a red- and dense-burning material, of rather high air- and fire-shrinkage, but excellently adapted to the manufacture of stiff-mud brick and drain-tile.

The Asbury clay is well exposed west of Asbury Park, and is usually a dark sandy clay with laminæ of sand, adapted only to common-brick manufacture.

Pleistocene Clays

Pleistocene clays are widely scattered over the State. To the north of the terminal moraine (Fig. 57) they consist of first, basin-shaped beds occurring in the valleys; second, stony clays or till found in the glacial drift (Pl. III, Fig. 1); and, third, estuarine clays, occurring in great abundance in the vicinity of Hackensack (Pl. XXXII, Fig. 2). They are all impure materials adapted in most cases only to the manufacture of common brick or drain-tile.

In the region south of the terminal moraine the most important clays are those of the Cape May formation. These clays occur in a sand and gravel formation, found underlying terraces along the rivers from the coast inland to an altitude of from 40 to 60 feet. Along the Delaware River they are specially prominent, but other points are Cohansey Creek near Bridgeton, the Maurice River south of Millville, etc. The beds of clay are usually of limited extent and grade into sand.

The Cape May clays are of value chiefly for the manufacture of red brick and drain-tile, but occasionally small lenses of buff-burning clays are found.

Up to the present time no fire-clays have been found in the Cape May formation.

In the following tables will be found the analyses and physical tests of a number of representative samples of New Jersey clays:

ANALYSES OF NEW JERSEY CLAYS

	I.	II.	III.	IV.	V.	VI.
Sand	66.67	66.66	77.72	72.37	66.12	1.50
Combined silica (SiO_2)						42.90
Alumina (Al_2O_3)	18.27	14.15	15.74	14.40	22.07	38.34
Ferric oxide (Fe_2O_3)	3.11	3.43	0.49	3.43	1.31	0.86
Lime (CaO)	1.18	2.15	trace	0.75	0.50	....
Magnesia (MgO)	1.09	0.38	0.81	0.49	0.25	....
Potash (K_2O)	2.92	2.32	trace	1.60	1.81	0.26
Soda (Na_2O)	1.30	1.38	trace			0.18
Titanium oxide (TiO_2)	0.85	....	....	....	....	1.20
Ignition	4.03	8.40	5.62	6.70	7.94	13.50
Moisture	....	....	....	....	....	1.10

	VII.	VIII.	IX.	X.	XI.	XII.
Sand	5.20	64.00	8.10	60.1	51.56	68.38
Combined silica (SiO_2)	40.40		39.80			
Alumina (Al_2O_3)	38.40	29.08	36.34	23.23	33.13	20.11
Ferric oxide (Fe_2O_3)	1.20	1.12	1.01	3.27	0.78	1.71
Lime (CaO)	0.22	....	....	1.00	trace	....
Magnesia (MgO)	0.25	....	0.04	0.67	trace	0.73
Potash (K_2O)	0.59	2.64	0.15	2.58	trace	2.58
Soda (Na_2O)	....	....	....	0.80	trace	....
Titanium oxide (TiO_2)	*	*	*	....	1.91	1.01
Ignition	12.50	6.80	12.90	8.54	12.50	5.55
Moisture	1.30	....	1.20			

	XIII.	XIV.	XV.	XVI.	XVII.
Sand	45.76	28.81	51.80	48.40	68.96
Combined silica (SiO_2)		31.12	20.00	19.44	
Alumina (Al_2O_3)	39.05	26.95	18.92	21.83	17.87
Ferric oxide (Fe_2O_3)	trace	1.24	0.88	1.57	3.27
Lime (CaO)	0.95	....	....	0.28	0.25
Magnesia (MgO)	0.04	0.07	....	0.24	0.25
Potash (K_2O)	trace	trace	0.48	2.24	2.10
Soda (Na_2O)	trace	trace	....	....	
Titanium oxide (TiO_2)	....	1.90	....	....	....
Ignition	14.46	9.63	6.70	5.90	6.95
Moisture	....	0.57	0.50	0.80	

* With A_2lO_3.

LOCALITIES OF THE PRECEDING

No.	Locality.	Geological Age.	Uses.	Ref.
I.	Little Ferry	Pleistocene	Bricks	B 373
II.	Budd Bros., Camden	Clay Marl I.	Bricks	B 396
III.	H. Hylton, Palmyra	Raritan	Fire-bricks	B 392
IV.	A. E. Burchem, Buckshutem	Cape May	Bricks	B 415
V.	Clayville Min. & Brick Co., Clayville	Cohansey	Conduits	B 409
VI.	Geo. Such, Burt Creek	South Amboy, Raritan	Ball-clay	A 198
VII.	E. Roberts, Florida Grove	do.	No. 1 fire-clay	A 135
VIII.	Crossman Clay Co., Sand Hills	Woodbridge	Top-white clay	A 145
IX.	R. N. and H. Valentine, Sand Hills	Woodbridge	Fire-bricks	A 154
X.	Sayre and Fisher, Sayreville	Woodbridge	Common brick	B 467
XI.	No. 1 fire-clay, Anness and Potter, Woodbridge	“	Fire-brick	B 441
XII.	W. H. Berry, Woodbridge	“	Sewer-pipe	A 82
XIII.	W. H. Cutter, Woodbridge	“	Ball-clay	B 443
XIV.	W. B. Dixon, Woodbridge	Raritan	Fire-clay	A 79
XV.	Extra sandy clay, Loughridge and Powers, Woodbridge	Woodbridge	Fire-clay	A 93
XVI.	S. A. Meeker, Woodbridge	“	Stoneware-clay	A 99
XVII.	D. Haines & Son, Yorktown	Alloway	Brick and tile	B 496

A, Report on Clays of New Jersey, 1878. B, N. J. Geol. Surv., Fin. Rept., VI. 1904.

The physical tests are given on page 423.

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2. Hollick, A., Minerals from Fire-clay Beds at Green Ridge, Staten Island, Amer Nat., XXV, p. 403, 1891.

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4. Newberry, J. S., On the Raritan Clays of New Jersey, Amer. Assoc. Adv. Sci., 1869.

5. Ries, H., Kümmel, H. B., and Knapp, G. N., The Clays and Clay Industry of New Jersey, N. J. Geol. Surv., Fin. Rept., Vol. VI. 1904.

6. Smock, J. C., Mining Clay, Amer. Inst. Min. Eng., Trans., III, p. 211.

7. Smock, J. C., Plastic Clays of New Jersey, Amer. Inst. Min. Eng., Trans., VI, p. 177.

PHYSICAL TESTS OF NEW JERSEY CLAYS

		I.	II.	III.	IV.	V.
Per cent water required		18.5	21	20	32	33
Air-shrinkage, per cent		2	2	5.3	7	3.4
Plasticity		low	fair	fair	fair	fair
Average tensile strength, lbs. per sq. in.		51	150	65	52	33
Cone 05	Fire-shrinkage, per cent	1.6	2	1.3	—	—
	Absorption, per cent	16.14	6.56	—	—	—
Cone 1	Fire-shrinkage, per cent	4.6	—	—	3	—
	Absorption, per cent	8.82	—	—	19.69	—
Cone 5	Fire-shrinkage, per cent	7	—	1.3	5	6.2
	Absorption, per cent	3.26	—	14.52	16.75	—
Cone 8	Fire-shrinkage, per cent	—	—	2	—	14.6
	Absorption, per cent	—	—	12.82	—	7.14
Cone of viscosity		—	1	27	27+	4+
Color when burned		red	red	buff	buff	white

		VI.	VII.	VIII.	IX.	X.
Per cent water required		33	33	30.5	25.5	20
Air-shrinkage, per cent		4.4	5	4	6.5	6
Plasticity		fair	fair	good	good	good
Average tensile strength, lbs. per sq. in.		48	41	72	88	156
Cone 05	Fire-shrinkage, per cent	—	—	—	1.5	1.3
	Absorption, per cent	—	—	—	17.93	16.54
Cone 1	Fire-shrinkage, per cent	—	—	6.6	3	2.6
	Absorption, per cent	—	—	10.17	13.61	12.68
Cone 5	Fire-shrinkage, per cent	13.6	7.1	7	3.7	2.3
	Absorption, per cent	7.07	13.74	9.30	9.98	10.17
Cone 8	Fire-shrinkage, per cent	13.8*	11	8	6	—
	Absorption, per cent	6.47	9.10	—	10.70	—
Cone of viscosity		32	34+	12	12?	8
Color when burned		buff	buff	red	red	red

		XI.	XII.	XIII.	XIV.	XV.
Per cent water required		34.9	27	23.4	27.2	22
Air-shrinkage, per cent		10	7.6	8	7	6
Plasticity		high	high	high	high	good
Average tensile strength, lbs. per sq. in.		286	229	293	291	108
Cone 05	Fire-shrinkage, per cent	3.3	1	.3	3.3	4.3
	Absorption, per cent	11.12	13.42	11.65	12.46	7.88
Cone 1	Fire-shrinkage, per cent	3.3	2.7	3.3	6	8.6
	Absorption, per cent	9.92	8.9	6.2	5.5	.10
Cone 5	Fire-shrinkage, per cent	—	—	4	7	
	Absorption, per cent	—	—	4.36	3.51	
Cone 8	Fire-shrinkage, per cent	—	5.7	5	—	
	Absorption, per cent	—	1.21	—	—	
Cone of viscosity		10	12+	—	—	3+
Color when burned		red	red	buff	red	red

* Cone 10.

Localities of the Preceding

No.	Locality.	Geological Age.	Uses.	Ref.
I.	Port Murray	Hudson River	Fireproofing	A
II.	Kingsland	Triassic	Brick	B
III.	H. Hylton, Palmyra	Cretaceous	Fire-brick	C
IV.	C. S. Edgar, Bonhamtown	Raritan	Saggers	D
V.	W. H. Cutter, Woodbridge	Woodbridge fire-clay beds	White ware	E
VI.	R. H. and N. Valentine, Sand Hills, No. 1 blue clay	do.	Fire-brick	F
VII.	No. 1 clay, Anness and Potter, Woodbridge	do.	"	G
VIII.	Sayre and Fisher, Sayreville	Woodbridge black laminated clay	Common brick	H
IX.	Carman and Avery, Cliffwood	Cliffwood laminated sands and clays	" "	I
X.	Budd Bros., Camden	Clay Marl I.	" "	J
XI.	One mile south of Collingswood	Clay Marl II.	Brick and tile	K
XII.	Yorktown	Alloway	" "	L
XIII.	May's Landing	Cohansey	Pressed brick	M
XIV.	A. E. Burchem, Buckshutem	Cape May	Common brick	N
XV.	Little Ferry	Pleistocene	" "	O

Ref. A, N. J. Geol. Surv., Fin. Rept., VI, p. 507; B, do., p. 374; C, do., p. 392; D, do., p. 449; E, do., p. 442; F., do., p. 447; G, do., p. 440; H, do., p. 467; I, do., p. 474; J, do., p. 394; K, do., p. 397; L., do., p. 495; M., do, p. 370; N., do, p. 414; O, do., p. 373.

NEW MEXICO

Adobe brick are made at many points from the calcareous valley clays, and common burned brick are also manufactured at different points. The Cretaceous shales at Las Vegas have yielded good results with the dry-press brick process. Fire-clays have been worked at Socorro and were formerly made into fire-brick.

In the San Juan district the clay industry is limited to the Animas and San Juan valleys. Surface clays are worked for brick-making at Farmington, Flora Vista, Aztec, and Fruitland, but at Shiprock the Mancos shale is employed.

At Gallup a semi-refractory clay is mined for use as converter linings in the copper smelters of Southern Arizona (see Analysis I below). The Mancos shale is worked for brick-making near Gallup (Analysis II) but the high carbon contents cause trouble, although they are not given in the analysis.

ANALYSES OF NEW MEXICO CLAYS

	I.	II.
Silica (SiO_2)	64.73	56.29
Alumina (Al_2O_3)	17.75	23.18
Ferric oxide (Fe_2O_3)	6.53	
Lime (CaO)		3.73
Magnesia (MgO)		2.91
Ignition	5.09	11.53
Moisture	4.36	
	98.46	97.64

References on New Mexico Clays

1. Shaler, M. K., and Gardner, J. H., Clay Deposits of the Western Part of the Durango-Gallup Coal Fields of Colorado and New Mexico, U. S. Geol. Surv., Bull. 315, p. 296, 1906.

NEW YORK

The greater portion of New York State is underlain by sedimentary rocks of Palæozoic age, ranging from the Cambrian to the Carboniferous inclusive. These consist in very large part of shales, but sandstones and limestones are at times prominent. The Cretaceous and Tertiary formations, so abundant in States farther south, are found in New York only, on Staten Island, Long Island, and Fisher's Island.

Overlying all of the above are Pleistocene deposits. Residual clays are rare. The clay-deposits of the State may, therefore, be grouped as follows: Residual clays, Palæozoic shales, Cretaceous, and Tertiary clays, Pleistocene clays.

Residual Clays

These are of but little importance in New York State, and may be passed over with the statement that some deposits of kaolin have been found east or southeast of Sharon, but so far as known none have ever proven of economic value.

Palæozoic Shales

Those occurring in New York State and including beds of value to the clay-worker belong to the Medina, Salina, Hamilton, Portage, and Chemung. The Hudson, Clinton, and Niagara formations are of little or no value for the manufacture of clay-products. All of these shale formations, with the exception of the Hudson, form bands of variable width extending across the State in an east-west direction, and their distribution can best be seen by reference to the geologic map of New York, from which it will appear that the oldest formations outcrop towards the north, in belts running parallel to Lake Ontario. Their characters are briefly as follows:

Hudson River shale.—This formation, although widely distributed in the eastern part of the State, is of no economic value for the manufacture of clay-products, since it is deficient in plasticity and is very siliceous.

Niagara shale.—This also, on account of its calcareous and siliceous character, is of little or no value.

Medina shale.—Along the Niagara River at Lewiston, and also along the Genesee River, there are outcrops of this rock. It is not utilized in New York State, but has given good results for dry-pressed brick in Ontario.

Clinton shales.—These are about 30 feet thick in places, notably in eastern Wayne County, and 24 feet thick at Rochester and Wolcott Furnace. They have not been used and are probably often calcareous.

Salina shales.—This series forms a belt extending from Syracuse westward. The shale is soft, weathers easily, and possesses good plasticity, but may be quite calcareous, and not infrequently carries lumps of selenite. It is red-burning, and used for common and paving brick, drain-tile, or conduits.

Hamilton shale.—Though extending from the Hudson River to Lake Erie, this formation shows considerable lithologic variation ranging from a sandstone to a clay-shale. The latter phase is more common in the western part of the State. It is worked for paving-brick at Cairo, Greene County, and beds of good quality are known at Windom, Erie County.

Portage shale.—This overlies the Hamilton stratigraphically, and hence outcrops to the south of the Hamilton belt. It consists of shales and sandstones, the former being well exposed along Cashaqua Creek, also along Seneca Lake and at Penn Yan, but becomes very gritty east of this point. The shale has been worked at Angola for fireproofing, at Jewettville for pressed brick, and at Hornellsville for paving-bricks.

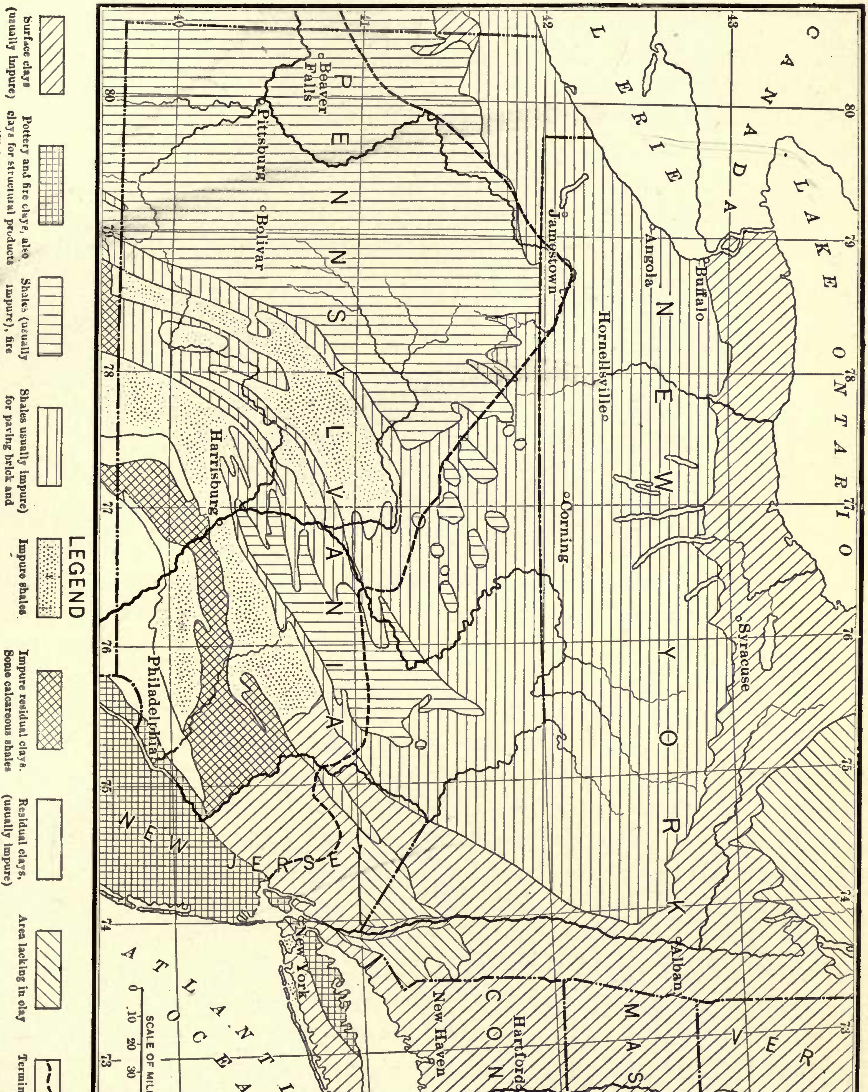

Fig. 58.—Map of northeastern States, showing distribution of clay-bearing formations. (After Ries, U. S. Geol. Surv., Prof. Pap. 11, p. 64, 1903.)

Chemung shale.—This somewhat extensive shale formation, the most southern in New York State, has been utilized at several points for making clay-products. At Corning (Pl. XXXIII, Fig. 1) it is quarried for paving-brick, at Alfred Center for roofing-tile, and at Elmira for common brick.

Cretaceous and Tertiary Clays

These include the Cretaceous clays of the Coastal Plain region of Long Island, Staten Island, and Fisher's Island, as well as some others of possible Tertiary age, but the deposits are of exceedingly variable character, ranging from ferruginous ones to others of good refractoriness. They, moreover, partake of the character of other Coastal Plain clays in being often of highly siliceous character as well as pockety or lens shaped in form. The more important points at which these clays are exposed are at Kreischerville, Staten Island; Little Neck near Northport, West Neck, Oyster Bay, Wyandance, and Farmingdale, Long Island. All of these, except the first two, are adapted only to the manufacture of common brick. The deposits at Glencove and Northport have been worked for a number of years, those of the latter locality having been used for fire-brick, stove-linings, and stoneware.

Pleistocene Clays

These can be divided into four groups, namely, (1) morainal clays; (2) lacustrine clays; (3) pond deposits; (4) estuarine deposits.

The morainal clays are usually too stony to be of any value, although at Newfield, Tompkins County, one lens in the moraine has been worked for fifteen years.

The lacustrine clays were laid down during post-Glacial time, when the waters of Lakes Erie and Ontario were dammed up to the north by the retreating continental glacier, and spread over the land in the western and northwestern part of the State, much clay being deposited during this time. These clays underlie the flats around Buffalo, Lancaster, Tonawanda, and other places in western New York, and are used for making brick and drain-tile. They often contain lime pebbles.

The pond deposits are widely distributed throughout the State, being found in many of the flat-bottomed valleys. They are prevailingly impure, often contain sandy streaks, and are rarely deep. Most of them burn red and are worked for common brick or tile, but hollow brick are also manufactured.

The estuarine clays are confined to the Hudson River and Champlain Valleys, and were deposited during post-Glacial times. They form an extensive and often thick deposit, which underlies the terraces bordering these valleys (Pl. XXXIII, Fig. 2). The section usually involves an upper sand-bed, a yellow weathered clay, and a blue clay. The clays

PLATE XXXIII

Fig. 1.—Bank of Chemung shale used for brick, Corning, N. Y. (After H. Ries, N. Y. State Mus., Bull. 35, p. 838, 1900.)

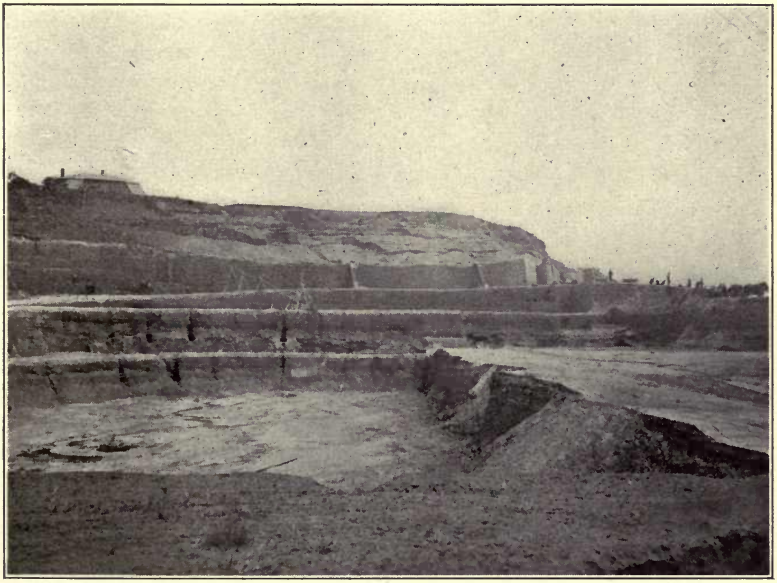

Fig. 2.—Bank of Pleistocene clay overlain by sand, Roseton, N. Y. (After H. Ries, N. Y. State Mus., Bull. 35, p. 698, 1900.)

are laminated materials, plastic, red-burning, and easily fusible. Those in the Hudson Valley especially are extensively dug for the manufacture of common brick, but are probably useless for much else, although certain beds near Albany make an admirable slip-clay which is shipped to all parts of the United States.

In the following tables there are given a number of selected analyses and physical tests of New York clays:

ANALYSES OF NEW YORK CLAYS *

	I.	II.	III.	IV.	V.
Silica (SiO_2)	59.50	52.30	65.15	53.20	68.34
Alumina (Al_2O_3)	20.60	18.35	15.29	23.25	19.89
Ferric oxide (Fe_2O_3)	8.00	6.55	6.16	10.90	0.90
Lime (CaO)	0.80	3.36	3.50	1.0	0.35
Magnesia (MgO)	0.35	4.49	1.57	0.62	trace
Potash (K_2O)	3.60	4.65	5.71	2.69	3.55
Soda (Na_2O)		1.35			0.84
Combined water (H_2O)	5.50	+organic 5.30	....	6.39	6.03
Miscellaneous	....	CO_2 3.04	....	MnO_2 0.52 TiO_2 0.91 SO_3 0.41	

	VI.	VII.	VIII.	XI.	X.
Silica (SiO_2)	47.40	55.00	51.61	57.36	51.30
Alumina (Al_2O_3)	39.01	34.54	19.20	16.20	12.21
Ferric oxide (Fe_2O_3)	0.15		8.19	4.55	3.32
Lime (CaO)	trace	5.33	7.60	5.34	11.63
Magnesia (MgO)	trace	3.43	1.25	3.90	4.73
Potash (K_2O)	trace	0.48	5.32	6.98	4.33
Soda (Na_2O)	trace				
Combined water (H_2O)	14.10	1.22	$+CO_2$ 7.25		
Moisture	....				
Miscellaneous	....	....	....	....	organic 1.50

* From N. Y. State Mus , Bull. 35.

PHYSICAL TESTS OF THE ABOVE

	I.	III.	IV.	VI.
Per cent H_2O to form plastic mass	16	21.4	20	38
Plasticity	lean	fair	moderate	fair
Average tensile strength, lbs. per sq. in	15	92	61	11–14
Air-shrinkage	3	4	4	10
Fire-shrinkage	6	10	9	8.7
Incipient fusion	cone .04	06	06	
Vitrification	1	01	01	35+
Viscosity	4	4	3	35+

LOCALITIES OF THE PRECEDING

No.	Locality.	Geological Age.	Uses.
I.	Lewiston.	Medina.	Not worked
II.	Warners	Salina.	Paving, common, and hollow brick
III.	Angola.	Portage.	Flue-linings
IV.	Alfred Center. .	Chemung.	Roofing-tile
V.	Near Northport	Cretaceous	Stoneware
VI.	Kreischerville. .	"	Fire-brick
VII.	Roseton.	Pleistocene.	Common brick
VIII.	Croton Point. . .	"	" "
IX.	Buffalo.	"	" "
X.	Newfield.	" (drift)	Common and paving brick

References on New York Clays

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2. Jones, C. C., A Geologic and Economic Survey of the Clay-deposits of the Lower Hudson River Valley, Amer. Inst. Min. Eng., Trans., XXIX, p. 40, 1900.

3. Martin, D. S., A Note on the Colored Clays Recently Exposed at Morrisania, N. Y. Acad. Sci., Trans., IX, p. 46.

4. Merrill, F. J. H., Origin of the White and Variegated Clays of the North Shore of Long Island, N. Y. Acad. Sci., Annals, XII, p. 113, 1900.

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6. Prosser, C. S., Distribution of Hamilton and Chemung Series of Central New York, N. Y. State Geologist, 15th Ann. Rept., p. 87, 1899.

7. Ries, H., Clays of New York, their Properties and Uses, N. Y. State Museum, Bull. 35, 1900.

8. Ries, H., Physical Tests of Devonian Shales of New York State, 15th Ann. Rept., N. Y. State Geologist, Vol. I, p. 673, 1897.

9. Ries, H., On the Occurrence of Cretaceous Clays at Northport, Long Island, School of Mines Quart., XV, p. 354, 1894.

NORTH CAROLINA

The clay-deposits found in North Carolina are of two types, namely, residual clays and sedimentary clays, these subdivisions corresponding more or less closely also to geological ones, that is to say, the residual clays are derived from rocks of pre-Cambrian and Palæozoic age, while the sedimentary clays are of Mesozoic age or younger.

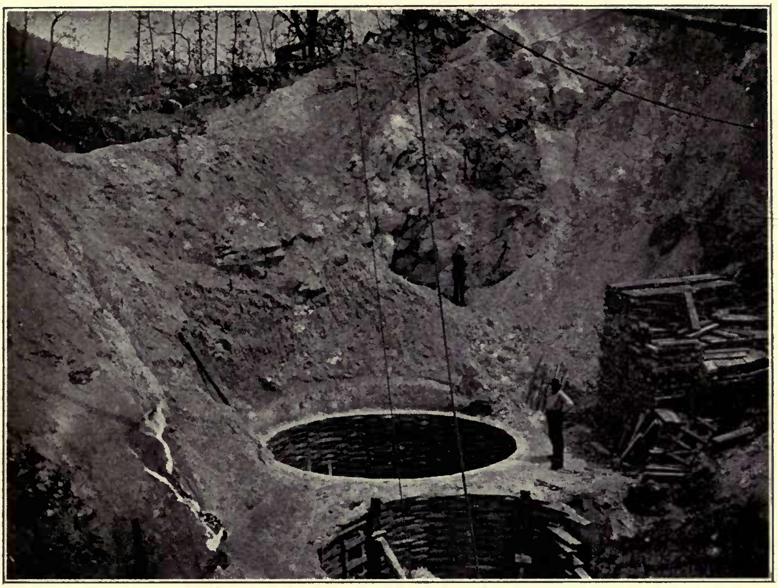

Fig. 1.—Kaolin-mine near Webster, N. C., showing kaolin mining by circular pits. (After Ries, N. C. Geol. Surv., Bull. 13, p. 56, 1897.)

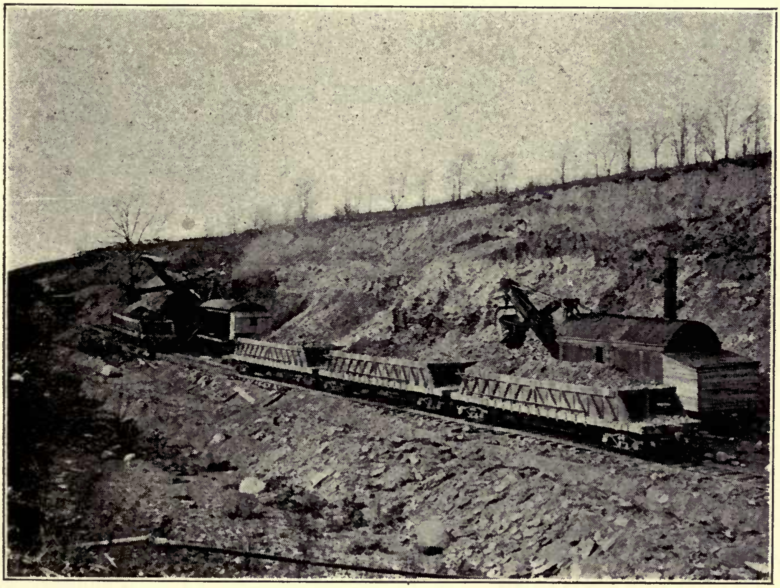

Fig. 2.—Bank of Carboniferous shale near Akron, O. (Photo loaned by Robinson Clay-product Co.)

Residual Clays

These may occur in any portion of the State west of the coastal plain region. The eastern border of this area passes through Halifax, Franklin, Wait, Chatham, Moore, and Anson. The clays are usually impure and gritty, and suited for little else than the manufacture of common brick, although in a few instances, as at Pomona and Grover, they may be of semi-refractory character. A noteworthy exception to the above occurrences are the deposits of kaolin which are found in the western part of the State in the Smoky Mountain region. Here many veins of pegmatite, carrying coarsely crystalline quartz, feldspar, and mica (generally muscovite), with some garnet, have been weathered to kaolin to a depth of from 60 to 100 feet. The veins vary in width from a few inches to several hundred feet and may be many hundred feet long. They also branch or curve and pinch or swell. The most important of these deposits is near Webster, but others have been noted at Sylva, Jackson County; Bostick's Mills, Richmond County; Troy, Montgomery County; West's Mills, Macon County; two miles west of north of Bryson City, Swayne County; two miles south of Hall Station, Jackson County; and two and a half miles southwest of Canton, Haywood County. All of these kaolins need washing before they can be shipped to the market, and have been extensively used for the manufacture of white ware.

Sedimentary Clays

Beds of these are found widely distributed throughout both the coastal plain area and the broader upland valleys of the State. In the former area there are many extensive beds of laminated clay which are often well exposed in the river-banks traversing that region. Most of the clay-deposits found in the Coastal Plain area are rather lenticular in their character and pass horizontally into beds of sand. Among the best deposits of sedimentary clays thus far developed in the State may be mentioned those around Fayetteville, Goldsboro, Weldon, Greensboro, etc. They are nearly all red-burning, and are used for the manufacture of a brick or drain-tile. In many valleys of the uplands the rivers are bordered by terraces underlain by clays of Pleistocene age, such clays being abundant along the Catawba River near Morgantown and Mount Holly, on the Clark River at Lincolnton, along the French Broad River at Asheville, and along the Yadkin River at Wilkesboro. The depth of these terrace-clays commonly ranges from 5 to 10 feet, and they are in most instances covered by from 6 inches to a foot or more of sandy loam. The majority are adapted only to the manufacture of common brick, but here and there we find beds of very plastic material, sufficiently free from grit to be used for the manufacture of common stoneware. The Triassic shales form a narrow belt in Grandville, Durham, Chatham, Moore, Southeast, Montgomery, and Anson counties, but their value for making clay-products is said to have been but little tested. At Pomona a weathered-shale outcrop has been used in the manufacture of sewer-pipe.

Analyses of North Carolina Clays

ULTIMATE ANALYSES

	I.	II.	III.	IV.	V.
Silica (SiO_2)	53.07	45.70	56.81	50.17	64.93
Alumina (Al_2O_3)	29.54	40.61	20.62	28.77	17.08
Ferric oxide (Fe_2O_3)	1.27	1.39	6.13	2.88	5.57
Lime (CaO)	0.15	0.45	0.65	0.05	0.43
Magnesia (MgO)	0.14	0.09	0.58	0.22	0.59
Potash (K_2O)	1.28	2.82	4.47	1.04	3.85
Soda (Na_2O)	0.87				
Combined water, ignition	9.93	8.98	8.60	14.03	6.58
Moisture	1.29	0.35	1.64	2.08	2.48
Miscellaneous	FeO 1.00				

	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	58.17	59.27	70.45	69.58	53.75
Alumina (Al_2O_3)	20.10	22.31	17.34	14.03	24.91
Ferric oxide (Fe_2O_3)	7.43	6.69	3.16	6.41	7.99
Lime (CaO)	0.60	0.25	0.25	0.40	0.70
Magnesia (MgO)	0.77	0.13	0.22	0.27	1.12
Potash (K_2O)	2.60	0.90	0.70	1.65	2.94
Soda (Na_2O)					
Combined water, ignition	7.34	9.00	6.63	5.73	7.60
Moisture	3.23	1.90	0.98	1.68	1.03
Miscellaneous	....	....	FeO 0.33		

RATIONAL ANALYSES

	I.	II.	III.	IV.	V.
Clay substance	61.99	96.81	58.85	73.19	53.13
Free sand	36.55	25.40	40.65	26.05	45.90

	VI.	VII.	VIII.	IX.	X.
Clay substance	48.09	67.20	48.26	45.47	34.04
Free sand	52.15	33.25	51.50	51.28	46.00

Nos. I–X from N. C. Geol. Surv., Bull. 13, 1897.

PHYSICAL TESTS OF NORTH CAROLINA CLAYS

	I.	II.	IV.	V.
Per cent water for working	28	42	30	28
Plasticity	good	lean	very good	good
Air-shrinkage, per cent	8	6	12	8.5
Fire-shrinkage, per cent	5	4	7	5
Average tensile strength, lbs. per sq. in.	39	20	148	144
Rate of slaking	slow	slow	slow	fast
Texture	fine	very fine	fine	medium
Incipient fusion, degrees F.	2100	2300	1950	1900
Vitrification, degrees F.	2300	2500	2100	2050
Viscosity, degrees F.	2500	2700 +	2250	2200
Color when burned	whitish	white	{ gray brown	red
Specific gravity	2.24	2.43	2.35	2.55

	VI.	VII.	VIII.	IX.	X.
Per cent water for working	28.5	28	26	36	25
Plasticity	fair	lean	lean	slight	lean
Air-shrinkage, per cent	9.8	10	10	9.6	5
Fire-shrinkage, per cent	7	6	2	4.5	10
Average tensile strength, lbs. per sq. in.	84	66	47	60	74
Rate of slaking	slow	fast	slow	fast	fast
Texture	fine	coarse	coarse	fine	fine
Incipient fusion, degrees F.	1850	2100	2150	1950	1900
Vitrification, degrees F.	2050	2400	2350	2100	2100
Viscosity, degrees F.	2250	2500	2550	2250	2300
Color when burned	red	red	buff	red	deep red
Specific gravity	2.45	2.46	2.55	2.59	2.63

LOCALITIES OF THE PRECEDING.

No.	Locality.	Geological Age.	Uses.
I.	Grover	Residual	White pressed brick
II.	Webster	“	White ware
III.	Greensboro	“	Brick
IV.	N.W. of Blackburn		Stoneware
V.	Fayetteville (average)		Bricks
VI.	Fayetteville		Not worked
VII.	Greensboro	Pleistocene	Brick
VIII.	Pomona		Brick
IX.	Morgantown	Columbia	Not worked
X.	Wilkesboro	“	“ “

Nos. I–X from N. C. Geol. Surv., Bull. 13, 1897.

References on North Carolina Clays

1. Holmes, J. A., Notes on the Kaolin and Clay-deposits of North Carolina, Amer. Inst. Min. Eng., Trans., XXV, p. 929, 1896.

2. Kerr, W. C., and Genth, F. A., Report on Minerals and Mineral Localities of North Carolina, 1885.

3. Pratt, J. H., The Mining Industry of North Carolina, N. Ca. Geol. Survey; separate bulletins issued for 1901, 1902, 1903, and 1904.

4. Ries, H., Clay-deposits and Clay Industry in North Carolina, N. Ca. Geol. Surv., Bull. 13, 1897.

CHAPTER VII

NORTH DAKOTA TO WYOMING

NORTH DAKOTA

The North Dakota clays (Ref. 2) are found in the Cretaceous, Tertiary and Pleistocene formations (Fig. 58*a*).

Cretaceous

Most of the divisions of this system of rocks carry extensive deposits of clay, whose character is briefly as follows:

The Benton, Niobrara and Pierre clay-bearing formations extend across the east central part of the State in a broad belt several hundred miles wide (Fig. 58*a*).

Benton.—The Benton is best developed in the Pembina Mountains, where it shows about 150 feet of soft shales which are easily mined. Ferruginous concretions and gypsum are not uncommon, in fact the latter is present in such quantity near top of the formation as to render the shale nearly worthless. The Benton shales are plastic, red-burning, and yield a hard body at low temperatures, in fact their use for vitrified brick is regarded as possible.

Niobrara.—This formation overlies the Benton, but is not sharply separated from it. It is usually calcareous, and may carry from 20–75 per cent of lime carbonate.

Pierre.—The Pierre shales are separated from the underlying Niobrara by a peculiar horizon of banded black, white and red shales. The maximum thickness of 300 feet is developed in the Pembina Mountains, but it is exposed at other points. The shales which are quite uniform in character, and of a dark gray or black color, contain many small iron concretions, and are usually low in lime except near the base. They are very plastic, with high air and fire shrinkage, and red-burning. Much trouble is caused in burning by gypsum and pyrite. The lowest beds are the worst, but about 200 feet from the bottom of the formation the clay is lighter colored, has less impurities and is semi-refractory.

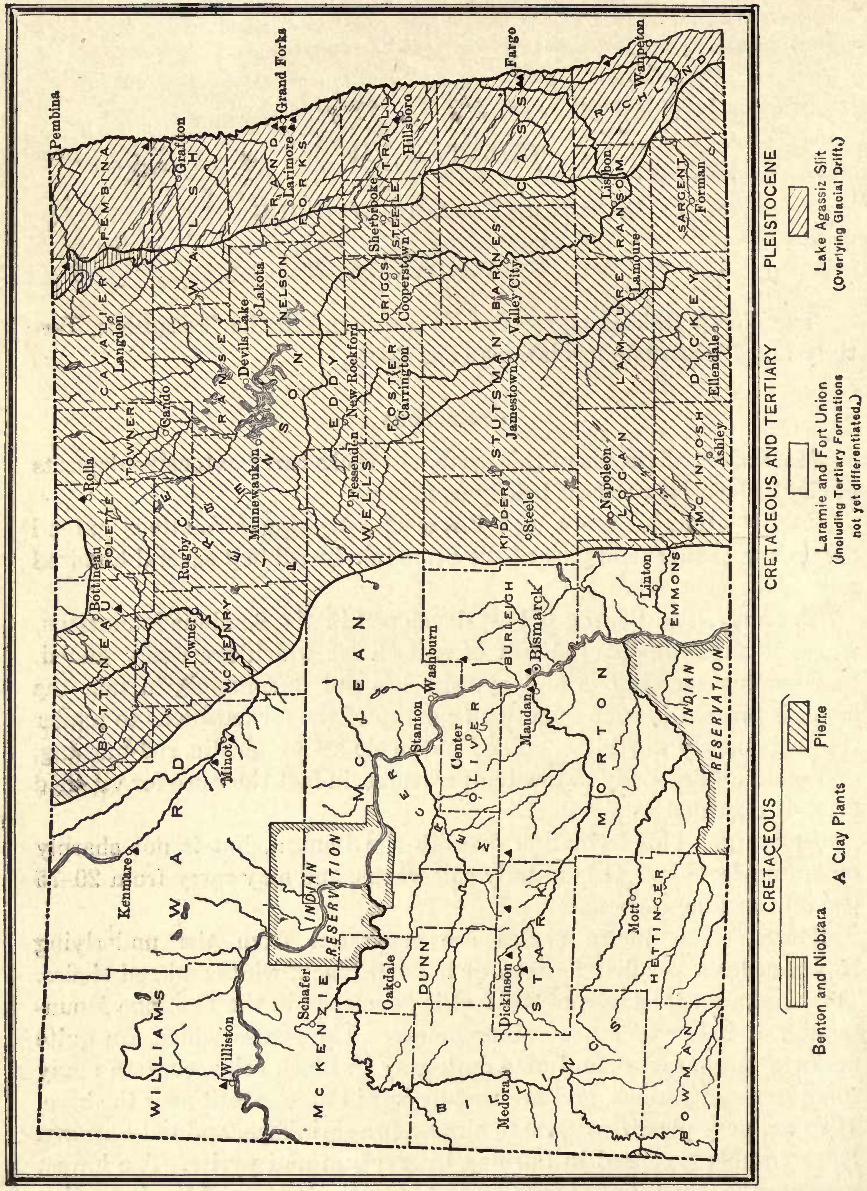

FIG. 58a.—Geologic Map of North Dakota. (After Leonard.)

Laramie and Tertiary

Nearly the entire western half of the State is underlain by strata of Laramie and Tertiary age, the exact boundary between the two being doubtful. Lithologically, the so-called Laramie consists of (1) a basal member of clays and sands, many of them calcareous and lignitic; (2) a series of beds not exceeding 150 feet in thickness, carrying high grade, light-burning and sometimes refractory clays; (3) 300 or 400 feet of sand, cemented in part by calcareous cement. The clays of the first two divisions are of value for little else than common brick. Those of the third are an important clay resource of the State, being regarded by Mr. Clapp as of value for making pressed brick, fire-brick and pottery. They occupy an area approximately 50 miles east-west by 90 miles north-south, the eastern limit being about on the meridian passing through Hebron. These clays lie on both sides of the Northern Pacific railroad and have been developed around Dickinson, Gladstone and Hebron.

Pleistocene

Pleistocene clays of blue or yellow color, and often of gravelly or stony character, are found over a large portion of the State. They are frequently calcareous, and around Grand Forks are worked for cream-colored brick. Red-burning brick clays occur along the Missouri River, near Bismarck, and are much used. Grayson, Walhalla and Fargo are also promising localities.

The following analyses, taken from the Fourth Biennal Report of the North Dakota Geological Survey, have been selected by C. H. Clapp as representative.

References on North Dakota Clays

1. Babcock, E. J., First Biennial Report, N. Dak. Geol. Surv., p. 29, 1901.

2. Babcock, E. J., Clapp., C. H., Leonard, A. G., The Clays of North Dakota, N. Dak. Geol. Surv., Fourth Biennial Report, 1906.

3. Clapp, C. H., The Clays of North Dakota, Econ. Geol., II, p. 551, 1907.

REFERENCES TO TABLE OF ANALYSES OF NORTH DAKOTA CLAYS

I. Dickinson Brick Co., Dickinson.
II. Typical of white sandy Tertiary clay.
III. Black Butte.
IV. Buttes between Gladstone and Dickinson, north of railroad.
V. Hebron Brick Company's clay bank.
VI. Buttes, 1½ miles north of Taylor.
VII. Buttes, 2 miles north of Gladstone.
VIII Breaks of Little Missouri River at Mannings' ranch.
I–VIII, Tertiary clays.
IX. Benton clay. Mayo Brick Co.
X. Pierre clay (representative), Jamestown.
XI. Laramie clay. Mott.
XII. Laramie clay. Coal mine at Richardton.
XIII. Pleistocene clay. Grand Forks.
I–XIII from Vol. 4, N. Dak. Geol. Surv.

Physical Tests of North Dakota Clays

	Number.	I.	II.	III.	IV.
	Per cent water required	25.2	22.6	18.9	22.1
	Per cent air-shrinkage	4.7	2.	3.8	5.
	Tensile strength, lbs. per sq. in	138	90	110	141
	Plasticity	very good	fair	good	very good
Cone 05	Fire-shrinkage, per cent	1	−.3	....	0.
	Color	light pink	pink white	....	orange
	Absorption, per cent	....	19.8	....	....
Cone 03	Fire-shrinkage, per cent	....	....	.3	....
	Color	....	....	white	....
	Absorption, per cent	....	....	....	....
Cone 1	Fire-shrinkage, per cent	6.	.9	.5	1.7
	Color	buff white	cream white	yellow	yellow
	Absorption, per cent	....	....	14.	....
Cone 5	Fire-shrinkage, per cent	6.6	2.	2.8	5.3
	Color	gray white	white	buff	buff
	Absorption, per cent	2.4	14.1	12.4	4.7
Cone 10	Fire-shrinkage, per cent	9	2.5	2.9	5.
	Color	white	white	buff brown	yellow gray
	Absorption, per cent	.5	13.1	9.3	3.4
Fusibility cone	Incipient	3	....	17	7
	Vitrification	12	....	....	16
	Viscosity	25	unaffected 25	....	25+

	Number.	V.	VI.	VII.	VIII.
	Per cent water required	20.6	27.9	26.7	25.9
	Per cent air-shrinkage	3.8	5.2	5.	4.8
	Tensile strength, lbs. per sq. in	122	91	78	90
	Plasticity	good	good	good	good
Cone 05	Fire-shrinkage, per cent	0	1.8	.8	1.7
	Color	cream	cream	pink white	red
	Absorption, per cent	15.9	....	....	13.0
Cone 03	Fire-shrinkage, per cent	.8	2.4	.9	1.5
	Color	buff	cream	pink white	light red
	Absorption, per cent	....	17.2	....	....
Cone 1	Fire-shrinkage, per cent	1.*	2.4*	3.3*	2.5*
	Color	light buff	cream white	cream white	salmon
	Absorption, per cent	....	....	14.1	....
Cone 5	Fire-shrinkage, per cent	2.9	8.2	5.9	4.7
	Color	light buff	cream	cream white	light brown
	Absorption, per cent	10.6	4.7	6.1	6.1
Cone 10	Fire-shrinkage, per cent	5.8	8.3	8.9	5.9
	Color	gray white	gray white	gray	brown black
	Absorption, per cent	1.8	1.1	1.8	3.8
Fus. cone	Incipient	8	4	3	11
	Vitrification	15	15	16	13
	Viscosity	25+	25+	25+	18

* Cone 01.

Physical Tests of North Dakota Clays—*Continued*

	Number.	IX.	X.	XI.	XII.	XIII.
	Per cent water required	46.3	45.6	26.5	29.0	25.1
	Per cent air-shrinkage	5.7	5.3	5.1	4.0	2.7
	Tensile strength, lbs. per sq. in.	108	89	110	133	127
	Plasticity	fair	good	good	good	fair
Cone 010	Fire-shrinkage, per cent	2.3	1.	.9	.9	−.5
	Color	orange red	orange	light red	light red	orange
	Absorption, per cent	....	....	18.8	23.1	31.4
Cone 05	Fire-shrinkage, per cent	4.3	4.	.9	5.4	−1.
	Color	orange red	orange	light red	light red	pink
	Absorption, per cent	21.8	26.2	18.9	10.9	33.1
Cone 03	Fire-shrinkage, per cent	5.5	4.5	6.7	7.3	−.6
	Color	red	orange red	red	red	cream
	Absorption, per cent	18.9	24.2	5.4	11.1	22.5
Cone 01	Fire-shrinkage, per cent	7.3	5.8	....	9.8	2.0
	Color	red brown	red	....	red brown	cream to green
	Absorption, per cent	15.8	21.6	....	1.5	17.9
Cone 5	Fire-shrinkage, per cent	9.3	6.8			
	Color	dark brown	brown			
	Absorption, per cent	8.5	19.8			
Fus. cone	Incipient	5	7	02	06	1
	Vitrification	8	15	1	1	3
	Viscosity	14	220	3	5	4

Analyses of North Dakota Clays.

	I.	II.	III.	IV.	V.	VI.
Silica (SiO_2)	64.84	73.20	60.98	75.27	73.90	65.46
Alumina (Al_2O_3)	24.31	18.56	26.24	17.29	16.49	20.97
Ferric oxide (Fe_2O_3)	1.60	.50	1.34	.83	1.25	1.83
Lime (CaO)	.11	.29	.34	.46	.29	.23
Magnesia (MgO)	.24	.52	.94	.18	.46	1.14
Soda (Na_2O)	.32	.38	1.22	trace	.22	.72
Potash (K_2O)	trace	.36	1.26	.32	1.20	1.38
Loss on ignition	8.58	5.93	7.85	5.75	5.52	6.79
Total	100.00	99.74	100.17	100.10	99.33	98.52

	VII.	VIII.	IX.	XI.	XII.	XIII.
Silica (SiO_2)	65.64	53.32	69.90	57.94	61.67	51.27
Alumina (Al_2O_3)	22.74	23.76	10.66	17.46	17.41	9.33
Ferric oxide (Fe_2O_3)	1.66	9.30	2.32	4.58	3.65	3.52
Lime (CaO)	.29	.25	1.04	4.14	2.32	11.15
Magnesia (MgO)	.61	1.26	2.10	3.84	3.71	2.31
Soda (Na_2O)	1.76	.10	undet.	....	....	2.08
Potash (K_2O)	1.46	2.10	undet.	....	....	.50
Loss on ignition	6.15	8.50	6.09	7.67	6.07	
Total	100.31	98.59	92.11	95.65	94.83	

For references to tables see p. 441.

OHIO

The geologic scale of Ohio includes strata ranging from the Ordovician to the Permian, while overlying these are beds of Quaternary age.

Ordovician and Silurian[1]

The rocks of these two ages underlie a larger area in the western half of the State, those of the former age being found chiefly in the southwestern part. They include several shale formations, among them the Eden, Lorraine, Richmond, Saluda, and Osgood; but most of these are highly calcareous and of little value for the manufacture of clay-products. The Saluda has been used for drain-tile.[2]

Devonian

The Devonian rocks underlie a large area in the northwestern corner of the State, and also extend across the west-central part from Lake Erie to the Ohio River.

The shale formations are the Oletangy and the Ohio. The former is 20 to 35 feet thick in central Ohio with numerous outcrops and shows even greater thickness in the northern part of the State. It is actively worked at Delaware for making drain-tile and fireproofing, but has also been used at Columbus for the manufacture of sewer-pipe and common brick.

The Ohio shale is divisible, in the northern part of the State at least, into three parts, known as the Huron, Chagrin, and Cleveland shales. Professor C. S. Prosser states that the Chagrin shale is gray to greenish, and extends from the Black River as surface outcrops along the shore of Lake Erie in a belt several miles broad to Pennsylvania, and is regarded as promising for the manufacture of clay-products. Many red pressed brick are made from it at Cleveland.

Lower Carboniferous

The Bedford shale, which is an important shale formation extending clear across the State, is in part at least frequently of red color; but its greenish phases resemble the Chagrin shales of similar color. It is worked at Bedford, Akron, Independence, and a number of other localities for pressed-brick manufacture; at Willow Station for paving-brick; and at Summit Station for common and sewer brick. It promises to become one of the most important shale formations of Ohio.

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[1] Profs. E. Orton, Jr., and C. S. Prosser have kindly given the author much information regarding the shale formations of the State.

[2] Ohio Geol. Surv., Vol. VII, Pt. I, p. 56.

The Logan shale, occurring in the lower part of the Logan formation, is now extensively used at a number of points, including Newark, Hanover in central Ohio, and Sciotoville in the Ohio Valley regions, but, according to Professor E. Orton, Jr., is of non-refractory character.

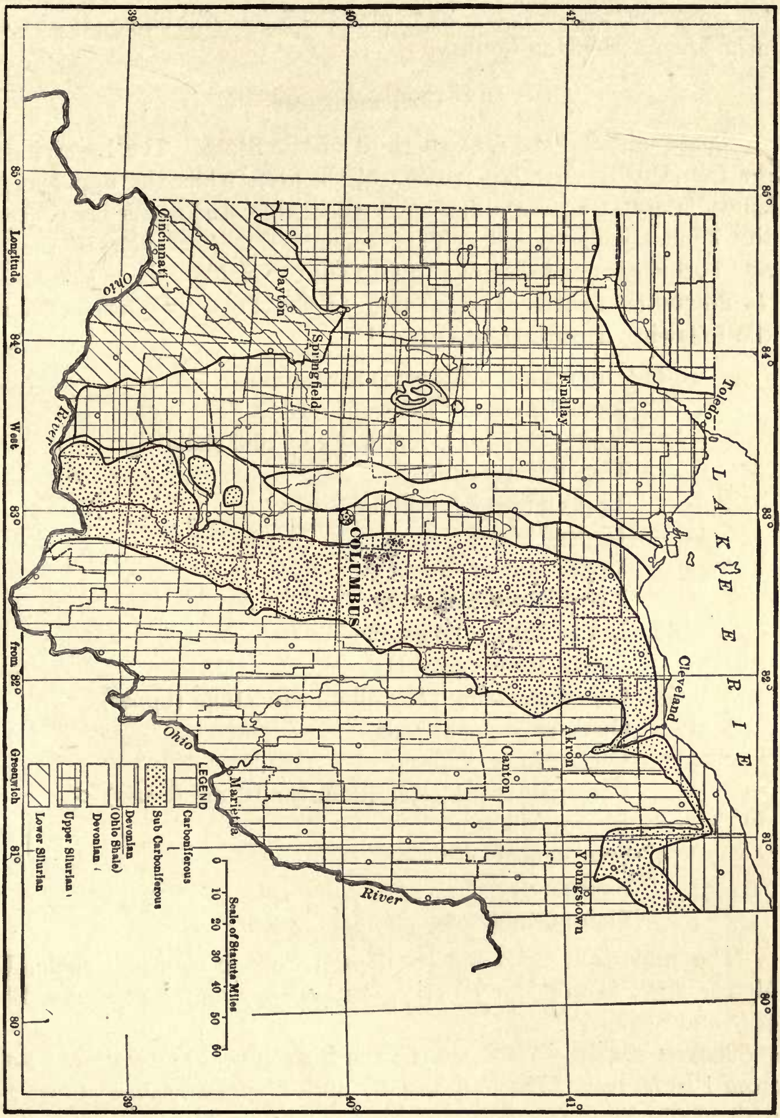

FIG. 59.—Map of Ohio, showing distribution of clay- and shale-bearing formations. (After Orton, Geology of Ohio, VI, 1888.)

Professor E. Orton states (Ref. 2) that the Lower Carboniferous or

Maxville limestone holds a valuable clay-deposit at a few places in southern Ohio, while in many places in Kentucky a hard flint-clay comes into the section. It has been worked largely at Sciotoville and Portsmouth for fire-brick, and is hence known at the Sciotoville clay. It also occurs near Logan, Hocking County.

Coal-measures

These underlie the eastern third of the State. The lower members are found in the western portion of the area, while the upper members immediately underlie the surface in the middle and eastern parts towards the Pennsylvania border. They include the best clays in the State, and both shales and clays are numerous throughout the entire series.

Pottsville series.—The section of the Pottsville formation shows the following according to Orton:[1]

Homewood (Tionesta) sandstone
Mount Savage (Tionesta) coal
Mount Savage (Tionesta) clay and shale
Upper Mercer ore
Upper Mercer limestone
Upper Mercer coal
Upper Mercer fire-clay
Lower Mercer iron ore
Lower Mercer limestone
Lower Mercer fire-clay
Conoquenessing (Massillon) sandstone (upper)
Quakertown coal-beds
Quakertown shales
Conoquenessing (Massillon) sandstone (lower)
Sharon shales
Sharon coal
Sharon clay
Sharon sandstone

The important beds are the Mount Savage clay and shale, Upper Mercer clay, Lower Mercer clay, Quakertown clay and shales, Sharon clay and shales.[2]

Sharon shales.—These overlie the Sharon coal and vary in thickness from 1 to 50 feet. They are usually dark blue, sometimes almost black, with heavy iron-ore nodules at certain levels. The shales proper have become the basis of one of the largest sewer-pipe industries in the United

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[1] The names in parenthesis are those given in Orton's report, Ohio Geol. Surv. VII, while the names in front of them are the later ones.

[2] Orton, Ohio Geol. Surv., VII, Pt. 1, p. 59.

States, at Akron and its immediate neighborhood. The same deposit is also worked for roofing-tile, but the shale is usually high in iron oxide.

Quakertown clay and shale.—These occupy a space between the two divisions of the Conoquenessing sandstones, when such a separation occurs. They overlie and underlie the Quakertown coal, although the latter may become extremely thin at times. The shales or clays of this age have been worked in Summit, Portage, and Stark counties. The Summit deposits have furnished stock for the potteries of Springfield, and the Portage bed supplies the Mogadore potteries. The Massillon Fire-brick Company has developed an important deposit at this horizon. It is a streak of hard fire-clay 4 to 5 feet thick immediately underlying the Conoquenessing, and representing the Quakertown coal. The bottom of the clay is 30 feet above the Sharon coal (Ref. 2).

Lower Mercer clay and shale.—Overlying the Lower Mercer limestone there is often an iron ore, while under it is a coal-seam of little value. Underlying the coal there is a shale or more often clay, which has been extensively worked in Stark, Tuscarawas, Muskingum, and especially Hocking counties. The Columbus Brick and Terra-cotta Company at Union Furnace have used it, and it has also been worked at Millersburg, Holmes County. The clay shows considerable variation and is nowhere of high character. The shale or clay immediately overlying the Lower Mercer limestone is also promising.

Upper Mercer clay and shale.—The Upper Mercer coal is not of economic importance, but the accompanying under-clay is more important. It is a light-colored plastic clay, of wide-spread occurrence in the State, and at Haydenville, Hocking County, is extensively worked under the name of the Mingo clay. It is one of the most valuable clay-deposits found within the Haydenville coal-field, and runs from 8 to 10 feet thick.

Mount Savage clay.—This, formerly named the Tionesta, occurs from a few feet to 20 feet above the last-named deposits, and there is found at times another valuable clay-bed. It has been used at Union Furnace.

Allegheny or Lower Coal-measures

The most important clay-deposits of the Ohio coal-measures are given as follows:

Upper Freeport clay and shales
Lower Freeport clay and shales
Middle Kittanning clay and shales
Lower Kittanning clay

Ferriferous limestone clay
Putnam Hill limestone clay and shales
Putnam Hill limestone horizon

Putnam Hill or Brookville clay.—This underlies the Brookville coal and is a valuable clay-deposit in several of the central coal-measure counties of Ohio, although of no importance in parts of western Pennsylvania. It is said to be specially well developed and largely worked in Muskingum County, but is also of importance in the counties of Coshocton, Tuscarawas, and Stark, where it has been much used. Promising beds are also mentioned in Perry, Hocking, and Vinton counties. It has been worked at or near Zanesville for buff- or cream-colored brick, encaustic tiles, and fire-brick, and at Canton for the manufacture of paving-brick. Other workings are at Greenford, Mahoning County, and New Lexington, Perry County.

A red shale said to be of this same age is also worked at the last locality.

In the Zanesville area the Brookville clay is stated to vary from 3 to 10 feet in thickness with an average of 6 feet. It is usually divisible into an upper or plastic portion and a lower or more siliceous division.

A section six miles above Zanesville on the west side of the river gave:

	Feet.
Putnam Hill limestone	—
Putnam Hill limestone shale	11
White clay	4–5
Dark clay	2
Fire-clay	2
Sandstone and sandy shale	5
Brown clay	14

Ferriferous or Vanport limestone and clays.—The clays of this formation are light-colored, plastic, and of fair quality, with a thickness ranging from 2 to 6 feet. Professor E. Orton, Jr., has informed the author that this yields a valuable stoneware-clay in the district running from Zanesville down to New Lexington on the Cincinnati and Muskingum Valley Railroad. It is also used in southern Ohio around Scranton, either as a potter's clay or for shipment as a second-grade fire-clay.

Lower Kittanning clay and shale.—These were pointed out by Professor Orton to constitute the great clay horizon of the State, and lie stratigraphically between the Ferriferous limestone and Lower Kittanning coal, often filling the interval between them. In the more important occurrences its thickness ranges between 8 and 30 feet, and sometimes is even continuous with the clays above the Lower Kittanning, only the coal-seam being between, and thus giving a combined section of not less than 50 feet. The Lower Kittanning clay is best seen where it enters the State from Pennsylvania, and again where it leaves the State in its extension into Kentucky. At both of these localities in the Ohio Valley, namely, in Columbiana and Jefferson counties on the one side and in Lawrence County on the other, it shows great quantities of clay of good quality. Other counties in which it has been developed are Tuscarawas, Stark, and Muskingum; extensive mining has gone on at Haydenville, Hocking County, and Canton, Stark County. The plastic clay from this horizon is used by the eastern Ohio potteries,

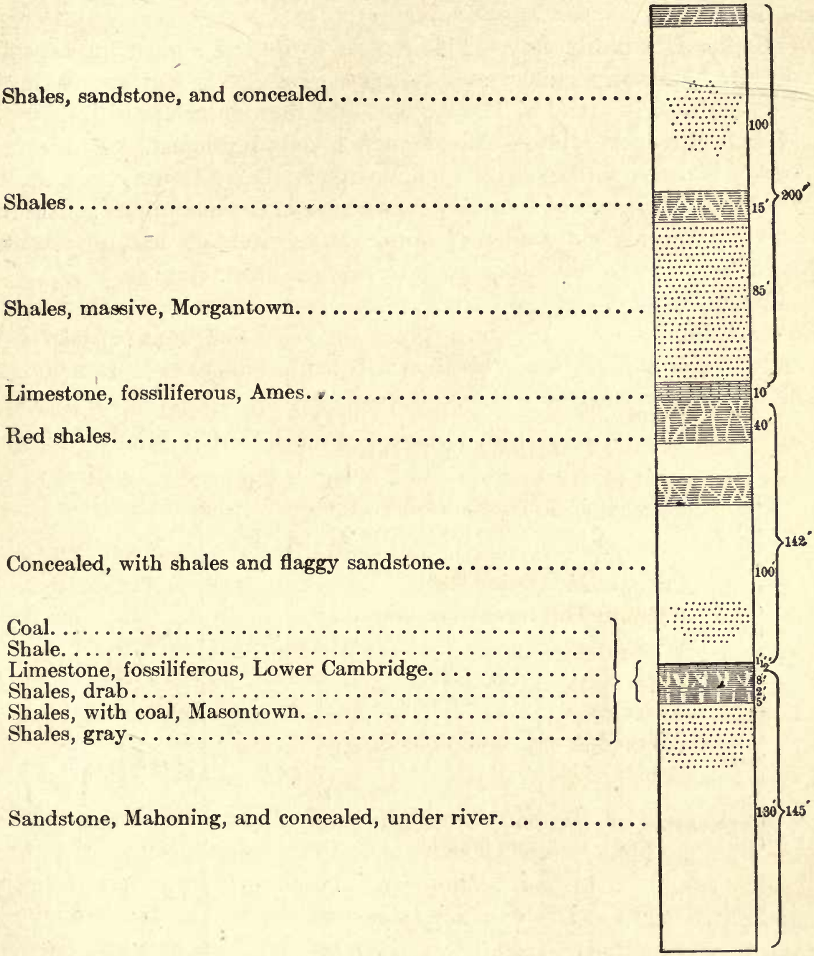

FIG. 60.—Section of Barren Measures opposite Steubenville, Ohio. (After White, U. S. Geol. Surv., Bull. 65, p. 77, 1891.)

while a flint-clay is also found at some points, as in Stark, Tuscarawas, and Carroll counties.

The clay has been used wholly or in part for the manufacture of saggers, Rockingham, yellow and stone ware, sewer-pipe, paving-brick, and fire-brick.

Middle Kittanning clay.—This is said to furnish a good fire-clay at Oak Hill, Jackson County, and is there used for fire-brick. Nodules of iron are seen in many of its outcrops, and these interfere with its use.

Lower Freeport clay.—This is not much developed, but at one locality, namely, in the vicinity of Moxahala, Perry County, the seam is found in the nature of flint-clay, but contains too much iron to permit its use for the highest grades of ware. More often the clay represents the impure type so abundant in the coal-measures.

Upper Freeport clay and shale.—This bed is more important than the preceding, since it occurs in great quantity and more widely distributed than the coal-seam from which it gets its name. It assumes a flinty phase at several points.

Section at Bellaire, Ohio

		Feet.	Inches.	Feet	Inches.
Coal, Waynesburg		—		2	
Shale, sandy		6		40	
Shale		12			
Limestone		3			
Concealed		5			
Coal, blossom, Little Waynesburg					
Concealed		14			
Coal, blossom, Uniontown				1	
Shale		4		127	6
Sandstone		6			
Shale, argillaceous		20			
Concealed		32			
Shale		2			
Sandstone		3			
Shale		3			
Concealed		33			
Calcareous shale, with thin limestones		24	6		
Coal, Sewickley	Coal	4		27	6
	Shales, sandy	13	10		
	Coal	0	8		
	Shales, argillaceous	6			
	Coal	3			
Shale, argillaceous		2		38	
Limestone, thin clay in center		8			
Limestone, magnesia-cement rock		5			
Clay		1			
Limestone		11			
Concealed		11			
Coal, Redstone, blossom				2	
Concealed		17		18	
Shale		1			
Coal, Pittsburgh				7	
Total				263	

Conemaugh or Lower Barren Measures.—These contain vast deposits of shale, which are extensively used for the manufacture of paving-brick. They are distributed through the entire series, but about the middle portion of this division beds of special prominence occur, as in the Sunday Creek Valley. An excellent shale has been found underlying the coal at Bellaire. Fig. 60 by White (Ref. 6) gives the section of the Barren Measures opposite Steubenville, Ohio.

Monongahela or Upper Productive Measures.—This series extends from the base of the Pittsburg coal up to the Cassville. The section on page 397, given by I. C. White (Ref. 6), from Bellaire, Belmont County, shows the character of the series.

The area of outcrop forms a narrow, sinuous band extending in a northeasterly direction from Gallipolis to Steubenville, and southward from there to beyond Bellaire.[1]

Dunkard or Upper Barren Measures.—In Ohio these underlie an area extending through the counties of Belmont, Monroe, Washington, Athens, Meigs, and Gallia.

Pleistocene

Pleistocene clays are found in all parts of the State, but they are used chiefly for common brick and drain-tile.

ANALYSES OF OHIO CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.
Silica (SiO_2)	76.24	63.09	52.52	61.86	69.37	69.79	56.44
Alumina (Al_2O_3)	16.87	20.17	31.84	26.02	19.08	19.31	26.60
Ferric oxide (Fe_2O_3)	0.16	2.12	0.67	0.63	1.26	......	2.00
Lime (CaO)	0.50	......	0.50	1.26	0.60	......	0.47
Magnesia (MgO)	trace	......	0.19	0.19	0.63	......	0.63
Potash (K_2O)	1.09	2.76	0.59	0.31	2.14	......	3.20
Soda (Na_2O)			....		0.02	......	0.26
Water (H_2O)	5.14	5.41	11.68	9.73	5.57	5.09	7.57
Moisture		6.45	0.69	......	0.94	1.02	2.48
Titanium oxide (TiO_2)	......	......	1.68	......	0.29		

	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.
Silica (SiO_2)	68.13	66.21	57.15	57.10	49.30	58.20	57.28
Alumina (Al_2O_3)	20.80	21.13	20.26	21.29	24.00	22.47	21.13
Ferric oxide (Fe_2O_3)	1.20	1.28	7.54	7.31	8.40	5.63	8.52
Lime (CaO)	0.42	0.51	0.90	0.29	0.56	0.62	5.79
Magnesia (MgO)	0.37	0.18	1.62	1.53	1.60	0.98	2.13
Potash (K_2O)	2.28	1.42	3.05	3.44	3.91	3.08	
Soda (Na_2O)	0.27	0.38	0.58	0.61	0.19	0.42	
Water (H_2O)	5.72	6.29	5.50	6.00	9.40	6.15	5.22
Moisture	1.00	1.65	2.70	1.30	1.20	1.65	
Titanium oxide (TiO_2)							

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[1] See U. S. Geol. Surv., Bull. No. 65, Map Pl. I.

ANALYSES OF OHIO CLAYS—*Continued*

	XV.	XVI.	XVII.	XVIII.	XIX.	XX.
Silica (SiO_2)	52.19	53.38	44.60	59.92	57.80	51.72
Alumina (Al_2O_3)	14.61	19.36	40.05	27.56	25.54	30.10
Ferric oxide (Fe_2O_3)	10.00	14.86	0.80	1.03	2.51	1.94
Lime (CaO)	......	1.48	0.27	trace	0.25	0.62
Magnesia (MgO)	......	1.06	trace	trace	0.61	0.53
Potash (K_2O)	......	......	trace	0.67	2.51	2.74
Soda (Na_2O)	......	......	trace	......	0.18	
Water (H_2O)	5.62	......	14.23	9.70	8.35	9.95
Moisture	12.62	......	......	1.12	2.25	1.05
Titanium oxide (TiO_2)	......	......	......	......	......	1.35

LOCALITIES OF THE ABOVE

No.	Locality.	Geological Age.	Uses.
I.	Haydenville	Lower Carboniferous	Fire-brick
II.	North Industry	Lower Coal-measures	Paving-brick
III.	Mineral Point	Lower Kittanning	Refractory wares
IV.	Darlington	“ “	Paving-brick
V.	Roseville		Stoneware
VI.	Roseville		Cooking ware
VII.	Steubenville		Stoneware
VIII.	Akron	Lower Carboniferous	Stoneware
IX.	Zanesville	Lower Coal-measures	Cooking ware
X.	Gloucester	Cambridge	
XI.	Canton	Lower Coal-measures	Paving-brick
XII.	Waynesburg	Middle Kittanning	Brick
XIII.	Zanesville	Freeport shale Kittanning clay	
XIV.	Northern Ohio	Bedford shale	Paving-brick
XV.	North Industry	Lower Carboniferous	Paving-brick
XVI.	Canton	“ “	
XVII.	Scioto County	“ “	Fire-brick
XVIII.	Salineville		Fire-brick
XIX.	East Palestine	Upper Freeport	Paving-brick
XX.	Jefferson County		Sewer-pipe

Nos. I–XX from Ohio Geol. Surv., VII, 1893.

References on Ohio Clays

1. Leverett, F., On the Significance of the White Clays of the Ohio Region, Amer. Geol., X, p. 18, 1893.

2. Orton, E., The Clays of Ohio, their Origin, Composition, and Varieties, Ohio Geol. Surv., VII, p. 45, 1893.

3. Orton, E., Jr., The Clay-working Industries of Ohio, Ohio Geol. Surv., VII, p. 69, 1893.

4. Prosser, C. S., Geological Scale of Ohio, Ohio Geol. Surv., Bull. 7, 1905.

5. Stevenson, J. J., Carboniferous of the Appalachian Basin, Geol. Soc. Amer., Bull., XV, p. 37, 1904.

6. White, I. C., Correlation Papers, Carboniferous, U. S. Geol. Surv., Bull. 65, 1891.

7. See also annual reports of inspector of mines.

OKLAHOMA TERRITORY[1]

The rocks of the greater part of Oklahoma consist of deposits of red clay-shale. In the eastern part of the Territory these clays are of Pennsylvanian age, while farther west they belong to Permian formations. In the Osage Nation, and the counties bordering on the Arkansas River, there are beds of gray and drab clay contained between ledges of flinty limestone of Pennsylvanian and Permian age, while in the Wichita Mountains in the southwestern part of the Territory there are beds of kaolin, formed from the disintegration of granite and gabbro rocks. On the uplands in Beaver and Woodward counties there are deposits of Tertiary clay, but much of this contains a considerable amount of lime, and might not therefore be suited to the manufacture of clay-products. Dakota (Cretaceous) clays occur in the extreme northwestern part of Beaver County, and alluvial clays are found in the river valleys in all parts of the Territory.

The only use that has been made of the clay-deposits in Oklahoma is for the manufacture of brick. In nearly every small town common brick are made, chiefly of alluvial clay. Pressed-brick plants are in operation at Oklahoma, Chandler, Guthrie, Geary, Mangum, El Reno, and Anadarko. On account of the utilization of natural gas for fuel at the Kansas brick-yards, and consequent cheaper cost of production, much of the brick used in Oklahoma comes from that State.

An analysis of clay from Stucks Canyon, four miles west of Ferguson, Blaine County, yielded:

Silica (SiO_2)	64.17
Alumina (Al_2O_3)	14.80
Ferric oxide (Fe_2O_3)	8.10
Lime (CaO)	1.34
Magnesium carbonate ($MgCO_3$)	.27
Magnesium sulphate ($MgSO_4$)	5.57
Water (H_2O)	6.54
Total	100.79

This shows a curiously high percentage of magnesium sulphate.

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[1] The notes relating to this Territory have been supplied to the author by Professor C. N. Gould. The general geology of the Territory is described in U. S. Geol. Surv., Water-supply and Irrigation Bull. No. 148, by C. N. Gould.

PENNSYLVANIA

The geologic formations of Pennsylvania range from the pre-Cambrian crystalline rocks to those of Pleistocene age.

In the western part of the State, except the northwestern counties, the rocks are nearly all of Carboniferous age, the beds being bent into a series of gentle folds; but often the exposure of the lower or older beds is due partly to the overlying strata having been worn away.

To the eastward the rocks become highly folded in the central counties of the State, so that the strata often have a very steep dip, and not only the Carboniferous, but also the lower-lying Devonian and Silurian formations are exposed, giving rise to bands which extend in a general northeast-southwest direction.

On the eastern edge of the State there is a fringe of coastal-plain formations, but, with the exception of the Columbia loams, they have little value in Pennsylvania. North of the terminal moraine the drift-clays are wide-spread.

Residual Clays

These might occur at almost any point in the area lying south of the terminal moraine, but the deposits of greatest economic value are those found in the Great Valley, along the line of which, as well as in the South Mountain region, Fig. 60*a*, there are a number of deposits of white and variegated clays (Pl. XXXV, Fig. 1). These have been derived from the decomposition of hydromica slates, which are interstratified with Ordovician limestones and quartzites, talcose slates, and limestones of Cambrian age. Of recent years these white clays have been much worked for paper manufacture, and to a less extent for tile and fire-brick.

Productive localities have been South Mountain, Cumberland County; Mertztown, Berks County; Ore Hill, near Roaring Springs, in Blair County, etc. Around Mt. Holly Springs are exceptionally thick deposits (Ref. 18).

A number of localities are mentioned in the reports of the Second Pennsylvania Geological Survey,[1] but many of these are no longer worked. More recently they have been described by T. C. Hopkins.[2]

A second type of white residual clay or kaolins are those of Delaware and Chester counties, which have been formed by the weathering of

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[1] Second Pa. Geol. Surv., Rept. C4, pp. 137, 272, 275, 277, 279, 325, 340, and Rept. CC, p. 203.

[2] Rept. Penn. State College for 1898, 1899, and 1900.

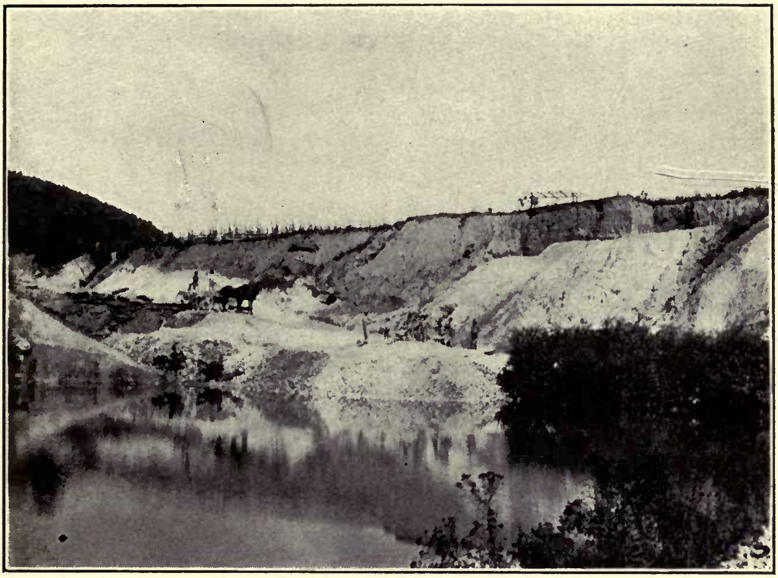
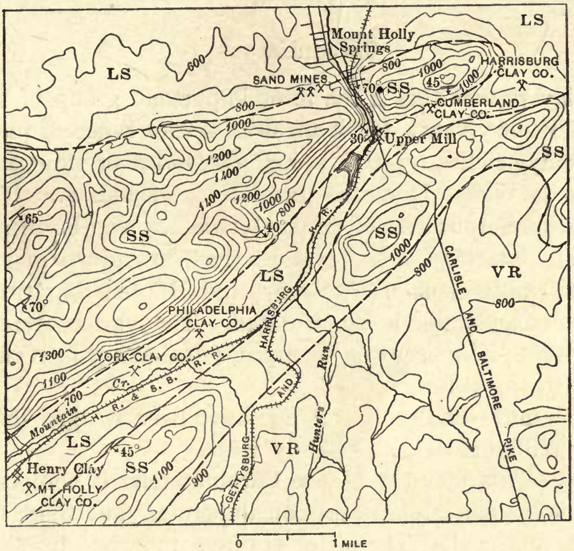


FIG. 1.—Kaolin-deposit at Upper Mill, Mt. Holly Springs, Pa. (After Hopkins.)

FIG. 2.—White sedimentary clay, Aiken area, S. C. (After Sloane, S. C. Geol. Surv., Bull. 1, 1904.)

pegmatite veins. These have been worked near Kaolin P. O., Brandywine Summit, etc., but the output is less than formerly, because the deposits, being the product of weathering, have in some cases been exhausted with depth.



VR, pre-Cambrian volcanic rocks; SS. Cambrian sandstone and shale, LS, Cambrian limestone

FIG. 60*a*.—Map of South Mountain region, Pa., showing distribution of clays. (After Stose, U. S. Geol. Surv., Bull. 315, 1907.)

These kaolins are washed for the market, and in some instances the siliceous material left behind is used for silica brick.

Silurian and Devonian Shales

The vast beds of shale occurring in these formations in the eastern and south-central portions of Pennsylvania should afford an excellent field for exploitation by the clay-worker.

The Devonian is found overlying large areas in northwestern Pennsylvania and may be of value, but in the northeastern counties the beds are often too siliceous.

To the south and southeast the Silurian and Devonian formations appear as a series of bands in Lackawanna, Luzerne, Carbon, Cumberland, Snyder, Juniata, Perry, and other counties, and the shale-beds found in them are worked at several localities for the manufacture of both building- and paving-brick. The Clinton shales have been dug for brickmaking in Laurelton and Hartleton townships of Union County; and the Hudson River shale at Reading.

Carboniferous

To the clay-worker this is the most important group of formations occurring in Pennsylvania, for it includes a wide range of plastic materials, from sandy shales up to the highest grades of fire-clay. Unfortunately, no detailed systematic study of the shales and fire-clays of the entire Carboniferous area of Pennsylvania has ever been undertaken, although many scattered references to them are given in the reports of the Pennsylvania Geological Survey, and Hopkins has treated those of Western Pennsylvania in some detail. The various references are found on p. 469. The occurrences are here taken up in regular order, beginning with the oldest.

Mauch Chunk.—Shales of this age have been worked for bricks at Pine Grove, Williamsport, and Sandy Run.

Pottsville.—This member of the Carboniferous is composed chiefly of sandy beds, as sandstones and conglomerates, but there are several beds of shale and coal. The latter is often underlain by shale and in some instances fire-clay.

Mercer or Alton fire-clay.—The Upper Mercer coal is said to be underlain by a fire-clay in Elk, Butler, Huntington, McKean, and Cameron counties, while in Beaver, Lawrence, and Mercer counties shale-beds have been noticed, but no fire-clays. Plastic clay is also recorded from Mayport, Clarion County (Ref. 13); flint-clay from Climax and St. Charles, Armstrong County (Ref. 3), and correlatable with the Mount Savage clay; and in Clearfield County (Ref. 2).

Sharon upper coal fire-clay.—In Elk County a bed of fire-clay is said to be often associated with the upper Marshburg coal-bed, and has been worked in Benezette township. Another is also found in Mercer County.

Savage Mountain fire-clay.—This clay is of importance in Somerset County, and while not of the highest grade is said to have given excellent satisfaction for coke-oven brick.

Allegheny or Lower Productive Measures.—These contain a number of important beds of fire-clay and coal in western and western-central Pennsylvania. The formation rests on the Pottsville sandstone, and extends to the top of the upper Freeport coal.

Along the upper Ohio River, where the section is specially important, the following beds are seen:[1]

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[1] U. S. Geol. Surv., Bull. 225, p. 467, 1904.

Section along the Upper Ohio River in Pennsylvania

1.	Upper Freeport coal; "Four-foot" or "Hookstown vein"	0 to 4	180
2.	Fire-clay	2 to 4	
3.	Limestone	1 to 4	
4.	Shale and	50 to 70	
5.	Sandstone		
6.	Lower Freeport coal (usually absent)	0 to 2	
7.	Fire-clay	0 to 5	
8.	Limestone (sometimes present)	.....	
9.	Sandstone, or sandstone and shale	70 to 90	
10.	Darlington; "Block vein" at Smith's Ferry	1 to 2	
11.	Fire-clay	4	
12.	Black slate with iron nodules	20 to 30	
13.	Lower Kittanning coal; "Sulphur vein"	2 to 3	
14.	Fire-clay	6 to 10	
15.	Sandstone	40	
16.	Shale		
17.	Limestone, ferriferous, "Vanport limestone"	1 to 20	
	Black shale	15	100
18.	Fire-clay Sandy shale Fire-clay	20	
19.	Clarion coal	1 ±	
20.	Fire-clay	4 to 6	
21.	Sandstone	23	
22.	Shale	25	
23.	Brookville coal	6	
24.	Fire-clay	4	

Brookville clay.—The Brookville coal is underlain by a persistent and widely distributed clay. In the upper Ohio and Beaver River region it is irregular and often impure,[1] but in other regions is more promising. It is said to have been used for fire-brick manufacture at Sandy Ridge, Blueball, Woodland, and Hope Station, Clearfield County; Benezette, Elk County; Parkville, Jefferson County; Queens Run and Farrandsville, Clinton County. It has also been mined for many years at Blacklick, Indiana County, but has to be handpicked to remove the ferruginous concretions.

In Fayette County it is a flint-clay, and has been extensively used for fire-brick manufacture.[2] At Brookville, Jefferson County, the coal is underlain by 15 feet of fire-clay, but only the upper part appears to be of high purity.[3]

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[1] R. R. Hice, Trans. Amer. Ceram. Soc., Vol. VII, Pt. II, p. 251.

[2] Geologic Atlas, U. S., Folio 82, U. S. Geol. Surv., p. 20.

[3] For other references to this clay, see reports of Pa. Geol. Surv., as follows: HH, p. 146; H, pp. 120, 124, 134, 225; Q3, pp. 27, 81, 111, 134, etc.

Clarion clay.—This clay underlies the Clarion coal, and is said to be of good quality at most localities. It has been used at Bolivar for fire-brick.[1] and has also been mined on Brady's Run, Beaver County, but does not appear to have been much developed in that locality, even though purer than the Lower Kittanning clay. This is thought to be due to the fact that it is less accessible than the Kittanning clays, and because it takes a longer time to weather, and is therefore more difficult to wash for pottery purposes.[2]

Other important deposits have been reported from near Kittanning,[3] where they have been worked for buff brick. The clay is also present at Johnstown, and Ben's Run, Cambria County, and Pinkerton Point, Somerset County.

A shale under the Clarion coal is worked for brick in Clarion County west of New Bethlehem (Ref. 13), and a plastic fire-clay at Templeton and Mahoning in the Rural Valley quadrangle (Ref. 3).

Ferriferous coal under-clay.—According to the Pennsylvania Survey reports[4] a deposit of fire-clay occurs between the Ferriferous coal-bed and the Buhrstone iron ore in Armstrong County. It is probably purely local and of doubtful value.

Lower Kittanning fire-clay.—Underlying the Lower Kittanning coal there is, in many localities, an important bed of fire-clay which is often more vaulable than the coal, and has been extensively used for the manufacture of clay-products. At times there is an interval of as much as 30 or 50 feet between this clay and the ferriferous limestones, but at others the former rests immediately on top of the latter.

White[5] states that "eastward from the Allegheny River this clay does not appear to be very important, but westward from that point it is generally present, and attains its maximum development along the Beaver, and westward from there down the Ohio. It is much used by the pottery and tile works at New Brighton, East Liverpool, etc."

Hice[6] states that in the Upper Ohio and Beaver River region it is persistent, quite constant in quality, and has a good roof, and, on account of the extent to which it has been worked in this area, is sometimes called the "New Brighton Clay."

The Lower Kittanning clay appears to vary from 5 to 15 feet in

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[1] Second Penn. Geol. Rept. K3, p. 43.

[2] R. R. Hice, Trans. Amer. Ceram. Soc., Vol. VII, Pt. II, p. 253.

[3] Pa. Geol. Surv., Rept. H5, p. 245.

[4] H5, pp. 239, 249.

[5] U. S. Geol. Surv., Bull. 65, p. 172, 1891.

[6] l. c.

thickness, and often consists of two portions, an upper soft clay and a lower hard clay. White states that the latter is used for fire-brick,[1] but Woolsey claims that this is the more siliceous portion.[2] This clay-bed has been extensively used in Beaver County to supply the factories of pottery, hollow ware, fire-brick, and paving-brick. It is not to be understood, of course, that the same grade is used for all purposes, but that different parts of the deposits are used, either alone or mixed with other clays.

The sections given in Fig. 61 represent the position of the Lower Kittanning clay at several localities. The Second Pennsylvania Geological Survey reports refer to it in the counties of Armstrong,[3] Beaver,[4] Fayette, and Westmoreland.[5]

Stoneware clay at this horizon is reported from Girty,[6] a flint-clay from the Little Mahoning Creek drainage basin of Central Pennsylvania (Fig. 60*b*) (Ref. 2); plastic clay from Clarion County (Ref. 13); and a persistent bed of flint-clay of variable quality from the northern half of the Kittanning and Rural Valley quadrangles (Ref. 3).

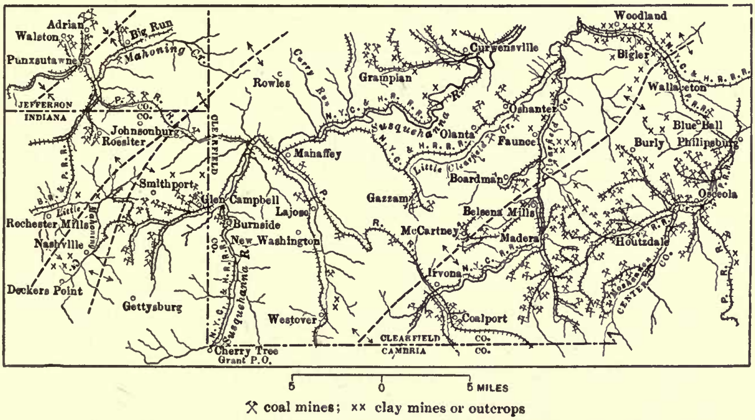

FIG. 60*b*.—Map of South Clearfield and parts of Indiana and Jefferson counties, Pa. (After Ashley, U. S. Geol. Surv., Bull. 285, 1906.)

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[1] l. c., p. 172.

[2] l. c., p. 470.

[3] H5. See also Hopkins, Clays of Western Pennsylvania, Ann. Rept. Pa. State College, 1897, p. 33.

[4] Q, pp. 58, 59, 190, 193, 195, 205, and 215.

[5] K3, p. 40.

[6] U. S. Geol. Atlas, Folio, Elders Ridge, No. 123.

Middle Kittanning clay.—This bed, known also as the Darlington, is sometimes found under the coal of the same name, and has been noted by the geologists of the Second Pennsylvania Geological Survey in Allegheny, Armstrong, Tioga, Blair, and Beaver counties, but was incorrectly referred by them to the Upper Kittanning. It does not appear to be an important bed. According to Hice[1] it is worked on Brady's Run in Beaver County, and is there partly a flint-clay. The clay is not uniform in thickness, and of more variable quality than the Lower Kittanning.

Woolsey[2] states that in the Ohio Valley the bed is a very persistent one, but rarely worked on account of the iron nodules which it contains.

Ashley (Ref. 2) reports a flint-clay from this horizon at a number of widely separated points in Central Pennsylvania, especially about Westover and near McCartney in Clearfield County. It is worked for stoneware at Hawthorne, Clarion County (Ref. 13).

Upper Kittanning clay.—There seems to be a difference of opinion regarding the occurrence of a clay-deposit at this horizon. While it may be present, it is in general of no great value.

Lower Freeport clay.—Above the Kittanning series come the Freeport series, consisting of two coals and underlying fire-clays, and two limestones which underlie the clays.

The Lower Freeport clay does not appear to have assumed much importance, and little mention has been made of it in print. In the Upper Ohio and Beaver River region it is generally quite thin, but in places reaches a workable thickness, and at one point on Brady's Run 22 feet have been mined. It has been used for low-grade fire-brick, but usually carries too many impurities to allow its use for refractory purposes. It is generally thoroughly vitrified at cones 6 and 7.[3] "On Block House Run, Beaver County, it has been worked for sewer-pipe."[4]

Upper Freeport limestone clay or Bolivar fire-clay.—This limestone is quite generally distributed in western Pennsylvania, but when absent or but slightly represented there is found at its horizon a bed of high-grade fire-clay known as the Bolivar clay, and long mined at the locality of the same name in Westmoreland County. It represents a non-plastic or flint-clay, which has been extensively used in fire-brick manufacture. On the Ohio and Beaver rivers this seems to be replaced by a less refrac-

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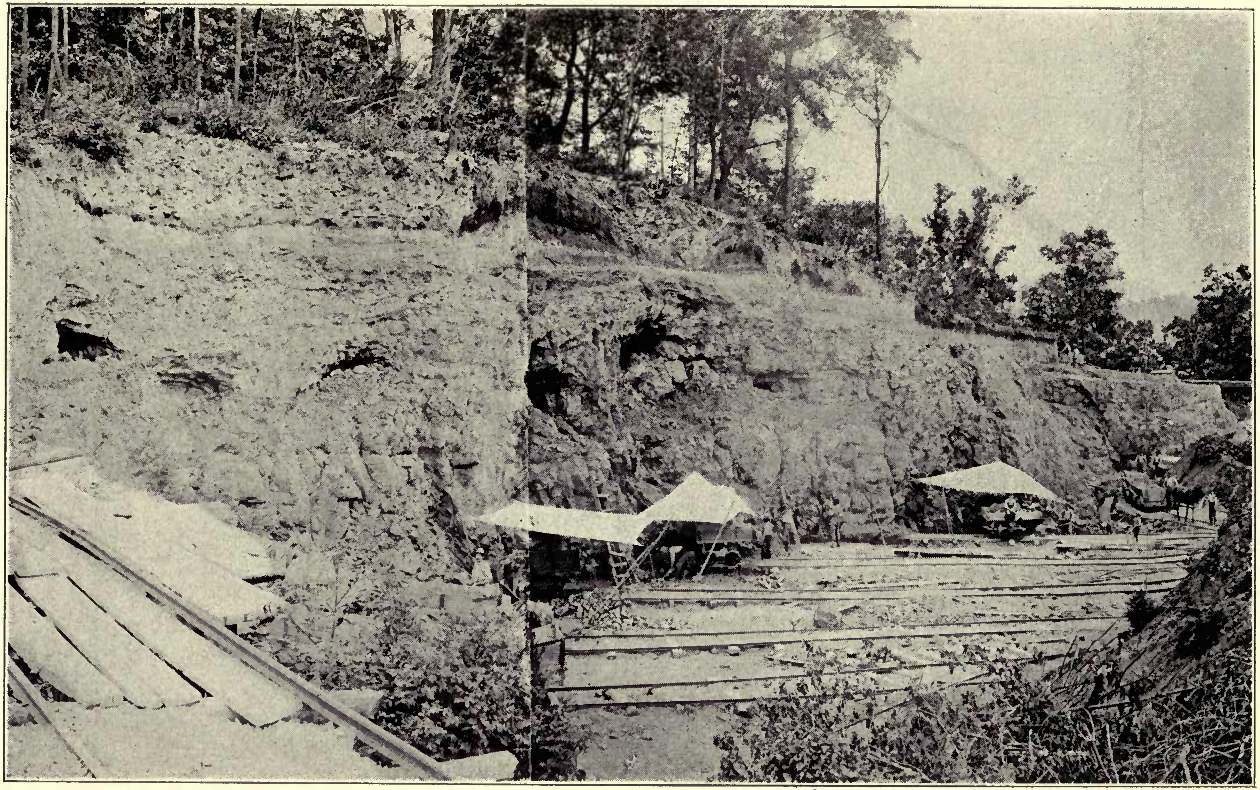
[1] l. c.

[2] l. c., p. 472.

[3] Hice, l. c.

[4] Woolsey, l. c., p. 472.

PLATE XXXVI



Bolivar flint-clay, Bolivar, Pa. This clay is about 22 feet thick and overlain by impure clay, coal, and sandstone. (After Hopkins.)

tory shale. At some points the Bolivar clay and upper Freeport clay above, and for which it has sometimes been mistaken, may lie close together, as at Salina, Westmoreland County. It is also known in Fayette, Indiana, and other counties of western Pennsylvania.

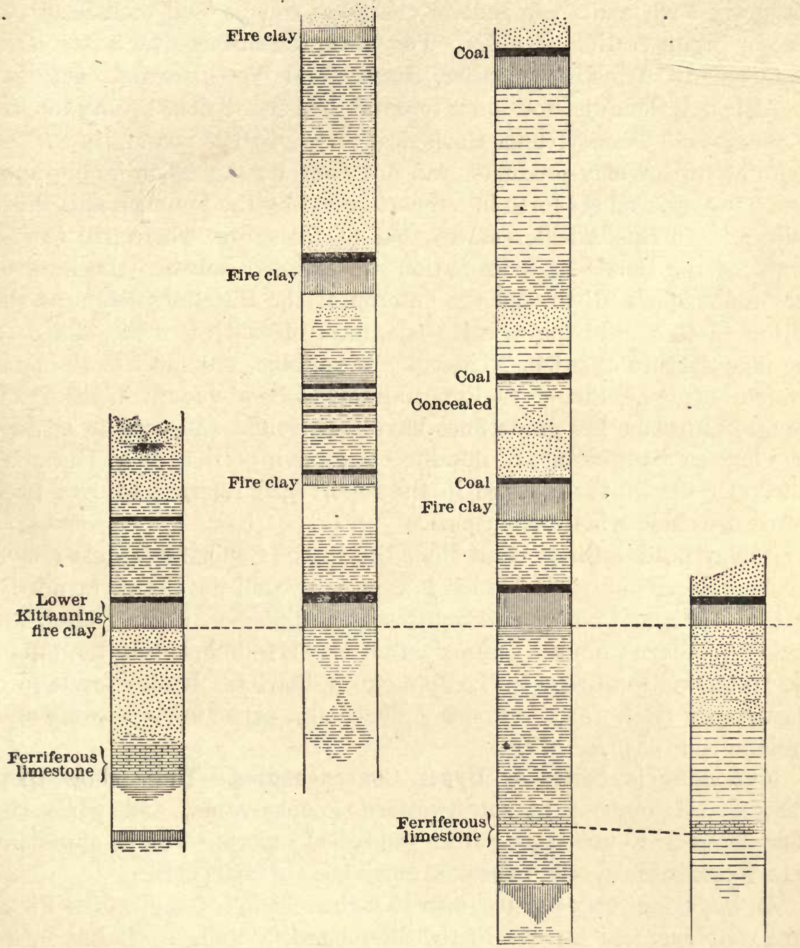


FIG. 61.—Vertical sections near New Brighton, Pa. (After Hopkins.)

Upper Freeport clay.—This underlies the Upper Freeport coal, but is often more persistent than its coal-bed. In the Ohio Valley region it is found at several points,[1] and has been used for fire-brick, being sometimes mixed with the Lower Kittanning clay. It has also been worked around Bolivar and Salina.

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[1] Woolsey, l. c., p. 472.

Conemaugh Series or Lower Barren Measures.—These consist largely of shales and sandstones with some limestones, the shales predominating in the upper beds of the section and the sandstones in the lower. They extend from the Upper Freeport coal to the base of the Pittsburg coal, and their general character can be well seen from the accompanying section (Fig. 62). They form the surface over a large area in Allegheny, Armstrong, Butler, Beaver, and Westmoreland counties.[1]

Although their distribution is referred to in the various county reports of the Second Pennsylvania Geological Survey, their possibility for the manufacture of clay-products was not considered. Their importance was, however, well set forth in a report issued by the Pennsylvania State College.[2] In this Affelder states that at Pittsburg, where 320 feet of strata of the Conemaugh formation are exposed between the level of the Monongahela River and the outcrop of the Pittsburg coal near the hilltop, almost all of the rock is shale, most of which is well adapted to the manufacture of brick. The color is variable, but most of the beds are red-burning. Fire-clays do not appear to be abundant in the Conemaugh, but some low-grade ones have been found and used to advantage for the manufacture of building- and paving-brick, as at Harmonville. Of the 57 yards listed in the report just referred to over two-thirds use shale wholly or in part.

Ashley notes an important shale bed in the Conemaugh, just above the Mahoning sandstone, which is especially well developed in northeastern Indiana County and southeastern Jefferson County (Ref. 2). In southwestern Cambria County a flint-clay is found close to the top of the Mahoning sandstone in the Johnstown district. It may grade into plastic clay (Ref. 15). Promising shales also occur in Armstrong and Indiana counties (Ref. 17).

Monongahela Series or Upper Coal-measures.—These show their greatest development in southwestern Pennsylvania, and while the shale-deposits do not appear from published reports to be as abundant as in West Virginia, still occasional thick beds of shale occur.

An important clay-parting, 6 to 10 inches thick, is found in the Pittsburg coal-bed, and is used in the Monongahela Valley. It has to be removed in mining the coal and can hence be made a source of profit. The shale over the coal has been used at Fayette City for making red brick, while at Pittsburg the shale of this group is used for making brick and terra-cotta lumber.

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[1] See map, U. S. Geol. Surv., Bull. 65.

[2] The Clays of Western Pennsylvania, Ann. Rept. Pa. State College, 1897, p. 137

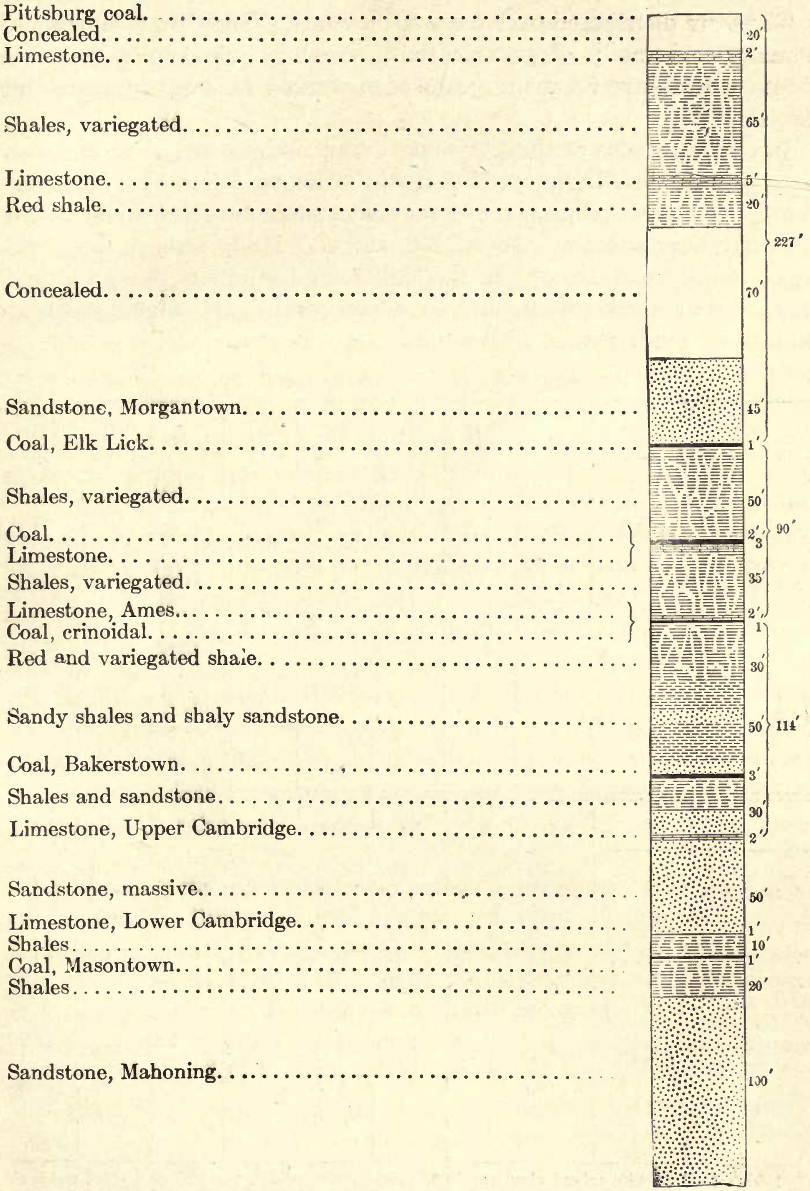

Fig. 62.—Section of Upper Barren Measures in Pittsburg region, Penn. (After I. C. White, U. S. Geol. Surv., Bull. 65.)

Pleistocene Clays

These are distributed over most of the State. They are of superficial character and rarely of great extent. Around Philadelphia the Columbian loams have for many years been worked for both common and pressed brick.

In western Pennsylvania clays are found under many river terraces, notably along the Allegheny, Monongahela, Beaver, Ohio, and Youghiogheny.[1] Along the Ohio and Beaver rivers there are three well-marked terraces, lying respectively 30–50, 150, and 200–250 feet above the river-level. Clays, which are dug in the highest and lowest of these, are used for brick and earthenware, and excellent results are sometimes also obtained by mixing these with shales.

ANALYSES OF PENNSYLVANIA CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	73.30	59.83	46.26	51.72	44.04	55.21	45.65	58.75
Alumina (Al_2O_3)	17.43	26.96	36.25	21.73	39.44	31.18	34.73	25.17
Ferric oxide (Fe_2O_3)	0.37	1.98	1.64	FeO 7.87	FeO 0.94	0.07	3.54	FeO 2.19
Lime (CaO)	0.02	0.11	0.19	0.06	0.07	0.18	0.11	0.71
Magnesia (MgO)	1.28	0.50	0.32	2.37	0.11	0.11	0.61	0.93
Potash (K_2O)	2.99	0.94	1.69	4.58	0.72	0.23	5.75	3.53
Soda (Na_2O)	0.17	0.24	0.85					
Water (H_2O)	4.68	9.56	13.54	......	......	13.02	......	8.11
Titanium oxide (TiO_2)	......	......	......	0.87	......	......	......	1.05
Ignition	......	......	......	10.78	14.13	......	9.65	
Sulphur trioxide (SO_3)	......	......	......	......	trace			
Organic and loss	......	......	......	......	......	0.23		
Mang. dioxide (MnO_2)	......	......	......	......	......	......	......	trace

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
Silica (SiO_2)	50.37	62.89	51.92	55.33	46.16	67.78	61.81	54.09
Alumina (Al_2O_3)	32.89	21.49	31.64	27.84	26.97	16.29	27.18	19.95
Ferric oxide (Fe_2O_3)	FeO 1.64	FeO 1.81	FeO 1.13	FeO 2.91	7.21	4.57	6.96	9.84
Lime (CaO)	0.31	0.38	0.03	0.58	2.21	0.60	2.00	0.72
Magnesia (MgO)	0.35	0.56	0.44	0.75	1.52	0.72	1.50	1.55
Potash (K_2O) Soda (Na_2O)	0.29	2.52	0.40	3.91	3.24	2.00	......	3.31
Water (H_2O)	......	7.58	13.49	7.49	11.22	6.34	......	2.20
Titanium oxide (TiO_2)	1.03	1.82	1.16	1.14	0.74	0.78		
Ignition	13.76	......	......	CO_2 .45	......	......	......	8.98
Moisture	......	1.16						

I. Mount Holly, white mixed clay, residual. II. Conshohocken, parti-colored clay, residual. III. Brandywine Summit, residual. IV. Wilmarth Station, Mercer fire-clay. V. Fletcher mine, Elk County, Sharon fire-clay. VI. Somerset County, Mt. Savage fire-clay. VII. Sandyridge, Clearfield County, Brookville under-clay. VIII. Kittanning, Clarion coal under-clay. IX. Allegheny Furnace, ferriferous coal under-clay. X. New Brighton, Kittanning lower coal under-clay. XI. Salina, Kier Bros., Bolivar under-clay, flint-clay. XII. Salina, Kier Bros., Bolivar under-clay, plastic clay. XIII. New Brighton, Mendenhall & Chamberlain, terrace-clay. XVI. New Brighton, Elverson & Sherwood, terrace-clay. XV. Allegheny, Allegheny Brick Co., analysis of brick. XVI. Butler. Butler Brick and Tile Co. Nos. I–XVI from U. S. Geol. Surv., Prof. Pap. 11.

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[1] Hopkins, Am. Rep. Pa. State College, 1897, p. 144.

References on Pennsylvania Clays

1. Ashburner, C. A., Report on the Brandywine Summit Kaolin Bed, Delaware County, Geol. Surv. Pa., Ann. Rept. for 1885, p. 592, 1886.

2. Ashley, G. H., Notes on Clays and Shales in Central Pennsylvania, U. S. Geol. Surv., Bull. 285, p. 442, 1906.

3. Butts, C., Economic Geology of the Kittanning and Rural Valley Quadrangles, Pa., U. S. Geol. Surv., Bull. 279, p. 162, 1906.

4. Clapp, F. G., Economic Geology of the Amity Quadrangle, Eastern Washington County, Pa., U. S. Geol. Surv., Bull. 300, p. 129, 1907.

5. Hice, R. R., The Clays of the Upper Ohio and Beaver River Region, Trans. Amer. Ceram. Soc., VII, Pt. II, p. 251, 1905.

6. Hopkins, T. C., Feldspars and Kaolins of Southeastern Pennsylvania, Jour. Frankl. Inst., CXLVIII, p. 1, 1899.

In other parts of the State many local deposits are employed for common and pressed brick.[1]

7. Hopkins, T. C., Fire-Clays, Mines and Minerals, XIX, p. 53, 1898.

8. Hopkins, T. C., Clays and Clay Industries of Pennsylvania, Pt. III; Clays of the Great Valley and South Mountain Areas, Pa. State Coll., Ann. Rept., 1899–1900, Appendix, 45 pp.

9. Hopkins, T. C., Clays and Clay Industries of Pennsylvania, Pt. II. Clays of Southeastern Pennsylvania (in part), Pa. State Coll., Ann. Rept., 1898–99, Appendix, 76 pp., 1900.

10. Hopkins, T. C., A Short Discussion of the Origin of the Coal-measure Fire-clays, Amer. Geol., XXVIII, p. 47, 1901; also Mines and Minerals, XXII, p. 296, 1902.

11. Hopkins, T. C., The White Clays of Southeastern Pennsylvania, Eng. and Min. Jour., LXX, p. 131, 1900.

12. Hopkins, T. C., Clays and Clay Industries of Pennsylvania, Pt. I; Clays of Western Pennsylvania (in part), Pa. State Coll., Ann. Rept. for 1897, Appendix, pp. 1–183, 1898.

13. Lines, E. F., Clays and Shales of Clarion Quadrangle, Clarion County, Pa., U. S. Geol., Bull. 315, p. 335, 1907.

14. Platt, F., Tests of Fire-brick, Pa. Geol. Surv., Rept. MM, p. 270.

15. Phalen, W. C., and Martin, L., Clays and Shales of Southwestern Cambria County, Pa., U. S. Geol. Surv., Bull. 315, p. 344, 1907.

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[1] Many localities are noted in Prof. Paper 11, U. S. Geol. Surv., pp. 235–238.

16. Ries, H., Clays of the United States, East of the Mississippi, U. S. Geol. Surv., Prof. Pap. 11, 1903.

17. Stone, R. W., Mineral Resources of the Elders Ridge Quadrangle, Pa., U. S. Geol. Surv., Bull. 256, p. 77, 1905.

18. Stose, G. W., White Clays of South Mountain, Pa., U. S. Geol. Surv., Bull. 315, p. 322, 1907.

19. Wright, G. F., The Age of the Philadelphia Brick-clay (Pennsylvania), Science, n. s., iii, p. 242, 1896.

20. Many Analyses in Penn. Geol. Surv., Rept. MM, p. 257 et seq.

21. Scattered notes in Reports of Sec. Penn. Geol. Surv., especially H4, H5, C4, C5.

22. Woolsey, L. H., Clays of the Ohio Valley in Pennsylvania, U. S. Geol. Surv., Bull. 225, p. 463, 1904.

RHODE ISLAND

This State has very limited clay resources. Glacial clays are known at a few points around Narragansett Bay, but the principal occurrence is found in the town of Barrington, where the deposits of bluish-gray, sometimes sandy clays are worked for the manufacture of common brick.

References on Rhode Island Clays

1. Woodworth, J. B., Shaler, N. S., Marbut, C. F., The Glacial Brick-clays of Rhode Island and Southeastern Massachusetts, U. S. Geol. Surv., 17th Ann. Rept., Pt. I, p. 957, 1896.

SOUTH CAROLINA

The northwestern part of the State is underlain by crystalline rocks, which extend to the edge of the coastal plain, the line of division passing a short distance southeast of Chesterfield and Camden, through Columbia and west of Aiken.

Residual Clays

These are to be sought for throughout the crystalline belt, and are usually impure. No kaolins are reported, but many of the white-burning sedimentary clays of the coastal plain are incorrectly termed such.

Coastal-plain Clays

The formations of this area range from Potomac to Columbian in age,[1] and consist of clays, loams, and marls. Of these the Potomac

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[1] Darton. U. S. Geol. Surv.. Bull. 138.

PLATE XXXVII

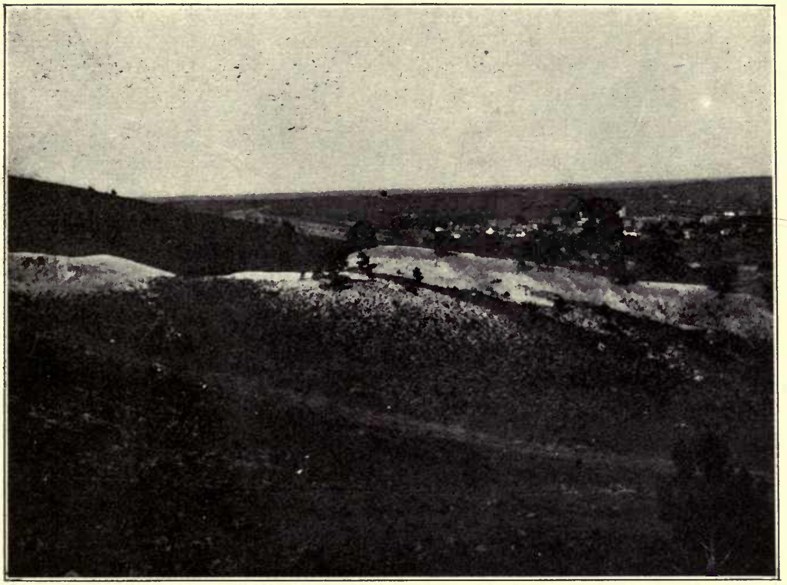

Fig. 1.—Beds of Cretaceous fire-clay, southwest of Rapid City, S. Dak. (After Todd, S. Dak. Geol. Surv., Bull. 3, p. 113, 1902.)

Fig. 2.—General view of valley at Thurber, Tex., underlain by paving-brick shale. (Photo by H. Ries.)

beds are by far the most important, outcropping in a belt from 4 to 5 miles wide, reaching from Augusta, Ga., through Aiken south of Lexington and through Columbia to Camden and Cheraw.[1] This contains lenses of white clay which are worked at Aiken, Columbia, Sievern, and other points. The clay usually has to be washed and is sold chiefly to paper manufacturers. The Eocene deposits to the southeast of the Potomac area also carry clays of value. These deposits have recently been described in some detail by the South Carolina State geologist.[2]

The chemical and physical properties of a number of these, taken from this report, are given in the accompanying table.

ANALYSES OF SOUTH CAROLINA CLAYS

	I.	II.	III.	IV.	V.
Silica (SiO_2)	44.23	43.18	44.11	45.69	42.30
Alumina (Al_2O_3)	38.98	37.36	38.19	37.47	36.94
Ferric oxide (Fe_2O_3)	0.77	0.91	1.55	1.01	2.64
Lime (CaO)	0.03	....	0.14	trace	0.80
Magnesia (MgO)	0.07	0.50	trace	....	0.78
Potash (K_2O)	0.26	2.00	0.50	0.08	
Soda (Na_2O)	0.55	....	0.53	0.69	
Titanium oxide (TiO_2)	0.85	....	1.30	1.44	
Ignition	13.58	14.32	13.37	13.98	15.43

	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	79.40	53.19	54.40	52.46	52.41
Alumina (Al_2O_3)	10.70	33.41	30.14	26.81	21.14
Ferric oxide (Fe_2O_3)	2.57	1.67	2.10	1.79	12.02
Lime (CaO)	0.58	0.10	0.46	0.81	1.04
Magnesia (MgO)	1.05	0.25	0.54	0.33	0.56
Potash (K_2O)	1.21	0.66	0.87	....	0.95
Soda (Na_2O)	0.23	0.12	0.12	....	1.12
Titanium oxide (TiO_2)	0.55	0.37	....	....	1.47
Ignition	3.94	10.63	11.37	14.44	8.95

I. Immaculate Kaolin Co., Langley.
II. Sterling Kaolin Co., near Warrenville.
III. J. Brodie, 12 miles north of Aiken.
IV. Imperial Kaolin Co., Sievern.
V. Carolina Fire-brick Co., east of Killian.
VI. A. W. Suder, Clarendon County.
VII. Dents' Pond.
VIII. A. B. Osborne, Union County.
IX. R. Hamilton, Jonesville.
X. Dr. Parker, Edgefield.

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[1] Darton, U. S. Geol. Surv., Bull. 138, p. 208.

[2] E. Sloan, S. C. Geol. Surv., Series IV, Bull. I, 1904.

SOUTH DAKOTA

Very little information has been published regarding the clays and shales of this State, and it is difficult to discuss them by formations, as has been done with most of the other States.

Aside from scattered references, the best and most recent information is that given by J. E. Todd,[1] from which most of the facts below are taken.

Clays abound in many parts of the State, the most important deposits being found in the Cretaceous, which is largely composed of clay- or shale-deposits, but clays of the lower grades are not wanting in the Pleistocene formations. None appear to have been noted from the Carboniferous. It seems likely that, owing to the absence of local demand, distance from important markets, and in some cases remoteness of the deposits from railroads, the development of the beds, unless of high grade, will be necessarily slow.

Kaolin, apparently derived from the weathering of a granite vein, has been reported from the vicinity of Custer, but much of it is said to be white-burning and of comparatively easy fusibility. The possibility of finding it in the Harvey Peak and Nigger Hill regions is also suggested.

Fire-clays are found at three or four horizons in the Fuson formation of the Cretaceous, and are best developed in the vicinity of Rapid City, where they have been used for fire-brick manufacture. Similar beds occur at Hot Springs. Analyses of the Rapid City clays are given below.

It is possible that fire-clays may underlie the lignite beds of the Laramie in the Cave Hills, but no search has been made for them.

Potter's clays have not been definitely located, but there are many drab and gray plastic shales in the Fuson, Dakota, Pierre, and Laramie formations of the Cretaceous, which might answer for this purpose. Some of the Tertiary beds may also prove of value.

These materials are distributed in all parts of the State, but east of the Missouri River the heavy covering of glacial deposits renders them more or less inaccessible, except where they have been exposed along the larger streams.

Brick-clays have not been extensively worked. Professor Todd states that: "Over much of the State, particularly in close proximity to the principal towns, good brick-clay is not very accessible. This results from the fact that the settlements have been mainly made in the glacial region east of the Missouri and in the mountainous region of the Black

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[1] S. Dak. Geol. Surv., Bull. No. 3, pp. 101–107, 1902.

Hills, where the clays are generally stony. . . . In the regions between, where clay is more abundant, the population has been small and fuel scarce."

Alluvium is used for common and pressed brick at Vermilion, Clay County, and the same products are made from similar materials at Rapid City, De Smet, Big Stone City, Lead City, etc.

The glacial clays are usually unsatisfactory, because of the pebbles and concretions which they contain.

Analyses of South Dakota Clays

	I.	II.	III.
Silica (SiO_2)	83.30	76.78	81.98
Alumina (Al_2O_3)	12.30	14.43	13.08
Ferric oxide (Fe_2O_3)	0.80	0.18	0.21
Lime (CaO)	1.30	2.18	1.46
Magnesia (MgO)	trace	0.95	0.31
Alkalies (Na_2O,K_2O)	.....	trace	trace
Loss on ignition	.....	4.62	4.07
	97.70	99.14	101.11

I. Rapid City.
II. East slope of ridge at Rapid City.
III. Rockerville Hill, Rapid City.
} From S. Dak. Geol. Surv., Bull. 3.

References on South Dakota Clays

1. Todd, J. E., The Clay and Stone Resources of South Dakota, Eng. and Min. Jour., LXVI, p. 371, 1898.
2. Todd, J. E., The Mineral Resources of South Dakota, S. Dak. Geol. Surv., Bull. 3.

TENNESSEE

Probably less is known regarding the clays of Tennessee than those of any other Eastern States. The geologic formations occurring in Tennessee include pre-Cambrian, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, Eocene, and Pleistocene.

The pre-Cambrian rocks occur in small areas along the eastern border, while west of them, and folded into many narrow belts, lie rocks of Cambro-Silurian age. The Carboniferous extends from the eastern edge of the Cumberland Plateau westward to beyond the Tennessee River. A large area of Silurian is found in the central part of the State, while another is found along the Tennessee River in the southern half of the State. This is followed by a broad belt of Tertiary, which in turn is separated from the Mississippi River by a band of Pleistocene.

Pre-Cambrian Clays

No kaolin-deposits have been described from the crystalline area of eastern Tennessee, although it is probable that some at least exist, as the author has seen samples of kaolin from this region. They will be of little commercial value, however, unless located fairly close to lines of transportation.

Palæozoic Residual Clays

The rocks of the Palæozoic formations yield residual clays from both limestones and shales. These are usually impure, although often tough and plastic, and are much used for brick- and tile-making.[1]

Some of the highly siliceous clays derived from the Knox dolomite are refractory,[2] and fire-brick are made from them near Cleveland. At Smithville a white clay, derived from the slate in the upper part of the Fort Payne division, is used for pottery.

Carboniferous

There is but little recent reliable information relating to Carboniferous clays or shales in Tennessee.

J. M. Safford, in his report on the Geology of Tennessee published in 1869, refers to the following occurrences of clay in the Carboniferous:

Near the Cumberland Iron Works, in Stewart County, is a bed of fire-clay of Lower Carboniferous age;[3] another occurs 4 miles southwest of Cumberland City, in Stewart County; in the valley of Crow Creek, near Anderson station, the coal-measures at the margin of the table-land show a fire-clay 3 feet thick, 163 feet below the top of the cliff;[4] in Franklin County, near the Grundy County line, and 4 miles northwest of the track of Sewanee road at the old Logan bank, is a bed of clay 115 feet below the conglomerate;[5] near the lower end of the Battle Creek Valley, in Marion County, is a bed of fire-clay 2 feet thick; 5 miles southeast of Tracy City, and 1½ miles from Parmly Bank, a bed of clay underlies the main Sewanee coal;[6] another occurs at the north end of Lookout

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[1] Many scattered references, but of very brief character, are to be found in the U. S. Geol. Surv., Geol. Atlas Folios, as follows: No. 21 (Pikeville); 16 (Knoxville); 59 (Bristol); 4 (Kingston); 8 (Sewanee); 2 (Ringgold); 53 (Standingstone); 40 Wartburg; 27 (Morristown); 22 (McMinnville).

[2] U. S. Geol. Surv., Geol. Atlas, Folio No. 2 (Ringgold).

[3] Safford, Geology of Tennessee, p. 349.

[4] Ibid., p. 372.

[5] Ibid., p. 373.

[6] Ibid., p. 380.

Mountain, below the upper conglomerate.[1] Many of the under-clays of the coal-seams, according to Safford, are of refractory character.[2] Fire-clays, mostly undeveloped, are said to be associated with the coals in the areas covered by the following Geologic Atlas Folios: Standingstone, No. 53; Wartburg, No. 40 (used for pottery).[3]

In the Kingston region the beds of clay which underlie the coals are no doubt refractory in many cases, but they are wholly undeveloped.[4]

Tertiary

In western Tennessee the plastic clay immediately underlying the Lafayette formation serves as the basis of a rather active stoneware and fire-brick industry. The section usually seen in the clay-pits involves red Lafayette sands, which seem to overlie unconformably the beds of stoneware-clay and white sands.

One pottery, located at Grand Junction, used clay from the various pits of the vicinity. The clay varies in quality. In the pits of the Irwin Clay and Sand Company, 1¼ miles east of the station, along the railroad, the section is:[5]

	Feet.	Inches.
Red Sand....................		
White sand..................	8	
White clay..................	8	
Gray lignitic clay.............	8	10
White clay..................	20	

The clay-deposits are very irregular, sometimes running together to form overlapping lenses in the white and yellow sand. Potteries are in operation at Mackenzie, Jackson, and Pinson, but at the latter locality the clay is also used for fire-brick and tiles.[6]

The clay at Hico, 3 miles south of Mackenzie, is shipped to the potteries at Akron and East Liverpool, Ohio, and Louisville, Ky., while the clays from Hollow Rock are shipped to Nashville.

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[1] Safford, Geology of Tennessee, p. 385.

[2] Ibid., p. 513.

[3] See also Geologic Atlas U. S. Folio, 33 Briceville; Folio 21, Pikeville; Folio 4, Kingston.

[4] Idem, Folio 4, Kingston.

[5] Eckel, U. S. Geol. Surv., Bull. 213, 1903, p. 382. This district has been more recently referred to by Crider, U. S. Geol. Surv., Bull. 285, p. 417, 1906.

[6] Idem.

Three miles east of Currier are the pits of I. Mandle, where an area 60 by 50 feet has been opened up. The section is as follows:

East Side.	West Side.
2 feet clay	Reddish sand
4 feet clay	15 feet light-gray clay
1 foot black clay (lignitic)	1 foot black clay
5 feet brown clay (ball-clay)	5 feet ball-clay

The bases of the two sections are at the same level, hence the beds are very irregular. The light-gray clay is shipped to East Liverpool, Ohio, for saggers, and the ball-clay is known as Tennesssee ball-clay No. 3. Tests of samples of this clay, made by S. Geijsbeek, show that it leaves 10 per cent residue on a 175-mesh sieve. Its rational composition is:

	Per cent.
Clay substance	91.35
Feldspar	2.70
Quartz	5.95

It will carry as much as 72 per cent of non-plastic material. The shrinkage at cone 1 is 12.5 per cent; at cone 2, 18 per cent. It burns white at cone 1 and gray at cone 8, being vitrified at that temperature. This is located 5 miles from Paris, and the clay is shipped from Currier, which is 3 miles from the mine.

Tennessee ball-clay, No. 1, found in Henry County, shows the following rational analysis:

	Per cent.
Clay substance	86.20
Feldspar	2.70
Quartz	11.10

It carries 60 per cent non-plastic material to the mixture. The total fire-shrinkage at cone 8 is 15 per cent, and at this temperature it burns to a cream-white color and dense body.

Alluvial Clays

Alluvial clays are found in many of the river valleys, and in most cases are the wash from the residual clays of surrounding areas. They often underlie the river terraces. These terrace-clays are used in the Maynardville area.[1] Others are common in the region around Morris-

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[1] See Geologic Atlas U. S. Folio 75, Maynardville.

town,[1] especially in the low grounds of the Lick Creek, Nolichucky, and French Broad valleys.

The following analyses of Tennessee clays have been gathered from different sources:

ANALYSES OF TENNESSEE CLAYS

Locality.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Alk.	H_2O.	Moisture.	MnO.	Remarks.
Loudon.......	45 06	30.03	4.50	4.70	4.80	.....	10	1	......	Crossley, analyses of clays
Powdes Station.	68 35	12.96	6.44	0.23	1	2.14	7	8	0.9	J. W. Slocum, anal.
Chattanooga...	68 96	20.42	1.84	0.16	0.33	2.18	6.50	......	trace	Tennessee Paving-brick Co.
Robbins.......	70.57	15.19	7.97	0.78	0.32	2.80	.....	......	......	Clay-worker, Dec., 1893

References on Tennessee Clays

1. Eckel, E. C., Stoneware and Brick-clays of Western Tennessee and Northwestern Mississippi, U. S. Geol. Surv., Bull. 213, p. 382, 1903.

2. Ries, H., The Clays of the United States East of the Mississippi River, U. S. Geol. Surv., Prof. Pap. 11, 1903.

TEXAS

Deposits of clay or shale are scattered over all parts of Texas, but only those in the eastern part of the State have been systematically investigated. Indeed, it is not likely that those occurring in the western part will be developed to any extent for some time, owing to the sparsely settled character of the country and lack of transportation.

The annual reports of the First Geological Survey contain scattered references to clay-deposits, but few tests. In 1903 the University Mineral Survey undertook an examination of those deposits lying east of the 99th meridian, and the results of this work have appeared in condensed form.[2] The following remarks, unless otherwise stated, deal with the area mentioned.

The map, Fig. 63, shows the location of nearly all the deposits examined, their relation to the geology of the State, and the type of clay found at each locality. From this map it will be seen that the clay-deposits found within the area under discussion range from Carboniferous to Pleistocene in age, the older deposits being found in the northwestern

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[1] Geologic Atlas U. S., Folio 27, Morristown.

[2] Amer. Inst. Min. Eng., Bimon. Bull., 1906.

part of the area, while those of the Cretaceous and Tertiary lie to the east, southeast, and south. The Pleistocene clays are found in part in

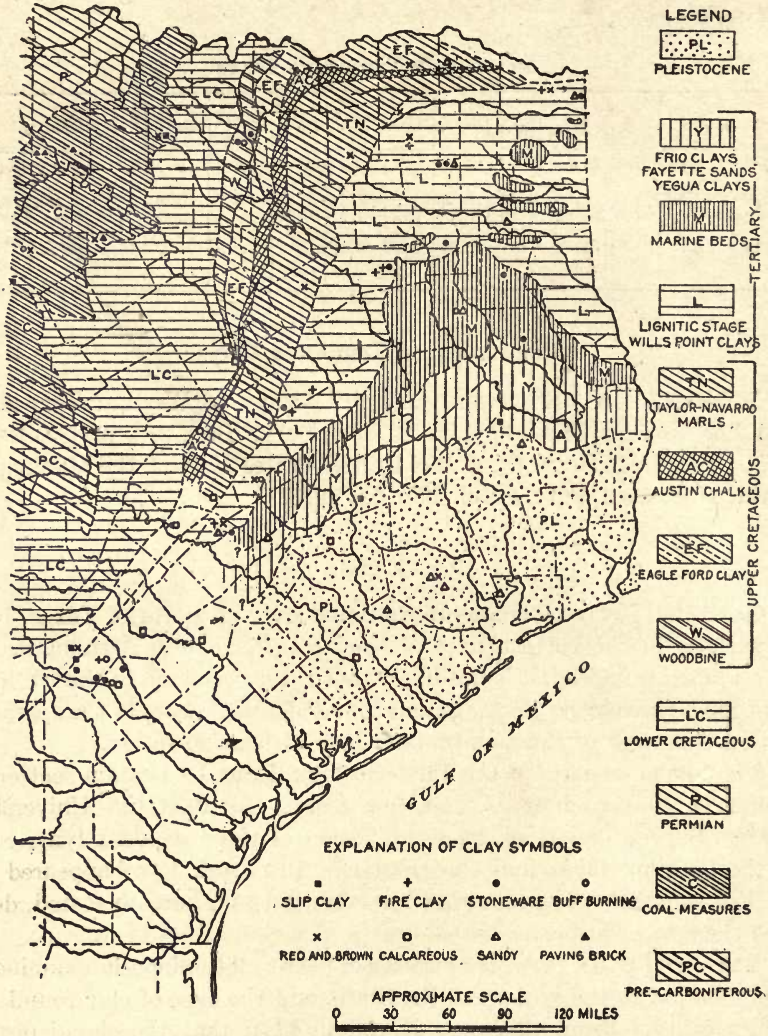

Fig. 63.—Map of eastern Texas, showing distribution of clay-bearing formations. (Compiled from various survey reports.)

a belt along the coast, and in part along many of the larger rivers, where they often underlie extensive terraces.

Carboniferous Clays

The Carboniferous rocks of northern Texas outcrop in a broad belt extending from the south side of the Colorado River Valley, between Lampasas and Concho counties, northward as far as the Red River in Montague County. This belt is about 250 miles long and averages about 45 miles in width. The rocks consist of a succession of shales and sandstones, together with occasional beds of limestone and coal, showing a gentle west and northwest dip of a few feet per mile. The entire series is subdivided into five groups (Ref. 2). Scattered through these are a number of beds of shale of excellent quality, some of which are associated with the coal-seams and could be mined in connection with them, while others outcrop on the surface (Pl. XXXVII, Fig. 1), where they are easily accessible for working.

These shales have been worked at only three localities, namely, Thurber, Millsap, and Weatherford, and are used for dry-pressed brick, stiff-mud paving-brick, and for pottery. Other good deposits are known to occur at Graham, Bridgeport, and Cisco. None of these, as far as known, are of refractory character. Some, as might be expected from their close association with coal-seams, are quite carbonaceous, and therefore of less value, because of the trouble they would cause in burning. The uniformity of the Carboniferous shale-beds is much greater than that of the Tertiary clays, and they moreover extend over greater areas.

Cretaceous Clays

Lower Cretaceous.—The formations of this age occupy an area to the east and south of the Carboniferous beds. They are not utilized, nor do they appear to contain any deposits of use for anything better than common brick. They can therefore be passed over. Near Leaky, Edwards County, Texas, there occur some most curious deposits of a white clay, which has usually been referred to as kaolin.[1] The material is a whitish clay, with pink and purplish mottlings, which forms vein-like deposits in the Edwards limestone. Scattered through it are crystalline masses of aragonite(?). Owing to the condition of the workings it is difficult to determine its exact relations to the surrounding limestone. As the deposits are of small extent and 40 miles from the railroad their commercial value is doubtful.

Upper Cretaceous.—This division of the Cretaceous carries a number of important clay-deposits, some of which are of great extent, but unfortunately are not the most valuable clay-beds in the State.

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[1] First Geol. Surv. of Texas, 2d Ann. Rept., p. li, 1891.

The Upper Cretaceous rocks extend across Texas in a broad belt from the Red River north of Sherman down to Eagle Pass, which lies about the middle of the band. Fort Worth is on the western edge and Austin towards the southeastern border. A second belt extends along the Red River, with narrowing width, until it passes out of the State in the northeastern corner. Since the dip is to the southeast, the older beds are found along the western edge of the belt, and the higher or younger ones on the east where they pass below the Tertiary strata. Owing to the dissimilarity of the several numbers of this group, it becomes necessary to refer to them individually, beginning with the oldest.

Woodbine formation.—This consists of a series of sandstones, clays, and clayey sands, often containing leaf impressions and lignite. While the clay-beds are usually sandy or even bituminous, they become locally pure enough, as at Denton, to be utilized for clay-products, although even here the beds are rarely of great extent and usually interbedded with sands. The clays, which are worked at both Denton and Lloyd, closely resemble the stoneware-clays of the Tertiary beds to the southeast. They are mostly of very plastic, semi-refractory, buff-burning character and are utilized for both common stoneware and pressed brick.

Eagle Ford formation.—This includes a series of bituminous clay-shales, which in places contain thin limestone beds. It is one of the most extensive and thickest clay-bearing formations in the entire State of Texas, and occupies a rather long narrow belt, as shown in Fig. 63. While the Eagle Ford clay is of great thickness and well located for working, it contains about all the undesirable elements that a clay might have, namely, concretions, limestone pebbles, gypsum lumps, and even pyrite. Moreover, its bituminous character, as well as extreme toughness, causes great trouble in its manipulation, and practically forces the clay-worker to mold it by one method, the dry-press process, other means yielding a brick of too dense character to permit the carbon in the clay to burn off. The clay is red-burning, and extensively used for bricks around Paris, Sherman, Dallas, and Waco.

Taylor-Navarro marls, overlying the Eagle Ford stratigraphically but separated from it by the Austin Chalk, form an extensive belt of clay, which parallels that of the Eagle Ford formation. The beds are marly clays, and in their general physical and chemical properties bear a close resemblance to the Eagle Ford beds. The Taylor marls are not clearly distinguishable from the Navarro marls, which outcrop to the southeast of them and resemble them closely, and for this reason the two are included under a single head.

The Taylor-Navarro marls are all plastic, sometimes glauconitic, red-burning clays, and are worked for dry-press brick at Cooper, Greenville, Corsicana, Taylor, and Ferris.

At Eagle Pass, which lies outside the east and central Texas area studied, the Eagle Pass formation, which occurs at the top of the Upper Cretaceous, contains shales associated with the coals, and while some of these at least are probably adapted to the manufacture of clay-products, no tests of them are available.

Tertiary Clays

The clays found in the Tertiary formations include the most important ones in eastern Texas, but, owing to the lenticular character of the beds and the enveloping deposits of sand with which they are frequently associated, prospecting for them is often rendered more or less difficult. From the wide distribution of the deposits (Fig. 63) it would appear that in certain belts of the Territory at least, as mentioned below, clays are to be sought for with excellent chances of success.

In Webb County, west of Laredo in southern Texas, shales are found associated with the Eocene coals, and some of those obtained from the mines at Cannel are weathered and then shipped to Laredo for making dry-pressed brick.

The other Tertiary beds of eastern Texas consist largely of unconsolidated materials which range from coarse gravels to very fine clay, but containing occasional beds of sandstone, limestone, and lignite. Several members are recognized, namely, Will's Point, Lignitic, Marine, Yegua, Fayette, and Frio. Of these only the Lignitic and Marine are of importance.

Lignitic.—These beds outcrop in a long but irregular belt (Fig. 63), and contain the following types:

1. Beds of plastic, buff-burning, semi-refractory clay associated with the lignite deposits; they are well adapted to the manufacture of pressed brick.

2. Red-burning, plastic, gritty clays, overlying the lignites, and worked at Rockdale for dry-pressed brick.

3. Red-burning, tough, shaly clay, occurring at New Boston and Sulphur Springs.

4. A widely distributed series of grayish, highly plastic clays of refractory or semi-refractory character, and used for stoneware, firebrick, etc. The following analyses p. (431) represent groups I, II, III.

Analyses of Tertiary Clay Types

	I.	II.	III.
Silica (SiO_2)	69.33	72.99	70.65
Alumina (Al_2O_3)	19.38	14.70	18.14
Ferric oxide (Fe_2O_3)	1.06	4.5	0.82
Lime (CaO)	0.86	0.6	0.339
Magnesia (MgO)	0.86	0.3	0.628
Potash (K_2O)	trace	1.5	0.41
Soda (Na_2O)	0.08	0.7	0.55
Titanic acid (TiO_2)	1.40	1.00	1.14
Water (H_2O)	5.49	4.20	6.18

Stoneware is made from these clays at Elmendorff, Athens, etc.; fire-bricks at Athens and Sulphur Springs; sewer-pipe at Saspamco, and pressed brick at Elgin, Athens, Malakoff, etc.

Marine beds.—These are usually of sandy or glauconitic character, but here and there carry clay-deposits of some economic value, and adapted to making buff brick and stoneware. They are worked at Nacogdoches, Henderson, and Rusk.

Pleistocene

This formation includes clays of several types. They form a rather broad belt along the Gulf Coast (Fig. 63), where they are mostly of sandy character, the Beaumont clays worked for brick around Beaumont and Houston being the most notable exception. These are tough, plastic, brown, blue, and yellow clays, carrying irregularly distributed nodules of limestone and underlying a broken belt extending from Calhoun County to Jefferson County. They are all red-burning, and used chiefly for common brick and to a lesser extent for dry-press brick.

A second important type includes the river silts found underlying the terraces along many of the large rivers, such as the Rio Grande, Colorado, Neches, etc. These clays are always silty or sandy and highly calcareous, the lime carbonate being present as concretions, lumps, shells, or in a finely divided condition, and forming at times over 50 per cent of the material without apparently diminishing its plasticity. They are especially well seen and extensively worked at Austin and Laredo. Though chiefly used for common brick, these clays have also been worked for pressed brick, and in a few localities, as near San Antonio, they are of the proper character for employment as a slip for stoneware. For practical purposes the clays found within the area just discussed can be divided into the following groups: I. Fire-clays; II. Stoneware-clays; III. Brick-clays; (*a*) Buff-burning, non-calcareous; (*b*) Red and brown-burning; (*c*) Calcareous; (*d*) Sandy; IV. Paving-brick clays;

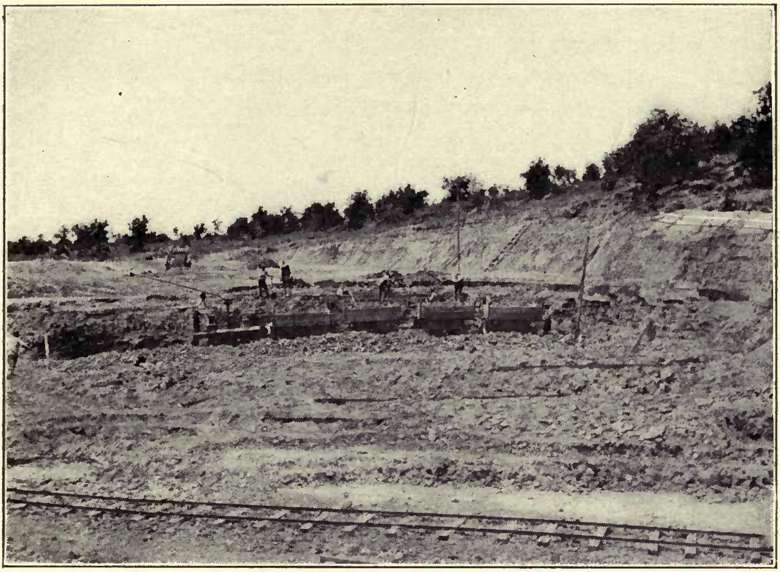

FIG. 1.—Bank of sewer-pipe clay in Lignitic (Tertiary) formation, Saspamco, Texas. Shows electric system of haulage. (Photo by H. Ries.)

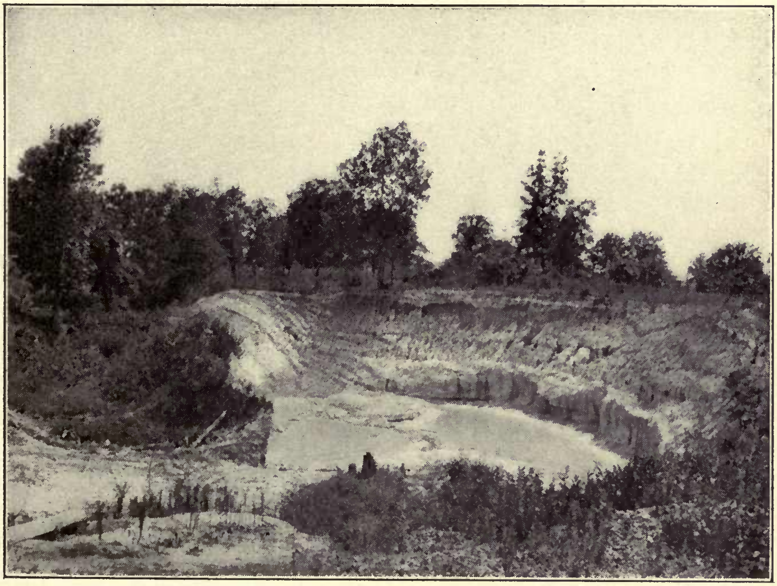

FIG. 2.—Pit in Beaumont clay, Houston, Tex. The walls of the pit are a very sandy clay underlying the other. (Photo by H. Ries.)

V. Slip-clays. Their distribution is shown on the map Fig. 63 and a few representative analyses are given below.

ANALYSES OF TEXAS CLAYS

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Silica (SiO_2)	63.07	63.43	45.44	55.10	49.45	73.00	72.9	64.84
Alumina (Al_2O_3)	19.43	23.42	40.30	23.80	17.11	15.79	14.7	22.44
Ferric oxide (Fe_2O_3)	4.75	1.15	0.54	3.51	3.45	0.63	4.5	0.80
Lime (CaO)	1.32	0.45	trace	3.28	12.67	1.29	0.6	trace
Magnesia (MgO)	0.50	1.23	trace	1.24	1.77	1.53	0.3	0.74
Potash (K_2O)	......	0.07	trace	0.50	0.13	0.10	1.5	0.12
Soda (Na_2O)	......	0.26	0.38	0.21	0.21	0.16	0.7	0.71
Titanic acid (TiO_2)	1.47	1.13	trace	1.05	0.70	0.43	1.0	1.40
Water (H_2O)	6.90	7.00	13.29	6.00	4.84	5.76	4.2	6.42
Sulphur trioxide (SO_3)	0.15	......	......	3.37	2.00			
Organic matter	......	0.40	......	......	......			
Carbon dioxide (CO_2)	......	......	......	1.75	7.10			
Total	97.59	98.54	99.95	99.81	99.43	98.69	100.5	97.47

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.
Silica (SiO_2)	74.04	66.01	57.01	77.75	49.40	90.00	53.6
Alumina (Al_2O_3)	15.15	18.82	11.85	11.04	17.90	4.60	9.0
Ferric oxide (Fe_2O_3)	0.50	6.33	3.02	3.19	4.50	1.44	2.6
Lime (CaO)	0.50	0.55	9.56	0.84	9.50	0.10	17.8
Magnesia (MgO)	0.27	1.88	1.20	0.38	1.88	0.10	1.2
Potash (K_2O)	0.42	0.16	0.75	......	......	trace	1.8
Soda (Na_2O)	1.12	0.08	2.01	......	trace	trace	trace
Titanic acid (TiO_2)	1.31	0.95	1.13	1.23	1.05	0.70	.8
Water (H_2O)	6.00	4.80	4.00	3.24	4.58	3.04	1.
Sulphur trioxide (SO_3)	......	......	......	0.51			
Organic matter	......	......	......				
Carbon dioxide (CO_2)	......	......	8.00	......	9.55	......	11.6
Total	99.31	99.58	98.53	98.18	98.36	99.98	99.40

PHYSICAL TESTS OF TEXAS CLAYS

		I.	II.	III.	VI.	VIII.	IX.
Per cent water required		25.3	23.1	44	33	33	30.8
Plasticity		good	good	low	high	high	high
Average tensile strength, lbs. per sq.in.		333	202	159	487	304	257
Air-shrinkage, per cent		7.7	9.6	6.2	12.4	9.3	10.2
Cone 05	Fire-shrinkage, per cent	5.6	5	5	4*	1	1.6
	Absorption, per cent	3.58	2.02	32.79	......	12.9	11.44
Cone 1	Fire-shrinkage, per cent	6.3	......	10	4*	2.7	3.3
	Absorption, per cent	0.10	......	20.47	......	7.87	6.57
Cone 5	Fire-shrinkage, per cent	......	......	13.7	......	3.5	5.7
	Absorption, per cent	......	......	10.7	......	3.15	2.83
Cone 9	Fire-shrinkage, per cent	......	vit'd	14.7	......	......	9.4
	Absorption, per cent	......	......	8.6	......	......	0.82
Cone of fusion		5	14	35	5	12	28
Color after burning		red	buff	white	red	red	buff

* Dry Pressed.

PHYSICAL TESTS OF TEXAS CLAYS—*Continued*

		X.	XI.	XII.	XIII.	XIV.	XV.
Per cent water required		23.1	37.4	23.1	23	25.4	25.3
Plasticity		good	high	good	high	low	good
Average tensile strength, lbs. per sq. in.		155	154	303	316	77	253
Air-shrinkage, per cent		8.5	11.6	9.4	9.3	4	6.2
Cone 05	Fire-shrinkage, per cent	0	5.33*	0.3	0.4	−0.3	−4.7
	Absorption, per cent	15.68	16.49	10.52	6.63	9.14	......
Cone 1	Fire-shrinkage, per cent	1.6	11.33*	0.3	0.8	0	1
	Absorption, per cent	13.13	5.77	9.39	4.43	9.45	23.49
Cone 5	Fire-shrinkage, per cent	3	......	0.4	......	0.7	7
	Absorption, per cent	14.05	......	7.29	......	9.55	5.95
Cone 9	Fire-shrinkage, per cent	4.3	......	......	......	1.3	......
	Absorption, per cent	6.83	......	......	......	8.39	......
Cone of fusion		30	5	9	5	12	7
Color after burning		buff	red	red	red	red	cream

* Dry pressed.

LOCALITIES OF PRECEDING ANALYSES

No.	Location.	Age.	Use.
I.	Thurber, Erath County	Coal-measures	Paving-brick
II.	Top clay over lower coal, Minera, Webb County	Cretaceous	Unworked
III.	Leaky, Edwards County	“	“
IV.	Dallas, Dallas County	Eagle-Ford-Cretaceous	Brick
V.	Ferris, Ellis County	Taylor marls	“
VI.	S. E. of Lena, Fayette County	Tertiary	Unworked
VII.	Vogel mine, Rockdale, Milan County	Lignitic-Tertiary	Brick
VIII.	Saspamco, Bexar County	“ “	Sewer-pipe
IX.	Athens, Henderson County	“ “	Fire-brick
X.	New Boston, Bowie County	Tertiary	Pressed brick
XI.	Alazan Creek, San Antonio, Bexar County	Pleistocene	Slip-clay
XII.	Beaumont, Jefferson County	“	Pressed brick
XIII.	Houston, Harris County	“	“
XIV.	Colmesneil, Tyler County	“	Common brick
XV.	Austin, Travis County	“ terrace-clay	Common brick

Nos. VII and XV, S. H. Werrell, analyst; the rest analyzed by O. H. Palm.

References on Texas Clays

1. Adams, G. I., Oil- and Gas-fields of the Western Interior and Northern Texas Coal-measures, U. S. Geol. Surv., Bull. 184, pp. 37 to 47, 1901.

2. Drake, N. F., and Thompson, R. A., The Colorado Coal-field of Texas, 4th Ann. Rept., Tex. Geol. Surv., p. 357, 1893.

3. Hayes, C. W., and Kennedy, W., Oil-fields of the Texas Louisiana Gulf Coastal Plain, U. S. Geol. Surv., Bull. 212, pp. 15 to 32, 1903.

4. Hill, R. T., Geology and Geography of Black and Grand Prairies, U. S. Geol. Surv., 21st Ann. Rept., Pt. VII, p. 295, 1901.

5. Kennedy, Wm., Texas Clays and Their Origin, Science, XXII, p. 297, 1893.

6. Penrose, R. A. F., Preliminary Report on the Geology of the Gulf-Tertiary of Texas, Tex. Geol. Surv., 1st Ann. Rept., p. 5, 1890.

7. Ries, H., The Clays of Eastern Texas, Trans. Amer. Inst. Min. Eng., Bimonthly Bull., 1906 and Bull. of Univ of Tex., 1908.

8. Taff, J. A., and Leverett, S., The Cretaceous Area North of the Colorado River, Tex. Geol. Surv., 4th Ann. Rept., p. 241, 1893.

9. Vaughan, T. W., Reconnaissance in the Rio Grande Coal-fields of Texas, U. S. Geol. Surv., Bull. 164, 1900.

10. See also scattered references in the first to fourth annual reports of Texas Geological Survey, especially under county descriptions.

UTAH

The writer has not seen any published information of value regarding the clay resources of this State. Common brick-clays are to be found at many points, and at the St. Louis Exposition there were exhibited samples of fire-bricks and crucibles made by the Utah Fire-clay Company of Salt Lake City, while kaolin samples were shown from Millard County and Lehi.

VIRGINIA

Residual Clays

The crystalline rocks, consisting of granite, gneisses, and schists with some intrusives extend across the State from north to south in a belt of increasing width, whose western boundary follows approximately a line running from Harper's Ferry southwestward, passing a few miles east of Front Royal. The eastern edge coincides approximately with the "Fall-line." Residual clays are not uncommon throughout this area, but they are usually impure, and adapted to little else but common brick.

Kaolin is found in Henry and Patrick counties and some promising deposits have been developed in the former (Pl. XXXIX, Figs. 1 and 2).

The Cambro-Silurian shales and limestones yield an abundance of impure residual clay, which is well adapted to brick manufacture. These clays, which are likely to be used throughout the Great Valley region, are all red-burning so far as known.

Carboniferous

Though containing important beds of coal, the clayey members of this formation in southwestern Virginia have received but little notice, but it seems highly probable that they contain shale-deposits of sufficient value for making vitrified wares, and even now they are successfully worked at one locality, namely, Millhall.

Triassic

The Triassic shales associated with the coals of the Richmond basin have not proven of any value for the manufacture of clay-products.

Tertiary

The Tertiary and Pleistocene formations of the coastal-plain area have received the most attention by clay-workers in the State.

The Tertiary beds consist of a series of clays, sands, marls, sandstones, and greensands, which dip gently to the southeast, and are overlain by later formations.

The clay-deposits, which are of Miocene age and usually of lenticular character, are most abundant towards the northwestern border of the coastal plain, and have been noted near Richmond, Bermuda Hundred, Curle's Neck, etc. They are red-burning and often yield a vitrified body, but, although to be ranked as among the best clays in the State, they are little used.

Some promising Eocene clays are known between Fredericksburg and Stafford Court House.

The diatomaceous earths form an extended series of deposits along the Rappahannock River and around Richmond, but they are worked at but one locality, namely, Wilmont (Pl. XL, Fig. 1), to make boiler-setting brick and fireproofing.

Pleistocene

Pleistocene clays occur at a number of points, but the deposits are, with few exceptions, of shallow character and the material red-burning. The clays are extensively dug around Richmond for common-brick manufacture, as well as at Norfolk, Suffolk, Petersburg, and several points along the James River (Pl. XL, Fig. 2). A semi-refractory Pleistocene clay is found near Wilmont on the Rappahannock.

Around Alexandria the Columbian loams are worked on a large scale for the manufacture of common and pressed brick, which supply the Washington market.

The following table contains the analyses and physical tests of some of the coastal-plain clays:

FIG. 1.—View of kaolin-pit near Oak Level, Va. The ferruginous clay walls are clearly contrasted to the white kaolin. (Photo by H. Ries.)

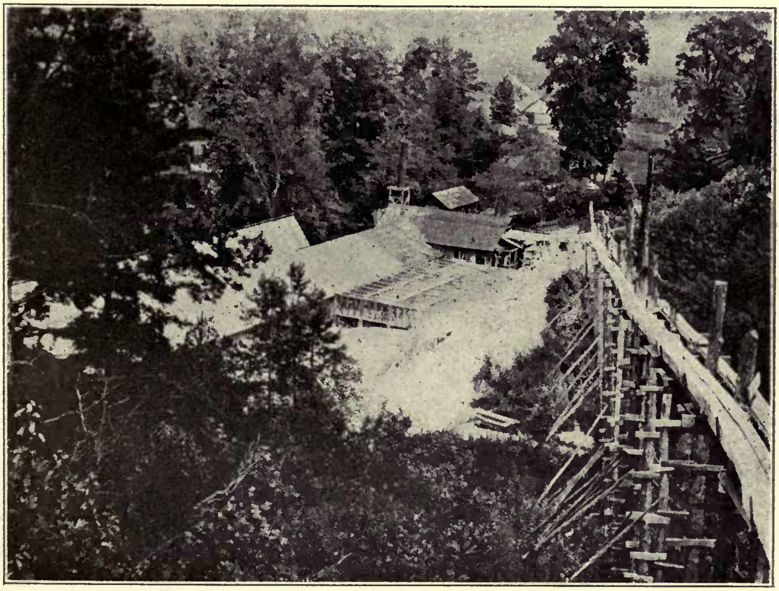

FIG. 2.—General view of kaolin washing plant near Oak Level, Va. The crude clay is washed down the trough from the mine. (Photo by H. Ries.)

Analyses and Physical Tests of Virginia Clays

		I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Silica (SiO_2)		71.50	69.74	61.83	73.84	65.97	64.39	51.12	82.85	45.70
Alumina (Al_2O_3)		13.86	12.64	21.26	15.08	17.38	20.49	26.14	6.76	39.18
Ferric oxide (Fe_2O_3)		4.78	6.00 *	6.85	3.39	6.74	4.40	10.70	2.34	0.78
Lime (CaO)		0.56	1.46	0.38	0.62	1.16	0.17	0.10	0.35	0.44
Magnesia (MgO)		0.11	1.18	0.78	0.12	0.17	0.91	0.25	1.06	0.05
Potash (K_2O)		2.29	2.54	2.44	2.17	2.46	2.31	1.78	1.07	1.78
Soda (Na_2O)		0.81	0.92	1.01	0.71	0.93	0.54	0.77	0.99	0.20
Titanic acid (TiO_2)		1.44	0.06	0.08	1.22	1.04	0.08	0.47	1.09	0.28
Water (H_2O)		4.61	4.41	5.32	2.81	4.10	6.66	8.63	3.40	12.09 †
Total		99.96	98.95	99.95	99.96	99.95	99.95	99.96	99.91	100.50
Per cent water required		20.9	25.3	29.7	20.3	20.9	31.9	36.3	62.4	
Plasticity		good	low	good	good	good	high	fair	low	
Air-shrinkage, per cent		6.4	9.3	8.6	7.6	7.4	11.6	9.3	3.6	
Average tensile strength, lbs. per sq. in.		89.6	177.3	148.8	111.5	134.8	143.8	115.3	34.4	
Cone 010	Fire-shrinkage, per cent	0	0	0.3	0	0	1.3	0.6	1.3	
	Absorption, per cent	17.40	18.2	22.04	16.3	17.7	16.9	28.2	50.96	
Cone 05	Fire-shrinkage, per cent	1.6	1.3	5.7	1.6	4.7	4	2.6	1.6	
	Absorption, per cent	15.08	14.2	12.9	15.04	10.1	8.87	23.1	48.4	
Cone 1	Fire-shrinkage, per cent	5	2.3	10.7	3.6	8.3	7	7	4.6	
	Absorption, per cent	7.1	7.54	0.12	7.2	1.5	1.5	12.06	41.4	
Cone 5	Fire-shrinkage, per cent	6.6	viscous	4.6	6.6	3	beyond	10.3	5.3	
	Absorption, per cent	1.4	at cone 3	2.11	1.08	2.6	vit'n	3.5	38.3	
Color when burned		red	red	red	red	red	red	red	buff	white

* Also one per cent FeO.

† Includes 1.98 moisture.

I. Brick-clay, Richmond, Pleistocene.
II. Gray clay, 2 miles south of Chester, Tertiary, not worked.
III. Tile-clay, one mile northwest of Bermuda Hundred, Pleistocene.
IV. Brick-clay, Oldfield on James River. Pleistocene
V. Tile-clay, 6 miles southeast of Richmond, Miocene, not worked.
VI. Blue clay for bricks, Suffolk, Pleistocene.
VII. Brick-clay between Stafford Court House and Fredericksburg, Eocene, not worked.
VIII. Diatomaceous earth, Wilmont on Rappahannock River, Miocene.
IX. Washed kaolin, Oak Level, Henry County. Unpublished analysis of Va. Geol. Sur.

Nos. I–VIII from Bull. II, Va. Geol. Surv., 1906.

References on Virginia Clays

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2. Ries, H., A Preliminary Report on a Part of the Clays of Virginia. Va. Geol. Surv., Bull. II, 1906.

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WASHINGTON

No systematic account of the Washington clays has been printed, and the few published references are scant and unsatisfactory.

The deposits are divisible into (1) Clay-shales, (2) Residual clays, and (3) Glacial clays.

Clay-shales.—These appear to be chiefly of Tertiary age. Flint-clay and sewer-pipe clay, interbedded with sandstone and coal, occur at Kummer and Taylor on the Columbia and Puget Sound Railroad, and are mined for making fire-brick, sewer-pipe, etc. Tertiary fire-clays are also found two miles east of Little Falls station, while clays suitable for brick, terra-cotta, and stoneware are dug at Clayton, 30 miles north of Spokane. Others are known at Sopenah and stoneware-clays are obtained near the town of Palouse.

Residual clays.—Deposits of this type occur only in the non-glaciated part of the State. In western Washington, between Puget Sound and the Columbia River, these clays are very thick in places, and derived from the weathering of shale. A residual basalt clay is used for red brick in eastern Washington.

Glacial clays.—The glacial clays are widely distributed over the glaciated area of Washington. Brick plants are located close to the larger centers of population and on the shores of the Sound. The clays are mostly red-burning.

References on Washington Clays

1. Landes, H., Clay-deposits of Washington, U. S. Geol. Surv., Bull. 260, p. 550, 1905.

2. Landes, H., Wash. Geol. Surv., Ann. Rept., Vol. I, p. 172, 1902.

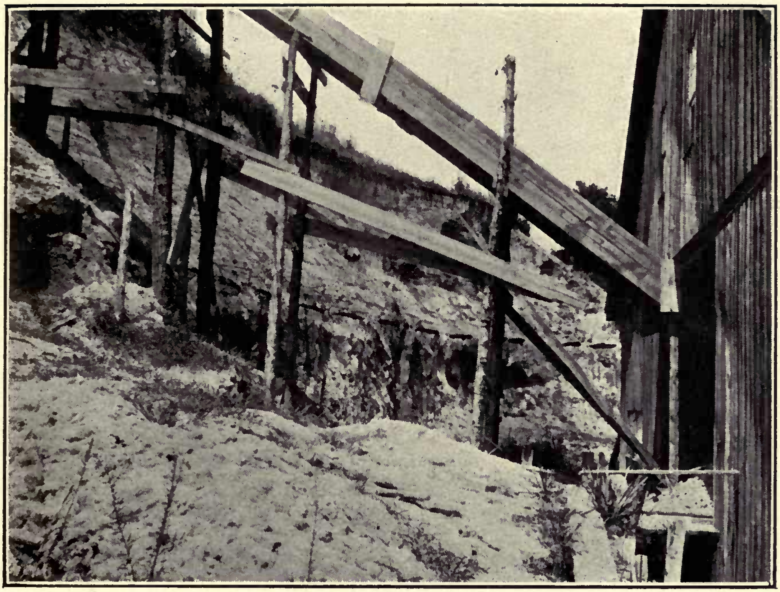

FIG. 1.—Section showing diatomaceous earth (Miocene) overlain by Pleistocene clay, Wilmont, Va. (After H. Ries, Va. Geol. Surv., Bull. II, p. 175, 1906.)

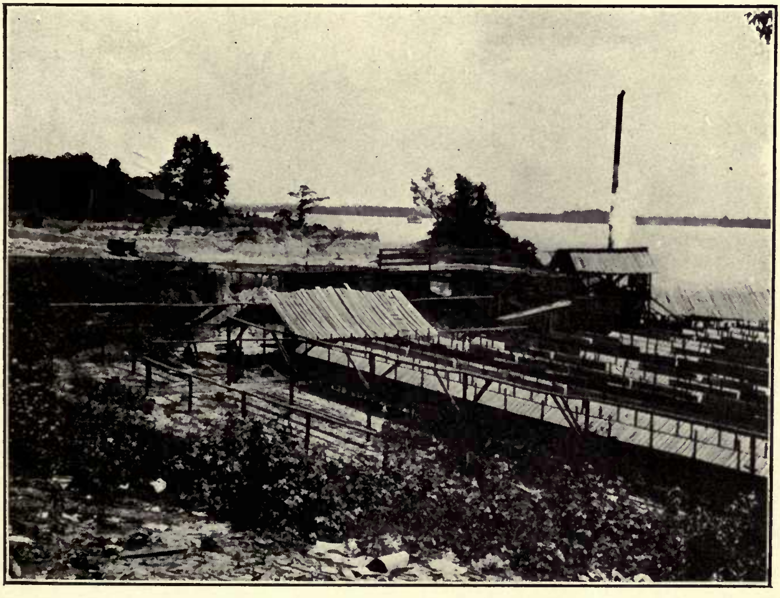

FIG. 2.—Pleistocene brick and tile-clay underlying terrace, Oldfield on James River, Va. (After H. Ries, Va. Geol. Surv., Bull. II, p. 166, 1906.)

WEST VIRGINIA [1]

With the exception of a few Pleistocene deposits, the clay-bearing formations of West Virginia are all of Palæozoic age.

Silurian

The residual clays derived from the Shenandoah limestone are found over large areas in Berkeley, Jefferson, and parts of Hardy, Hampshire, and Pendleton counties; they have been worked at Charlestown and Shepherdstown for red brick.

The shales of this age, known as the Martinsburg shale from their type occurrence at the town of that name, are hard and slaty when fresh, but weather down to a clayey mass which can be used for red-brick manufacture.

Red shales of Medina age and brown and gray Clinton shales outcrop in belts along the mountain-slopes of Mineral, Grant, Hardy, and Pendleton counties, but are not favorably located for working.

Devonian

The Devonian formations, according to Grimsley, consist of sandstones and shales, being found in Mineral, Grant, Hardy, Pendleton, Preston, Tucker, Randolph, Pocahontas, Greenbrier, and Monroe counties. They are grouped under the Hamilton, Chemung, and Catskill formations. Many of them are adapted to brick manufacture, but they are worked only at Elkins, Randolph County.

Lower Carboniferous

The Mauch Chunk shales, consisting of red and grayish-blue shales, green sandstones, and a few thin limestones, form a belt extending across the State from Preston County, through Tucker, Randolph, Pocahontas, Greenbrier, Monroe, and Summers counties.

The red shales and their residual clays form an excellent material for making red-pressed brick, the deposits moreover being well located, but up to the present time they have not been utilized.

Carboniferous

Pottsville series.—This contains clays, shales, sandstones, conglomerates, and coal-beds, but the only clay thus far worked is that occurring beneath the Homewood sandstone and known as the Mount Savage

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[1] Grimsley, G. P., W. Va. Geol. Surv., III, 1906.

fire-clay. This is mined at Piedmont for fire-brick manufacture, and consists of both plastic and flint fire-clay, the two forming a bed about 15 feet thick.

Allegheny series.—In this series there are found a number of important coal-seams with their underlying fire-clays, the two important groups being the Kittanning coals and clays, and the Freeport group of coals and clays.

The two most valuable beds of fire-clay are the Lower Kittanning and the Bolivar.

The shales in the series have also been successfully used for building-brick.

Clarion clay.—The Clarion coal at the base of the Allegheny series is often underlain by a thick bed of fire-clay, but it is not worked in West Virginia.

Kittanning clays.—The Lower Kittanning coal is very persistent through Ohio and Pennsylvania, but in West Virginia it is absent entirely as a workable bed in many regions of the State, and its place taken by the fire-clay.

The Lower Kittanning clay under the coal of that name is 5 to 15 feet at Hammond where it is worked.

Between the Upper and Lower Kittanning coals is an interval of sandstone, which at New Cumberland and Hammond carries the Middle Kittanning coal and its underlying fire-clay.

At New Cumberland, which is the largest brick-manufacturing center in the State, the Lower and Middle Kittanning clays are employed for the manufacture of building-brick and paving-blocks, and the Lower Kittanning clays for sewer-pipe. The shales between these two were formerly burned into common brick.

The following section at the Globe Works, given by Grimsley, is stated by him to be fairly typical of this region:

	Feet.	Inches.
Sandstone	40	
Coal	2	6
Flint-clay	6	
Gray shale-clay	4	
Blue shale-clay	12	
Sandstone floor	4	
Fine laminated shales	40	
Coal (Lower Kittanning)		3
Clay (Lower Kittanning)		10

The bottom clay is used for sewer-pipe, while the flint-clay and blue and gray shales are mixed together for brick and paving-blocks.

FIG. 1.—Red-burning brick-clay bank at Freeman, Wash. (Photo loaned by Washington Brick, Lime, and M'f'g Co.)

FIG. 2.—Shale-bed of Mahoning horizon, Charleston, W. Va. The shale is blue and red with some fire-clay mixed through it. (After Grimsley, W. Va. Geol. Surv., III, 1906.)

Upper Freeport clay.—There are some good outcrops of this clay on Decker's Creek above Morgantown near Dellslow, with good railroad connection, and could be easily developed.

Conemaugh series.—This series consists chiefly of sandstones and limestones, but contains scattered shale-deposits and some fire-clay. Overlying the Upper Freeport coal, or at times separated from it by the dark fossiliferous Uffington shales, are the Lower and Upper Mahoning sandstones. They are seen from Upshur southwest into Mingo, western Wyoming, and Raleigh counties. Between the two there is often found the Mahoning coal, which is worked near New Cumberland, while under the coal, and sometimes replacing it, there is a good bed of fire-clay found in a few regions and mined at Thornton, where it shows 18 feet of flint and soft clay. Near Ceredo, Wayne County, the clay is present without the coal.

At many points a shale-bed occurs between the two sandstones. Those worked around Charlestown may belong in part to this horizon, although some of the beds have been doubtfully referred to the Kanawha series of Virginia.

Overlying the Mahoning sandstone is the Cambridge limestone followed by the Ames limestone, and between these two is a mass of Pittsburg red shales, 30 to 100 feet thick, which extend from the Pennsylvania line southward to the Big Sandy River. These shales, which will undoubtedly prove of economic value, are as yet used only at Huntington for roofing-tile manufacture. They also occur at Barlow, Charlestown, etc.

In Preston County near Reedsville, Masontown, and Kingwood, as well as near Collier and Wellsburg in Brooke County, the shales are partly replaced by the Saltzburg sandstone. Overlying the Ames limestone is the Birmingham shale.

A very complete section of the Conemaugh series is exposed at Morgantown, Monongalia County, but the only shales worked are the Pittsburg ones. They make a building- and paving-brick.

Monongahela series.—A series of coals, limestones, sandstones, and shales are included in this group, the general section being well exposed in Pinnickinnick Hill at Clarksburg. The Pittsburg coal at the base of the Monongahela is an important and well-recognized horizon. At Clarksburg the shales underlying and overlying this coal-seam are worked for building- and paving-brick.

The shales worked near Spilman for paving-blocks and building-brick lie near the top of the Monongahela series, and those at Moundsville are also near this horizon.

Dunkard or Permo-carboniferous.—The rocks of this age cover a belt 40 to 60 miles wide, bordering the Ohio River. They include a number of utilizable shales, but at present they are being worked only at Parkersburg, Wood County, for making roofing-tile.

Pleistocene

A number of brick plants in the State obtain their raw material from deposits near creeks or rivers. These clays underlie terraces and occur either near the present river-level or a number of feet above it. The former are flood-plain deposits built up by the rivers in recent times, while the latter represent the remnants of lake-beds formed when the valleys were dammed by ice, thus giving rise to the formation of temporary lakes. The clays of the Monongahela, Teays, and adjacent valleys are of the second type.

ANALYSES OF WEST VIRGINIA CLAYS

	I.*	II.	III.	IV.	V.	VI.
Silica (SiO_2)	54.35	57.75	58.78	56.3	61.44	52.24
Alumina (Al_2O_3)	21.49	20.17	22.57	19.07	26.18	29.28
Ferric oxide (Fe_2O_3)	8	7.00	4.13	9.58	0.30	2.73
Ferrous oxide (FeO)	....	0.33	1.40	....	0.36	0.51
Lime (CaO)	0.30	0.22	0.18	0.69	0.12	0.68
Magnesia (MgO)	0.79	1.22	1.00	2.01	....	0.2
Soda (Na_2O)	trace	0.62	0.54	....	0.02	0.37
Potash (K_2O)	6.35	2.59	3.15	....	....	2.11
Titanic oxide (TiO_2)	0.86	0.87	1.03	0.71	1.39	1.2
Moisture	1.62	2.75	1.05	....	0.77	1.28
Phosphoric acid (P_2O_5)	0.09	0.09	0.35	....	0.01	0.07
Sulphur trioxide (SO_3)	trace	....	....	....	....	....
Ignition	5.70	5.94	5.43	8.01	9.07	10.12
Total	99.55	99.55	99.61	96.37	99.66	100.79

	VII.	VIII.	IX.	X.	XI.	XII.
Silica (SiO_2)	57.58	59.76	57.52	57.89	66.69	56.19
Alumina (Al_2O_3)	21.41	22.79	21.76	21.59	21.83	26.31
Ferric oxide (Fe_2O_3)	3.75	0.60	3.41	5.62	0.37	2.82
Ferrous oxide (FeO)	3.45	3.53	3.7	1.26	1.00	0.96
Lime (CaO)	0.46	0.59	0.60	0.61	0.33	0.39
Magnesia (MgO)	1.44	1.23	0.88	1.55	0.10	1.44
Soda (Na_2O)	0.1	0.42	0.03	0.29	0.08	0.50
Potash (K_2O)	3.14	3.79	3.57	3.28	0.48	3.90
Titanic oxide (TiO_2)	0.84	0.82	0.83	0.72	1.11	0 63
Moisture	0.38	0.54	0.86	1.27	0.99	1.39
Phosphoric acid (P_2O_5)	0.11	0.46	0.14	0.21	trace	trace
Sulphur trioxide (SO_3)	....	....	....	....	....	....
Ignition	7.25	5.26	7.27	6.18	7.13	5.48
Total	99.91	99.79	100.57	100.47	100.11	100.01

* For references see foot of table, p. 450.

PLATE XLII

Shale-pit of High-grade Shale Brick Co., Clarksburg, W. Va. Coal-streak near top is the Redstone coal of Monongahela series. (After Grimsley, W. Va. Geol. Surv., III, 1906.)

Analyses of West Virginia Clays—*Continued*

	XIII.	XIV.	XV.	XVI.	XVII.
Silica (SiO_2)	55.63	58.28	50.80	68.42	63.88
Alumina (Al_2O_3)	20.76	21.26	19.47	16.38	17.18
Ferric oxide (Fe_2O_3)	3.94	1.87	8.83	3.05	5.72
Ferrous oxide (FeO)	4.17	3.37	1.9	1.89	0.50
Lime (CaO)	0.86	0.78	1.51	0.94	0.16
Magnesia (MgO)	1.70	1.35	1.74	1.8	1.3
Soda (Na_2O)	0.34	0.39	0.89	0.63	0.6
Potash (K_2O)	2.97	2.87	2.24	0.93	2.29
Titanic oxide (TiO_2)	0.98	0.86	0.68	0.88	0.87
Moisture	1.03	1.30	0.6	......	1.76
Phosphoric acid (P_2O_5)	0.23	0.39	0.2	0.08	0.36
Sulphur trioxide (SO_3)	trace	......	......	......	......
Ignition	6.98	6.84	11.37	4.58	5.60
Total	99.59	99.56	100.23	99.58	100.22

Physical Tests of West Virginia Clays

	I.	II.	III.	V.	VI.	VII.	VIII.
Water required, per cent	......	28	25	2.1	28	24	26
Tensile strength, lbs. per sq. in.	......	122	34	32	58	40	46
Air-shrinkage, per cent	......	4	3.5	3	4	4	4
Cone of incipient vitrification	......	1	......	......	......	1	1
Cone of vitrification	5	5	1	......	26	5	5
Cone of viscosity	......	......	5+	30+	28		
Fire-shrinkage, per cent	......	11	10	......	2	6	6
Color when burned	red	......	red	buff	buff	brown	brown

	IX.	X.	XI.	XII.	XIII.	XIV.	XVII.
Water required, per cent	26	27	20	24	22	25	32
Tensile strength, lbs. per sq. in.	40	36	75 to 90	89 to 100	109	78	140
Air-shrinkage, per cent	3.5	4	4	4	4.5	4.5	6
Cone of incipient vitrification	1	1	......	1	......	1	1
Cone of vitrification	5	5	30	5	1	5	5
Cone of viscosity	......	......	......	......	5		
Fire-shrinkage, per cent	10	8	0	6	2	.7	12
Color when burned	red	red	buff	red	red	red	red

I. Residual limestone clay, Charlestown, Silurian.
II. Residual shale-clay, Martinsburg, Silurian.
III. Shale, Elkins, Randolph County, Hamilton.
IV. Shale, Decker's Creek near Morgantown, Mauch Chunk.
V. Fire-clay, Piedmont, Mount Savage clay.
VI. Flint-clay
VII. Gray shale } Clifton Mine, New Cumberland, Middle Kittanning.
VIII. Blue shale
IX. Clay
X. Shale } Ætna mine, New Cumberland, Lower Kittanning.
XI. Flint-clay
XII. Plastic clay } Thornton, in Conemaugh series, Mahoning coal horizon.
XIII. Shale, Morgantown, Pittsburg red shale.
XIV. Blue shale, Huntington, Conemaugh series.
XV. Mixture of Spilman shales, Spilman, Conemaugh series.
XVI. Parkersburg, Dunkard shale.
XVII. River-clay, Parkersburg, Pleistocene.

Nos. I–XVII selected by Dr. Grimsley as representative ones, from Vol. III, W. Va. Geol. Surv.

References on West Virginia Clays

1. Grimsley, G. P., The Clays of West Virginia, W. Va. Geol. Surv., III, 1906.

2. White, I. C., Correlation Papers, Carboniferous, U. S. Geol. Surv., Bull. 65.

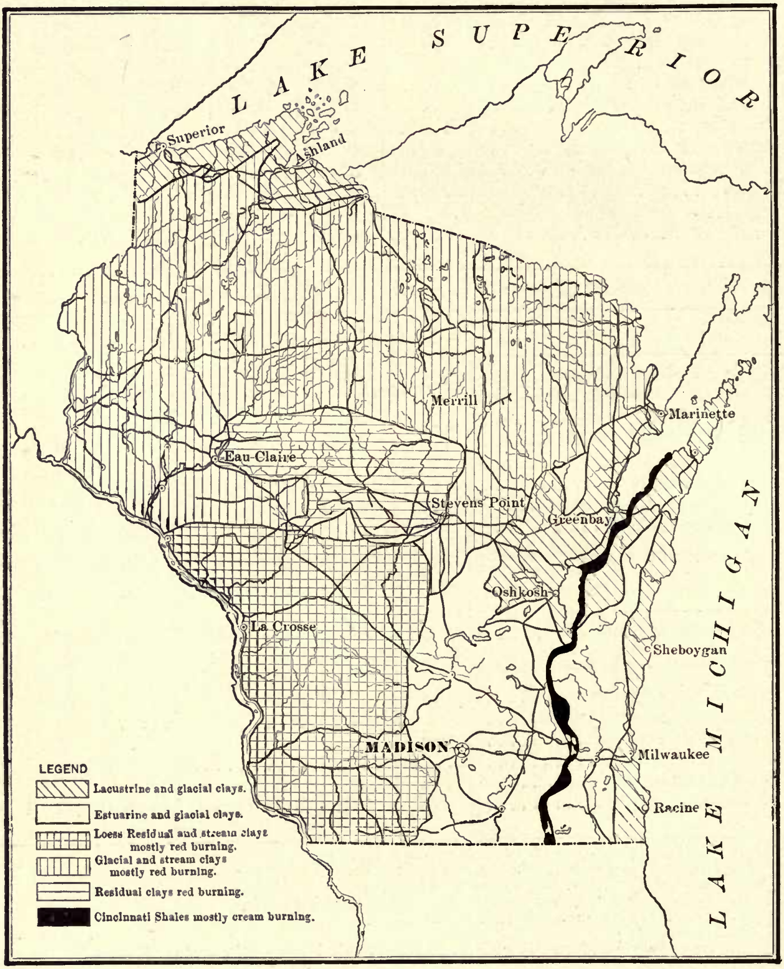

Fig. 64.—Map of Wisconsin, showing distribution of clay-bearing formations. (Adapted from Buckley, Wis. Geol. and Nat. Hist. Surv., Bull. VII, 1901.)

WISCONSIN

In this State the clay-deposits belong to formations representing somewhat the two extremes of the geological column. Those belonging

PLATE XLIII

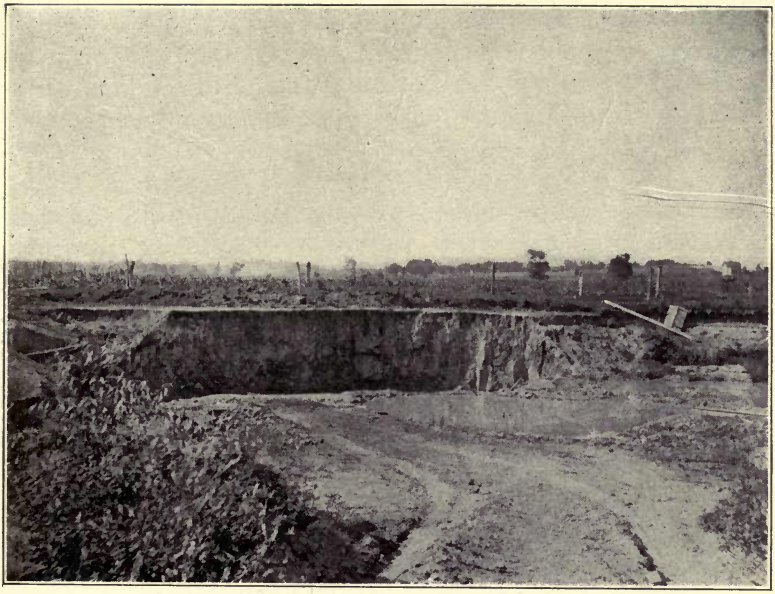

FIG. 1.—Pit of estuarine clay, Fort Atkinson, Wis. The flat area is underlain by clay, while the surrounding low hills are of sand. (Photo by H. Ries.)

FIG. 2.—Pleistocene brick-clay, Milwaukee, Wis. The mound in middle of pit is sand and is left standing. (Photo by H. Ries.)

to the older formations are nearly all of residual character, while those belonging to the sedimentary deposits are of very recent geologic age. It seems best, therefore, to divide them into two groups, namely, the residual clays and the sedimentary clays.

Residual Clays

These have been derived from a variety of rocks, including granites and gneisses, greenstones and allied volcanic rocks, limestone and dolomite, sandstone and shale.

Pre-Cambrian residuals.—These occur at a number of points in the central part of the State, in Eau Claire, Jackson, Wood, Portage, Marathon, and Clark counties. They are usually gritty clays which have been formed by the decomposition of schists or gneisses, and vary in depth from perhaps 2 or 3 feet to as much as 40. Although sometimes reaching nearly to the surface, they are at other times covered by a bed of Potsdam sandstone which has apparently protected them from erosion. Deposits of this occur in the vicinity of Grand Rapids, Eau Claire, Black River Falls, Stevens Point, Abbotsford, etc. They are nearly all red-burning, and while refractory ones low in iron are known to occur, the deposits of them so far as found are rather small. Their main use is for the manufacture of common brick, but at Halcyon near Black River Falls the material has been found adapted to the manufacture of dry-press brick and even paving-brick.

Potsdam shales.—In a few localities there occurs at the base of the Potsdam a tough plastic clay which has been derived by the weathering of a siliceous shale. This material has been exposed near Merrillan, Durand, and other points, but has not been utilized to any extent for the manufacture of clay-products.

Ordovician limestone residuals.—Within the driftless area of Wisconsin the cherty galena limestone is found weathered in its upper portion to sandy residual clay containing many flint fragments scattered through it. Up to the present time it has not been used for the manufacture of common brick to which it is chiefly adapted, nor is there any likelihood of its ever becoming of any importance.

Sedimentary Clays

Hudson River shale.—This shale forms a narrow belt in the eastern part of Wisconsin which extends from the southern boundary of the State up to Green Bay. In this State it is not very well adapted to the manufacture of brick, but on weathering breaks down rather easily to a yellow clay which has very fair plasticity and is usually red-burning.

The material has been worked at Stockbridge, Calumet County, and at Oakfield, Fond du Lac County, for the manufacture of brick. At the former locality a mixture of the weathered shale and the partly weathered material is used with excellent results. A second area of these shales is known to occur in Lafayette County, to the east and southeast of Plattville, where the material is to be found around the base of the Mound Hills so prominent in that region. It weathers to a yellow clay of high plasticity and one which burns to a very hard body of excellent red color.

Pleistocene Clays

The Pleistocene clays of Wisconsin have been grouped by Buckley (Ref. 1) as follows: 1. Lacustrine deposits; 2. Stream deposits; 3. Estuarine deposits, and 4. Glacial clays.

Lacustrine deposits.—These respresent a very extensive type, and were laid down during the former inland extension of the Great Lakes, so that they are now often found some distance from the present lake shore. Thus, around Racine, they occur 18 miles inland. They are also found at Sheboygan, over parts of Door County, and in parts of Manitowoc, Calumet, and Fond du Lac counties; much of Green Lake, Waushara, and Waupaca counties too are underlain by them, while to the north they are found as far as Shawano. These lacustrine deposits, adjoining Lake Michigan on the east and Lake Superior on the north, are an important source of cream-burning brick-clays, and the beds often exceed 100 feet in thickness. Sometimes the upper few feet burn red, owing to the fact that the carbonate of lime has been leached out of them. Around Green Bay, Manitowoc, and Racine these clays are much used for the manufacture of common, pressed brick and drain-tile, but they are of little value for anything else.

Estuarine clays.—These include all the clays of eastern Wisconsin which are underlain by limestone and have been modified by glacial action. They were formed at the same time and in association with the lake-deposits, but differ from them usually in showing a more variable lime-content and burn hard and dense at a lower temperature. Thus, for example, the lake-clays apparently have to be burned up to cone 3, while the estuarine clays can be burned at cone 05 to 1. These estuarine deposits are found along the Fox, Wolf, Rock, Wisconsin, Eau Claire, Chippewa, Black, Red, Cedar, and many other rivers in the eastern, northeastern, and southern parts of the State.

Glacial clays.—These have been deposited over a large part of the northern half of the State and include a series of deposits of uncertain extent and variable character and thickness. In some places they consist of bowlder-clay and are therefore of a very stony character, while at others they may represent deposits that have been formed in temporary lakes during the last glacial epoch. Those worked at Athens belong to the former type, and those worked at Menomonie and forming the basis of an extensive local industry belong to the latter type. Under this heading we should perhaps also include the silty loess-clays which cover a large area in the western part of the State and are worked at Platteville, Menomonie, La Crosse, and other places. They represent a good character of clay, which in many instances is used only for common brick, but is also adapted to the manufacture of dry-press brick.

Analyses of Wisconsin Clays

	I.	II.	III.	IV.	V.
Silica (SiO_2)	64.50	62.59	35.93	48.39	44.18
Alumina (Al_2O_3)	26.20	17.42	11.75	12.50	10.83
Ferric oxide (Fe_2O_3)	0.07	5.88	4.08	5.40	3.30
Lime (CaO)	....	none	12.43	10.88	14.05
Magnesia (MgO)	....	1.24	9.92	4.82	5.91
Potash (K_2O)	0.31	8.08	2.46	3.90	3.10
Soda (Na_2O)	....	0.52	1.24	0.68	0.70
Loss on ignition	8.90	4.15	22.06	13.02	17.34
Titanic acid (TiO_2)	....	0.30	0.30	0.43	0.30
Manganese oxide (MnO)	....	SO_3 trace	0.10	trace	

	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	40.17	31.90	71.77	65.44	69.86
Alumina (Al_2O_3)	9.14	8.74	13.74	13.51	13.55
Ferric oxide (Fe_2O_3)	3.00	3.00	3.60	5.40	5.46
Lime (CaO)	14.49	17.06	1.23	2.95	0.71
Magnesia (MgO)	8.34	10.63	1.17	2.20	1.43
Potash (K_2O)	3.06	2.20	2.30	3.44	2.36
Soda (Na_2O)	0.34	0.82	1.20	1.54	1.78
Loss on ignition	21.37	25.19	5.00	4.69	4.40
Titanic acid (TiO_2)	0.35	0.25	0.45	0.60	0.77
Manganese oxide (MnO)	0.09	0.19	trace	trace	trace

Localities of the Above

No.	Locality.	Geological Age.	Uses.
I.	Hersey	Residual	Not worked
II.	Merrillan	Potsdam	“ “
III.	Oakfield	Hudson	Common brick
IV.	Green Bay	Pleistocene	Brick
V.	“ “	“	“
VI.	Milwaukee	“	“
VII.	Watertown	“	“
VIII.	Chippewa Falls	Glacial	“
IX.	Menomonie	“	Pressed brick
X.	Whittlesey	“	Brick

Nos. I–X from Wis. Geol. and Nat. Hist. Surv., Bull. 7, 1901.

References on Wisconsin Clays

1. Buckley, E. R., The Clays and Clay Industries of Wisconsin, Wis. Geol. and Nat. Hist. Surv., Bull. 7, Pt. I, 1901.

2. Chamberlain, T. C., Geol. of Wis., I, p. 669.

3. Irving, R. D., On the Kaolins of Wisconsin, Wis. Acad. Arts and Letters, Trans., 1876.

4. Irving, R. D., Geol. Wis., II, p. 630.

5. Irving, R. D., Mineral Resources of Wisconsin, Amer. Inst. Min. Eng., Trans., VIII, p. 478.

6. Ries, H., Clays of Wisconsin, Mining World, Mar. 25, 1905. See also forthcoming bulletin, Wis. Geol. and Nat. Hist. Surv.

7. Sweet, E. T., Milwaukee Clay, Amer. Jour. Sci., iii, XXIV, p. 154.

WYOMING

Little is known regarding Wyoming clays, owing largely to their lack of development. W. C. Knight says:[1] "So far as is known, the clays of Wyoming that have any commercial importance occur in beds of the sedimentary rocks. These clay-beds are most numerous in the Jurassic and Cretaceous formations, but are found to some extent in the Tertiary." The formations containing these clays are found flanking nearly all of the mountain-ranges in the State, and the clay-beds vary in thickness from 4 to 40 ft. Bowlder-clays, that are so common in the East, are not known and will be found only in small and isolated localities. With the exception of the manufacture of common brick no attention has been paid to any of the clay industries, and all of the fire-clay goods used in Wyoming are manufactured in Colorado, while pressed brick are shipped in from various points. This condition is largely due to the limited population of the State, and the slight demand for clay-products. The common brick which are, as a rule, manufactured from loess, are very siliceous and fragile, although in a few places there is clay enough in the loess to make a medium-grade brick. Judging from the appearance of the clay-beds and their geological position, they will, when tested, prove equal to the Colorado beds.

At Cambria, Weston County, the clays associated with the coals have been found adapted to the manufacture of dry-press brick.

Bentonite.—A peculiar variety of clay found in Wyoming and known as *bentonite* was first described by W. C. Knight under the name of

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[1] Eng. and Min. Jour., LXIV, p. 546, 1898.

taylorite.[1] Finding that the latter name was preoccupied, he proposed the name of bentonite for it [2] from its occurrence in the Benton formation. The deposits in the northeastern part of the State, in the vicinity of Newcastle, were first described in detail by N. H. Darton.[3]

Bentonite when fresh has a yellowish-green color, but assumes a light cream tint on exposure. It is fine-grained, soft, and absorbs three times its weight of water, accompanied by swelling. Its specific gravity is 2.18. Professor Knight pointed out its resemblance to the *ehrenbergite* of Germany, but it differs from it in containing less alkali. The soda reported in the analyses is, as a rule, found in the clay in thin seams as sodium sulphate. T. T. Read thought, from analyses examined by him, that it most closely resembled *montmorillonite* (Ref. 8).

It will be seen from the analyses given below that the clay shows a somewhat variable composition, and that its peculiar properties are due no doubt to physical rather than chemical conditions.

ANALYSES OF BENTONITE

	I	II.	III.	IV.	V.	VI.
Silica (SiO_2)	59.78	61.08	63.25	65.24	64.0	60.18
Alumina (Al_2O_3)	15.10	17.12	17.62	15.88	22.9	26.58
Ferric oxide (Fe_2O_3)	2.40	3.17	3.70	3.12	3.1	
Lime (CaO)	.73	2.69	4.12	5.34	1.0	.23
Magnesia (MgO)	4.14	1.82	3.70		2.0	1.01
Potash (K_2O)	....	....	....	....	.....	1.23
Soda (Na_2O)	....	.20	....	....	.....	
Sulphur trioxide (SO_3)	....	0.80	1.53			
Water (H_2O)	16.26	12.10	und. ?	9.17	7.0	10.26
Total	98.41	98.98	93.92	98.75	100.0	99.49
Specific gravity	2.18	....	2.132			

I. Rock Creek, } Wyoming Exper. Sta., Bull. 14 p. 193, 1893.
II. Crook County, }
III. Weston County, } W. C. Knight, analyst.
IV. Natrona County, }
V. Cosgriff. J. Ogden, analyst. U. S. Geol Surv., Bull. 285, p. 446.
VI. Cassa Mining Co., T. T. Read, analyst. U. S. Geol. Surv., Bull. 285, p. 446.

The peculiarity of composition of this clay lies in its high combined water-content as compared with the alumina percentage.

The clay, which occurs mainly in the Benton group of the Creta-

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[1] Eng. and Min. Jour., LXIII, p. 600, 1898.

[2] Ibid., LXVI, p. 491.

[3] Geologic Atlas, Folio No. 107, 1904.

ceous, and some in the Niobrara, has been found extensively in Wyoming in Crook, Johnson, Weston, Converse, Natrona, Carbon, Albany, and Laramie counties. More recently additional deposits have been discovered 8 miles east of Frannie, and 5 miles north of Cowley, Wyoming.[1] The distribution of the Benton formation in Wyoming is shown in Fig. 65.

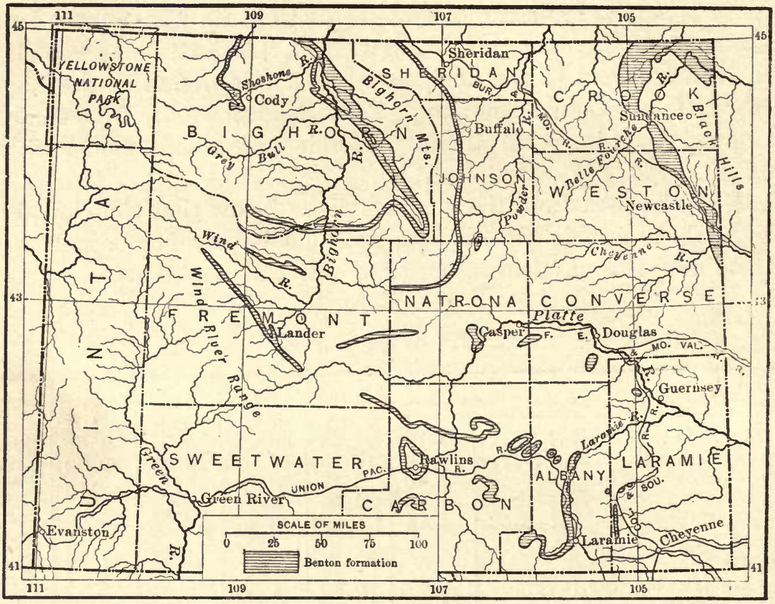

Fig. 65.—Map of Benton formation in Wyoming. (After Fisher, U. S. Geol. Surv., Bull. 260.)

Bentonite has been used in the manufacture of soap, as a packing for a special kind of horseshoe, as a diluent for certain powerful drugs sold in the powdered form, and as an adulterant of candy. It has also been employed in the manufacture of antiphlogistine, and makes a good retarder for cement plasters, but its chief use so far is for weighting and filling paper. The clay brings $6.00 to $7.00 per ton f.o.b.

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[1] U. S. Geol. Surv., Bull. 260, 562, 1905.

References on Wyoming Clays

1. Darton, N. H., U. S. Geol. Surv., Geol. Atlas Folio 107, 1904.

2. Fisher, C. A., The Bentonite Deposits of Wyoming, U. S. Geol. Surv., Bull. 260, p. 559, 1905.

3. Knight, W. C., Bentonite, Eng. and Min. Jour., LXIV, p. 491, 1898.

4. Knight, W. C., Wyoming Clays and Building-stones, Eng. and Min. Jour., LXIV, p. 546, 1898.

5. Knight, W. C., Eng. and Min. Jour., LXIII, p. 600.

6. Knight, W. C., Mineral Resources of Wyoming, Wyo. Exper. Sta., Bull. 14, 1893.

7. Merrill, G. P., Non-metallic Minerals, N. Y., 1904, pp. 233, 243.

8. Read, T. T., Bentonite, Eng. and Min. Jour., LXXVI, p. 48, 1903.

9. Siebenthal, C. E., Bentonite of the Laramie Basin, Wyoming, U. S. Geol. Surv., Bull. 285, p. 445, 1906.

CHAPTER VIII

FULLERS' EARTH

Properties

FULLERS' earth is a peculiar type of clay which has a high absorbent power for many substances, on which account it is used for decolorizing oils and other liquids. The statement usually seen in print that it lacks plasticity and falls to pieces in water is misleading and of no value. When dried, fullers' earth often adheres strongly to the tongue, but so do some ordinary clays which have no clarifying powers. The color is also variable. Its specific gravity ranges from 1.75–2.5.

The quantitative analysis shows that its common chief difference from ordinary clay lies in its relatively higher percentage of combined water, but a chemical analysis is of little value, and a practical test is necessary in order to determine its worth. An incorrect statement often seen in print is that fullers' earths contain a high magnesia-content.

Dana [1] defines fullers' earth as including many kinds of "unctuous clays, gray to dark green in color, and being in part kaolin and in part smectite." It is placed by him with several clay-like minerals (all of them hydrous silicates), namely, smectite and malthacite, of not very definite chemical composition, but all having a high percentage of combined water.

Smectite proper is defined as a "mountain-green, oil-green, or gray-green clay, from Cilly in Lower Styria."

Malthacite is defined as occurring in thin laminæ or scales, and sometimes massive, with the color white or yellowish. The original occurrence is the result of disintegration in a basalt at Steindörfel, in Lausitz. Beraum, in Bohemia, is another locality. It is not quite clear on what evidence Dana proves fullers' earth to be a mixture of "kaolin"

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[1] System of Mineralogy, 1893, p. 695.

(he probably meant kaolinite) and smectite, for the chemical analysis alone would not warrant this statement, and petrographic examinations (see below) afford little aid in this matter.

Indeed none of the published analyses of fullers' earth show a composition at all similar to either smectite or malthacite, and what their mineral composition is has not been proven.

Merrill[1] states that "the English earth, when examined under the microscope, consists of extremely irregular colored particles of a siliceous mineral which in its least altered state is colorless, but which in nearly every case has undergone a chloritic or talcose alteration, whereby the particles are converted into a faintly yellowish-green product. The grains are of all sizes up to .07 mm., but the larger portion of the material is made up of particles fairly uniform in size and about the dimensions mentioned. In addition to these are minute colorless fragments down to sizes .01 mm. and even smaller. The minute size of these colorless particles renders a determination of their mineral nature practically impossible, but the outline of the cleavage flakes is suggestive of a soda-lime feldspar."

"The Gadsden County, Fla., earth under the microscope shows the same greenish, faintly doubly refracting particles as does the English, intermixed with numerous angular particles of quartz."

Just what the mineralogical composition of fullers' earth is has not been definitely proven, but J. T. Porter (Ref. 4) has argued that since different writers have mentioned gabbro, diorite, diabase and basalt as rocks from which fullers' earth is derived, it is but natural to suppose that minerals common in these rocks—such as augite, hornblende, olivine, magnetite, etc.—may be present in the earth. Reasoning therefore from this basis he gives a list of 62 minerals which he considers are likely to be found in fullers' earth. He also lists an additional 14, all hydrous silicates. The presence of considerable magnesia in some earths he regards as corroborative of his theory of its source.

Following out this idea, it is suggested by Porter that there may exist a well-defined relationship between the rational composition and the class of coloring matters which a given earth removes most efficiently.

The following rational compositions are given of two earths, whose ultimate analysis will be found on page 519. Porter's calculations being based on the percentages of silica, alumina, etc., soluble or insoluble, in the different strengths of acids, but it should be remarked that the rational analysis does not balance exactly with the ultimate.

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[1] Guide to the Study of Non-metallic Minerals, p. 337, 1901.

Mineral.	Total.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	CO_2.	H_2O.	P_2O_5.
OWL EARTH, FLA.									
Apatite	2.62	.....	.....	.....	1.42	.....	.....	.....	1.20
Calcite	16.82	.....	.....	.....	9.42	.....	7.40		
Magnesite	1.01	.....	.....	.....	.....	.48	.53		
Montmorillonite	32.04	17.21	9.70	.....	.....	.....	.....	5.13	
Free hydrous silica	5.46	5.00	.....	.....	.....	.....	.....	.46	
Iron oxides	.82	.....	.....	.82					
Magnesia (?)	1.24	.....	.....	.....	.....	1.24			
Anauxite	24.41	14.84	6.25	.....	.....	.....	.....	3.32	
Augite, etc.	5.90	1.93	1.41	1.15	.....	1.41			
Feldspar and quartz	9.73	9.22	.44	.12					
	100.0	48.20	17.80	2.09	10.84	3.13	7.93	8.91	1.20
FAIRBANKS.									
Apatite	.14	.....	.....	.....	.08	.....	.....	.....	.06
Free hydrous silica	11.97	11.90	.....	.....	.....	.....	.....	.07	
Prehnite (?)	10.16	4.43	2.54	.....	2.75	.....	.....	.44	
Other zeolites	2.07	.57	.....	.....	.11	1.39			
Iron oxides	2.12	.....	.....	2.12					
Anauxite	45.88	27.90	11.74	.....	.....	.....	.....	6.24	
Augite, etc.	19.76	9.61	3.30	4.91	.43	1.51			
Quartz and feldspar	7.43	5.00	2.32	.11					
	99.53	59.41	19.90	7.14	3.37	2.90	....	6.75	.06

The cause of the bleaching power of fullers' earth still remains to be explained.

Both Ries and Porter have called attention to the probable presence of hydrous silica in the earth, but the second writer doubts if the bleaching power is entirely due to this, as boiling with sodium carbonate does not injure it much.

Sloan[1] believes that the bleaching is due to the mechanical entanglement of the suspended coloring matter by the contained clay substance, remarking that "when the alumina exceeds one-fifth the amount of silica present, the critical point is approximated beyond which an increase in the densely bedding aluminous matter prejudices filtration. The silica therefore serves to maintain the required porosity."

This statement regarding the alumina-silica ratio does not seem to hold true in all cases.

Porter (Ref. 4) by a series of tests on different earths has brought out their difference in behavior towards different solvents.

The results of his tests on the Owl earth from Quincy, Fla., and an earth used by the Fairbanks Company, of Chicago, are given below:

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[1] Preliminary Report on the Clays of South Carolina, S. Ca. Geol. Surv., 1904, pp. 59–61.

Analyses of Fullers' Earth and Clay

Calculated to 100 per cent [1]

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	CO_2.	H_2O.	P_2O_5.	Total.
OWL FULLERS' EARTH, QUINCY, FLA.									
Original earth	48.20	17.80	2.09	10.84	3.33	7.93	8.91	1.20	100.30
Insol. in dilute HCl	74.20	12.90	1.94	.05	n. d.	.....	9.28	n. d.	98.37
Insol. in dil. HCl and NaOH	70.70	15.80	1.70	.08	n. d.	.....	9.36	n. d.	97.64
Insol. in dil. HCl and sol. in NaOH	79.72	10.52	tr.	.....	n. d.	.....	9.58	n. d.	99.82
Insol. in conc. HCl	90.88	3.40	.....	.05	.....	.....	5.14	n. d.	99.47
Insol. in H_2SO_4 and NaOH	91.10	4.35	1.09	3.46	.....	.....	.....	n. d.	100.00
Insol. in H_2SO_4 and sol. in NaOH	83.17	2.81	.....	14.02	.....	.....	.....	n. d.	100.00
Sol. in NaOH alone	82.4	17.60	.....	.....	.....	.....	.....	n. d.	100.00
FAIRBANKS FULLERS' EARTH									
Original earth	59.41	19.90	7.14	3.29	2.90	.04	6.75	.06	99.49
Insol. in dil. HCl	66.60	19.20	5.54	.48	1.67	.....	7.11	n. d.	100.60
Insol. in dil. HCl and sol. in NaOH	18.80	n. d.	n. d.	n. d.	n. d.	.....	n. d.	n. d.	
Insol. in conc. HCl	86.80	5.95	.90	.27	.27	.....	4.55	n. d.	98.74
Insol. in H_2SO_4	92.95	3.66	1.83	n. d.	n. d.	.....	n. d	n. d.	98.44
Insol. in H_2SO_4 and NaOH	75.75	13.79	1.67	.80	n. d.	.....	n. d.	n. d.	92.01
Sol. in NaOH alone	11.89	n. d.	n. d.	n. d.	n. d.	.....	n. d.	n. d.	

[1] The strength of the reagents is not given.

The theory advanced by him is as follows:

"1. Fullers' earth has for its base a series of hydrous aluminum silicates.

"2. These silicates differ in chemical composition.

"3. They are, however, similar in all possessing amorphous colloidal structure.

"4. The colloidal structure is of a rather persistent form, and is not lost on drying at a temperature of 130° C. or possibly higher.

"5. These colloidal silicates possess the power of absorbing and retaining organic coloring matter, thus bleaching oils and fats.

"(The term colloidal is used in its broadest sense to cover the whole range of conditions expressed by the words colloid, pectoid and hydrogel.)"

Tests made indicate that acids affect the bleaching efficiency of some oils more than others, and in some cases bleaching may be increased by acid treatment, if the latter removes limonite, calcite or possibly hydrous alumina, which may exert a clogging effect (Ref. 4).

The injurious effect of lime on the bleaching power has also been commented upon by Parsons (Ref. 3), who also points out that the calcareous earths are not among the best bleachers.

Acid treatment may possibly increase the colloidal matter in an earth, and thus improve it.

If the different minerals in fuller's earth have a varying preference for different colors, then this may explain why certain ones are very efficient for vegetable oils, but useless for mineral oils and vice versa (Ref. 4). It is favorable to the colloid theory to note that heating the earth destroys its efficiency for bleaching cottonseed oil, and perhaps adverse to it to find that the petroleum can be burned out of the earth in kilns without injuring its bleaching power for mineral oil.

Pipe clay has some slight bleaching power, but is improved by drying and treatment with sulphuric acid, which latter increases the colloidal matter.

Parsons (Ref. 3) has brought out the interesting fact that the Southern earths are almost generally very acid in the reaction by the regular methods used in testing soils for acidity, still they contain no acid. The property is therefore simply one of adsorption such as is characteristic of many clays.[1]

This so-called "acidity" is found to be a direct measure of their absorptive capacity for such bases as lime, but it is by no means proportional to their power to extract colors from solutions in oil. This acidity Parsons found to vary from O in the Longstreet earth up to a point where it required 1.5% of CaO to "neutralize" it in some others.

While the absorptive power is not proportional to the bleaching power of oils, it is directly proportional to the effect which many earths have of producing a rancid odor in edible oils, and this effect can be counteracted or destroyed if the earth is first treated with lime water until it no longer reacts acid to litmus paper, or gives an acid filtrate when shaken up with salt. But this treatment may at the same time destroy the bleaching power, so that only partial neutralization can be made, without endangering the value of the earth.

Strongly "acid" earths when suspended in water and subjected to the action of an electric current, acted like positively charged colloids, migrating slowly to the negative electrode, which Parsons says accounts for their yielding an acid filtrate when shaken up with salt solution, and their absorption of azo colors from an oil solution, changing them at once to the same shade as if they had combined directly with a true acid.

Some earths when mixed with oil cause the latter to oxidize so rapid-

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[1] In this connection see Cameron, Bureau of Soils, Bull. 30.

ly and violently in contact with the air, that the contents of the filter presses burst into flame immediately on exposure to the atmosphere.

Parsons believes that the phenomenon of bleaching is one of simple adsorption, as shown by the fact that an earth which has taken up all the color it will readily hold, yields almost all of this color to alcohol after the adhering oil has first been extracted with ether or gasoline. The earth thereby regains most of its bleaching power.

Treatment.—(Refs. 3 and 4).

Mineral oils.—When petroleum is bleached, this is done by allowing the oil to flow down through columns of earth, much the same as a sugar solution is decolorized by bone black. The first oil passing out is nearly colorless, but it gradually grows darker until the earth has absorbed all the color it will remove. The earth can be revivified by burning off the adhering petroleum in rotary kilns and used again. The high heat does not appear to injure its bleaching power for petroleum oils, but would ruin the earth for use on animal and vegetable oils and fat.

The heavier oils require a coarse-grained earth, while for the lighter oils earth ground as fine as 124 mesh can be used.

Animal and vegetable oils.—For treating these the oil is heated by steam, the finely ground earth added, stirred for two or three minutes and the hot oil run into filter presses. The temperature used is variable, but commonly is not more than a few degrees below 100° C. The quantity of earth required varies with the kind of oil and earth.

Lard and lard oil generally require about 1% earth; cottonseed oil about 5%, and certain dark tallows and greases need much more.

After bleaching it is usually necessary to refine the cottonseed oil in order to improve its taste and odor.

A larger per cent of earth is required to reach a certain standard color if a lower temperature is used, but still this is thought by some to improve the flavor and odor.

Requisites of good earth.—Parsons names the following:

It must bleach as well as the English earth.

It must not cause the oil to revert to its original color.

It must filter well.

It must absorb no more oil than the English earth.

It must not catch fire when removed from the filter press.

It must give no permanent taste or odor to the oil.

Laboratory test.—This may be made in several ways. A method followed by the writer and also used by Parsons (Ref. 3) is as follows: Two hundred c.c. of oil are heated to 100° C., a definite quantity of earth (6% for cottonseed or 1% for lard oil) is added, and the mixture stirred steadily for three minutes. Filter as quickly as possible and run into a 120 c.c. oil bottle. This is placed in a colorimeter and color standardized with red and yellow glasses of the Lovibond scale.

Porter (Ref. 4) proceeds as below.

Fifty c.c. of cottonseed oil is put in a comparison tube of 120 c.c. capacity and heated to 220° F. in an oil bath. To this add 2.5 grams of the earth to be tested, remove from bath, close tube with rubber stopper and shake for 5 minutes. Filter hot, and protect from light.

Porter found that this protection was necessary because certain samples bleached out very rapidly after treatment if exposed to the light. The oil after bleaching is compared with a set of standard samples.

Mining and Uses

According to Ries (Ref. 5) "The Florida earth is usually mined with picks and shovels." A good method is to use mattocks, which shave the material off in thin pieces, and saves subsequent labor in breaking up the fullers' earth after it has been spread upon the drying-floor. After mining the usual method is to spread the material in a thin layer over a drying-floor constructed of planks. It is thus dried in the sun, and in drying it bleaches to a white color. The material is then gathered into sacks for shipment. By this air-drying about 50 per cent of moisture is removed. Drying can be done more rapidly by passing the earth through a hot cylinder.

Fullers' earth was originally used for fulling cloth, that is, cleansing it of grease, but this is now its least important application. It is also employed in the manufacture of certain soaps. Its use for removing calcium carbonate from water for boiler-supply, thus preventing deleterious incrustations, is also suggested.[1]

Its most important use at the present time is for bleaching cotton and lard-oil, but it is also employed on castor, linseed, cocoanut and other oils, as well as on tallow and greases. Mineral oils are also filtered through it.

Distribution in the United States

Up to within a few years ago nearly all of the fullers' earth used in the United States was imported from England, where large deposits of this material exist, but since that time deposits have been found in a number of States, including Florida, Georgia, Alabama, Arkansas,

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[1] U. S. Geol. Surv., Min. Res. for 1904, p. 1121, 1905.

FIG. 1.—Fullers'-earth pit, Quincy, Fla. Behind it are the drying-floors. (Photo by H. Ries.)

FIG. 2.—Outcrop of fullers' earth, northeast of Fairburn, S. Dak. (After Todd, S. Dak. Geol. Surv., Bull. 3, p. 121, 1902.)

Colorado, New York, South Dakota, California, South Carolina, and Massachusetts.

But little has been published regarding the American fullers' earth occurrences.

Georgia-Florida.—Those of northern Florida and the adjoining parts of Georgia were first described by H. Ries (Ref. 5) and later by T. W. Vaughan (Ref. 8) and D. T. Day (Ref. 1). According to these writers extensive deposits of fullers' earth are found in the southern part of Decatur County, Ga., and in Gadsden County, Fla., in the western portion of Leon County, Fla., and a few other points.

According to Vaughan's (Ref. 8) determinations the stratigraphic position of the fullers' earth, excepting that from Alachua County, is Upper Oligocene. The sections seen in the pits vary at the different localities, but the following might serve as representative:

	Feet.
Overburden (Sandy clay)	5 to 20
Fullers' earth	6 to 10
Sandstone with crystals and lumps of calcite or aragonite	3 to 4
Fullers' earth	5 to 6

Most of the earth when dry is of whitish color, flaky, brittle, and adheres strongly to the tongue. Analyses are given below, and a view of one of the pits is shown in Pl. XLIV, Fig. 1.

South Carolina, North Carolina, and Virginia.—Earth of very fair quality has been obtained from near Sumter, South Carolina, and deposits are also known in North Carolina and Virginia, but the earth from the last two is more or less sandy.[2]

New York.—In this State deposits of fullers' earth occur at McConnellsville, 12 miles north of Rome. The material is a fine-grained, dense, Quaternary clay in layers 2 to 8 inches thick, interbedded with layers of sand of similar thickness. This earth has been used only for cleansing woolen goods (Ref. 6).

Arkansas.—Deposits of earth are worked in Arkansas, and analyses of some fullers' earth from that State are given in the table below.

South Dakota.—In South Dakota (Ref. 7) the first deposits were located and opened up five miles southeast of Fairburn, Custer County, the section showing:

	Feet.
Micaceous sandy clay	6
Fullers' earth	9
Micaceous sandstone	..

The earth is a yellowish gritty clay, with a somewhat nodular structure. Other deposits are known near Argyle and Minnekata. The deposits are of Jurassic age.

California.—Fullers' earth is said to occur in Kern and San Bernardino counties, but only that in the former appears to have been worked.[1] It is said to range from 15 to 50 feet in thickness. The deposits are of Cretaceous, Tertiary, and Pleistocene age.

The following table gives the composition of fullers' earth from a number of different localities:

ANALYSES OF FULLERS' EARTH

	I.	II.	III.	IV.	V.
Silica (SiO_2)	51.21	50.17	47.10	62.83	67.46
Alumina (Al_2O_3)	12.25	10.00	16.27	10.35	10.08
Ferric oxide (Fe_2O_3)	2.07	9.75	10.00	2.45	2.49
Lime (CaO)	2.13	0.50	2.63	2.43	3.14
Magnesia (MgO)	4.89	1.25	3.15	3.12	4.09
Potash (K_2O)	....	....	....	0.74	
Soda (Na_2O)	....	....	....	0.20	
Water (H_2O)	27.89	24.00	....	7.72	5.61
Moisture	....	....	15.12	6.41	6.28
Loss on ignition	....	....	5.73		
Total	100.41	100.06	100.00	96.25	99.15

	VI.	VII.	VIII.	IX.	X.
Silica (SiO_2)	58.72	50.36	74.90	54.32	63.19
Alumina (Al_2O_3)	16.90	33.38	10.25	18.88	18.76
Ferric oxide (Fe_2O_3)	4.00	3.31	1.75	6.50	7.05
Lime (CaO)	4.06	....	1.30	1.00	0.78
Magnesia (MgO)	2.56	....	2.30	3.22	1.68
Potash (K_2O)	2.11	....	1.75	4.21	0.21
Soda (Na_2O)					1.50
Water (H_2O)	8.10	12.05	5.80	....	7.57
Moisture	2.30	....	1.70		
Loss on ignition	....	....	....	11.86	
Total	98.45	99.10	99.75	99.99	100.74

I. Smectite from Cilly. Pogg. Ann., LXXVII, p. 591, 1849.
II. Malthacite from Steindörfel. Dana, Syst. Min., 1893.
III. Woburn sands, Eng. (yellow), R. H. Harland, anal.
IV. Gadsden County, Fla., P. Fireman, anal. U. S. Geol. Surv., 17th Ann. Rept., Pt. III (ctd.), p. 880.
V. Decatur County, Ga., ibid.
VI. Fairburn, S. Dak., E. J. Riederer, anal. U. S. Geol. Surv., 17th Ann. Rept., Pt. III (ctd.), p. 880.
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VIII. Sumter, S. Ca., H. Ries, anal. U. S. Geol. Surv., Min. Res., 1901, p. 932, 1902.
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X. Alexander, Ark., 1 S., 13 W., Sec. 8, S. W. ¼ of S. E. ¼. Branner, Amer. Inst. Min. Eng., Trans., XXVII, p. 62, 1898.

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[1] Calif. State Min. Bur., Bull. 38, p. 274, 1906.

Production.—The total production of fullers' earth for 1907 is given by the U. S. Geological Survey as 32,851 tons valued at $291.773, the greater part of the supply coming from Florida, and the balance from Arkansas, Alabama, Massachusetts, Colorado, and New York.

The total imports of both prepared and crude earth in 1907 amounted to 14,648 long tons valued at $122.221.

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